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The Correlation between Smart Cities and Carbon Footprint

Do smart cities contribute to reduction in greenhouse gas emissions?

Bachelor's thesis in Renewable Energy
Supervisor: Juudit Ottelin
May 2024

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Preface

This bachelor thesis is a collaboration between three engineering students, at the Norwegian University of Science and Technology in Trondheim. The authors are Ingvild Amundsen, Torill Oldernes, and Marthe Teigen Refsnes. All students are enrolled in the study program Renewable Energy with specialization in Energy Storage. The bachelor's thesis is a final, mandatory project conducted during the spring of 2024, and accounts for 100% of the final grade in the course FENT2900.

In collaboration, the team has chosen to write an empirical study that analyzes if smart cities contribute to reduction in greenhouse gas emissions. Further, it addresses other factors that could contribute to variations in carbon footprints and rank of smartness. The election of this topic was strongly based on the authors' interest in technological systems responding to climate change. In regard to this, avoiding bias has been an emphasized challenge.

Another reason for the thematic choice was the previous literature published on the field. This study fills a gap in publications on smart city rankings and greenhouse gas emissions. The writers are hoping that this study could be beneficial for other researchers or policymakers examining smart cities. The study consists of a background section assessing relevant theoretical topics, a literature review, the methodology applied, the results, and lastly, the discussion. To conduct the study, it was necessary to simplify the smart city concept to some degree. This was done by selecting two ranking indexes to assess.

Throughout the semester, the workload has been distributed equally amongst the team members. The analysis has provided a more profound understanding of the opportunities, complexities, and challenges related to smart cities, and their associated greenhouse gas emissions. Performing the analysis has also provided the team valuable experience in writing an empirical study.

The team would like to express their gratitude to their supervisor Juudit Ottelin for helpful insights, and constructive feedback on the topic, as well as guidance on conducting an empirical analysis. Additionally, the team expresses their gratitude to Senior Scientist Daniel Moran, who provided an extensive data set containing carbon footprints for specific cities.

The cover page image is retrieved from the site *The Challenges and Opportunities of Smart Cities* by the technological company *Smart City*. [53]

Abstract

The global climate is heavily affected by increased amounts of greenhouse gases released to the atmosphere, resulting in an increased surface temperature. The pre-industrial eras' level of global average concentrations of CO_2 was surpassed with 50% in 2022. In addition, estimations suggest that 80% of the global population will live in urban areas by 2050. The demographic shift regarding the move from rural to urban areas, puts a considerable strain on natural ecosystems and biodiversity, as well as intensifying energy consumption, and increases air pollution in these urban areas. This emphasizes the necessity for "Sustainable Cities and Communities", encouraged by *United Nations* Sustainable Development Goal 11. A central strategy that has emerged to address these challenges is the smart city concept.

The smart city concept seems to be a topic of increasing interest. When engaging in literature, there appears to be a gap in publications related to ranked smart cities and their corresponding greenhouse gas emissions. For this reason, the aim of this study is to perform a global assessment that analyzes if smart cities contribute to reduction in greenhouse gas emissions. In correlation to this, this study analyzes to which degree other smart city aspects and geographic factors contribute to variations in carbon footprint and rank of smartness. Consumption-based emissions is chosen as the environmental indicator, as it includes the emissions of imported goods. The evaluated smart cities are selected from the top 100 ranked cities in two smart city ranking indexes, published by the *IMD* and *2ThinkNow*. This approach aims to create a more nuanced result of the general trends.

The study was conducted by firstly collecting data for every city present in the two indexes. This includes consumption-based emissions, temperature data, gross domestic product per capita, education levels, and energy mixes. With this data, single- and multivariate regression analyses were conducted. Several limitations arose during the data-collecting process, especially for carbon footprints and per capita gross domestic products.

The results from this study indicate that the evaluated smart cities do not contribute to reduction in greenhouse gas emissions, in fact, the greenhouse gas emissions vaguely increase in line with increasing smartness. It is, however, detected more apparent correlations between the other variables considered. An increase in per capita gross domestic product seems to increase both carbon footprints and rank of smartness, and an increase in temperature indicates an increase in carbon footprints. A frequently appearing challenge is determining the causality or the direction of influence between variables, where it is difficult to establish which variable influence the other. Despite this uncertainty, this study reveals that there needs to be clearer measures taken by the smart cities in order to contribute to reduction of greenhouse gas emissions.

List of Terms and Abbreviations

Abbreviations	Explaination
CF	Carbon Footprint
GDP	Gross Domestic Product
GGMFC	Global Gridded Model of Carbon Footprints
GHG	Greenhouse gas
HDI	Human Development Index
ICI	Innovation Cities^{TM} Index
ICT	Information and communications technology
IMD	International Institute for Management Development
IoT	Internet of things
IRENA	The International Renewable Energy Agency
MVRA	Multivariate Regression Analysis
OECD	The Organisation for Economic Cooperation and Development
PPP	Purchasing Power Parity
SC	Smart City
SCI	Smart City Index
SDG	Sustainable Development Goal
UN	United Nations

Terms	Explaination
Economic sustainability	Sustainability that focuses on creating a balance between economic growth, increasing efficiency and social justice in society.[2]
Environmental sustainability	Sustainability that considers long term consequences from human actions on ecosystem integrity, biodiversity and climate change, while fostering human development. [2]
Social sustainability	Sustainability that emphasizes issues regarding community, especially equality, education, participation and institutional stability.[2]

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1 Introduction

The current concentration of CO_2 in the atmosphere has exceeded any point than for the past 800,000 years. While the earth naturally cycles through emissions and absorptions of CO_2, human activities since the industrial revolution have significantly disrupted this natural balance at an accelerated rate. This is concerning, as CO_2 and other greenhouse gases (GHGs) contribute to heating the earth's surface above natural levels. Increased surface temperature leads to more frequent and intensified natural disasters. This steers to a worldwide imperative to reduce GHG emissions in order to mitigate this trend and its associated impacts. [66]

Globalization is causing a demographic shift as populations increasingly relocate from rural to urban areas. Estimations suggest that by 2050, approximately two-thirds of the global population will reside in urban areas. This demographic shift presents significant hurdles, imposing a considerable strain on natural ecosystems and biodiversity within these urban landscapes. Additionally, it poses issues such as heightened poverty levels, intensified energy consumption and increased air pollution, thereby causing significant risks to human health. [61]

This escalating demographic shift and its following emissions emphasizes the necessity for sustainable development, prompting a heightened focus on the *United Nations* (*UN*) Sustainable Development Goal (SDG) 11: Sustainable Cities and Communities.[55] Within this context, the smart city (SC) concept has emerged as a central strategy to address these challenges. SCs encourage technological innovation to minimize environmental impact, foster economic growth and enhance the quality of life for the citizens.[29] Despite its significance, the SC concept remains broad and vaguely defined.[60]

When reviewing literature regarding this topic, it becomes evident that the interest in SCs has increased over the last five years. Most studies seem to address the concept, to decide which elements to emphasize when classifying a SC. Publications addressing the performance of SC appears to be primarily addressed in single-city case studies, while the impact of smart technologies on emissions is mainly addressed in specific studies focused on the technology. The existing literature is valuable as it lays the foundation for understanding components and technologies of SCs, enabling further research to build on these insights. However, there appears to be a notable gap in the literature associated with ranked SCs and their corresponding GHG emissions. The aim of this study is to fill this gap by conducting a global analysis, answering the research question: *Do smart cities contribute to reduction in GHG emissions?*. The main environmental indicator selected is the consumption-based emissions, i.e. carbon footprint (CF), as it includes the emissions of imported goods. The evaluated SCs were drawn from the top 100 ranked cities from the *IMD* Smart City Index (SCI) and the *2ThinkNow* Innovation Cities^{TM} Index (ICI). By evaluating two indexes, the aim is to create more nuanced results. Engaging in the research has evoked an interest in examination of additional factors influencing emissions. This has led to the sub-research question: *To which degree do other smart city aspects and geographic factors contribute to variations in carbon footprints and rank of smartness?*.

This empirical analysis commences by providing a brief overview of definitions and explanations of key terms in the background section. Subsequently, a thorough review of existing literature on the topic is conducted. Following this, the methodology is explained and clarified, and the results are presented. The discussion section analyzes and interpret the findings while also addressing any inconsistencies observed. Furthermore, limitations of the study will be acknowledged, and recommendations for future research and for policymakers are proposed.

2 Background

This section serves to form the foundation for the study by establishing its theoretical framework, which will be a referencing structure throughout the study. The smart city (SC) concept will be presented based on a small collection of definitions, the relevant climate change aspects will be presented, as well as economic relevance, educational aspect, and the necessary statistics to understand the results.

2.1 Smart City Definition

Currently, there are few established guidelines or principles that cities must follow in order to be considered "smart", resulting in an ambiguous and vaguely defined concept of SCs.[25] To achieve an understanding of today's concept, this section will examine three perspectives on SC definitions, presented in Table 2.1.

Table 2.1: Three perspectives on SC definitions from different sources

Entities:	**Definition**
European Commission	"a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and business." [49]
The International Organization for Standardization; ISO 37122	"...one that increases the pace at which it provides social, economic and environmental sustainability outcomes. Smart cities respond to challenges such as climate change, rapid population growth, and political and economic instability . . . .." [29]
"The Concept of Sustainability in Smart City defintions" by Toli and Murtagh	"Smart city is a concept of urban transformation that should aim to achieve a more environmentally sustainable city with a higher quality of life, that offers opportunities for economic growth for all of its citizens, but with respect to the particularities of each locality and its existing inhabitants." [60]

The definition provided by the *European Commission* emphasizes the use of digital solutions to improve the quality of life for the inhabitants and benefit industries.[49] Alternatively, the ISO 37122 defines SCs as cities who are skilled at addressing and acting upon emerging challenges while ensuring environmental, social, and economic sustainability.[29] The third definition, derived from a case study encompassing 43 definitions, found that each concept prioritizes different sustainable elements based on their unique goals, scopes, and purpose. Based on the findings, Toli and Murtagh conducted their own definitions, which emphasizes the importance of environmental sustainability, improved quality of life, and economic growth.[60]

By comparing these definitions, several common themes emerge, including improved living standards, digital solutions, efficiency, and environmental sustainability. This aligns with one of the Sustainable Development Goals, SDG 11, which aims to foster inclusive, safe, resilient and sustainable cities and human settlements. SDG 11.6 more specifically states "By 2030, reduce the adverse per capita environmental impact of cities (...)". This goal is part of *The 2030 Agenda for Sustainable Development* presented by the *United Nations* (*UN*) in 2015, emphasizing the imperative for cities to contribute to climate-positive solutions. [55]

2.2 Climate Change

Reducing environmental impact includes cutting greenhouse gas (GHG) emissions. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the three main GHGs contributing to climate change. The global average concentrations of CO_2 surpassed the pre-industrial era by 50% in 2022, marking a historic milestone. This trend persisted in 2023, with CO_2 levels continuing to rise. Additionally, CH_4 concentrations experienced growth, and N_2O observed its most substantial year-on-year increase on record between 2021 and 2022.[40] Figure 2.1 shows the increase in global concentration of the three main greenhouse gases recorded from 1985 to November of 2023.

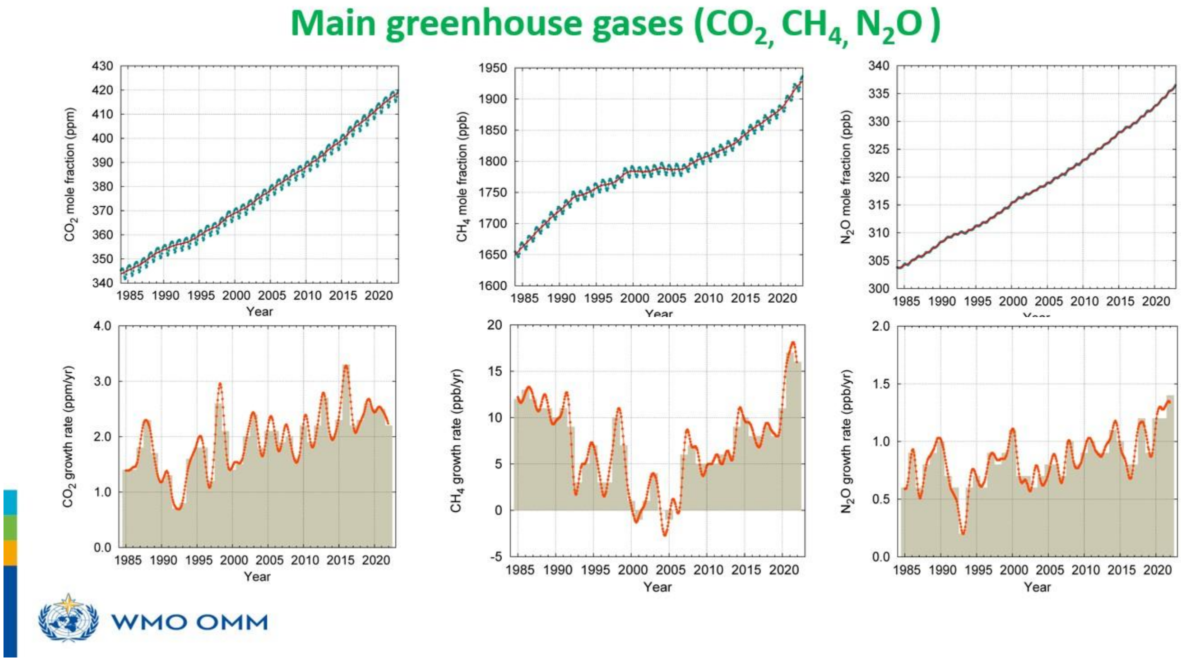


Figure 2.1: Mole fraction and growth rate for the three main GHG from 1985-2023. [40]

These tendencies are worrying given the main goal of the Paris Agreement made in 2015; emissions need to be reduced by 45% by 2030 and reach net-zero by 2050.[56] The Paris Agreement will be further addressed in Section 2.3.

Numerous approaches can be used to measure GHG emissions within cities. Two of them are categorized as territorial-based and consumption-based emissions. The territorial-based emissions include all emissions taking place within the system boundaries, usually within a country's territorial boundaries, including exports and excluding imports. The consumption-based emissions are calculated based on consumer behavior and include imports. [5]

2.3 Carbon Footprint

Having introduced these two ways of categorizing emissions, the one relevant for this study is the consumption-based emissions. The consumption-based emissions are the data considered for estimating the Carbon Footprint (CF). The CF is a calculated value or index that makes it possible to compare the total amount of GHGs that an activity, product, company, or country adds to the atmosphere.[64] For this study, the CFs are measured in tonnes of emissions (CO_2-eq.) per capita.

The Paris Agreement is a landmark international treaty aimed at addressing climate change. Adopted in 2015, the agreement's primary goal is to limit global warming to well below 2 °C above pre-industrial levels, with efforts to limit the temperature increase to 1.5 °C if possible. A total of 196 countries signed the agreement. By signing, the country agrees to work towards the set goal. Additionally, the countries commit to regularly reporting on their GHG emissions and their progress towards reducing them. Every country that is included in this study has signed the agreement and should be working towards these goals. [56]

The 2021 article "*Lifestyle carbon footprints and changes in lifestyles to limit global warming to 1.5 °C, and ways forward for related research*" discusses lifestyle change options aimed at achieving the 1.5 °C climate goal from the Paris Agreement. The authors of the article have estimated that the CF per capita should be 2.5–3.2 tons CO_2-eq. by 2030 and 0.7–1.4 tons CO_2-eq. by 2050.[32] These targets are demonstrated in Figure 2.2.

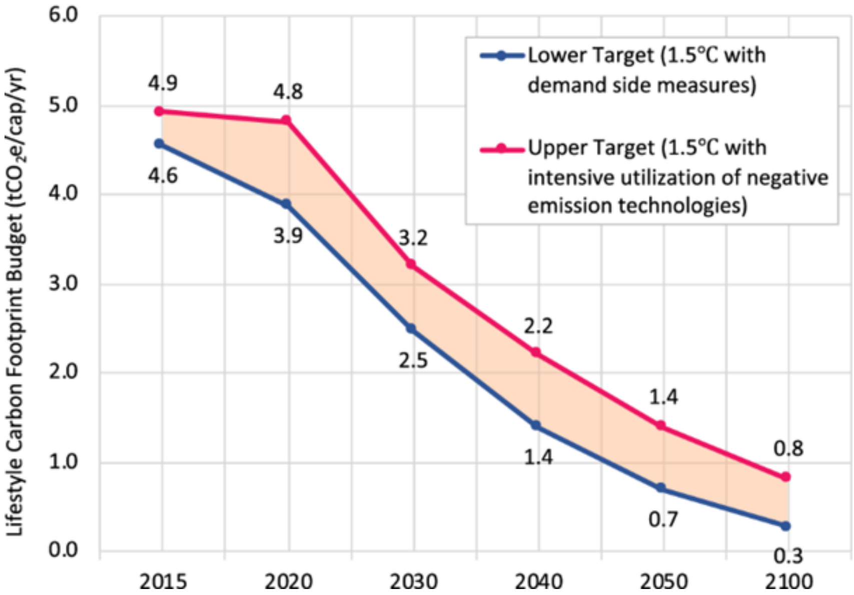


Figure 2.2: Annual CF targets to reach the goal of the Paris Agreement from IGES et al.. [32]

These estimates will serve as benchmarks to measure how the evaluated SCs contribute with their CFs to the overarching goal of the Paris Agreement.

2.3.1 Emissions related to Energy Sources

CFs are directly related to consumption of energy. Fossil fuels, including coal, oil, and gas, significantly contribute to global climate change, responsible for more than 75% of global GHG emissions and nearly 90% of all CO_2 emissions. As of 2021, there are enough renewable sources to replace 65% of the fossil fuels in use, meaning it could decarbonize 65% of the power sector by 2030. [38] The *International Renewable Energy Agency* (*IRENA*) has presented their energy transition solutions to reach the goal of the Paris Agreement. Their aim is for around 90% of all decarbonization strategies to rely on renewable energy sources in the end-use sector by 2050. [20]

Given that a shift from fossil fuels to renewable energy is one of the main solutions to cut GHGs, it is clear that a city that utilizes fossil fuels will evidently emit more GHG emissions than a city utilizing renewable energy. Mapping the energy-consumption patterns for the SCs evaluated in this study will therefore give a broader understanding of the reasons behind the GHG emissions.

2.4 City Economy

Considering the economy when evaluating CFs of cities is significant due to its influence on consumption patterns, production processes, and overall resource utilization. The economy of a city directly impacts factors such as industrial activity, transportation infrastructure, energy consumption, waste generation, and consumer behavior, all of which contribute to carbon emissions. The *IRENA* stated that as a result of this, economic growth has been closely tied to a rise in GHG emissions through most of modern economic history. [57]

Gross domestic product (GDP) is a widely recognized tool to measure economic wealth, and according to the World Bank, more than 80% of the world's GDP is generated in cities.[41] The possible correlation between economic wealth, CFs, and smartness in cities is therefore an interesting relationship to investigate. Section 2.4.1 will for that reason offer an overview of GDP.

2.4.1 Gross Domestic Product

GDP represents the total value of all products and services produced within a region or a country during a specific period in time, commonly one quarter or one full year. This includes both sold and non-sold products and services, incorporating volunteer work and home-produced commodities for private consumption. GDP is an important indicator for the economic size and growth within the given geographical region, frequently applied to compare economic performance across national boarders. Additionally, it is a useful tool to analyze economic trends and measure efficiency of economic policies. [65]

The 2016 empirical study *Is there a relationship between economic growth and carbon dioxide emissions?* explores the possible correlation between CF and GDP per capita for both industrialized countries and poor countries. Every country classified as "Industrialized" in the 2016 study, are present in this analysis. For the results of the study, environmental damage is measured in CO_2 emissions per capita and accounts for the year of 2012. However, it is undefined whether the study has used consumption-based or territorial-based emissions. Figure 2.3 shows the results of the study in the form of a Multivariate Regression Analysis (MVRA). In the figure, CO_2 emission level is the dependent variable, and GDP per capita is the independent variable. The theory and understanding of MVRA is presented in Section 2.6.1. [10]

Dependent variable CO_2 emission level			
Models	**2a**	**2b**	**2c**
Independent variable	Estimated Coefficient (Standard Error)	Estimated Coefficient (Standard Error)	Estimated Coefficient (Standard Error)
Constant	1.0113 ** (0.468392)	3.03509 *** (0.755046)	0.0619705 (0.0916098)
GDP/Capita	0.000355778 *** (3.46417e-05)	0.000235249 *** (5.28430e-05)	0.000296528 ** (0.000296528)
GDP/Capita^2	−2.26823e-09 *** (3.52351e-010)	−1.92398e-09 *** (6.63186e-010)	−1.02046e-08 (2.46062e-08)
Mean dependent var	4.844110	6.486654	0.367472
R-squared	0.441578	0.327403	0.479838
Adjusted R-squared	0.435638	0.307022	0.455069
P-value(F)	1.64e-24	2.07e-06	1.09e-06

Figure 2.3: MVRA of the relationship between CO_2 emissions and GDP per capita. [10]

The MVRA compares 3 different models. Model **2a** represents all countries with available data (190 observations), Model **2b** represents industrial countries (71 observations), and Model **2c** represents poor countries (45 observations). Model **2b** is a fitting comparison for this study, as 50 of the 71 industrialized countries are present in this study. The MVRA shows that the estimated coefficient has a 31% chance of variation in CO_2 emissions being explainable by variation in data. [10] These findings reinforce the reason as to why it is pertinent to take GDP into consideration when evaluating GHG emissions for this study.

2.5 Education Level

The education level of a country is a complex measuring scale that may have varying factors depending on which education index is considered. *DataPandas* subtract their data from the *UN*'s HDI, and their main findings on education levels are presented in this paragraph. As of 2022, the trends observed when looking at education levels are firstly that Nordic countries, including Iceland, Norway, Denmark, and Finland, consistently rank high on the education index. Nations formerly under Soviet influence, including Slovenia, Estonia, Latvia, and Lithuania, have improved their education systems since then. Economic dominating countries including the UK, Australia, Canada, and the US rank high, however disparities exist; for instance, the US ranks 13th, falling behind Germany (2nd) and New Zealand (3rd). Developing and underdeveloped countries in Africa and South Asia typically rank lower. Asian nations show varying results, for example South Korea (36th) and Japan (27th) excelling due to competitive education systems, while others like Pakistan and Afghanistan face challenges stemming from political instability and limited resources. The two factors; expected and actual years of schooling, and educational achievements at all levels are the mainly considered factors for this applied index. [19]

SCs often rely on skilled and educated work forces to drive innovation and economic growth.

Measuring education levels helps assess the competitiveness of a city's workforce by evaluating the availability of skilled labor in fields such as technology, engineering, data science, and management. Especially technology and data science are two examples of fields that many of the SCs actively implement to increase the efficiency of multiple aspects of city management. These aspects are further addressed in the literature review in Section 3. [52]

2.6 Statistics

To determine whether trends observed in the results are due to actual data variances, the R^2 number could be an informative tool. The R^2 number is calculated using Equation 2.1.

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y}_i)^2} \tag{2.1}$$

In the equation, y is the dependent variable, $\hat{y}$ is the dependent variable in the regression line, and $\overline{y}$ is the mean dependent variable. In other words, the R^2 number is the percentage of how much of the variance in the dependent variable can be explained by the independent variable, in terms of a total minus the squared distance from the regression line, or the residuals, over the squared distance from mean. [46] For social sciences, an R^2 above 10% is considered acceptable only if some or most of the independent variables are statistically significant. [42]

To determine whether two groups' means are significantly different from each other, a t-test is a useful tool. The t-test is used to evaluate means by setting a null hypothesis (H_0). It can be performed with one- or two samples, or paired samples. The test is used to evaluate whether the groups differ from each other or a known value. H_0 can from the test be discarded or not discarded, depending on the absolute value of the statistical t-value, t_{stat}, the critical t-value, t_{crit}, and a p-value. [3]

t_{stat} is a measuring value of how many standard errors a sample is away from the mean of the population. It is calculated as described by Equation 2.2. [54]

$$t_{stat} = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{2.2}$$

In the equation, $\bar{x}_1$ and $\bar{x}_2$ are the means of the samples, s_1 and s_2 are the standard deviations of the samples, and n_1 and n_2 are the sizes of the samples. The result is the difference between the means in terms of the standard error, to determine the likelihood of observing the difference by chance or variances in data. Further, the t_{crit} is a predetermined value based on the sample sizes. [54]

The p-value is a decimal number between zero and one, and determines the likelihood of observing values as extreme as or more extreme than the previously observed data, under the true H_0. A large p-value leads to a failure to reject H_0 as the observations are likely under it. [4] The closer to zero the p-value, the stronger evidence against H_0.[17] If $|t_{stat}| > t_{crit}$ and p is smaller than a predetermined limit, then H_0 can be discarded. [58]

2.6.1 Statistics for Multiple Variables

Several variables are considered is this study, and one way to consider them all-together statistically is through what is called a Multivariate regression analysis, (MVRA). When taking multiple variables into consideration in statistics, there will be as many p-values as there are variables. However, the p-values are only valid to assess if the H_0 is rejected. For the H_0 to be rejected, the Significance-F value should typically be lower than 10%, 5%, or 1%. This is dependent on what type of study is performed. [27]

The Significance-F value corresponds to the p-value explained above, however the meaning of the output will be different when looking at multiple variables. The Significance-F gives the probability that the model is wrong, hence it needs to be small for the model to be valid. If valid, the p-values will tell the probability that the coefficient of the independent variable in the regression model is not reliable or that the coefficient in the regression output is zero. [27]

Performing a MVRA also provides the R^2 -value presented in Equation 2.1, and it holds the same meaning. However, the "Adjusted R^2-value" is a more representative value to look at when multiple variables are included. This value takes into account the number of predictors in the regression model, and adjusts from there. [27]

As the primary purpose of any regression analysis is to find the relationship between the variables being analyzed, the coefficients for the regression equation is found through performing the MVRA. For this study, the regression equation is presented in Equation 2.3.

$$y = a + bX_1 + cX_2 + dX_3 \tag{2.3}$$

In the equation, y is the dependent variable being predicted, X_n is the independent variables, a is the intercept at which the regression line intercepts the Y-axis, and b, c, and d are the covariates for their representative X's.

3 Literature Review

SCs is a subject of increasing interest, and the literature on the topic has coherently increased. When searching for ("smart cities" OR "smart city") in *Web of Science*, 41,955 results appear, where 40,826 (97%) are from the last 10 years, and 22,870 (55%) are from the last five years. These substantial numbers of search results pose a significant challenge related to reviewing and assessing all available literature. The main goal of this literature review is to explore the trends, general characteristics and potential gaps in publications for SCs and adjacent topics. The review process and necessary scope constraints are presented in Section 3.1.

3.1 Aim and Method

Three SC definitions were presented in Section 2.1, showing how ambiguous and complex the concept is. The range of incorporated SC elements varies from the technologies that should be included, to the presence of necessary resources, as well as specific qualities that should be emphasized, and the specific goal and scopes of the cities.[60] A deeper evaluation of literature on SC components and elements than previously discussed will be made. According to Xia et al., the challenges related to climate change and environmental issues have to be addressed as the severity is increasing.[68] In line with this statement, a review of papers related to SCs and sustainability will be assessed. Patrão et al. points to city rankings as a tool to "simplify the complexities of the smart city concept".[44] In addition to avoid bias, a review of SC rankings is also performed to simplify the SC concept.

The literature is gathered through the *Web of Science* database. The assessed papers are sourced from publicly available full-text data in English. Data collection occurred between April and May of 2024. The objective is to conduct a review of papers pertaining to the topic of "smart city/cities", with the search parameters presented in Table 3.1. To achieve a comprehensible, yet attainable review, the scope of the literature review was narrowed to studies including SC concepts, emission analysis, and/or ranking of SCs. The main aim has been reviewing publications including "smart" and/or "city/cities" in the title field, when finding which papers to review. However, some sources are discovered through papers within the search parameters, even though they did not appear in the searches. These papers are not included in the table. Case studies on single cities and countries were not reviewed, as the aim was to research papers similar to our approach, meaning addressing multiple countries, cities, or rankings. The papers were chosen based on the considered relevance from the abstract, and some of the reviewed papers were considered irrelevant after reading. It is worth mentioning that as this study is not solely dedicated to reviewing papers on the topic, a structured literature review is not preformed. A more comprehensive table of the reviewed literature is presented in Appendix D, alongside the respective authors, publication-year and country.

Table 3.1: Search terms, results, and review collection for the literature review

Search Terms - All fields	Search Results	Within last 5 years	Review Collection
("smart cities" OR "smart city")	41,955	22,870	-
("smart city" OR "smart cities") AND "components" AND "elements"	111	64	8
("smart city" OR "smart cities") AND "climate change" AND "emissions"	168	121	7
("smart cities" OR "smart city")(all fields) "ranking" OR rankings (title)	69	42	7
("smart cities" OR "smart city") AND "comparison" AND "rankings"	9	5	-
("smart cities" OR "smart city") (all fields) AND "IMD" (topic)	8	8	-
("smart cities" OR "smart city") (all fields) AND "smart city index" (title)	4	2	-
("smart cities" OR "smart city") (all fields) AND "smart city index" AND "IMD ranking" (topic)	0	0	-
("smart cities" OR "smart city") (all fields) AND "2ThinkNow" (topic)	0	0	-
(smart cities" OR "smart city") (all fields) AND "Innovation city index" (topic)	0	0	-
("smart cities" OR "smart city") (all fields) AND "Innovation city index" AND "2ThinkNow" (topic)	0	0	-

3.2 Smart City Aspects

A range of perspectives exist regarding the essential concepts and components a city has to possess to qualify as a SC. Based on then-existing literature, Giffinger highlighted in 2007 the variations in SCs, spanning from an IT-district to the "smartness" of its inhabitants, relating to their educational level.[23] Recent research is more nuanced and aims for a more comprehensive approach by recommending a combination of components. For instance, Marzouk recommended that a SC should incorporate six groups of attributes, being the following; Human Capital, Municipality Orientation, Outdoor Environment, Transport, Infrastructure, and Technology.[35] With this approach, all three dimensions of sustainability, which are explained in the Terms and Abbreviations, are addressed. Interestingly, in a report from 2023, Dashkevych et al. revealed regional variations in the interpretation of SC components. "Economy and technology" was the primary focus in North America, "the environment" was emphasized in Europe, and Asian and Oceanian cities highlighted societal aspects.[18] This suggests that although attempts have been made to enhance the comprehensiveness of the SC concept, practical implementations seem to have fallen short, in addition to different interpretations across regions.

Within the concept of SC, analyses often focus on "hard" and "soft" strategies. The hard strategies include energy grids, mobility, infrastructure, smart water management, smart offices, and smart homes. In contrast, soft strategies primarily focus on improving quality of life through investments in education systems, encouraging social innovation, and expanding human and social capital.[33, 34, 60] Yigitcanlar et al. found that papers heavily focusing on technological solutions tend to prioritize these and dismiss solutions without technologies.[69] This aligns with SC concepts found within major technology, engineering, consultancy, and construction companies (e.g. Google, Huawei, Siemens, Ericsson, CISCO, Tesla) indicating that their main priority is "hard" strategies to promote their products. Given their considerable influence in society, these companies could have a significant effect in shaping SC concepts, thereby potentially causing a conflict of interest.[69, 70, 60] However, human-centric (soft) approaches have been observed to neglect certain technology-intensive dimensions, indicating a two-way issue.[33]

SCs are expected to solve modern city problems in an efficient way, by applying information and communication technologies (ICT).[45] One of the motivational forces for implementation of ICT is the desire to remove human error, as technologies are considered more reliable.[30] One key components within ICT is the Internet of Things (IoT). The use of IoT devices and components increased with 39% from 2015 to 2017, with about 1.6 billion components on the market in 2017.[43] Examples of IoT devices are sensors, wireless telecom networks, camera networks, building management and digitally controlled services.[31] Sensors are valuable devices within IoT, and can be used to optimize waste collection, to improve energy distribution to increase energy efficiency, and monitor and manage traffic to reduce traffic congestion, among other things.[45] The aim of these technological solutions is to make cities more sustainable.[70] However, the literature on the topic is unclear on whether these implementations actually contribute to sustainability. Obringer states that more use of ICT devices lead to higher consumption of electricity.[39] A study by Blasi et al. examining the correlation between the *UN*'s SDGs and SCs revealed that main topics related to SDGs were human rights, climate change and circular economy, inequality, and education. This did however not align with the topics related to SC, which were more related to "IT and business intelligence; security, privacy, and blockchain; governance, civic engagement, and quality of life; and urban mobility."[8] Obringer found that there is "little connection between SC initiatives and climate action plans in cities". Further, emphasizing that there is a lack in overlap within the government, resulting in SC and climate change strategies not aligning.[39] Yigitcanlar et al. emphasized the importance of collaboration between smart people, policies, and technologies for achieving smart and sustainable cities.[69]

Xia et al. referred in 2023 to SCs as policy practices for reducing urban carbon emissions.[68] Still, Paträo estimated in 2020 that cities in general generate 72% of the total global GHG emissions, along with 80% of all economic growth, despite only covering 3% of the earths surface.[44] In the 2020 article *Smart and Sustainable? Positioning Adaptation to Climate Change in the European Smart City*, Fernández et al. states that there are indicators that point to adaptation to climate change as part of the SC notion, while acknowledging that the development of SCs still is somewhat unexplored.[21] Contreras et al. finds in the 2019 report *Economic and policy uncertainty in climate change mitigation: The London Smart City case scenario* that most actions to mitigate climate change effects have predominantly occurred at the city level, particularly within the SC framework.[16] However, Wang et al. presents in the 2019 analysis *Energy savings from Smart Cities: A critical analysis* that SCs might face unintended challenges climate change wise. They argue that if the energy efficiency for one car trip is reduced sufficiently, the city's inhabitants might relocate from i.e. public transport to using their personal cars.[62]

It seems as though SCs do take climate action into consideration, however whether these actions reduce GHG emissions remain unanswered from these findings. The mention from Xia that 72% of global GHG emissions are generated in cities persists a noteworthy remark.

Cavada et al. presented in 2016 a report on SCs and CO_2 emissions. The analysis was executed based on the creation of a database of SCs, in addition to trends found in previous literature. Six SC categories were researched to find their respectful numbers of initiatives (actions) taken within the SCs, and the number of initiatives for each sub-category. The findings are presented in Figure 3.1. In the figure, environmental sustainability is presented as "sustainability".[9]

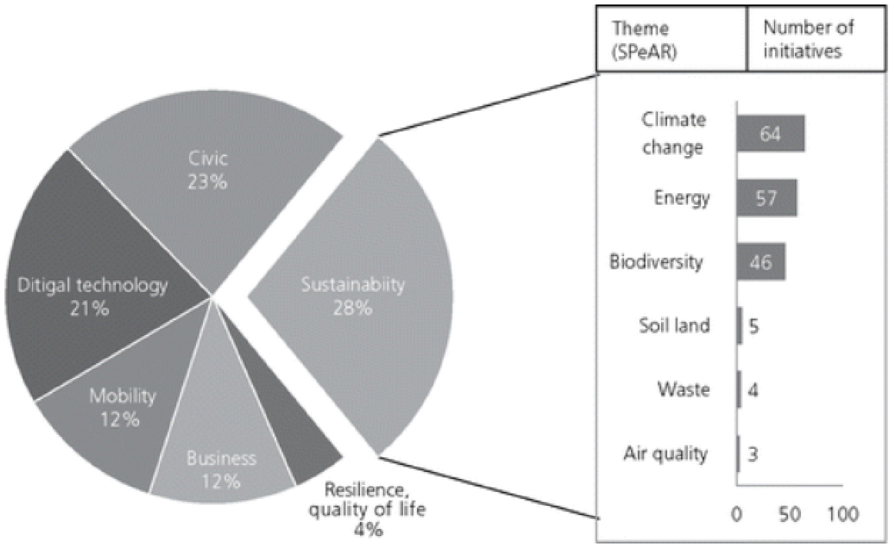


Figure 3.1: Initiatives for the different sectors in SCs according to Cavada et al., emphasizing environmental sustainability. [9]

As the figure shows, environmental sustainability is the category with the most initiatives (28%), and climate change is evidently the sub-category with the highest number of initiatives (64) under this category. As this study analyzed SC awards and rankings from the time period 2004 to 2014, the prominent reliance on environmental sustainability and climate change might be outdated. [9]

Climate change will not solely affect the atmospheric processes, but additionally indirectly influence numerous critical urban services.[39] Obringer et al. makes a point of these services adapting to climate change after having faced natural disasters. In an example, they refer to damage from hurricanes in the United States making cities prepare for climate changes as well as enhance the emphasis on climate resilience. A similar example of this is Rotterdam incorporating sensors to guard the city against floods, which is a SC concept made to protect the city against natural disasters.[39] However, this concept is energy-demanding and do not contribute directly to cuts in GHG emissions. This aligns with the issue stated by Sadorsky in 2012, that with increasing ICT, the energy demand also increases (for emerging economies).[48] As the energy supply sector is responsible for approximately 35% of GHG emissions, this poses a significant issue.[26]

Another issue with SCs in terms of climate change is mentioned by Ipsen et al., when evaluating the performance of various smart technology programs in terms of carbon emissions. This report investigates the consumption-related flows of SCs to determine changes in global warming potential for SC concepts. The authors find that smart energy grids, smart water infrastructure, and sensor-based waste collection successfully reduce the global warming potential and improve environmental performance, while technology such as smart windows and at-home graywater recycling decrease environmental performance.[28]

3.3 Smart City Rankings

City rankings have become a central tool for assessing and comparing urban environments.[22] Rankings are often based on the idea of evaluating cities from best to worst for different aspects. The rankings themselves are, in addition to this, also evaluated on different economic, social, and geographical elements.[23] Patrão et al. presents city rankings as a tool for evaluating the appeal of urban regions and for cities to improve competing-wise. The article points to the researcher's benefit of city rankings; to "develop new strategies for improvement of smart city performance", and "simplify the complexities of the smart city concept".[44] The aspiration behind these rankings is that they provide guidance for future city development, encouraging policymakers to utilize the findings.[22]

Despite these statements, there have been discussions regarding whether rankings are fitting methods for identifying and presenting SCs. Acuto et al. stated that one of the issues with indexing is that they are applied in a traditional sense of ranking, from best to worst, forming a kind of hierarchy that promotes a unilateral vision on cities success or failure. This does not take into account the complexity and diversity within urban environments.[1] The article *The role of rankings in growing city competition* stated that one of the main issues regarding rankings are that they only consider local facilities and endowments, not considering the behavior and preferences of the inhabitants.[22] In spite of these issues, it has been argued that the rankings should not be discarded but rather be made in a more nuanced form.[1] Marzouk promotes for rankings, declaring that examining two rankings studies rather than one gives a more reliable view of how well different cities are performing relatively.[35]

Despite disagreements on whether rankings are appropriate tools for city evaluations, some studies take several SC rankings into consideration to compare methodologies and results. Marzouk evaluated SC indexes between 2017 and 2019, presenting them as valuable tools to help reshape SC definitions over time. However, it is presented that there is a mismatch between the indexes evaluated, having found that some suggest that cities have become smarter and others suggest that the same city has become less smart.[35] Article *Human-centric, sustainability-driven approach to ranking smart cities worldwide*, written by Dashkevych et al. compares ten SC indexes. The study ranks the indexes based on *Google Search* popularity, the findings are presented in Figure 3.2.[18]

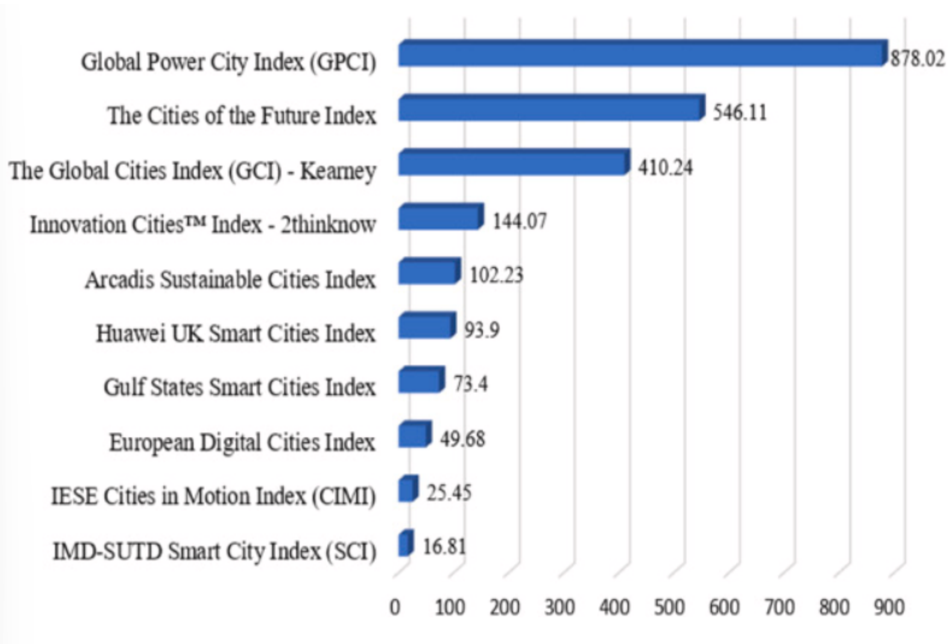


Figure 3.2: Indexes rated by Google Search requested SC-rating systems, presented in millions. [18]

According to the figure, the Innovation Cities^{TM} Index (ICI) is ranked as number four with 144 million searches, and the Smart City Index (SCI) is ranked last with 16.8 million. The same study conducts a comparative analysis of the indexes regarding to what extent they fulfill different assessment criteria. The assessment criteria include human centricity and the representation of environmental-, social-, and economic sustainability. Notably, the ICI and SCI both score "partially" on all categories. No indexes score higher than "partially" in any category; nevertheless, two studies receive a "No" on environmental sustainability.[18] The SCI is discussed in a study comparing six SC indexes, from these results the SCI differ from the other rankings, as none of its top five cities appear in the other index's top five. For this reason, the author addresses concerns about the methodology applied for the SCI.[59] The results from these two studies provide uncertainties in regard to the SCI, as the index is both less requested and discussed as using a questionable method. The index is not often mentioned or assessed in the papers, as shown in Table 3.1, which only provides eight and four results when searching for respectively "IMD" and "Smart city index" within the topic field. Searching for "2Thinknow" or "Innovation city index" provides zero results, which is surprising as the index has been available since 2007 and Figure 3.2 indicates that it is a highly requested index.

3.4 Geographical Scope of the Review collection

Figure 3.3 provides a map-visualization of the geographical locations of where the reviewed literature is published. The visualization is made using Datawrapper.

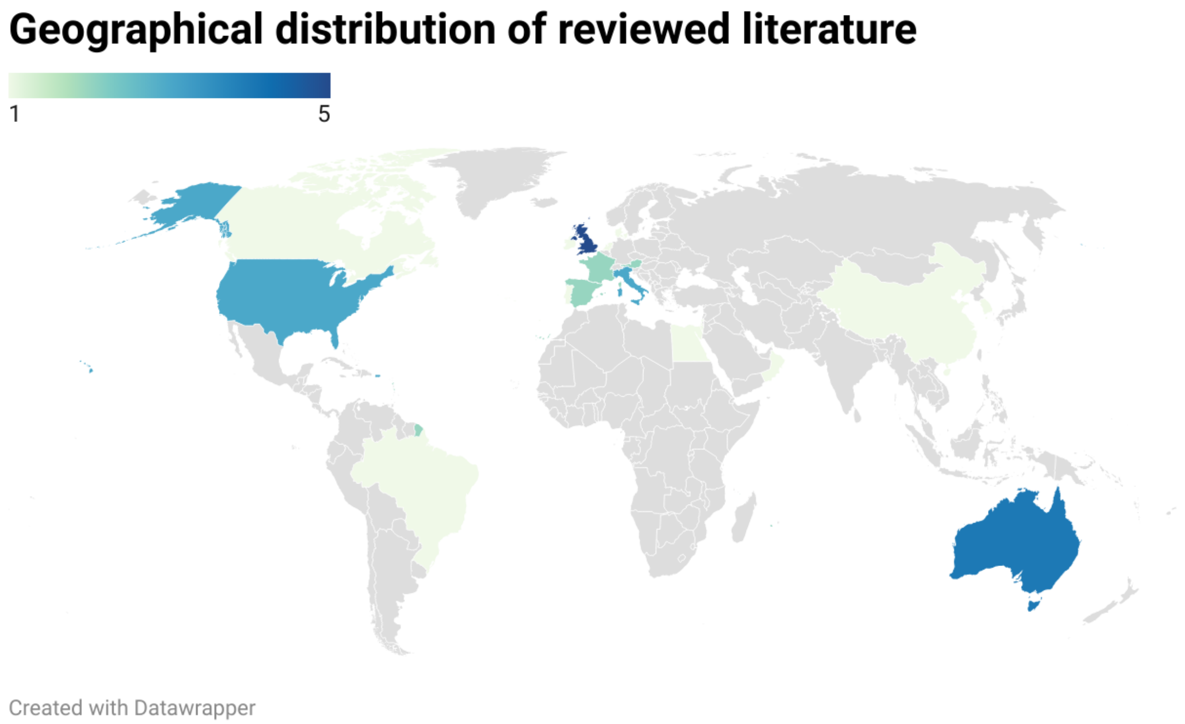


Figure 3.3: Geographical distribution of the reviewed literature.

As presented in the figure, the lighter green areas are the countries with fewer studies reviewed, while the darker blue are the countries where more of the studies originate from. A full overview of the reviewed literature is presented in Appendix D. Examining South America, French Guiana is marked green, however must not be confused with an actual South American country, as it is a department of France. The United Kingdom is most highly represented, with five studies. Generally, Oceania and South-Central Europe are highly represented, North America to some degree, while there are less African, South American and Asian studies.

3.5 Concluding Remarks

The aim of this study is to evaluate whether SCs contribute to reduction in GHG emissions. Based on the published literature on SCs, there seems to be an increased focus on the topic, especially over the past five years. This has been emphasized in Table 3.1. Most of the studies on SCs seem to be evaluating which elements should be included and are included in the SC concept. The actual performance of cities seems to mainly be addressed in single city case studies, not on a cross-continental basis, comparing multiple countries. The same trend is displayed in the evaluation of SC rankings, where the methodology has been the majorly discussed topic, as opposed to emissions/climate change. This might indicate a gap in the literature comparing rankings of SCs and the cities' respective GHG emissions.

There seems to be an increased focus on including environmental aspects in the SC concept, with the desire to contribute to emission reduction or prepare infrastructure to guard for natural disasters. Despite this increased focus, there is uncertainty in whether these concepts actually reduce GHG emissions. Due to this, and the previously mentioned gap found in the literature, this study will conduct a global analysis on the relationship between the smartness and the CF of cities. Two different SC indexes are compared. Consumption-based emissions, i.e., CF, was selected as the main environmental indicator, since it covers the emissions of imported goods as described in Section 2.3. The majority of existing literature assessing emissions in SCs seem to be focused on direct emissions of specific technologies. As these technologies are a part of what drives the emissions to increase or decrease, this focus is not misdirected. However, this analysis provides a unique contribution to the literature, by examining larger trends.

4 Methodology

This section offers insight in how the data is assembled and the reasoning for choosing the specific datasets. Additionally, it outlines the methodology for the calculations of the results. Every gathered value that is used to conduct this study is presented in Appendix I.

4.1 Ranking and City Selection

The collection of SCs to analyze was based on two SC rankings. The decision to base the analysis on rankings was made in line with the findings from Section 3, to simplify the SC concept and to provide a nuanced description of the cities' relative performances. The two rankings are the *IMD* Smart City Index (SCI) and the *2ThinkNow* Innovation Cities™ Index (ICI), both in line with some aspects of the SC definitions presented in Table 2.1 in Section 2.1.

The SCI was chosen as it was the least requested SC rating system according to the 2023 article *Human-centric, sustainability-driven approach to ranking smart cities worldwide*, as described in Section 3.2. Basing the analysis on the least searched for rankings allows for new findings, and for comparison between this and more highly requested rankings. Additionally, the applied methodology for the SCI is transparent, making it possible to thoroughly interpret the reasoning behind the variety of outcomes presented in the results. The ICI is ranked number four most requested ranking in Dashkevychs previously mentioned article.[18] The selection of the fourth ranking, as opposed to the first, was made partly to compare a non-company ranking to a company ranking to investigate more on the theory about hard and soft strategies mentioned in Section 3.2. The ICIs methodology for collecting data differs significantly from the SCIs method, which opens an additional discussion point on ranking methodologies. Additionally, the SCI and the ICI are both globally oriented, accessible, hold comparable numbers of cities, and are regularly updated. The SCI was published in 2024, and the ICI in 2022/2023. The recentness reflects trends and changes in the SC development from year to year. [14, 50]

The SCI assesses 142 cities, versus 500 for the ICI. The top 100 cities from both indexes were selected for this study. The decision to focus on 100 cities was motivated by challenges related to collecting data past this limit. Obtaining comparable data became increasingly difficult further down the list, which could introduce significant inaccuracies in the results due to data scarcity. There remains a degree of data uncertainty sporadically within the collected data for the top 100 cities, this will be further addressed in Section 6.9. Yet, the decision to study 100 cities is made to anticipate trends within SCs' development. The rankings of the cities for both indexes are presented in Appendix C alongside their respective continents, countries, population, city size and level of development. [14, 50]

4.1.1 IMD Smart City Index

The SCI is a yearly ranking of worldwide SCs. It is published by the Business School *International Institute for Management Development* (*IMD*) in collaboration with the international association *World Smart Sustainable Cities Organization* (*WeGO*) with the goal to become an internationally recognized tool for action policymakers. *IMD* and *WeGo* are respectively based in Lausanne, Switzerland and Seoul, South Korea. [50]

The methodology applied by the *IMD* and *WeGo* to rank the cities consists of data collection and surveys of 120 inhabitants in each evaluated city. The participants answer questions related to their perception of structure and technological solutions available in their city. The questions are within the topics health and safety, mobility, opportunities, activities, and governance. The key survey data that was available is presented in Appendix A in Figure A.1. The environment-, sustainability-, and nature-related indicators are listed below. Note that this is based on assumptions, and the relevance to the mentioned indicators might be vague, as the *IMD* do not make this specific partitioning. [36]

- Structure; Health&Safety; Recycling services are satisfactory.
- Structure; Health&Safety; Air pollution is not a problem
- Structure; Mobility; Traffic congestion is not a problem.
- Structure; Mobility; Public transport is satisfactory
- Structure; Activities; Green spaces are satisfactory
- Technology; Health&Safety; A website or app allows residents to effectively monitor air pollution.
- Technology; Mobility; Bicycle hiring has reduced congestion

Further, the cities are placed into four equally sized groups, based on how high they score on the Human Development Index (HDI). The final score the city receives is based on a combination between the survey and the results from last two years' index's and the perception of the city compared to other cities within the same group. [36]

4.1.2 2ThinkNow Innovation Cities^{TM} Index

The ICI is an annual ranking as well, and claims to be the original, largest and longest-running innovation city ranking. The ranking is performed by the Australian-based innovation agency *2ThinkNow*, profiting from selling data, data models, evidence-based analysis or training to help clients innovate. Some of their clients are the tech-companies Samsung, Hitachi, and CISCO.[63] The index is based on 1,200 data points, 162 indicators, 31 segments, and three factors. Each indicator holds one or more data points. Further, the three factors forms the basis of the ICI. These three factors are cultural assets, human infrastructure, and networked markets. A noteworthy remark is that this index is now majorly driven by algorithms. [14]

Each year, the 162 indicators are selected from 188 available indicators to create the ranking. The 188 indicators are divided between 31 industries, securing a broad specter of the city activities to be included. Eight indicators out of the 162 are related to environment, sustainability and nature, whereas one is solely dedicated to the emissions at city level, or, in some cases, state/national level. The environment-, sustainability-, and nature-oriented indicators are listed below. [14, 6]

- Measuring the city air cleanliness, and potential for air quality in given geography.
- Is the weather consistent and conducive to work? Data points measuring the average climate.
- Data points on emissions at a city level where available, or state/national level in some cases.
- Measuring recent history of natural disasters and potential impact of natural disaster such as earthquake, flood, bushfires, cyclones.

- Natural environmental assets such as beaches, parks, wetlands which may affect life quality, and drive tourism/eco-tourism.
- Measuring noise causes, and classifying limitation measures.
- Measuring city park protection, and natural and wildlife preservation areas within immediate metropolitan area and inner-city.
- The major water features in terms of importance (e.g. major river), range of amenity and cleanliness.

All indicators are presented in Appendix B. One indicator worth mentioning is the GDP per capita. The benchmark definition for this indicator states that the per capita GDP is calculated on a real basis and using Purchasing Power Parities (PPP) where this is available. It also states that it is measured at the city metropolitan area level. [6]

4.2 Collection of Data on Carbon Footprints

Section 2.3 addresses the CF, defined as the annual emissions of CO_2-eq. per unit of comparison. For this study, the unit of comparison is capita; population. To compare the smartness of a city with the CF of relevance, this study used the "Global Gridded Model of Carbon Footprints (GGMCF)". This is a model that offers a comprehensive, globally standardized view, with a spatial resolution of 250 meters, presenting estimates of CFs on both a per capita and absolute basis across 189 countries. This data is from the year of 2018. It integrates established subnational models for the United States, China, Japan, the European Union, and the United Kingdom. The model is a collaboration between five professors from the universities NTNU, Yale, Shinshu University and Lund University. As the emissions are gridded, and not directly extracted from the cities reported emissions, there are uncertainties in the numbers extracted from the model. This would be a more crucial source of error if this study was looking into the emissions of the specific cities in depth. However, as the goal of this data collecting is to compare the emissions of the cities to each other, this uncertainty is not necessarily determining for the trend lines presented in the results. [24]

The published data from the GGMFC only includes 500 cities, while the project it is extracted from deals with 13,000 cities.[37] This results in a few of the SCs not being included in the published list. The principal investigator of the study, Daniel Moran, shared the document where the data for GHG emissions and population for the remaining cities was included.

The results related to CFs are presented throughout Section 5. In Section 5.1, the CFs per capita are also compared to the cities' respective countries. This data was collected from *Worldometer*'s "CO_2 Emissions per Capita" overview.[15] *Worldometer* was selected as one of the best free reference websites by the *American Library Association*.[67] An overview of the respective countries for the cities are shown in Appendix C.

4.3 Collection of Data on Energy sources

In order to map the cities' energy mixes, one significant assumption has been made. As it was demanding to obtain specific data for energy-consumption by source for each and every city, it is assumed that the energy mixes for the cities are the same as they are for the countries.

The data used is the 2022 statistics extracted from *Our World In Data*. The data is measured in kilowatt-hours (kWh) of primary energy consumption per person, and the energy sources are fossil fuels, renewable energy, and nuclear energy.[47] The data were used to calculate the percentages consumed of each energy source for each country. Appendix G shows all the calculated data for the energy mixes of the cities/countries.

4.4 Collection of Data on GDP per capita

This study uses GDP per capita as a measuring scale for a city's economy. The cities' GDPs per capita are collected using the *Organisation for Economic Co-operation and Development* (*OECD*) statistics for cities' economy. The SCs' GDP per capita were collected using the *OECD* statistics table with the settings:

- Variable: GDP per capita (USD, constant prices, constant PPP, base year 2015)
- Time: 2019-2020
- Country: The cities' respective countries

Section 6.9.2 further describes the limitations met when collecting GDP per capita for the cities not appearing in the *OECD* table. As there were 52 remaining cities from the indexes combined, and 14 of them Chinese, 20% was decided too critical of a gap to leave out. A different method was used to collect the per capita GDPs for the Chinese cities. *Ceicdata* was used to find the GDP for all Chinese cities in 2020. All cities were stated in billion RMB. The average RMB/USD exchange rate for 2020 is 0.1445 US Dollars per Chinese Yuan Renminbi.[11] The 2020 GDPs for cities in China were translated to USD, and divided by population. The populations were collected using the *Citypopulation* website.[13]

4.5 Collection of Data on Education level

To map the education levels of the represented cities, the overview made by *Datapandas* was used. The data accounts for the year of 2022, and is based on the "Education Index", which is a part of the "knowledge" component of the *UN*'s HDI. This index evaluates factors such as expected and actual years of schooling, and educational achievements at all levels. A country scores better on this index and ranks higher as it approaches a score of 1. [19]

The gathered data has been used to identify the possible connection between CFs and education level. The level of education has been found for every country, except from Taiwan, representing Taipei/Taipei City. The assumption that the cities' levels of education are the same as for the respective countries has been made.

4.6 Collection of Data on Temperature

The average annual temperature has been found for every city represented in this study. These temperatures are collected from *Climate-Data*. All of their available data is based on the *European Centre for Medium-Range Weather Forecasts* (*ECMWF*) Data. The model has more than 1.8 billion data points and a resolution of 0.1 - 0.25 grade. The temperature data were collected between 1991 and 2021. All of *Climate-Data*s graphs and datasets can be used under this license: Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) .

In the results, the cities' average annual temperature has been sectioned into their respective continents and compared to the respective CFs.

4.7 Statistical Calculations

As described in Section 2.6, the R^2 value is a factor presenting how much of the variance in the dependent variable can be explained by the independent variable. This value was obtained for each trend line in *Microsoft* Excel, using the built-in function. The output is a decimal between zero and one, where one means 100% fit. For this study, an R^2 value above 10% is considered acceptable, in line with the description in Section 2.6.

To check if the R^2 values are valid, p-values were obtained using a t-test. This is an Excel function that requires the XLMiner Analysis ToolPak to use the Data-analysis, and the tests were run with the independent variable as Variable 1, and the dependent variable as Variable 2. H_0 is always no correlation. The outputs are one statistical t-value, t_{stat}, one critical t-value, t_{crit}, and one p-value, p. If the absolute value of t_{stat} is bigger than t_{crit}, and p is below 5%, the deviation from H_0 is assumed statistically significant for this study.

As explained in Section 2.6.1, a Multivariate regression analysis is a good tool to use when considering more than one variable influencing another. In order to carry out the analysis presented in Section 5.2, the Data-analysis "Regression" tool in Excel was used. The cut-off limit for the p-value is set to 5% for the variables to be considered as significant.

5 Results

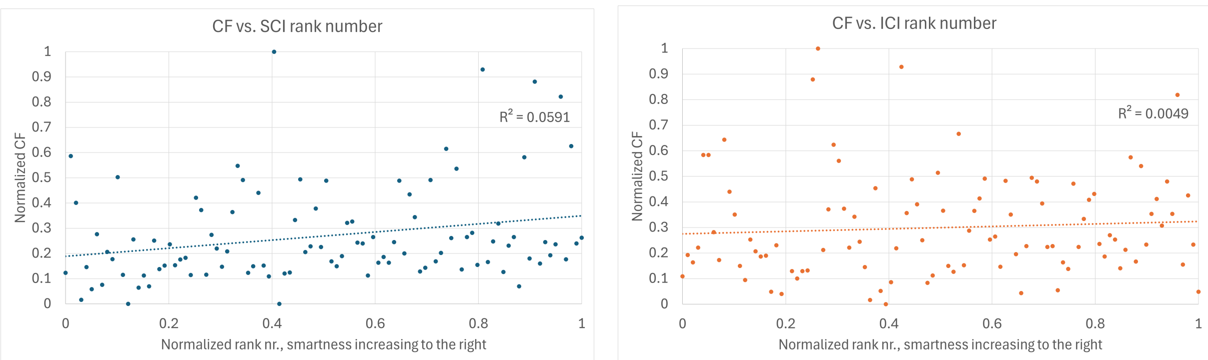
The results are presented in this section. Every graph has been computed in Excel. For graphs depicting rank numbers as the x-axis, the smartness increases to the right, along the axis. Every trend line is computed using the Excel "linear trend line" tool. For some plots, the linear trend might not be the best fit. However, these are still used as the aim of this study is pointing out general trends, not to establish a perfectly fitted trend. Also, knowing the linear models are not faultless outcomes, less reliance on the regression lines might reduce bias. The only exception from neglecting nonlinearity is the CF versus the smartness, as this is the main research question. In some cases, to provide a more distinct visualization of the trends, the cities are divided into three groups, ranked after smartness:

- Group 1: SCs ranked 1-33
- Group 2: SCs ranked 34-66
- Group 3: SCs ranked 67-100

The full rankings of the cities are as mentioned, presented in Appendix C. For the SCI, the color blue serves to present visualizations and to color code, whereas orange is designated for the ICI. All linear relationships are tested with t-tests. Statistical significance is determined when $|t_{stat}| > t_{crit}$ and $p < 0.05$ for all correlations.

5.1 Carbon Footprint vs. Smartness

Figure 5.1 shows the relationship between CF and the cities' rank numbers for both indexes. All values are normalized to be in a range from zero to one.



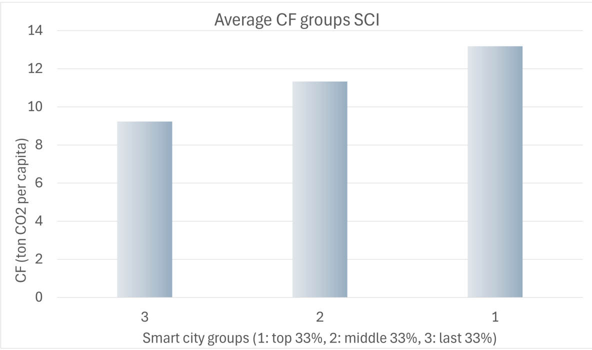
(a) SCI *(b) ICI*

Figure 5.1: Normalized CF vs. normalized smartness.

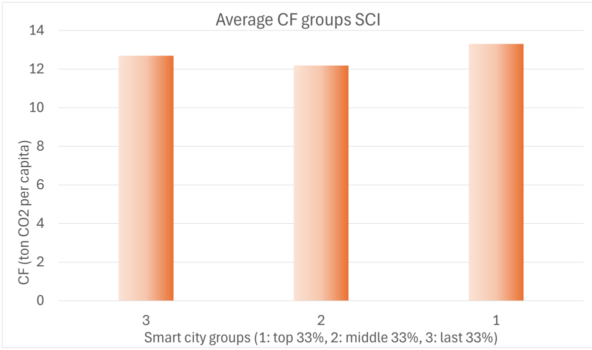
For the SCI, Figure 5.1a, the trend line shows that the CF increases with 16% as the smartness of the cities increases, while around 5% increase for the ICI in Figure 5.1b. Both correlations are statistically significant. As the R^2 for the SCI is approximately 6%, and 0.5% for the ICI, the variance in CF is not explainable by the smartness alone. However, there might be a small correlation, especially for the CF and the SCI cities' rank numbers. Comparing the figures, it is also evident that the trend shows that less smart SCI cities have lower CFs than the less smart ICI cities. The smartest cities, however, have around the same trend in CFs for both indexes. Other possible relationships between CF and smartness are tested and presented in Appendix F. The main findings from these tests are presented ass follows:

- The variations in the logarithmic CFs can not be explained by variations in smartness for either ranking. There does not seem to be a logarithmic relationship between CF and smartness.
- The variations in the square roots of the CFs can also not be explained by variations in smartness for either index.
- Dividing the rankings into the three groups by smartness does not provide any further explanation for the variations in CFs alone, for either index.

Figure 5.2 illustrates the average CFs for the three groups for both indexes.



(a) SCI

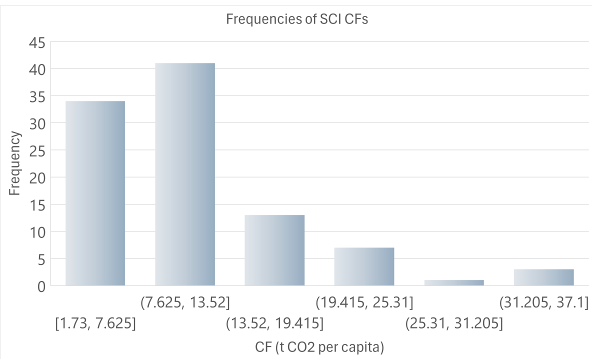


(b) ICI

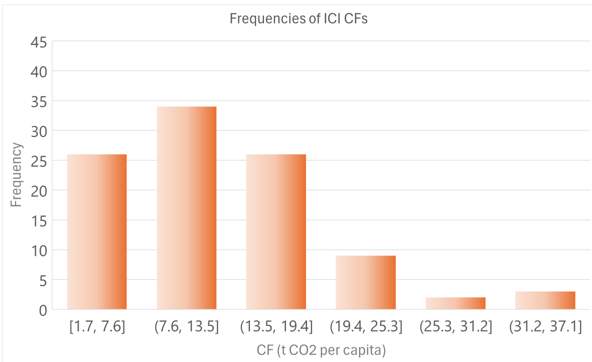
Figure 5.2: Average CFs for the cities grouped by smartness.

Figure 5.2a shows an indication of higher CFs for higher ranked SCI cities, and emphasizes the trend shown in the scattered plot, Figure 5.1a. From Group 3 to Group 2, the CF increases with 2.1 tons CO_2-eq. per capita, and from Group 2 to Group 1 with 1.85 tons CO_2-eq. per capita. The CF increases 3.95 tons CO_2-eq. per capita in total as the smartness of the groups increases. For the ICI SC groups, the footprint per capita does not strictly increase with the increasing smartness of the groups. From Group 3 to Group 2, there is a decrease of 5 tons CO_2-eq. per capita, and an increase of 11 tons from the second to the third. Another remark from these figures is that the CFs for all three SCI groups are lower than the corresponding ICI groups.

Figure 5.3 shows the frequencies of which different intervals of CFs appear for the cities in each index.



(a) SCI



(b) ICI

Figure 5.3: Histogram with frequencies of CFs.

The histograms in Figure 5.3 shows that there is higher representation among the lower CFs than the higher ones when dividing the CFs into six bins. For the SCI, as shown in Figure 5.3a, 75% of the cities' CFs are present in the two lowest CF bins. The remaining 25% of the CFs are in the upper four bins; 13 between 13.5 and 19.4; seven between 19.4 and 25.3; one between 25.3 and 31.2; and three between 31.2 and 37.1 tons CO_2-eq. per capita. As for the 75% lower CFs, 34 are between 1.7 and 7.6, and 41 are between 7.6 and 13.5 tons CO_2-eq. per capita. Examining the ICI CF frequencies, shown in Figure 5.3b, the distribution comes out slightly different. 86% are in the three lowest CF bins, while 60% are in the lowest two. Further, the distribution is 26 cities with CO_2-eq. per capita between 1.7 and 7.6; 34 between 7.6 and 13.5; another 26 between 13.5 and 19.4; nine between 19.4 and 25.3; two between 25.3 and 31.2; and, lastly, three between 31.2 and 37.1 CO_2-eq. per capita. To conclude, both indexes show higher representation of the lower CF groups. However, the SCI shows higher frequencies of CFs up to 13.5 tons CO_2-eq. per capita, 75%, compared to the ICI showing 86% of the CFs up to 19.4 tons CO_2-eq. per capita.

Appendix E provides a comparison of the cities' and the countries' CFs, the specific values are presented Appendix I. For the 100 SCI cities as included Figure I.1, 33 cities have lower CFs than their corresponding countries. For the ICI, as presented in Figure I.2, this is applicable for 38 of the 100 cities. When examining the SCI, a wide range of cities represented are West-Asian. It expands from Abu Dhabi, number 10, to Al-Khobar, number 99. The range of CFs varies from 7 to 33 tons CO_2, making it the geographical area with the widest range when looking at the SCI cities' CFs. This is in contrast to the ICI, there are four West-Asian cities. The first one is Dubai, number 14, and the last is Abu Dhabi, number 75. The CF range varies from 5.2 to 32.9 tons CO_2-eq. per capita. Looking at the specific CFs of the cities, these vary from 1.63 (Riga) to 37.1 (Shenzhen). For the SCI, seven cities considered has a CF below 4.85 tons CO_2-eq. per capita. These cities are Beijing, Riga, Bangkok, Tokyo, Chengdu, Osaka and Hanoi. For the ICI, CFs below 4.85 tons CO_2-eq. per capita applies to the nine cities Tokyo, Beijing, Osaka, Mexico City, Buenos Aires, Kyoto, São Paulo, Nagoya, and Yokohama.

Other findings from Appendix E worth mentioning are listed as follows:

- For the SCI, the CFs trend lines for West-Asia, East-Asia and Oceania decrease noticeably in line with the decreasing smartness, while they increase slightly for Europe and North-America, as the cities become smarter.
- For the ICI, the CFs trend lines for Oceania and South-America, East-Asia, and Europe decreases slightly in line with the smartness, while there is a slight increase for West-Asia and North-America.
- There are significant differences in average CF when comparing the continents to each-other:
  - Europe SCI: 9.43 tons CO_2-eq. per capita, Europe ICI: 8.7 tons CO_2-eq. per capita
  - Oceania: 14.04 tons CO_2-eq. per capita, Oceania ICI: 13.92 tons CO_2-eq. per capita
  - West-Asia: 17.30 tons CO_2-eq. per capita (excluding Muscat), West-Asia ICI: 17.98 tons CO_2-eq. per capita
  - East-Asia: 11.0 tons CO_2-eq. per capita, East-Asia: 12.15 tons CO_2-eq. per capita
  - North-America: 15.88 tons CO_2-eq. per capita, North-America ICI: 16.52 tons CO_2-

eq. per capita

  - South-America ICI: 2.9 tons CO_2-eq. per capita

- Some specific countries have a noticeably higher CF than the average of the geographical area. A common denominator for the cities listed below is that they take up a big part of their respective countries' area:
  - Singapore, a city-state
  - Hong Kong, an autonomous city
  - Shenzhen
  - Luxembourg
- For North-America, every Canadian city has a lower CF than Canada, while for the United States, this is only evident for a few of the cities.
- For Oceania, Australia and the Australian cities have a higher CF than New Zealand and its cities.
- South-America only has two cities included in the rankings, and both of them has relatively low CFs.

Looking at all the so far presented findings as a whole, and connecting them to the main research question: *Do smart cities contribute to reduction in greenhouse gas emissions?*, the simple answer to this is no, as the trend lines for CFs do not decrease as the smartness increases. Additionally, the majority of the SCs should have CFs below the benchmark of 4.85 tons CO_2-eq. per capita to sustain the aims of the Paris Agreement. When considering both indexes, only 13 out of 144 cities (9%) have CFs below 4.85. However, there are several factors that might impact the CFs of the SCs that could justify why there is such a low percentage sustaining the benchmark, leading this study to the next research question: *To which degree do other smart city aspects and geographical factors contribute to variations in carbon footprint and rank of smartness?*. Providing a possible answer to this research question will be the focus throughout the rest of the results-segment of this study, starting with presenting an MVRA in Section 5.2

5.2 Multivariate Regression Analyses

There has been conducted 40 MVRAs all together in this study, where the main findings from each are presented in Appendix H. Figure 5.4 shows the results from a multivariate regression analysis where the CF is the dependent variable, while independent variables are GDP per capita, smartness, education level and temperature. The theory related to these factors are presented in Section 2.6. The 79 observations for each analysis represent all the cities for which the GDP is included for this study. The values marked with color are the ones relevant for this study.

SCI MVRA: CF AS DEPENDENT VARIABLE WITH TEMPERATURE, EDUCATION LEVEL, RANK OF SMARTNESS , AND GDP AS INDEPENDENT VARIABLES								
Regression statistics								
Multiple R	0,491477561							
R-squared	0,241550193							
Adjusted R-squared	0,200552906							
Standard error	4,951400832							
Observations	79							
Analysis of variance								
	fg	*SK*	*GK*	*F*	*Significance-F*			
Regression	4	577,7878885	144,4469721	5,891858009	0,000358562			
Residuals	74	1814,211395	24,5163702					
Total	78	2391,999284						
	Coefficients	*Standard Error*	*t-Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Footprint (Intersection)	-11,55895002	6,442914104	-1,794056205	0,076888925	-24,39673661	1,278836564	-24,39673661	1,278836564
Temperature	0,5956737	0,167064439	3,565532573	0,00064067	0,262790538	0,928556862	0,262790538	0,928556862
GDP per capirta	7,06106E-05	2,77297E-05	2,546382966	0,012964074	1,53578E-05	0,000125863	1,53578E-05	0,000125863
Education level	12,23162583	6,666623993	1,834755618	0,070561065	-1,051912446	25,5151641	-1,051912446	25,5151641
Rank of smartness	0,018612537	0,021169661	0,879208055	0,382134605	-0,023568934	0,060794007	-0,023568934	0,060794007

(a) SCI

ICI MVRA: CF AS DEPENDENT VARIABLE WITH TEMPERATURE, EDUCATION LEVEL, RANK OF SMARTNESS , AND GDP AS INDEPENDENT VARIABLES								
Regression statistics								
Multiple R	0,433729363							
R-squared	0,18812116							
Adjusted R-squared	0,144235817							
Standard error	5,538917546							
Observations	79							
Analysis of variance								
	fg	*SK*	*GK*	*F*	*Significance-F*			
Regression	4	526,0511153	131,5127788	4,286651272	0,003565452			
Residuals	74	2270,290961	30,67960758					
Total	78	2796,342076						
	Coefficients	*Standard Error*	*t-Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Footprint (Intersection)	-11,11735391	7,239767201	-1,535595497	0,128902454	-25,54290496	3,308197132	-25,54290496	3,308197132
Rank of smartness	0,002428628	0,022489326	0,107990239	0,914295704	-0,042382333	0,047239588	-0,042382333	0,047239588
Temperature	0,474280267	0,143693617	3,300635601	0,001486274	0,187964486	0,760596049	0,187964486	0,760596049
Education level	15,69924691	8,339819638	1,882444416	0,063706996	-0,918206463	32,31670028	-0,918206463	32,31670028
GDP per capita	5,81275E-05	3,7258E-05	1,560135797	0,122994556	-1,61106E-05	0,000132366	-1,61106E-05	0,000132366

(b) ICI

Figure 5.4: MVRA: CF as dependent variable, temperature, education level, GDP, and smartness as independent variables.

The analysis for the SCI presented in Figure 5.4a presents several key findings. Firstly, the "R-squared" is calculated to be 24.16%. Specifically, this means that 24% of the variation in CF can be explained by the independent variables. However, since this analysis is considering more than one variable, the "Adjusted R-squared" of 20.06% might be a more fitting value for this analysis. Either way, both values are considered acceptable for this study. The same goes for the ICI analysis shown in Figure 5.4b, where the "R-squared" and "Adjusted R-squared" values are 18.81% and 14.42%, respectively. Even though they are also considered acceptable, these R^2 values indicate a lower possible explanation for variance in the ICI CFs due to the independent variables than for the SCI.

Secondly, the "Significance-F" indicates the probability that the regression model is wrong and needs to be discarded. Both presented values of 0.036% for SCI and 0.36% for the ICI are below 5% and therefore low enough to confirm that the model is certain enough to go further with, and the following step is to address the p-values. These values show the probability that the coefficient of the independent variable in the regression model is unreliable. With a cut-off limit at 5%, the analysis shows that for the SCI, the temperature and GDP per capita with a fail-probability of 0.06% and 1.3%, respectively, are ‘significant variables’. The education level and the rank of smartness, on the other hand, with respective fail-probabilities of 7.13% and 38.2%, are both above the cut-off level and are considered as ’insignificant variables’ having little influence on the CF. For the ICI, the education level, rank of smartness, and per capita GDP shows the respective p-values of 6.37%, 91.42%, and 12.30%. The only variable considered as significant for the ICI is the temperature, showing a fail-probability of 0.15%.

Lastly, the columns named “Coefficients” show the coefficients used to make the regression equations. This equation is one way to express the relationship between the variables in the form of a mathematical expression. The regression equations extracted from this analysis are presented in Equation 5.1 for the SCI and 5.2 for the ICI.

$$\begin{aligned} \text{CF SCI} = & -11.55895 + 0.5956737 \cdot \text{ Temperature [°C]} \\ & +12.23162583 \cdot \text{ Education level [0 to 1]} \\ & +0.018612537 \cdot \text{ Rank of smartness [1 to 100]} \\ & +7.06106 \cdot 10^{-5} \cdot \text{ GDP per capita [USD]} \end{aligned} \tag{5.1}$$

$$\begin{aligned} \text{CF ICI} = & -11.1173591 + 0.474280267 \cdot \text{ Temperature [°C]} \\ & +15.69924691 \cdot \text{ Education level [0 to 1]} \\ & +0.002428628 \cdot \text{ Rank of smartness [1 to 100]} \\ & +5.81275 \cdot 10^{-5} \cdot \text{ GDP per capita [USD]} \end{aligned} \tag{5.2}$$

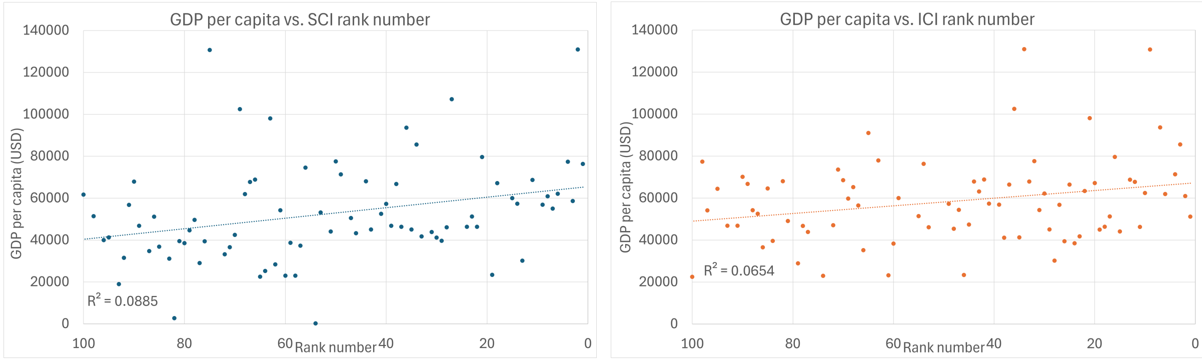
An interesting finding from the equations is the sign in front of the coefficients for all variables. In every case, these are positive, meaning that the independent variables only impact an increase in the CFs. However, it is important to underline that the coefficients for the insignificant variables has a higher possibility of being unreliable.

This MVRA reveals that there is a likely possibility that the variables GDP per capita and temperature might contribute to some degree to variations in CF, while there is a lower possibility of this being true for the variables education level and rank of smartness. Regardless, each variable will be further examined in this study.

5.3 GDP per Capita

5.3.1 GDP per Capita vs. Smartness

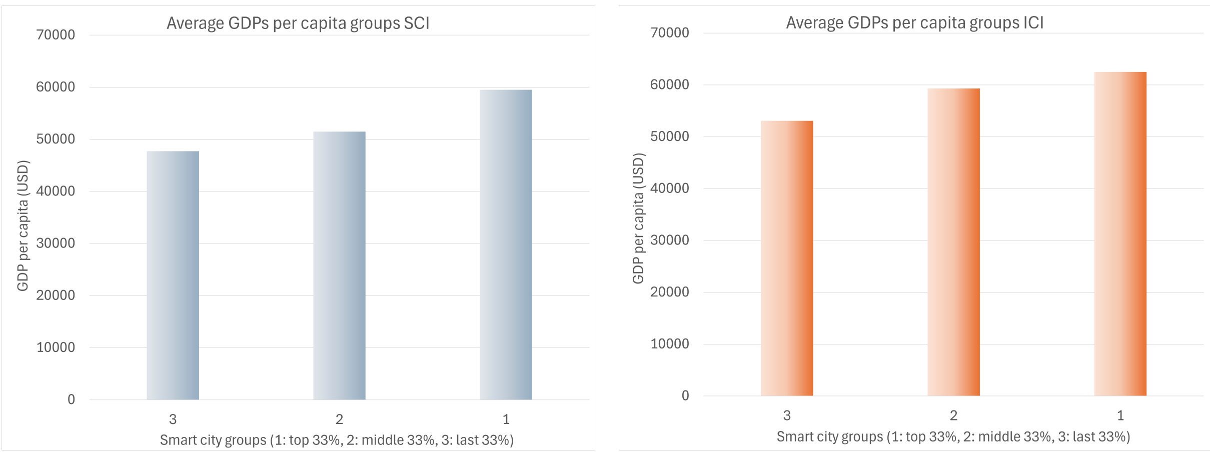
Figure 5.5 presents the cities’ per capita GDPs versus the smartness in terms of the cities’ rank numbers in the two indexes.



(a) SCI (b) ICI

Figure 5.5: GDP per capita vs. cities' rank numbers.

As the trend lines in the figures show, the smarter cities generally have higher per capita GDPs than the less smart. The trend line for the SCI in Figure 5.5a goes from around 40,000 to 65,000 USD per capita, which leaves a gap of ca. 25,000 USD per capita between the higher and lower end of smartness. As for the ICI, the trend line in Figure 5.5b goes from around 50,000 to 67,000 USD per capita, leaving a gap of ca. 17,000 USD per capita. There are many outliers, especially for the higher per capita GDPs. The R^2 number for the trend line is about 9% for the SCI and 7% for the ICI, and t-tests show that the relationships are statistically significant, however the correlation is small. Figure 5.6a presents average per capita GDPs for the grouped SCs.



(a) SCI (b) ICI

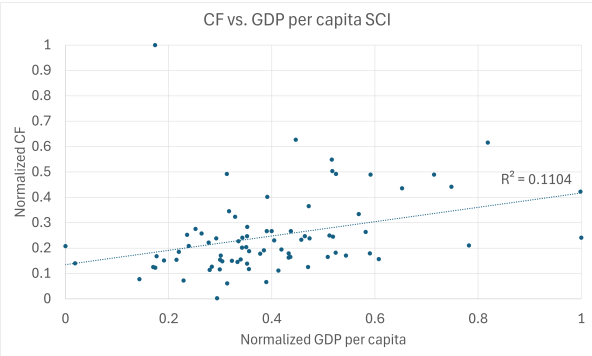
Figure 5.6: Average GDP per capita for the cities grouped by smartness.

From these figures, it becomes more apparent that the smarter city groups have slightly higher per capita GDPs than the less smart groups. For the SCI, Group 3 has an average GDP of 47,727 USD per capita, the average for Group 2 is 51,470 USD per capita, and the average for Group 1 is 59,509 USD per capita. In other words, the increase is more than doubled for Group 2-1 versus Group 3-2. As for the ICI, Group 3 has an average of 53,060, Group 2 has 59,317, and Group 3 has 62,514 USD per capita. This means the increase is almost doubled for Group 3-2 versus Group 2-1. Another remark is that all three ICI Groups have higher average per capita GDPs than the corresponding SCI groups.

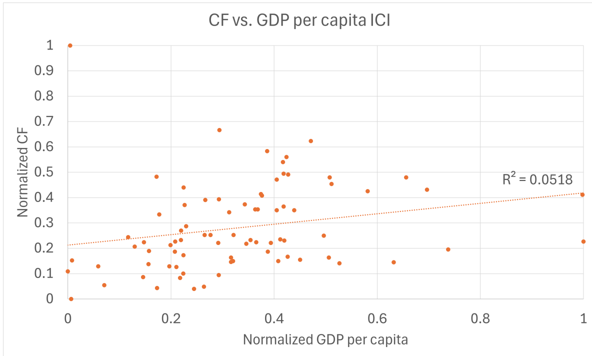
These findings indicate that higher GDPs per capita generally increase the smartness rank of a city vaguely. However, it is unclear whether it might be the other way around, meaning that the rank of smartness influences the GDP.

5.3.2 Carbon Footprint vs. GDP per Capita

Figure 5.7 shows two scatter plots of CF versus GDP per capita, one for each index. All values are normalized to be in a range from zero to one.



(a) SCI



(b) ICI

Figure 5.7: Normalized CF vs. normalized GDP per capita.

Both trend lines show that with increasing per capita GDP, the CF also increases. There are some statistical outliers here as well, and the R^2 number for the SCI is relatively low at about 11%. Running a t-test proves statistical significance. There can be assumed some correlation for the CF increasing with increasing GDP per capita for the SCI. However, the R^2 for the ICI is lower, at about 5%, with a $|t_{stat}| < t_{crit}$ and a p-value of 0.08, indicating statistically insignificance. The trend lines in the figures both suggest increasing CFs for increasing per capita GDP, however, the SCI correlation is more probable than the ICI.

Figure 5.8 shows how the SCI trend line would act for different data scenarios.

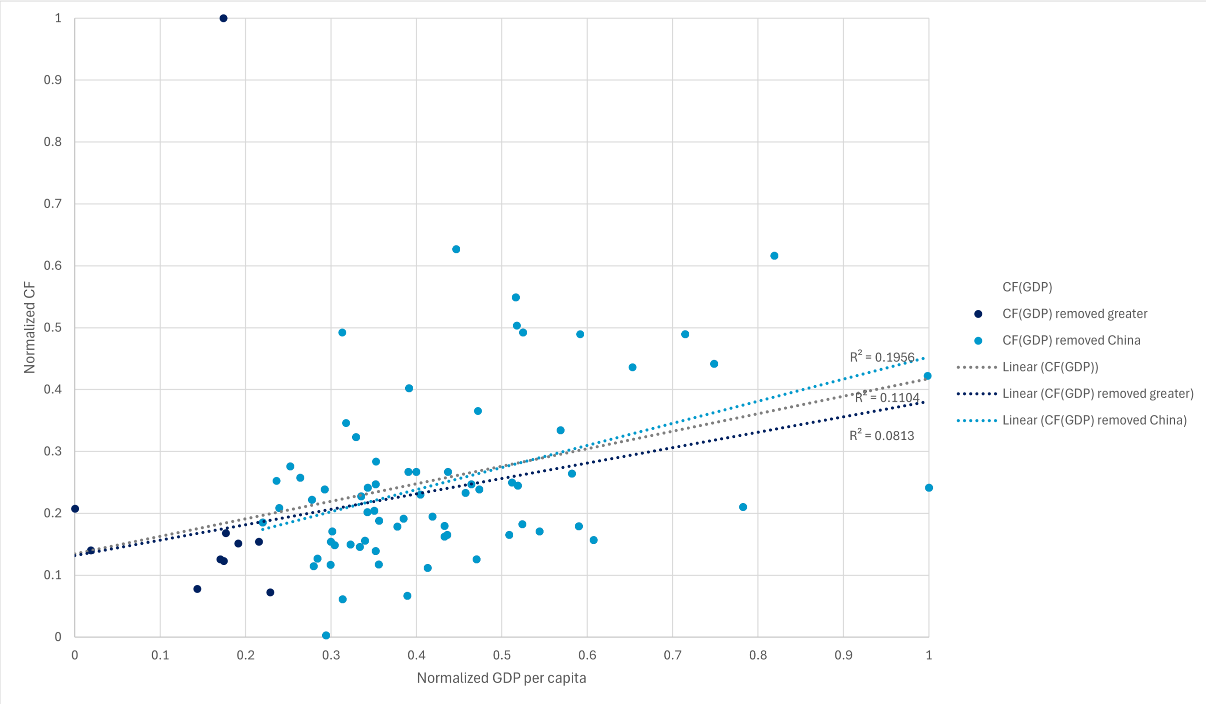


Figure 5.8: Normalized CF vs. normalized GDP per capita for three SCI scenarios.

In the figure, the CFs are the dependents on the per capita GDPs. The gray trend line in the figure is the trend for all the collected city data, showing increasing CFs for increasing per capita GDPs. With the limitations in mind, the dark and light blue lines are created for comparison purposes. The light blue line shows an additional increase in CF for increasing GDP per capita when Chinese cities are removed. The dark line shows a decrease in reference to the gray line, for when greater areas are removed. Examining the R^2 numbers, it is shown to decrease below 10% when removing greater areas, and increasing to almost 20% when removing Chinese cities. Both t-tests prove statistical significance. To summarize, the correlation showing CF increasing for increasing GDP per capita is more apparent when Chinese cities are removed from the data. This is another indication that the Chinese cities provide great uncertainties.

Figure 5.9 shows the CF as dependent on the GDP per capita, with trend lines for three scenarios using the ICI.

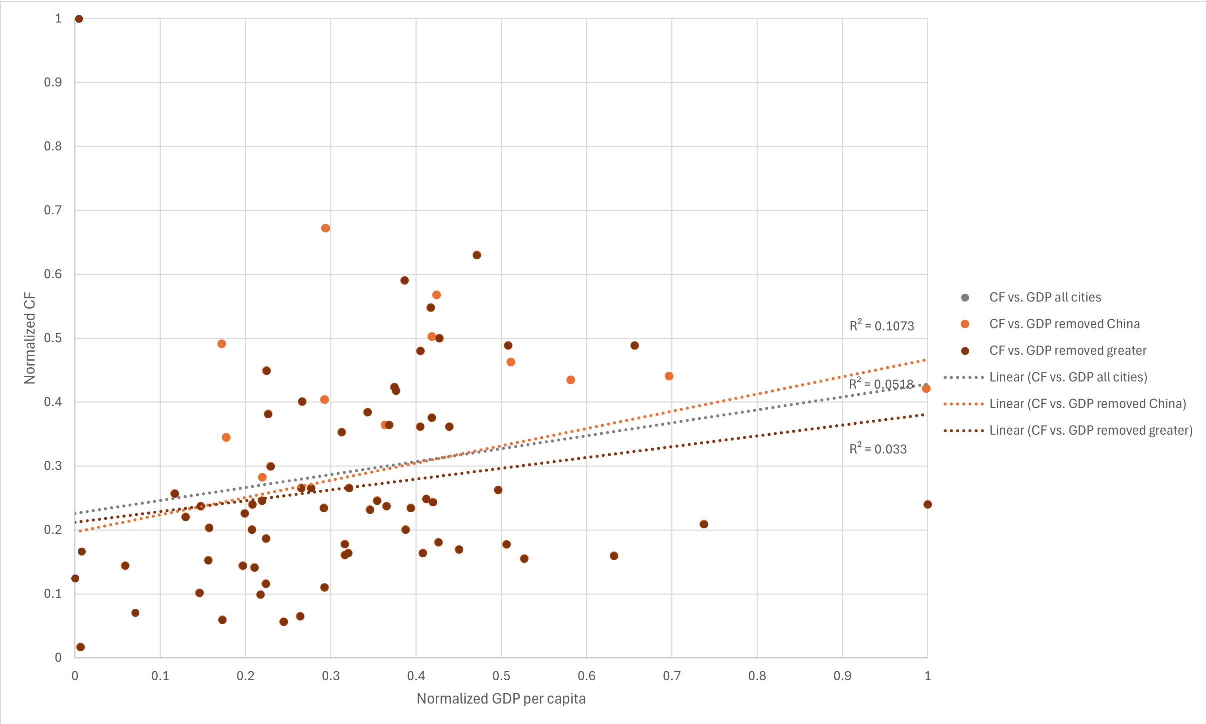


Figure 5.9: Normalized CF vs. normalized GDP per capita for three ICI scenarios

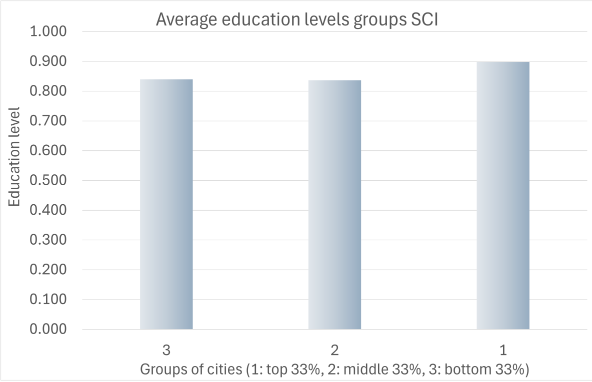
The gray line shows the same as in Figure 5.7b, the red line shows the CF for per capita GDPs when greater areas are removed, and the orange line shows when Chinese cities are removed. Examining the R^2 numbers, the scenario when Chinese cities are removed provides over 10%. Running a t-test for this scenario proves a statistically significant relationship. Running the t-test for the scenario where greater areas are removed proves statistically insignificant. However, the trend lines all point in the same direction, to the concept that CF increases with increasing per capita GDP, for the ICI as well. Also, removing Chinese cities further increases the CF, while removing greater areas proves less increasing CFs.

To address the research question of relevance, it appears as an increase in GDP contributes to an increase in CF. The degree of this contribution is uncertain, as there are several statistical outliers affecting the reliability of the results.

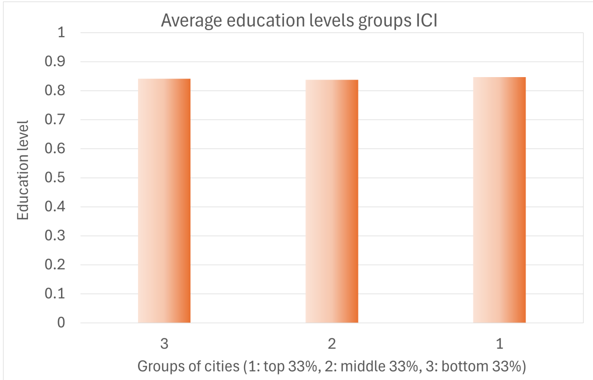
5.4 Education Level

5.4.1 Education Level vs. Smartness

Figure 5.10 presents the average education levels for the three groups of cities' countries for both indexes.



(a) SCI



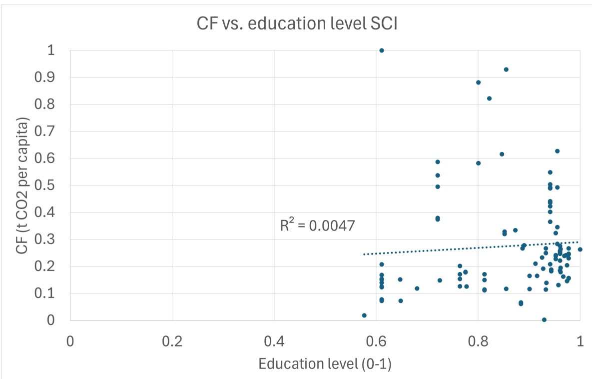
(b) ICI

Figure 5.10: Average education levels for the cities grouped by smartness.

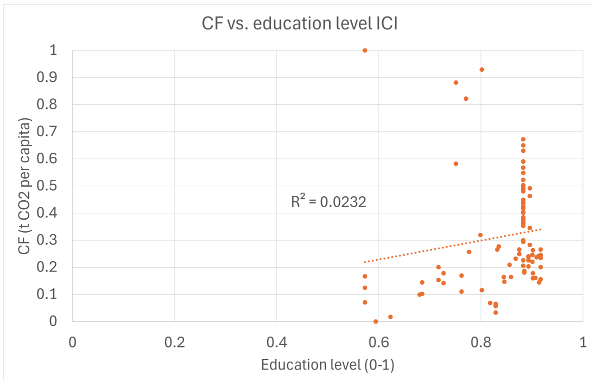
As evident from Figure 5.10a, the three SCI groups are in countries with different average education levels. The top 33% come out the highest, with an average education level of 89%. Further, the middle and the bottom has 84%. For the ICI groups of SCs, as shown in Figure 5.10b, the education levels are less distinguished. All three groups have average education levels at approximately 84%. Generally, there seems to be a very vague indication of higher education levels for higher ranked SCs, but there is no clear contribution of variations in smartness rank due to the variations in education level.

5.4.2 Carbon Footprint vs. Education Level

Figure 5.11 presents the CFs as dependents on the education levels for all the cities. The education levels are still the countries' education levels, however presented for the 100 cities for both indexes.



(a) SCI



(b) ICI

Figure 5.11: Normalized CF vs. education level.

Examining these figures, there seems to be little correlation between the education levels and the CFs. For the SCI cities, as shown in Figure 5.11a, the R^2 of the trend line is 0.5%, however, a t-test proves statistical significance. Further, Figure 5.11b presents the R^2 of the trend line for the ICI cities, which is 2.3%, yet also statistically significant. The trend line for the ICI shows a greater increase of CF with increasing education levels, in addition to the higher R^2 value. However, the relationship is not singularly explainable. In other words, there does not seem to be a singular explanation for variation in CF by examining education levels.

5.5 Annual Average Temperature

5.5.1 Carbon Footprint vs. Temperature

Figure 5.12 presents average CF and average temperature for the six present continents for both indexes.

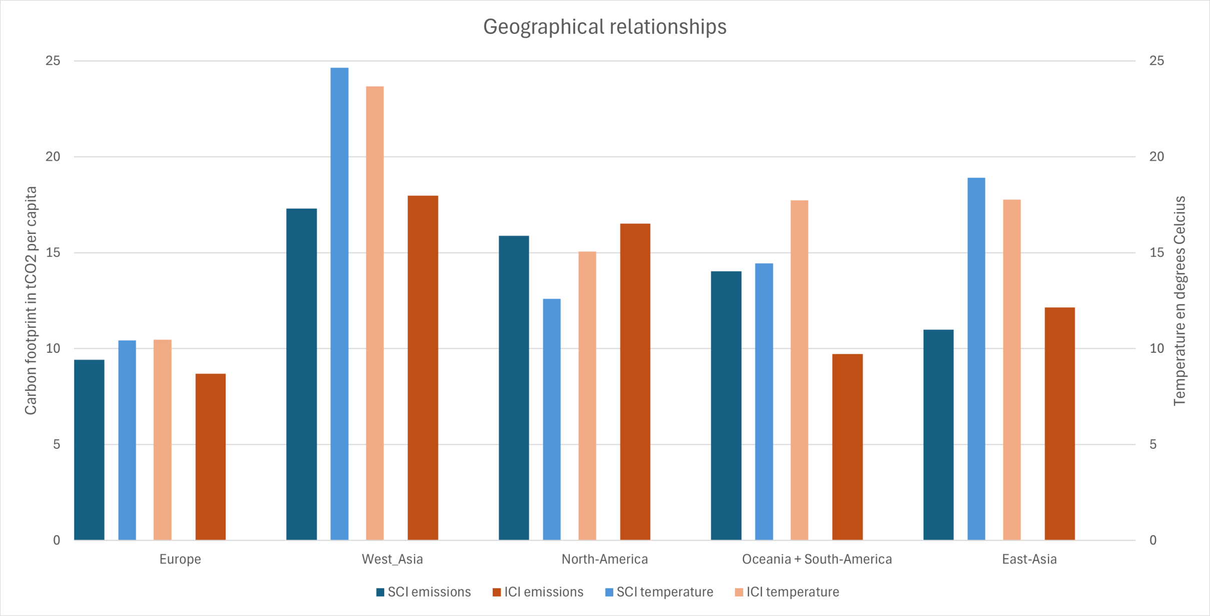
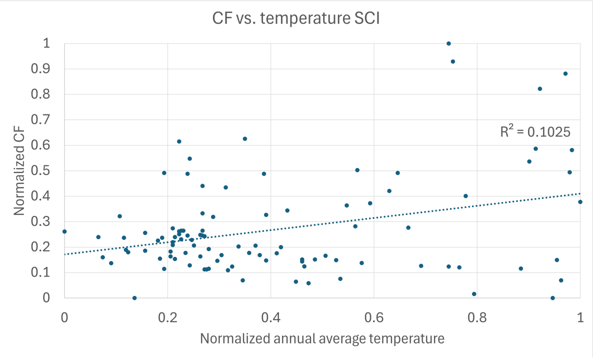
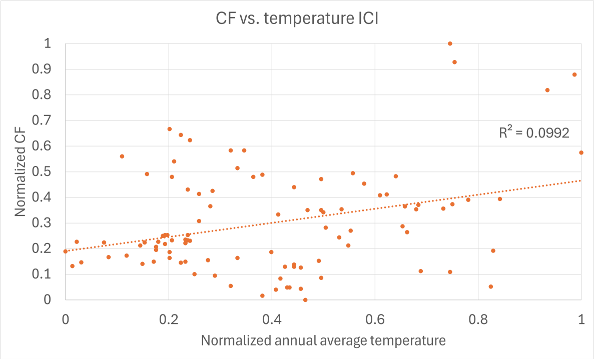


Figure 5.12: CF and temperature vs. geographical placement.

As the figure shows, the temperatures vary with the geographical placement of the cities. West-Asia has the highest average temperatures, while Europe has the lowest. Further, West-Asia also has the highest average CF for both indexes, while Europe has the lowest. This might point to some correlation, however the number of cities presented in each continent for each index vary. The outline of which cities are in the different continents is presented in Appendix C, Figure C.3. Figure 5.13 shows the relationship between the CFs and the temperatures for both indexes.



(a) SCI



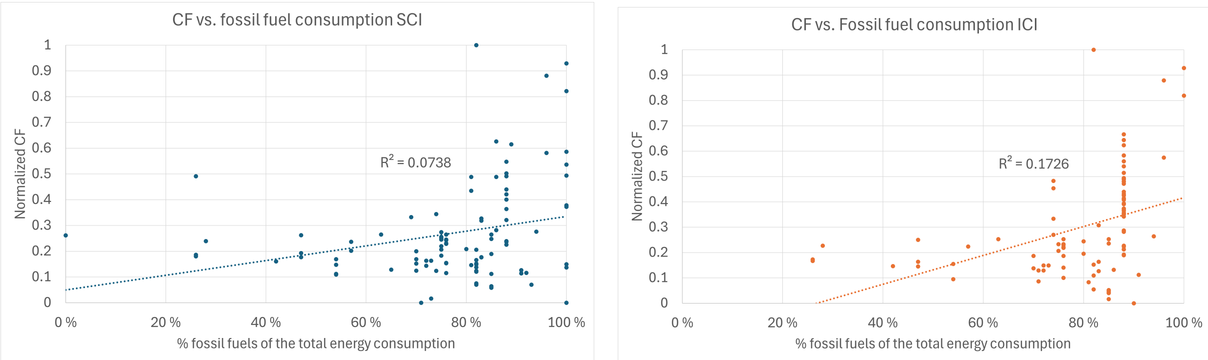
(b) ICI

Figure 5.13: Normalized CF vs. normalized temperature.

The trend line in both figures shows an increase in CFs when the temperatures increase, and the R^2-value for both indexes is 10%, indicating the CF variances can be explained by the temperature variances. Running t-tests proves statistical significance for both indexes. These results indicate that temperature might be a contributing geographical factor to variations in CF.

5.6 Carbon Footprint vs. Fossil Fuel Consumption

Figure 5.14 shows the normalized CF as dependent on the percentage of fossil fuels consumed by each city's country in each index. A full overview of the energy mixes for each city is provided in Appendix G.



(a) SCI *(b) ICI*

Figure 5.14: CF vs. fossil fuel consumption.

As shown in Figure 5.14a, the SCI cities' CFs increase as the use of fossil fuels increase in the cities' respective countries. However, the R^2 number is 7%, too small to state that the variance in CF is explainable by the use of fossil fuels alone. The t-test however, provides statistical significance. Yet, for the ICI cities, as presented in Figure 5.14b, the same trend is shown with a higher R^2 number of 17%. The t-test for this relationship also results in statistical significance. The ICI countries' consumption of fossil fuels might explain some variance in the CF for the ICI cities. When interpreting the fossil fuel consumption for each city, presented in the Appendix G, the average consumption is 77% for the SCI and 79% for the ICI. For the consumption of renewable energy, the average is 7% for the SCI and 6% for the ICI.

6 Discussion

In relation to the facing climate change treat and the consequence of globalization, introduced in Section 1, this study mainly aims to answer: *Do smart cities contribute to reduction in GHG emissions?* Delving into the research provided insights into the complexities of cities, engaging to the further research question: *To which degree do other SC aspects and geographic factors contribute to variations in carbon footprints and rank of smartness?* The findings are presented in Section 5, and this section will address the meaning of these findings in relation to the research questions.

Firstly, the current literature on the topic will be discussed. Further on, the main similarities and differences between the two indexes will be addressed. The different factors and SC aspects will then be presented chronologically based on the results. Addressed firstly, the correlation between CF and smartness. Secondly, comparing the respective GDP's with CF and smartness. Moreover, the correlation of CF and smartness with education level and annual average temperature, and with fossil fuel consumption in relation to CF. Each subsection will especially elaborate what the calculated R^2-values could indicate, as well as discussing the related MVRA results. The applied methodology in this study will further be discussed. Lastly, the limitations of this study will be addressed, which leads to the last section on recommendations for future research.

6.1 Comparison between the Findings and Previous Literature

In line with the findings presented in Section 5.1, based on the evaluated SC rankings, it seems that increasing smartness does not decrease the CF of a city. As there is no officially recognized definition of a SC, it is not clearly stated to which degree climate change should be taken into consideration. It aligns well with the findings by Dashkecych, where both the ICI and SCI scored "partially" on assessing environmental sustainability.

Based on the reviewed literature, the SC concept is still vaguely defined. There seems to be no clear definitions in regard to what researchers and policymakers can apply to identify SCs worldwide. However, Section 2.1 presented some SC definitions, showing that there has been attempts to conduct a comprehensive definition. Despite this, it does not seem like there is a definite answer to which definition to follow, but rather that one can choose the definition that best fits subjective goals and expectations.

The review processes highlighted the challenges related to defining SCs, primarily due to the multiple factors and elements that should be encompassed. The main elements and factors that recent researchers and academics highlighted were a combination of hard and soft strategies. This included for instance focus on ICT devices to improve existing systems and making them more efficient, as well as improving human rights, and enhancing social innovation all together. As mentioned, the challenges arise from the multiple factors involved in assessing SCs. The variations in factors likely stem from the complexity of cities themselves. There are many considerations that have to be made to ensure the well-being of citizens, preserve nature and biodiversity in the area, while also ensuring economic growth and technical development. It is difficult to agree on what should be emphasized the most among these topics, due to peoples' different perceptions and personal needs and values. This became more evident in the different methodologies applied for SCI and ICI, as presented in Sections 4.1.1 and 4.1.2. Had there been a consensus, perhaps there would have been one recognized standard ranking to adhere to.

Climate action and sustainable solutions seems to be increasingly focused on within literature on SC concepts, as the hope still is that SCs will be the sustainable solution for cities now and in the future. Figure 3.1 for instance, shows that environmental sustainability initiatives has been the biggest area of focus, with 28% of the initiatives. I line with added focus on environmental sustainability, more questions have been raised regarding the actual environmental effect of ICT devices. It has for instance been implied that sensors could lead to more control over energy consumption, making it possible to predict trends and by this save energy. Although this is the desired result, studies have found that ICT devices actually lead to higher energy consumption. It is not fully comprehensible why these the implementation does not have the desired result. However, one reason for this could be the inadequate implementation by society and that climate goals and SC goals for a city do not seem to align. Another reason could be that the overall environmental impact of such implementations have not been sufficiently examined prior to the implementation. In relation to climate change, if such installations oppositely result in higher energy demand, and this energy originates from fossil fuels, this could have a negative impact on CF in cities. An additional interesting aspect from the literature, is that some measures are not aiming to reduce emissions, contrary aiming to do preventive measures by implementing sensors and improving infrastructure. If such implementations are the main emphasized aspects in rankings of SC, one would potentially not experience reduction i emissions, contradictory maybe experience the opposite trend.

Based on the assessed literature on the topic, the most common way to assess SCs rankings is by comparing different methodologies to each other. From this, there are no clear indicators on which rankings are better than others, as most rankings for instance score "partially" on assessing environmental-, social-, and economic sustainability. This could be one reason for why there mainly is literature assessing methodologies, to attempt to identify the "perfect" SC ranking.

There is still some uncertainty concerning whether this is the most beneficial method to assess which cities are smart or not. However, the use of rankings is said to help simplify the concept, and that a combination of rankings help create a more nuanced picture of results of rankings. It seems to be a helpful tool for researchers to choose which cities to assess and compare, this has been the case in this study as well.

6.2 Comparison between the Evaluated Rankings

It is proposed that city rankings is a tool to simplify the complexities of the SC concept. To address this statement, a comparison between the applied methodologies in the SCI and the ICI was conducted. However, no exact similarities were identified, as they weigh various factors differently and collect data from different types of sources, even though some factors are within similar categories. The comparison of the methods only perplexes the overall impression of what factors different rankings value. However, the results presented throughout this study show a general similarity in trends between the two rankings. This emphasizes that even though the methods applied to decide which cities to include in the ranking may differ from each other, the overall performances are similar. This could indicate that if several rankings were included in the study, the overall trends would be similar. However, this cannot be definitively stated, as it could be a coincidence.

The sub-research question raises concerns about how different factors, e.g. geographical differences, could influence the CF and smartness of a city. Additionally, the different methodologies applied could lead to differences in the geographical results. Dashkevych, for instance, found that there are regional variations in the interpretation of SC factors. According to their study, environmental factors were emphasized in European cities, while societal factors were highlighted in Asian and Oceanian cities. As presented in Sections 4.1.1 and 4.1.2, the SCI is a collaboration between two non-companies located in Switzerland and South-Korea, and the ICI is a ranking conducted by an Australian-based company. This could thereby indicate that the SCI focuses more on environmental aspect in addition to societal aspects, while the ICI may mainly focus on societal aspects. This relation between geographies and ranking methodologies will be further explored throughout this discussion.

Also in terms of geographies affecting the rankings, the two rankings presented in Appendix C display various geographical differences. Within the first one hundred ranked cities, 56 of them are the same for both indexes. Additionally, of the total 50 countries included in the indexes, 32 countries are the same. This implies that there is some consistency in which cities are considered smart. However, with the representation of continents, the two indexes vary. Europe is represented the most in the SCI with 49 cities, in comparison to the ICI who included 35. Further, the highest represented continent for the ICI is North America with 40 cities, and only 14 cities included in the SCI. The representation of the other continents for the SCI and ICI are respectively; East-Asia 20 cities and 13 cities; West-Asia 10 and 4 cities; Oceania 6 and 5; South America 0 and 3. Neither of the lists have included any African cities within the first 100 cities. Thus, could it be interesting to include more African perspectives on SCs.

Another factor that could influence the results is the organization behind the ranking. The SCI is a collaboration between two non-companies, while the ICI is a "product" by *2ThinkNow*, a company with focus on data technology. In context with the hard and soft strategies and considering the finding that technology based companies mainly focus on hard strategies, one could assume that the SCI would have a soft strategy and the ICI would have a hard strategy. This could influence the indicators chosen to be evaluated, which further could explain the differences in chosen cities for the indexes. Based on the methodologies applied, by evaluating the indicators for each method presented in Appendix A it seems that both indexes have a combination of hard and soft strategies when evaluating city performance. The three substantial factors for the ICI, are for instance assessing cultural assets, human infrastructure and networked markets. While the SCI assesses health&safety, mobility, opportunities, activities, and governance in relation to structure and technology. However, since the ICI has 1,200 data points the overall methodology is far more comprehensive than the SCI's. Depending on whether their strategies are more hard, soft or a combination, this could have an influence on the results in terms of footprint, GDP and education level. This is however difficult to determine without a highly comprehensive analysis of the methodologies.

In regard to the main research question, assessing if the cities contribute to reduction in emissions, a relevant factor is to evaluate if the methodologies are assessing emissions. As described in Section 4.1.1, the SCI is based on data from surveys. In essence, the inhabitants' perceptions of the cities are what determines the cities' rank numbers. When looking at the environmental indicators, there are none of which the inhabitants are asked to assess their satisfaction with the emissions or the CFs of their city. Yet, the survey asks residents about their satisfaction with the cities' air quality, however these indicators are not to be confused.

As for the ICI, as described in Section 4.1.2, 162 indicators are annually selected, from which the cities are assessed. The eight options oriented around environment, sustainability, and nature contains one indicator directly related to emissions. It is unknown whether this indicator is included for the 2022/2023 index, however it is likely, as emissions were not less important for this year than any previous year. There is uncertainty about whether these emissions are consumption- or territorial-based. While the SCI inquires the attitudes of 120 residents in each city, which is a limited number as none of the cities have populations smaller than 100,000, the ICI mainly relies on algorithms to perform their indexing. Concluding, the degree of which both methods are assessing the CFs of the ranked cities is uncertain.

6.3 Carbon Footprint in relation to Smartness

As elaborated in Section 2.3, the CF for the cities should be decreasing over time to meet the aims of the Paris Agreement. All CFs are from 2018, including the ones presented in Section 5.1. When seen in context with Figure 2.2, the CFs should be between 4.0-4.85 tons CO_2-eq. per capita for that year to be considered as a contributing city to the climate goal of the Paris Agreement. As mentioned in the results, only 7% of the cities from the SCI and 8% of the cities from the ICI fulfill this criterion. These relatively low percentages suggest that there may be limitations or challenges in fully realizing the potential of smart technologies to address climate change. This is supported by Ipsens findings presented in Section 3.2; that not all SC technologies reduce environmental impact. They can also be an indication of gaps in policy frameworks and implementation of strategies at the city level. This is an opposing finding to the mentions from Xia and Contreras; that SCs are policy practices for reducing carbon emissions, and that action to mitigate climate change effects predominantly occurs at the city level. The low percentages could suggest that existing initiatives to promote sustainability and reduce emissions are insufficient or not effectively enforced. Evaluating the findings from Cavada, this seems reasonable as 28% of SC initiatives are within the field of environmental sustainability, and further, 36% of these initiatives are regarding climate change. This might highlight the need for stronger incentives and international cooperation to encourage cities to prioritize climate action and meet their commitments under the Paris Agreement. This supports the finding presented in Section 3.2 made by Obringer, that there is little connection between SC initiatives and climate action plans in cities.

Another aspect for consideration is how the city-emissions appear in relation to the country-emissions. As presented in the results, 33% of the cities in the SCI and 38% of the cities in the ICI have lower CFs than their respective country. In Section 2.1, it is mentioned that cities should focus on reducing their adverse per capita environmental impact to comply with SDG 11.6. Given that SCs are often characterized by their innovative approaches to sustainability and technology integration, one might expect a higher percentage of these cities to have lower CFs compared to their respective countries. The percentages of 33% and 38% suggests that while SCs might be making progress in implementing smart technologies and initiatives, there are still significant challenges to overcome in achieving substantial reductions in carbon emissions. This is concerning as Paträo estimates that 72% of worldwide GHG emissions are generated in cities. However, the fact that some SCs have achieved lower CFs than their countries demonstrates potential.

Further, the main research question addresses whether SCs contribute to reduction in GHG emissions, which in this case is defined as the CFs. Again, examining Figures 5.1 and 5.2, point to the indication that increasing smartness also increases CFs. From the first set of figures, it is shown that the increase is apparent for both the SCI and the ICI, however the tendencies are very small. The R^2 numbers indicate that variance in CF can not be explained solely by the smartness. As for the second set of figures, the CFs for the SCI display an even increasing trend, while the ICI does not. It can from these findings not be stated whether the CFs increase or decrease depending on the rank of smartness for rankings in general. It can, however, be argued that the SCI might have increasing CFs for increasing smartness. Further, a possible explanation to the average CF decrease from Group 3 to 2 for the ICI is found when studying the order of how the cities are ranked compared to each other. For instance, Abu Dhabi is included in both indexes, however, ranked as number 10 for the SCI and as number 75 for the ICI. The city has a CF of 33 tons CO_2-eq. per capita, placing it in the top 5% of the cities with the highest CFs. This probably has an impact on the results. Again, this indicates that the indexes weigh the CFs differently, and that the ICI might rank higher CFs as less smart.

Further examining the same figures, it is evident that the trends point to less smart SCI cities having lower CFs than what of the less smart ICI cities, while the trend lines increase towards approximately similar values. From the second set of figures, it is also shown that when dividing the cities into groups by smartness, the SCI have lower CFs for all three groups. The indexes weighing the CFs differently when ranking the cities is also shown in the histograms in Figure 5.3. The figures show a skewed normal distribution focused around CFs between 7.6 to 13.5 tons CO_2-eq. per capita. Combined, the distributions of these frequencies for the SCI and the ICI support the argument that SCs take emissions into consideration. However, the argument that the ICI is valuing lower emissions more heavily than the SCI in their ranking is not supported by these distributions.

The MVRA results are presented in Section 5.2. Figure 5.4a displays the results for the SCI, and Figure 5.4 for the ICI. When interpreting the p-values for the rank of smartness as an independent variable and the CF as the dependent, these also indicate that there is no significant correlation between the CFs and the rank of smartness for the cities. The p-values for the SCI and the ICI are 38% and 91%, respectively. The results from the remaining MVRAs presented in Appendix H can also not provide any explainable relationship between the CF and smartness for either index.

To summarize, only a small percentage of each index's cities have CFs below the Paris Agreement limit for 2018, less than half of the cities report lower CFs than their respective countries, and the relationships between CF and rank of smartness display little to no correlation for either index. Based on these arguments, it could be assumed that CF is not taken into any consideration when creating a SC index. However, there is as mentioned demonstrated potential for SCs to reduce their CFs, and this, in addition to one of the indexes including emissions as a factor when performing the ranking, suggests the opposite. Taking these findings into consideration, it might be stated that SCs do not contribute to reduction in GHG emission.

6.4 GDP per Capita in relation to Carbon Footprint and Smartness

As the correlation between CFs and smartness presents only a vague relationship, the correlation between GDP per capita and smartness presented in Section 5.3.1 is investigated. Taking into consideration the World Bank's statistics message that over 80% of global GDP per capita is generated in cities, and Paträos estimation that 80% of all economic growth is generated in cities, SCs should be no exception. In fact, as two of the three definitions stated in Table 2.1 in Section 2.1 mention either economic sustainability or economic growth, it could be assumed that SCs are economically stable. In addition to this, the *European Commission*'s definition takes efficiency of networks and services into consideration, which is in line with Marzouk's recommendation to incorporate technology in SCs. The cost of such systems is not negligible, and further supports the argument that SCs should have the economic capacities to incorporate these technologies. Examining Figure 5.5, it is apparent that when smartness increases, so does the GDP per capita for both indexes. However, perhaps not surprisingly, the variation in GDP per capita can not singularly be explained by the smartness. Figure 5.6a demonstrates the trends with more reliance, as each smarter city group for either index outdoes the previous in terms of average GDP per capita. According to the MVRA presented in Appendix H, when the per capita GDP is the dependent variable, smartness is a significant variable for some situations. However, the relationships are disregarded when evaluating the per capita GDPs as independent variables for the smartness. This supports the finding that some correlation is apparent between per capita GDP and rank of smartness, however ambiguous.

It is evident from the figure that the ICI groups all have higher average per capita GDPs than the respective SCI groups. It is also indicated from Figure 5.5 that the trend for the less SCs' GDP per capita differ around 10,000 USD between the indexes, where the SCI indicates a lower trend than the ICI. Yet, the trend for the smartest cities for both indexes point to similar and higher per capita GDPs. These indications point to the ICI valuing economic factors higher than the SCI, however the trends should not be interpreted directly as a correlation. The increases in average per capita GDPs differ between the groups in the indexes. As mentioned in Section 5.3.1, the increase from Group 2 to Group 1 is more than double the increase from Group 3 to 2 for the SCI, whereas the ICI displays an increase from Group 3 to Group 2 that almost doubles the increase from Group 2 to Group 1. The similarity in per capita GDP trend between the indexes indicate an interesting finding. As both trends are approximately as steep and as vague as each other, it might be argued that both indexes value per capita GDPs equally, and other factors are predominantly influencing the rankings.

As the relationship between per capita GDPs and rank of smartness shows a vague increase in per capita GDP for increasing smartness, it is interesting to evaluate the relationship between CF and per capita GDP. It is previously shown and discussed that increasing smartness increases CFs, even though the tendencies for this also are ambiguous. Comparing the previously discussed results, the assumption that increasing per capita GDP will, in turn, increase the CF does not seem radical. This is also in line with the statement by the *IRENA*; that economic growth has been closely related to increasing GHG emissions.

Examining the MVRA in Section 5.2, it is evident that the SCI CFs are dependent on the per capita GDPs, as the p-value is below 5%. However, the coefficient is very small, indicating that the per capita GDP drives the CFs to only a small extent. For the ICI, this correlation is not evident, as the p-value is above 5%. Figure 5.7 points to the same evidence; the SCIs CFs' relationship to the per capita GDPs is statistically significant and shows an increase in CFs with increasing per capita GDPs. The R^2 for this relationship also points to variation in CF being singularly explainable by variation in per capita GDPs for the SCI, as it is above the limit of 10%. The ICI displays the same trend, however no relationships are statistically significant. These results display unexpected differences between the indexes when taking the example from Section 2.4.1 into account. Here, another MVRA is performed with CO_2 emission level as the dependent, and GDP per capita as an independent variable. Model **2b** incorporates a scenario where industrialized countries are presented. This is as mentioned a fitting scenario for this study, as 50 of the 71 countries are present, however, some difference in outcome is to be expected as the model analyzes countries' CO_2 emission levels, and not cities. Examining the outcomes, however, they differ greatly from the results of this study. The adjusted R^2-value for the model is 31%, meaning the proportion of explainable variance in CO_2 emissions is 6 times higher for the model, than the proportion of explainable variance in CF for the SCI, when GDP per capita is the independent variable. This distinction is unforeseen, and further diminishes the confidence in the relationships found between the CFs and the per capita GDPs in this study. It is assumed that most global studies assessing countries evaluate territorial-based emissions, as these are more accessible and more frequently used than consumption-based emissions. As the model examines countries, as opposed to cities, it is probable that territorial-based emissions were used in the analysis. This might indicate that the relationship between territorial-based emissions and GDPs is stronger than for consumption-based.

Further analyzing the results for the scenarios when data for unoriginal methodologies are removed might explain the previously mentioned differences in outcomes from this study and Model **2b** in Section 2.4.1. As presented in Figure 5.8, the relationship between CF and GDP per capita is strengthened by removing Chinese cities for the SCI. There is a further trend of increase in CFs for increasing per capita GDPs, and almost a double proportion of variance in the CFs can be explained by the per capita GDPs. This notion might be explained by several influences. Firstly, there has been used a different approach to collecting Chinese per capita GDPs than for the remaining cities. The method of measuring GDPs might influence the per capita GDPs if different from the original method. Also, the area of which populations are collected could have tremendous impacts on the per capita GDPs. Investigating the Chinese cities' populations presented in Appendix C, they vary between 2 million and 24 million inhabitants. If these are estimated with different area sizes, it should remarkably increase or decrease the per capita GDPs. Also, the CFs are presumably calculated based on the household sizes, as the data for CFs are consumption-based emissions. If there are more people living in the same household, the CF will decrease, which could be the case according to Figure 5.8. In other words, it is uncertain why the Chinese cities provide such great uncertainties in the CFs versus the GDPs per capita for the SCI. Examining the ICI figure, the same indications are shown when removing Chinese cities, and the same uncertainties are provided. Some cities are noted "greater" when collecting per capita GDPs. Due to this notion, these areas are removed to form another scenario, in relation to the previously mentioned uncertainties difference in areas might prompt. For both indexes, this scenario provides lesser explanation of variance in CFs by per capita GDPs. Also for both indexes, the trend lines display slightly less increase in CFs as dependent on per capita GDPs.

Overall, the CF seems slightly related to GDP per capita, however other factors are assumed the main drivers of the increasing CF for increasing smartness, while the per capita GDPs might contribute some. The expectation was that the ICI value higher per capita GDPs than the SCI in their rankings, and this is disregarded, however true to some extent. As all results show the same tendencies for both indexes, it could be assumed the inhabitants answering the questionnaire for the SCI have an experience of the cities that aligns well with the data points for emissions and economy that are valued for the ICI.

6.5 Education Level in relation to Carbon Footprint and Smartness

The education levels for the countries of the cities were evaluated in context with smartness and CF in Section 5.4.1. As mentioned in the literature review, investments in education systems is one of the soft strategies in SCs that focuses on improving life. Also, Blasi finds that one of the most frequently mentioned concepts related to the SDGs is education. However, it turns out that none of the studies researched has evaluated education level as a single factor in context with SCs, it has only been included as a sub-factor under the HDI. Including this factor as an individual variable could therefore reveal undiscovered correlations. However, given the fact that all the included countries in this study are defined as industrialized, one could expect that the results might lack contrast, with industrialization driving the demand for educated workers and creating conditions that promote higher levels of educational attainment.

Looking at the scattered plots shown in Figure 5.11, neither of the indexes have included countries with a lower education level than 0.541 (Vietnam), and for both indexes there is no remarkable difference between Group 2 and 3 shown in Figure 5.10. When looking at the top 33% of the SCs for both indexes, there is an indication of a higher education level for the countries in the SCI with an average education level of 0.89, while it is 0.84 for the ICI. Looking into the data, this difference is most likely caused by the SCI having included Reykjavik (Iceland), the country with the highest level of education globally, in their top 33%. Additionally, the SCI generally has a higher concentration of European cities in their top 33% than the ICI, who has a higher concentration of North-American cities. As explained in Section 2.5, Nordic countries (European) generally score higher on education level than the US (North-American), providing a possible explanation for this result.

Looking at the scattered plots where the education level is compared with and CF, the correlation between the two is weak with respect to the presented R^2-values of 0.5% and 2.3% for the SCI and the ICI, respectively. When seen in context with the p-values of 7% for the SCI and 6% for the ICI, both indexes are above the 5% cut-off limit. This makes education level an insignificant variable when seen in context with CF, and any further discussion of a possible correlation between these two single variables would be speculation. This becomes more evident when analyzing the MVRA with education level as the dependent variable presented in Appendix H. In the MVRA, the rank of smartness is never considered a significant variable, and CF is only considered as significant in the one case where GDP is excluded. However, the MVRA does indicate that Education level might not be irrelevant as an aspect to consider in context with the SC concept. The presented Adjusted R-squared values are generally high for every case, averaging at around 40% for the SCI and 30% for the ICI. Every p-value is within the cut-off limit, and GDP and temperature are variables that are considered significant in every case where they are included. This suggests that variations in GDP and temperature may have an impact on variations of education level, and that this possible impact is stronger for the cities present in the SCI than for the cities in the ICI. This finding is not surprising, as it is assumable that citizens in cities with higher GDPs per capita may more easily access higher education, and cities with a higher average level of education might have the possibility to generate higher GDPs. Seen in context with the finding made by Dashkevych, that there are regional variation in the interpretation of SC components, it is expected that the SCI emphasizes both environmental and social aspects, and that the ICI focuses more solely on the social aspects. With education level being a social aspect, this finding is not contradictory nor congruent to the finding, as it has GDP and temperature as significant independent variables for both indexes on the basis of the MVRA.

6.6 Temperature in relation to Carbon Footprint

In the MVRA presented in Section 5.2, the only independent variable considered as significant for both indexes is the temperature. With the p-values being 0.07% for the SCI and 0.14% for the ICI, the fail-probability of this factor having an impact on the CF of a city is classified as very low. Since the geographical locations is what usually determines the temperatures, the cities evaluated were grouped by their respective continents and compared. Figure 5.12 shows a clear trend; The average CFs are higher in the continents where the average temperatures are higher. The scattered plots presented in Figure 5.13 shows the R^2-values of 10%, among the strongest correlations between CF and other single variables when examining both indexes collectively. Looking at the listed indicators for the ICI in Section 4.1.2, one of them measures the average climate. With the presumption of temperature being included in this measuring, it is assumable that the connection between CF and temperature would be more evident for the ICI. The results indicate that this is not the case.

This correlation opens multiple possibilities when connecting it to the reasoning behind it. Cities with similar temperatures have several possible features in common; respective country, electricity demand, energy sources, and economy, all of which have been researched. For most other cases in this study, these specific correlations have been studied deeper with a MVRA, however, including an MVRA with the temperature as the dependent variable would lead to misleading results. This is because the temperature of a city is a phenomenon that is decided by external factors that mainly cannot be influenced directly by humans as of today, especially for this specific case where the variables looked at would be GDP, education level, and level of smartness. These are all factors that are not proven to directly impact the temperature, even though a MVRA might have suggested so. In the case of CF increasing the global temperature, this might have a more severe impact on some cities, however, this is disregarded as these effects are of long-term.

6.7 Fossil Fuel Consumption in relation to Carbon Footprint

In an attempt to identify the reason behind the CFs for the cities, the energy mixes of each country present in this study was mapped and presented in Appendix G. With the assumption made that the mixes are the same for the cities as for the countries, Figure 5.14 provides an overview of the fossil fuel consumption for the SCs compared to their CFs. The figure meets the expectation of the CF increasing in line with the amount of fossil fuel consumed by the inhabitants of the cities, but the correlation is only considered as significant for the ICI. This could be explained by the high concentration of American cities being present in the ICI, with a fossil fuel consumption of 88%. Given that the ICI specifically includes emissions as an indicator in their ranking, it is expected that a higher share of renewable energy consumption should be valued more than for the SCI. However, with the average renewable energy consumption for the ICI of 16% being slightly lower than for the SCI (17%), the results are surprisingly similar. Either way, it is evident that the higher CFs can be explained by the fossil fuel consumption of the cities, especially when seen in context with the nearly 75% of all GHG emissions being due to this factor.

6.8 The Applied Methodology for this Study

In order to attempt an answer to the main research question, two rankings and their cities' CFs have been examined. As mentioned in Section 2.2, there are several ways to measure emissions for cities, and studying the CFs is only one of them. Including territorial-based emissions to the study could offer a deeper portrayal of the possible correlation. However, this type of data is only available for countries, and only including this could potentially overlook significant emissions associated with imported goods and the city-based emissions in the cases where these differ notably from the countries. Territorial-based emissions would need to be included in addition to the consumption-based emissions to strengthen the results.

Different ways for clustering the cities have been used in the results, mainly the three groups and to a certain extent the geographical areas. The approach of dividing the cities into these main groups might have led to bias and misleading results, where the observed correlations might be coincidental. Dividing the list over SCs in different ways could have conveyed other trends. However, the division is opted for to examine the major trends, and studying the top cities is interesting as these cities might use the rankings in their favor, competitively. For situations such as the one presented in Figure 5.6a, showing the average GDPs per capita for the grouped SCI cities, it is interesting that the difference between Group 1 and Group 2 is over doubled compared to Group 2 and Group 3. Dividing differently would not have exposed such major trends.

Similarly, evaluating per capita GDP is only one indicator of economic performance. In line with the obstacle of areas when gathering GDPs per capita as mentioned in Section 6.4, Gross Metropolitan Product could have been used. This could impact the results, as the population densities are higher for some areas. The areas of deployment for the CFs are, as mentioned, uncertain. Because of this, and because GDP is a more accessible measurement, the GDPs were used. Other indicators could have also been used, such as median household incomes, unemployment rates, poverty rates, or cost of living indexes. It is assumed that the results would still exhibit the similarities as is presented for the GDPs, especially when the SCI does not directly assess any commonly used economic indicators, only using gross national income as this is one indicator in the HDI, and the ICI includes several, as presented in Appendix B.

6.9 Limitations

This section critically evaluates the limitations that could affect the validity, reliability, and generalizability of the presented results. By acknowledging these limitations, the aim is to provide a nuanced understanding of the implications and boundaries of the findings.

6.9.1 Limitations related to Carbon Footprint

As mentioned in Section 4.2, the public data from the GGMFC initially only includes 500 cities. The remaining data collected from the shared document from Daniel Moran were used to calculate the emissions from the following cities:

- Oslo
- Canberra
- Geneva
- Lausanne
- Tallinn
- Reykjavik
- Luxembourg
- Wellington
- Ljublijana
- Gothenburg
- The Hauge
- Dusseldorf
- Busan
- Vilnius
- Hannover
- Bratislava
- Zaragoza
- Riga
- Bordeaux
- Leeds
- Kuala Lumpur
- San Francisco
- Krakow
- Bologna
- Kiel
- Bangkok
- Glasgow
- (Muscat)
- Cardiff
- Al-Khobar
- Newark
- Perth
- Kyoto
- Basel
- Riverside
- Quebéc
- Santa Ana
- Fort Lauderdale

However, Moran emphasizes that this data has not yet been quality checked, and are rough estimates for the time being. To ensure that the calculated footprints for these cities are realistic, the emissions for each of these cities were researched from a variety of different sources. Although the presented emissions are rough estimates, they correspond well to the public data. The CF for Muscat was not available either in this document nor in other public data, and is therefore excluded for every case where CFs are presented.

The city-based emissions are from 2018, while the country-based emissions are from 2016. Preferably, the data should be from the same year for a more precise comparison, and also closer to the year of writing to give the most compatible results. Due to lack of available data, this was not possible.

6.9.2 Limitations related to GDP per Capita

Presented in Section 4.4, the method for gathering per capita GDPs excluded some cities. As per quantity, this is the greatest source of error in this study. The cities that are left out of the statistics are:

- Singapore
- Abu Dhabi
- Dubai
- Hong Kong
- Taipei City
- Seoul
- Busan
- Riyadh
- Mecca
- Jeddah
- Medina
- Al-Khobar
- Reykjavik
- Ljubljana
- The Hague
- Doha
- Kuala Lumpur
- Muscat
- Tel Aviv
- Hanoi
- Newark
- Baltimore
- Oakland
- Orlando
- Kyoto
- Riverside
- Moscow
- São Paulo
- Yokohama
- Cleveland
- Santa Ana-Anaheim
- Kansas City
- Fort Lauderdale

As mentioned, there is an issue of areas. The SCI and the ICI present cities with certain areas, and it is not definite that the *OECD* areas remain the same. The *OECD* statistics specifically report some cities with the remark "Greater", which points to this source of error. The cities marked "Greater" are:

- Sydney
- Brisbane
- Melbourne
- New York
- Washington D.C.
- Los Angeles
- San Francisco
- Philadelphia
- Miami
- Detroit
- Perth
- Minneapolis-St-Paul

In one case, the city of Oslo, the GDP per capita was not stated in the source. However, the GDP was included, and this was divided by the population to include the GDP per capita in this study. This might be an answer to why the per capita GDP for Oslo is relatively high, as is apparent in Appendix I. The value was still included, as the GDP data was collected from the same source as most of the other cities' GDPs per capita.

Two countries, France and Japan, did not include 2020 per capita GDPs for their cities. This results in 9 cities without 2020 data, and 2019 data are used instead. Covid-19 occurred during 2020, and this might positively influence the cities who do not share their 2020 GDPs per capita, in the case the product was decreasing as a result of the pandemic. Generally, gathering data for several years would strengthen the study. As most of the per capita GDPs are from the year 2020, and this was the year the Covid-19 virus became a pandemic, including years before or after would provide more certainties. However, including several years is disregarded for limiting reasons.

6.9.3 Other Limitations

For education level and energy mixes, the assumption of similarity in data between the countries and the cities has been made. This is due to challenges in obtaining data directly related to each city specifically.

The education level of cities relative to countries can vary significantly and is influenced by numerous factors. Cities may have higher average education levels compared to entire countries, particularly in regions where cities serve as centers of education, innovation, and economic opportunity.

While cities are part of the broader energy systems of countries, they can have distinct energy mixes. This discrepancy arises due to several factors, including the availability of local energy resources, the infrastructure for energy distribution, and the specific energy policies and initiatives implemented at the city level. Furthermore, the energy consumption patterns of cities may differ from those of rural areas or industrial regions within the same country. Urban areas often have higher energy demands for transportation, buildings, and industry, which can influence the energy mix used within the city. Additionally, the data obtained for energy mixes is gathered from the year of 2022, and does not match with the data year for CFs (2018).

Generally, some of the obtained findings in the literature review might be outdated. For instance, Figure 3.1 displaying initiatives for the different sectors in SCs, is conducted based on 2004–2014 data. It would be interesting to explore how these initiatives might be weighed differently based on more recent data.

6.10 Recommendations for Future Research and Policymakers

Based on the presented limitations, the recommendations for future research is shown in the following list:

- Use more updated data for GHG emissions from the SCs and the countries. The data year should be equal for a fairer comparison.
- Use updated data for GDP from the same year, preferably aligning with the data year for GHG emissions.
- Obtain GDP data for the cities that were excluded in this study when regarding this as a factor.
- Expand the number of cities and/or indexes evaluated.
- Include other types of emissions in the data collection for comparison, like territorial-based emissions.
- Explore different ways of clustering the cities.
- Consider household sizes when evaluating the CFs to explore the possible relationship between the two.
- Use city-based data for education levels.
- Use city-based data for energy mixes.

- Assess any possible updated findings from the literature reviewed.
- Attempt to create a SC definition based on eventual index comparisons.

Based on the findings of this study, which have revealed important insights on the relationship between SCs and their respective CFs, this study offers the following recommendations for policymakers to consider in addressing the challenges and opportunities identified. The discrepancy in the correspondence between SC initiatives and climate action plans needs to be identified. Specifically, the two strategies should not be constructed isolated from each other in incoherent circumstances, but rather developed in context to each other. By doing this, policymakers can ensure that efforts to build smarter cities are aligned with broader climate objectives. This integrated approach requires policymakers to foster collaboration across sectors and levels of government, engage with stakeholders from diverse backgrounds, and prioritize investments in technologies and infrastructure that promote both smart and sustainable urban development. This is supported by Yigitcanlar, who emphasized the importance of collaboration between smart people, policies, and technologies for achieving smart and sustainable cities. Additionally, the policymakers should continue to encourage collecting information on various aspects of urban life, while subsequently reviewing the outcomes of the SC initiatives. This might help to gain valuable insights into emerging trends, to identify areas of concern, and to anticipate future challenges.

7 Conclusion

The prioritization of SC initiatives is increasing in response to the growing world population and the associated GHG emissions. With regard to the ongoing climate change, this has lead this study to examine whether these initiatives have contributed to the reduction of GHG emissions. While the reviewed literature indicate that the focus on climate change has increased within the SC concept, the findings from this study suggest otherwise. In fact, the findings indicate a vague, yet concerning trend of higher CFs in the higher ranked SC.

In an attempt to identify additional factors that might contribute to the observed variations in CFs and the rank of smartness, GDP per capita, education level, and temperature were analyzed through both single- and multivariate analyses. Considering the broader picture of the presented findings, it becomes apparent that numerous instances pose challenges in establishing causality or determining the direction of influence between variables. For instance, the results establish that there is a connection between GDP and smartness, and between GDP and education level. However, it is not evident from the results if GDP is influencing education level and smartness rank, or if the two factors are influencing GDP. Nevertheless, this study has revealed significant connections between CF and GDP for SCs, as well as between CF and temperature, both of which displays positive correlations. This implies that an increase in either variable yields an increase in CF. However, the mentioned ambiguity surrounding the causal relationships remains unresolved.

In an attempt to simplify the vague concept of SCs and assess smartness, two indexes were chosen. The indexes' methodologies were evaluated, as they might influence the outcomes. As the applied methods were significantly different, this could have provided opposing results. Surprisingly, the results from both indexes reveal a general alignment, suggesting that despite employing different methodologies, the findings yield similar results. This outcome carries several advantages. For instance, the consistency in trends may reinforce researchers' confidence in limiting their focus to a single index, streamlining the data analysis processes. Additionally, this finding contributes to the simplification of the ambiguous concept of SCs, facilitating clearer understanding and strategic planning.

Throughout this study, various assumptions have been made. These are important to consider in future research. Specifically, acquiring more precise data on CFs and GDPs for the listed cities outlined in the limitations, will enhance the reliability of the results. Additionally, utilizing data pertaining to energy mixes and education levels from the cities, rather than the countries as a whole, would further refine the analysis and yield more accurate results.

This study has effectively addressed a gap in the current literature by conducting a direct comparison between two SC indexes, while also exploring the broader trends concerning CFs, rank of smartness, education levels, GDP per capita, and temperature. The findings underscore a notable disparity between SC initiatives and climate action plans for the evaluated cities, leading this study to encourage policymakers and city management professionals to prioritize establishing a more cohesive connection between these two domains.

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A Appendix - SCI indicators

Figure A.1: Key survey data from IMD Smart City Index. [12]

	Structure	**Technologies**
Health and Safety:	Basic sanitation meets the needs of the poorest areas	Online reporting of city maintenance problems provides a speedy solution.
	Recycling services are satisfactory.	A website app allows residents to easily give away unwanted items.
	Public safety is not a problem	Free public WIFI has improved access to city services.
	Air pollution is not a problem	CCTV cameras have made residents feel safer.
	Medical services provision is satisfactory	A website or app allows residents to effectively monitor air pollution.
	Finding housing with rent equal to 30% or less of a monthly salary is not a problem	Arranging medical appointments online have improved access
Mobility:	Traffic congestion is not a problem.	Car-sharing apps have reduced congestion.
	Public transport is satisfactory	Apps that direct you to an available parking space have reduced journey time.
		Bicycle hiring has reduced congestion
		Online scheduling and ticket sales has made public transport easier to use.
		The city provides information on traffic congestion through mobile phones.
Opportunities: (Work & School)	Employment finding services are readily available.	Online access to job listings has made it easier to find work.
	Most children have access to a good school	IT skills are taught well in schools.
	Lifelong learning opportunities are provided by local institutions	Online services provided by the city has made it easier to start new business
	Businesses are creating new jobs	The current internet speed and reliability meets connectivity needs
	Minorities feel welcome	

	Structure	**Technologies**
Activities:	Green spaces are satisfactory	Online purchasing of tickets to shows and museums has made it easier to attend.
	Cultural activities (shows, bars, and museums) are satisfactory.	
Governance:	Information on local government decisions are easily accessible	Online public access to city finances has reduced corruption.
	Corruption of city officials is not an issue of concern.	Online voting has increased participation
	Residents contribute to decision making of local government.	An online platform where residents can propose ideas has improved city life
	Residents provide feedback on local governments projects.	Processing identification documents online has reduced waiting times.

B Appendix - ICI indicators

Figure B.1: Overview of the 188 indicators the 2ThinkNow used for the ICI. [6]

2THINKNOW SPECIFIC INDICATORS FOR ITHE INNOVATION CITIES™ INDEX			
Architectural Layering	Architectural complexity and layering of a city (architects refer to this as 'grain'), balancing preservation and new building.	Architecture, Planning & Heritage	Construction
Decorative Features	Presence of decorative features in buildings, and related sectors (stone masonry, carpentry, sculpture, street art).	Architecture, Planning & Heritage	Construction
Green Architecture	Cutting edge green buildings, experimental or new sustainable building designs.	Architecture, Planning & Heritage	Construction
History	The age of the city since its first major urban/population incarnation, with older cities having higher tourism value.	Architecture, Planning & Heritage	Construction
Neighborhoods	Quality of decentralised neighbourhoods that are walkable and interconnected.	Architecture, Planning & Heritage	Construction
Tradition of Innovation	A long standing history of trying new innovations and technologies applied to society. This can be differentiated between once avant-garde cities and current new tech adopters.	Architecture, Planning & Heritage	Construction
Vertical Living	Support for vertical development of cities into 'air' as opposed to horizontal development (urban sprawl). Correlates to urban density, but in a balanced way	Architecture, Planning & Heritage	Construction
Walking City	Safely walkable CBD with supporting transport modes.	Architecture, Planning & Heritage	Construction
Cinema & Film	Diversity of cinema offerings including film festivals.	Arts & Culture	Culture
Cultural Festivals	Cities with cultural festivals that attract a multitude of global (Edinburgh Comedy Festival), regional, national and local visits.	Arts & Culture	Culture
Dance & Ballet	Dance companies and ballet companies resident or transient in the city.	Arts & Culture	Culture
Fine Artists	Measuring the number of fine artists, and/or their support structures.	Arts & Culture	Culture
Handcrafts	Measuring support for local crafts and artisan items, substantial evidence needed.	Arts & Culture	Culture
Private Art Galleries	Measuring art dealers and related industries.	Arts & Culture	Culture
Public Art Galleries	Public art galleries can profile a city and support the art in that city.	Arts & Culture	Culture
Public Artworks	Public statues, external 2D and 3D art and external exhibitions or artistic items.	Arts & Culture	Culture
Public Museums	Measuring breadth and depth of museum infrastructure in city.	Arts & Culture	Culture
Satire & Comedy	Measuring support for comedy events, clubs and satire in local city.	Arts & Culture	Culture
Theatre & Plays	Theatres and plays (not movie cinemas) within CBD and surrounds accessible to visitors and residents.	Arts & Culture	Culture
Youth Activities	Data points on breadth of available activities for youth (from pre-school to teenage).	Arts & Culture	Culture
Banking & Finance	Central Bank independence and bank stability. Important: no bank failures.	Banking, Tax & Finance	Financial Services
Card Acceptance	Acceptance of major credit cards across all business and payment types.	Banking, Tax & Finance	Financial Services
Company Tax	Measuring the cities rate of company taxes, with lower company taxes allowing companies to establish in the city, and more easily attract innovative companies.	Banking, Tax & Finance	Financial Services
Crypto Currency	Support and development of crypto currencies in the private sector, and use in the public sector.	Banking, Tax & Finance	Financial Services

Foreign Exchange	Availability of Foreign Exchange in major currencies and formats to business and private travellers.	Banking, Tax & Finance	Financial Services
Multi-National Headquarters	No. of multi-national corporations headquartered within driving distance, and relative importance of proximate multinationals.	Banking, Tax & Finance	Financial Services
Sales Taxes	Is the city a globally competitive destination for low sales taxes, which thus drives greater revenues from product innovation?	Banking, Tax & Finance	Financial Services
Advertising in Media	Measures advertising and media agencies / services in city.	Business & Commerce	Business (B2B)
Business Approach	Measures whether the city is pro-business versus impediments to business.	Business & Commerce	Business (B2B)
Designers	Measures design (with a focus on graphic, business and industrial design) as a core skill of the innovation economy	Business & Commerce	Business (B2B)
Green Business	Potential for multiple green business development in city.	Business & Commerce	Business (B2B)
Industry Diversity	Single-industry focus is dangerous for cities. Measures the diversity of industries that creates global business links, and prevents single industry failure.	Business & Commerce	Business (B2B)
Professional Services	Availability of a range of accounting, consulting, legal and other professional services across all advice areas.	Business & Commerce	Business (B2B)
Public Meeting Spaces	Availability and affordability of meeting spaces of various types	Business & Commerce	Business (B2B)
Video & Film Production	Measures video and film production facilities and achievements relative to other cities.	Business & Commerce	Business (B2B)
Broad Based Innovation (Stable)	Broad Based Innovation measure across the 31 segments. Same basis as our ranking but a 'stable' result across multiple years. Effectively 'past performance'. (Past performance does not indicate future rankings). However, designed for models that need low volatility.	Communications & Technology	High Tech
Broadband Internet	Measuring estimated broadband internet penetration the cities economy relative to competing cities.	Communications & Technology	High Tech
Fixed Phone Network	Measuring the presence of a fixed phone network can be valuable in a crisis, and is still part of global business, even in a mobile world	Communications & Technology	High Tech
Government IT Policy	Government should be a customer of local I.T. and promote trade and exports. Is government supporting I.T. development?	Communications & Technology	High Tech
Internet Users	How many internet users are there in the city relative to competing cities?	Communications & Technology	High Tech
Metaverse Ready	Enabling the environment for the metaverse, and digital augmentation of cities.	Communications & Technology	High Tech
Mobile Phone Network	Measuring how many mobile phone users there are relative to competing cities.	Communications & Technology	High Tech
Nascent Tech	New emerging technologies and support for their eventual emergence.	Communications & Technology	High Tech
Smart Devices	Smart devices provide the mobile infrastructure to create technology that delivers innovative services to each city through apps and mobile browsers.	Communications & Technology	High Tech
Tech Adoption Rate	Rate of early technology adoption within the city - how likely users will adopt new tech.	Communications & Technology	High Tech
Video Gaming & 3D	Local city skills and development of video gaming & 3D technology (used industrially and for consumers as gaming/immersive tech/virtual)	Communications & Technology	High Tech
Wireless Internet	Wireless networks, and world class connectivity are a key part of business and service access in any global cities. Measuring business grade wireless.	Communications & Technology	High Tech
Department Stores	Breadth and range of department stores of a general or specialist nature within city area.	Consumer & Small Business	Consumer & Retail

Ecommerce Sales	The total volume and percentage of ecommerce shoppers within the city.	Consumer & Small Business	Consumer & Retail
Local Markets	Local markets including delicatessens, fresh food and other small shop functions within city.	Consumer & Small Business	Consumer & Retail
Local Shopping	Prevalence of 'high street' shops, and shopping 'streets' attractive to visitors, and/or 'destination' local malls with diverse (as well as global chain) wares.	Consumer & Small Business	Consumer & Retail
Retail Establishment	The ease, predictability and facility of establishing a retail presence.	Consumer & Small Business	Consumer & Retail
Small Retail Clusters	Retail cluster development in small and diverse mixed-use clusters.	Consumer & Small Business	Consumer & Retail
Social Media	Social media is a modern tool and platform for enabling innovation, and low cost global business message communication.	Consumer & Small Business	Consumer & Retail
Embassies & Trade Ambassadors	The presence of trade and diplomatic facilities globally.	Diplomacy & Foreign Affairs	Foreign Affairs
Relationships with Neighbors	Neighbor relationships impact trade and long-run economic wealth.	Diplomacy & Foreign Affairs	Foreign Affairs
Domestic Market Health	The health of the domestic market at a city-level not national based on key industries. Accessible domestic market size estimated for economic area (within own borders).	Economics & Policy	Economics & Policy
Domestic Market Size	Accessible domestic market size estimated for economic area (within own borders).	Economics & Policy	Economics & Policy
Exports	Exports national data points. Also attributed to city level through calculation.	Economics & Policy	Economics & Policy
Foreign Direct Investment	Foreign direct investment is a key metric. Attributed to city level through calculation.	Economics & Policy	Economics & Policy
GDP Per Capita	On a Real basis and PPP (where available). GDP per capita is measured at a city metropolitan area level.	Economics & Policy	Economics & Policy
Imports	Imports at a national level. Attributed to city level through calculation.	Economics & Policy	Economics & Policy
National Account	National account at a national and normalised as a city figure	Economics & Policy	Economics & Policy
Neighbors Market Size	Measures market size of immediate bordering or closest trading entities (states or nations, as applicable).	Economics & Policy	Economics & Policy
Property Prices	Property prices for units and houses, relative to income and value in the inner-city.	Economics & Policy	Economics & Policy
Reserves	National. Foreign exchange and gold reserves normalized into tiers. Includes calculations of city shares of reserves	Economics & Policy	Economics & Policy
Trade Diversity	Measuring the cities diversity of trading partners.	Economics & Policy	Economics & Policy
Trading Partners Economies	Health of major trading partners or free trade bloc for the city.	Economics & Policy	Economics & Policy
Unemployment Rate	Current unemployment rate at a city level, or analyst adjusted estimate based on state/region/national data adjusted for city.	Economics & Policy	Economics & Policy
Wealth Distribution	Equity in the society based on wealth equality, using best recorded Gini coefficients and other proxies.	Economics & Policy	Economics & Policy
Arts Education	Arts education drives arts and design industries. Measuring tertiary and commercial arts institutions.	Education & Science	Education, Science & Technical
Business Education	Mix and availability of business education options, international ranking and quality of business schools.	Education & Science	Education, Science & Technical

Science & Engineering	Science and engineering facilities and competitive position of city.	Education & Science	Education, Science & Technical
Student Population	Student populations size — a proxy for fresh approaches and affordable labor for new business models and experiments.	Education & Science	Education, Science & Technical
Technical & Specialist Innovation	Innovation measured purely as related to a primarily STEM understanding of innovation, without regard to innovation outside the tehcnical (narrow focus view)	Education & Science	Education, Science & Technical
University Breadth	Data points for breadth of university offerings in the city.	Education & Science	Education, Science & Technical
University Commercialization	Measuring ability of universities to commercialize technology.	Education & Science	Education, Science & Technical
Air Cleanliness	Measuring the city air cleanliness, and potential for air quality in given geography.	Environment, Sustainability & Nature	Sustainability
Climate & Weather	Is the weather consistent and conducive to work? Data points measuring the average climate.	Environment, Sustainability & Nature	Sustainability
Emissions	Data points on emissions at a city level where available, or state/national level in some cases.	Environment, Sustainability & Nature	Sustainability
Natural Disasters	Measuring recent history of natural disasters and potential impact of natural disaster such as earthquake, flood, bushfires, cyclones.	Environment, Sustainability & Nature	Sustainability
Nature	Natural environmental assets such as beaches, parks, wetlands which may affect life quality, and drive tourism/eco-tourism.	Environment, Sustainability & Nature	Sustainability
Noise Limiting	Measuring noise causes, and classifying limitation measures.	Environment, Sustainability & Nature	Sustainability
Public Green Areas	Measuring city park protection, and natural and wildlife preservation areas within immediate metropolitan area and inner-city.	Environment, Sustainability & Nature	Sustainability
Water features	The major water features in terms of importance (e.g. major river), range of amenity and cleanliness.	Environment, Sustainability & Nature	Sustainability
Fashion Designers	Measuring fashion designers and fashion events within the city.	Fashion, Clothing & Textiles	Fashion
Cafes & Tea Rooms	Diversity, range and sheer number of cafe's / tea rooms and suitability as multi-purpose business and visitor venues.	Food, Leisure & Hospitality	Hospitality
Fine Restaurants	Quality of restaurants, especially destination restaurants.	Food, Leisure & Hospitality	Hospitality
Food Diversity	Measuring the breadth in diversity of food cuisines.	Food, Leisure & Hospitality	Hospitality
Meal Affordability	Affordability of basic sandwich and beverage (or local equivalent) relative to other cities at a 'walk-in' food establishment.	Food, Leisure & Hospitality	Hospitality
Freight Dependencies	How dependent is the city on foreign freight and what is the potential for blockages, loss or slowing of the supply chain?	Geography	Geo-spatial
Physical location	How favourable is the geographic position of the city, and how favourable the traditional geographic features?	Geography	Geo-spatial
Trade Routes	Where is the city relative to global trade routes, and how does the city work as a current or future juncture in physical trade?	Geography	Geo-spatial
Digital Infrastructure	Digital infrastructure for the development of new skills, tools and opportunities within a secure framework. Allowing the digitalisation of many life functions.	Government & Politics	Government & Public Services

Public Libraries	Libraries and media centers for the public to access free information are crucial to new types of innovation.	Information, News & Publishing	Communications & Media
TV & Radio Networks	The number, existence and independence of local TV and radio networks.	Information, News & Publishing	Communications & Media
Underground Publications	Measures independent underground newspapers, zines or other 'dissent' publications.	Information, News & Publishing	Communications & Media
Web Censorship	Web censorship or control can lead to the blocking of business opportunities, and rampant industrial espionage (an emerging problem).	Information, News & Publishing	Communications & Media
Clerical Wages	Average wage affordability for a senior MS Office qualified clerical worker, and language fluency.	Labour, Employment & Workforce	Recruitment
Digital Skills	Relative skills in the labor force and local firms for deploying digital technologies.	Labour, Employment & Workforce	Recruitment
Education Level	Level of educated workforce availability now and in future.	Labour, Employment & Workforce	Recruitment
Labor Force	Labor force availability % applied to the population to show available workforce.	Labour, Employment & Workforce	Recruitment
Working Visa	Time and cost of achieving working visa for qualified Western nationals.	Labour, Employment & Workforce	Recruitment
Citizen Rights	Restrictions on citizen rights, such as freedom of speech, expression and potential non-structural separation of powers.	Law & Governance	Law
Policing	A community police force that is integrated and achieves lower crime and lower impact crime.	Law & Governance	Law
Separation of Powers	Structural separation and number of branches of government.	Law & Governance	Law
Container Freight	Container port efficiency in tonnage of port nearest to city, and relative ease of reaching port via road/rail.	Logistics & Ports	Logistics
Freight	Multi-modality of freight, and integration of freight modes.	Logistics & Ports	Logistics
Postal System	Postal services availability, and classifying reliability and frequency.	Logistics & Ports	Logistics
Railway Track	Measuring railway track available to a city using calculations.	Logistics & Ports	Logistics
Relative Military	What is the relative military strength of the state, and to a lesser extent, city in real terms?	Military, Defence & Aviation	Defence & Aerospace
Strategic Power	How is the perceived power of the city and it's host nation expressed as an ability to enforce favourable terms of trade?	Military, Defence & Aviation	Defence & Aerospace
Classical Music	Successful choirs, orchestras and classic music groups.	Music & Performance	Music
Music Venues	Measuring if the city has a comparable number and breadth of music venues	Music & Performance	Music
Nightlife	The quality, variety and mix of nightlife venues and the regulation (or self-policing) of venues.	Music & Performance	Music
Opera House	Is there an Opera House, and what is the degree of support for opera measured by opera infrastructure?	Music & Performance	Music
Popular Music	How many popular musicians or how much support for future contemporary music does the city provide?	Music & Performance	Music
Alternative Population	Evidence of alternative population may be evidence of creative and new ideas.	People, Rights & Families	Community Services
Citizen Privacy	How much privacy is afforded to citizens? Is citizen privacy adequate given current levels of cyber threat and intrusions into the lives of citizens? Privacy allows innovation to flourish whereas constant intervention limits the flourishing of new ideas.	People, Rights & Families	Community Services
Equality of Women	Are women equal (not in number/quotas) but in access measured by actual positions held (such as Mayor)?	People, Rights & Families	Community Services
Littering	Presence of litter and policies to beautify the city.	People, Rights & Families	Community Services
Population	Population of the city indicates size of the market.	People, Rights & Families	Community Services

Protest & Activism	Activism is common in cities that create new ideas, but may also destabilize. Classifying the size and ability of protest.	People, Rights & Families	Community Services
Remote Working	Readiness and ability for remote working (work from home) across the services and administrative sectors. (Manufacturing and agriculture cannot be fully work from home).	People, Rights & Families	Community Services
Wellness of Population	Wellness measures to ensure the health and wellbeing of populations facing challenges from social isolation or economic hardship. This includes 'self-measures' such as private health (not all government programs achieve their stated outcomes, and as such wellness remains a personal responsibility).	People, Rights & Families	Community Services
Crime	Measuring theft and predominately non-violent, non-lethal crime.	Police, Fire & Emergency Response	Emergency Services
Violent Crime	Violent crime rates from murder, rape to assault and punishment effect localized at a city level.	Police, Fire & Emergency Response	Emergency Services
Electricity & Gas	Measures renewable energy, availability and reliability of current electricity supply.	Primary Industries, Services & Energy	Agriculture, Sanitation, Water & Energy
Food Supply	Food quality measured with lower degree of processing, and proximity of farms/food supply to urban centre.	Primary Industries, Services & Energy	Agriculture, Sanitation, Water & Energy
Public Water Supply	Water supply quality and purity, and process of water supply.	Primary Industries, Services & Energy	Agriculture, Sanitation, Water & Energy
Waste Management	Comprehensiveness of waste treatment and recycling programs	Primary Industries, Services & Energy	Agriculture, Sanitation, Water & Energy
Places of Worship	Number of churches, mosques or all places of faithful worship.	Religion, Multi-Culturalism & Charities	NFPs
Resources	Measuring available resources at a national level with best available city allocations.	Resources, Mining, Oil and Gas	Resources
Fitness Facilities	Presence of gyms, and indoor and outdoor facilities for amateur and professional sports.	Sports, Wellbeing & Fitness	Sports
Sports Fanaticism	Level of support for a variety of sports codes, and general sports industry support.	Sports, Wellbeing & Fitness	Sports
Sports Stadiums	Quantity and modernity of stadium infrastructure in or near city.	Sports, Wellbeing & Fitness	Sports
Company Setup	How long does it take to set-up a private company? A more transparent, fast company process is part of entrepreneurial culture.	Start-Ups & Enterprise	Start-Ups & Enterprise
Growth Business Funding	Measuring the breadth and depth of venture capital availability options.	Start-Ups & Enterprise	Start-Ups & Enterprise
Start-Up Economy	Measuring the number of start-up enterprises, and relative strength of the 'start-up' economy at a city level.	Start-Ups & Enterprise	Start-Ups & Enterprise
Start-Up Office Spaces	Are the spaces for start-up or branch office companies to use for first offices? Do spaces allow collaboration? Are they affordable?	Start-Ups & Enterprise	Start-Ups & Enterprise
City Branding	Perception of city brand (commonly referred to as Placemaking or City branding) now drives the potential economic opportunities presented to a city. Includes Ranking.	Tourism & Travel	Travel
Global Airport Connections	How well connected and how close is the airport to other major airports in flying hours?	Tourism & Travel	Travel
Hotel Range	Range of hotels, motels, hostels and accommodation options with a strong mix and bed supply being optimal.	Tourism & Travel	Travel
Inbound Visitors	Number of inbound tourist arrivals in area by all recorded modes.	Tourism & Travel	Travel
International Conferences	Conference popularity and facilities within city, and whether all year round or seasonal.	Tourism & Travel	Travel
International Students	Number and professional mix of international students in city, compared to competing cities.	Tourism & Travel	Travel

Languages	How many languages do the citizens of a city speak? Are those languages international languages, or regional dialects. % of English fluency is a key	Tourism & Travel	Travel
Multi-Lingual	Multi-lingual cities, speaking major global languages, are open to further trade diversity than more isolated single language (or dialect) cultures.	Tourism & Travel	Travel
Tourist Entry	Ease of visitor entry for wealthier national tourists and casual visitors to country.	Tourism & Travel	Travel
Travel Advisories	Travel advisories by one of the UK, US, Canada, Australia or NZ can indicate negative reasons against travel.	Tourism & Travel	Travel
Visitor Entry	Measures visa requirements for entry and classifies degree of burden placed on a potential traveller.	Tourism & Travel	Travel
Visitor Information	Quality and quantity of printed, web and mobile information in English and other languages, that is easily available.	Tourism & Travel	Travel
Airport Transfers	Modes of airport transfer and direct integration and support on city transit networks.	Transport, Roads & Mobility	Transport & Automotive
Automobiles	Road quality and expansiveness, as well as car-sharing and environmental initiatives.	Transport, Roads & Mobility	Transport & Automotive
Bicycle Friendly	Availability of protected and designated bicycle facilities, as well as bicycle support.	Transport, Roads & Mobility	Transport & Automotive
City Transport Infrastructure	Measuring the capability and size of the public transport network in terms of commitment to fixed infrastructure.	Transport, Roads & Mobility	Transport & Automotive
Inter-City Connections	Availability of super-fast/fast-rail (higher benchmarks), rail or alternately airports or buses (lower).	Transport, Roads & Mobility	Transport & Automotive
International Airport	Major modern airport with full facilities measured against best airports.	Transport, Roads & Mobility	Transport & Automotive
Personal Mobility	Mobility via personal mobility devices (micro mobility like scooters etc), rideshare (and to a lesser extent automobile)	Transport, Roads & Mobility	Transport & Automotive
Public City Transport	City Transport Infrastructure - renamed	Transport, Roads & Mobility	Transport & Automotive
Service Delivery	Reliability of services, and amenity of services on an average day.	Transport, Roads & Mobility	Transport & Automotive
Service Frequency	Frequency of services to most suburban areas during the key peak and off-peak times.	Transport, Roads & Mobility	Transport & Automotive
Street Signage	Availability and international language-neutral approaches to signage.	Transport, Roads & Mobility	Transport & Automotive
Streets	Width and layout of streets, major streets that are well known globally.	Transport, Roads & Mobility	Transport & Automotive
Taxi Service	Availability, safety and reliability of taxi service and government policy towards taxis.	Transport, Roads & Mobility	Transport & Automotive
Transport Accessibility	Stated and actual accessibility for fixed and mobile public transport options (rail, buses, metro). Includes assessment of accessibility for People of Determination.	Transport, Roads & Mobility	Transport & Automotive
Transport Automation	Automation of mass-transit, driverless trains, transport infrastructure automation and driverless vehicle technology uptake.	Transport, Roads & Mobility	Transport & Automotive
Transport Coverage	Distribution of multiple transport modes across the city in existing and new suburbs.	Transport, Roads & Mobility	Transport &

500 of the most popular data points can be requested by this page.

C Appendix - Cities Information

Figure C.1: City Information for IMD SCI. [51]

IMD SCI	City	Country	Population
1	Zurich	Switzerland	433 890
2	Oslo	Norway	717 710
3	Canberra	Australia	453 558
4	Geneva	Switzerland	206 569
5	Singapore	Singapore	5 685 807
6	Copenhagen	Denmark	644 431
7	Lausanne	Switzerland	144 122
8	London	United Kingdom	8 799 728
9	Helsinki	Finland	674 500
10	Abu Dhabi	United Arab Emirates	1 202 756
11	Stockholm	Sweden	988 943
12	Dubai	United Arab Emirates	3 355 900
13	Beijing	China	21 893 095
14	Hamburg	Germany	1 853 935
15	Prague	Czech Republic	1 301 432
16	Taipei	Taiwan	2 594 581
17	Seoul	South Korea	9 586 195
18	Amsterdam	Netherlands	934 927
19	Shanghai	China	24 870 895
20	Hong Kong	Hong Kong	7 413 070
21	Munich	Germany	1 487 708
22	Sydney	Australia	4 856 693
23	Vienna	Austria	2 006 134
24	Tallin	Estonia	437 817
25	Riyadh	Saudi Arabia	7 009 120
26	Reykjavik	Iceland	136 894
27	Luxembourg	Luxembourg	134 697
28	Wellington	New Zealand	213 100
29	Bilbao	Spain	345 235
30	Brisbane	Australia	2 488 718
31	Auckland	New Zealand	1 695 200
32	Ljubljana	Slovenia	293 218
33	Melbourne	Australia	4 875 390
34	New York City	United States	8 804 194
35	Madrid	Spain	3 340 176
36	Boston	United States	650 706
37	Berlin	Germany	3 677 472
38	Warsaw	Poland	1 860 281
39	Gothenburg	Sweden	604 616
40	Brussels	Belgium	1 222 637
41	Rotterdam	Netherlands	671 125
42	The Hague	Netherlands	565 701
43	Vancouver	Canada	706 012
44	Dusseldorf	Germany	619 477
45	Busan	South Korea	3 349 016
46	Ottawa	Canada	1 071 868
47	Vilnius	Lithuania	556 490
48	Doha	Qatar	1 186 023
49	Paris	France	2 133 111
50	Washington D.C.	United States	689 546
51	Toronto	Canada	3 025 647

52	Mecca	Saudi Arabia	2 385 509
53	Hanover	Germany	535 932
54	Tianjin	China	11 052 404
55	Jeddah	Saudi Arabia	3 751 722
56	Bratislava	Slovakia	478 040
57	Zaragoza	Spain	736 649
58	Zhuhai	China	2 439 585
59	Riga	Latvia	614 618
60	Shenzhen	China	17 444 609
61	Lyon	France	522 250
62	Nanjing	China	7 519 814
63	Seattle	United States	749 256
64	Hangzhou	China	9 236 032
65	Guangzhou	China	16 096 724
66	Denver	United States	715 538
67	Chicago	United States	2 665 039
68	Los Angeles	United States	3 898 767
69	Dublin	Republic of Ireland	592 713
70	Bordeaux	France	259 809
71	Manchester	United Kingdom	551 938
72	Leeds	United Kingdom	811 953
73	Kuala Lumpur	Malaysia	1 998 600
74	Medina	Saudi Arabia	1 477 047
75	San Francisco	United States	873 959
76	Krakow	Poland	800 653
77	Newcastle upon Tyne	United Kingdom	300 125
78	Bologna	Italy	1 018 346
79	Kiel	Germany	246 243
80	Montreal	Canada	1 791 508
81	Barcelona	Spain	1 655 956
82	Chongqing	China	9 580 819
83	Birmingham	United Kingdom	1 144 919
84	Bangkok	Thailand	5 666 264
85	Lille	France	236 234
86	Tokyo	Japan	9 733 276
87	Glasgow	United Kingdom	631 690
88	Muscat	Oman	1 302 440
89	Budapest	Hungary	1 685 342
90	Philadelphia	United States	1 567 258
91	Milan	Italy	3 247 764
92	Cardiff	United Kingdom	362 310
93	Chengdu	China	13 568 357
94	Tel Aviv	Israel	467 875
95	Osaka	Japan	2 752 412
96	Ankara	Republic of Türkiye	5 186 002
97	Hanoi	Vietnam	3 605 364
98	Phoenix	United States	1 644 409
99	Khobar	Saudi Arabia	658 550
100	Bucharest	Romania	1 716 961

Figure C.1 presents the SC rankings by *IMD* and *WeGo* in order from most to least smart. The respective country and population for each city is presented. The populations are retrieved from citypopulation.de. [13]

Figure C.2: City Information for 2ThinkNow ICI. [7]

2ThinkNow ICI	City	Country	Population
1	Tokyo	Japan	9 733 276
2	London	United Kingdom	8 799 728
3	New York City	United States	8 804 194
4	Paris	France	2 133 111
5	Singapore	Singapore	5 685 807
6	Los Angeles	United States	3 898 767
7	Boston	United States	650 706
8	Seoul	South Korea	9 586 195
9	San Francisco	United States	873 959
10	Houston	United States	2 302 878
11	Berlin	Germany	3 677 472
12	Chicago	United States	2 665 039
13	Stockholm	Sweden	988 943
14	Dubai	United Arab Emirates	3 355 900
15	Toronto	Canada	3 025 647
16	Munich	Germany	1 487 708
17	Vienna	Austria	2 006 134
18	Sydney	Australia	4 856 693
19	Madrid	Spain	3 340 176
20	Amsterdam	Netherlands	934 927
21	Seattle	United States	749 256
22	Dallas	United States	1 304 317
23	Melbourne	Australia	4 875 390
24	Montreal	Canada	1 791 508
25	Atlanta	United States	499 127
26	Barcelona	Spain	1 655 956
27	Milan	Italy	3 247 764
28	Beijing	China	21 893 095
29	Vancouver	Canada	706 012
30	Copenhagen	Denmark	644 431
31	Miami	United States	449 514
32	Washington D.C.	United States	689 546
33	Philadelphia	United States	1 567 258
34	Oslo	Norway	717 710
35	Osaka	Japan	2 752 412
36	Dublin	Republic of Ireland	592 713
37	San Diego	United States	1 386 960
38	Brisbane	Australia	2 488 718
39	Helsinki	Finland	674 500
40	Tel Aviv	Israel	467 875
41	Hamburg	Germany	1 853 935
42	Denver	United States	715 538
43	Portland	United States	652 518
44	Austin	United States	974 447
45	Las Vegas	United States	656 274
46	Shanghai	China	24 870 895
47	Detroit	United States	639 115
48	Rome	Italy	2 617 175
49	Brussels	Belgium	1 222 637
50	Newark	United States	311 552
51	Baltimore	United States	585 693

52	Taipei	Taiwan	2 594 581
53	Istanbul	Republic of Türkiye	15 244 936
54	Zurich	Switzerland	433 890
55	Phoenix	United States	1 644 409
56	Oakland	United States	440 660
57	Orlando	United States	316 081
58	Hong Kong	Hong Kong	7 413 070
59	Prague	Czech Republic	1 301 432
60	Lisbon	Portugal	545 796
61	Mexico City	Mexico	9 209 944
62	Buenos Aires	Argentina	3 121 707
63	Perth	Australia	2 173 146
64	Kyoto	Japan	1 463 723
65	Basel	Switzerland	568 072
66	Athens	Greece	664 046
67	Sacramento	United States	528 001
68	Frankfurt	Germany	759 224
69	Tampa	United States	398 173
70	Minneapolis	United States	425 096
71	Pittsburgh	United States	302 898
72	San Antonio	United States	1 472 909
73	Riverside	United States	320 764
74	Shenzhen	China	17 444 609
75	Abu Dhabi	United Arab Emirates	1 202 756
76	Moscow	Russia	13 010 112
77	Auckland	New Zealand	1 695 200
78	Budapest	Hungary	1 685 342
79	Oporto	Portugal	237 591
80	Sao Paulo	Brazil	12 396 372
81	Nagoya	Japan	2 332 176
82	Dusseldorf	Germany	619 477
83	Yokohama	Japan	3 777 491
84	Quebéc	Canada	557 390
85	Stuttgart	Germany	626 275
86	Manchester	United Kingdom	551 938
87	Rotterdam	Netherlands	671 125
88	Lyon	France	522 250
89	Warsaw	Poland	1 860 281
90	Charlotte	United States	897 720
91	Nashville	United States	698 454
92	Cleveland	United States	361 607
93	Gothenburg	Sweden	604 616
94	Santa Ana	United States	308 189
95	Cincinnati	United States	309 513
96	Kansas City	United States	509 297
97	Cologne	Germany	1 073 096
98	Geneva	Switzerland	206 569
99	Fort Lauderdale	United States	183 146
100	Guangzhou	China	16 096 724

Figure C.2 presents the SC rankings by *2ThinkNow* in order from most to least smart. The respective country and populations for each city is presented. The populations are retrieved from citypopulation.de. [13]

Figure C.3 provides an overview of which continents the cities are located in. The smartness is decreasing downwards for the whole figure.

Figure C.3: Overview of the cities' continents for both indexes, decreasing smartness downwards.

Europe		West-Asia		North-America		Oceania		South-America		East-Asia	
SCI	ICI	SCI	ICI	SCI	ICI	SCI	ICI	SCI	ICI	SCI	ICI
Zurich	London	Dubai	Dubai	New York	New York	Canberra	Sydney		Mexico City	Singapore	Tokyo
Oslo	Paris	Riyadh	Tel Aviv	Boston	Los Angeles	Sydney	Melbourne		Buenos Aires	Beijing	Singapore
Geneva	Berlin	Doha	Istanbul	Vancouver	Boston	Wellington	Brisbane		Sao Paulo	Taipei	Seoul
Copenhagen	Stockholm	Mecca	Abu Dhabi	Ottawa	San Francisco	Brisbane	Perth			Seoul	Beijing
Lausanne	Munich	Jeddah		Washington DC	Houston	Auckland	Auckland			Shanghai	Osaka
London	Vienna	Medina		Toronto	Chicago	Melbourne				Hong Kong	Shanghai
Helsinki	Madrid	Muscat		Seattle	Toronto					Busan	Taipei
Stockholm	Amsterdam	Tel Aviv		Denver	Seattle					Tinjin	Hong Kong
Hamburg	Barcelona	Ankara		Chicago	Dallas					Zhuhai	Kyoto
Prague	Milan	Al-Khobar		Los Angeles	Montreal					Shenzhen	Shenzhen
Amsterdam	Copenhagen			San Francisco	Atlanta					Nanjing	Nagoya
Munich	Oslo			Montreal	Vancouver					Hangzho	Yokohama
Vienna	Dublin			Philadelphia	Miami					Guangzhou	Guangzhou
Talinn	Helsinki			Phoenix	Washington DC					Kuala Lumpur	
Reykjavik	Hamburg				Philadelphia					Chongqing	
Luxemburg	Rome				San Diego					Bangkok	
Bilbao	Brussels				Denver					Tokyo	
Ljubliana	Zürich				Portland					Chengdu	
Madrid	Prague				Austin					Osaka	
Belin	Lisbon				Las Vegas					Hanoi	
Warsaw	Basel				Detroit						
Gothenburg	Athens				Newark						
Brussels	Frankfurt				Baltimore						
Rotterdam	Moscow				Phoenix						
The Hague	Budapest				Oakland						
Dusseldorf	Oporto				Orlando						
Vilnius	Düsseldorf				Sacramento						
Paris	Stuttgart				Tampa						
Hannover	Manchester				Minneapolis						
Bratislava	Rotterdam				Pittsburgh						
Zaragoza	Lyon				San Antonio						
Riga	Warsaw				Riverside						
Lyon	Gothenburg				Quebéc						
Dublin	Cologne				Charlotte						
Bordeaux	Geneva				Nashville						
Manchester					Cleveland						
Leeds					Santa Ana						
Krakow					Cincinnati						
Newcastle					Kansas City						
Bologna					Fort Lauderdale						
Kiel											
Barcelona											
Birmingham											
Lille											
Glasgow											
Budapest											
Milan											
Cardiff											
Bucharest											

D Appendix - Overview of the reviewed literature

Table D.1: Reviewed publications - literature review.

Title	Author	Year	Country
Taking City Rankings Seriously: Engaging with Benchmarking Practices in Global Urbanism	Acuto, Pejic, Briggs	2021	Australia
"Smartening sustainable development in cities: Strengthening the theoretical linkage between smart cities and SDGs"	Blasi, Ganzarloi, Noni	2022	Italy
"Climate change 2013 - The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change."	Cambrigde Univesity Press	2014	United Kingdom
Do smart cities realise their potential for lower carbon dioxide emissions?	Cavada, Hunt, Rogers	2016	United Kingdom
"Economic and policy uncertainty in climate change mitigation: The London Smart City case scenario"	Contreras, Platania	2019	The Netherlands, France
Human-centric, sustainability-driven approach to ranking smart cities worldwide	Dashkevych, Portnov	2023	Israel
"Smart and Sustainable? Positioning Adaptation to Climate Change in the European Smart City"	Fernández, Peek	2020	Spain
Smart cities - Ranking of European medium-sized cities	Giffinger, Fertner, Kramar, Kalasek, Milanovic, Meijers	2007	Austria
The role of rankings in growing city competition	Giffinger, Haindlmaier, Kramar	2010	Austria
"Environmental assessment of Smart City Solutions using a coupled urban metabolism - Life cycle impact assessment approach"	Ipsen, Zimmermann, Nielsen, Birkved	2018	Denmark
The real-time city? Big data and smart urbanism	Kitchin	2013	Ireland
Smarter organizations: insights from a smart city hybrid framework	Lima	2020	France
Modelling the smart city performance	Lombardi, Giordano, Farouh, Yousef	2012	Italy & Egypt

Table D.1: Reviewed publications - literature review.

Title	**Author**	**Year**	**Country**
Compilation of Smart Cities Attributes and Quantitative Identification of Mismatch in Rankings	Marzouk	2022	Oman
"What makes a city 'smart' in the Anthropocene? A critical review of smart cities under climate change"	Obringer, Nateghi	2021	USA
"The Role of Internet of Things (IoT) in Smart Cities: Technology Roadmap-oriented Approaches"	Park, Pobil, Kwon	2018	South Korea
Review of Smart City Assessment Tools	Patrão, Moura, Almeida	2020	Portugal
Sensing as a service model for smart cities supported by Internet of Things	Perera, Zaslavsky, Christen, Georgakopoulos	2013	Australia
Information communication technology and electricity consumption in emerging economies	Sadorsky	2012	Canada
Smart city indexes, criteria, indicators and rankings: An in-depth investigation and analysis	Toh	2022	USA
The Concept of Sustainability in Smart City Definitions	Toli, Murtagh	2020	United Kingdom
"Smart Cities and Green Growth: Outsourcing Democratic and Environmental Resilience to the Global Technology Sector"	Viitanen, Kingston	2014	England
Energy savings from Smart Cities: A critical analysis	Wang, Moriarty	2019	United Kingdom, Australia
Evaluating the Impact of Smart City Policy on Carbon Emission Efficiency	Xia, Yu, Zhang	2023	China
Can cities become smart without being sustainable? A systematic review of the literature	Yigitcanlar, Kamruzzaman, Foth, Sabatini-Marques, Costa, Ioppolo	2019	Australia, Brazil, Italy
"Smart cities of the Sunshine State: Status of Queensland's local government areas - 2018 Summary Report"	Yigitcanlar, Kamruzzaman, MD, BUYs, Lauroe, Perveen, Sajida	2018	Australia

E Appendix - Carbon Footprints for geographical areas

The relation between smartness and carbon footprint was computed in Excel. The results are divided by continents in order to see a clearer connection than what would be shown in one connected figure. For every graph, the smartest ranked city of the continent will be the first one showing on the x-axis, and the smartness decreases to the right. The most interesting element to look at in the individual graphs is the trend line. The trend line shows how the carbon footprint either increases or decreases with the decreasing of smartness.

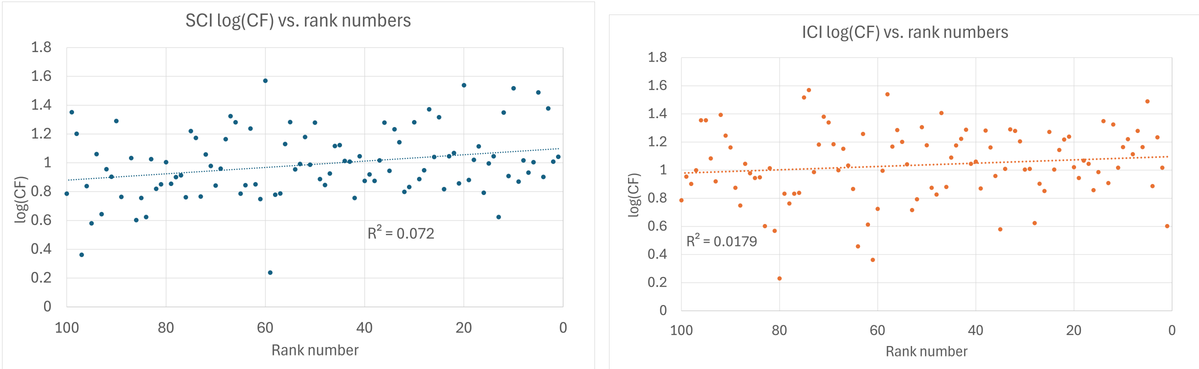
(a) SCI CF City vs Country

(b) ICI CF City vs Country

Figure E.1: Overview of the CF of the cities compared to the country for both indexes.

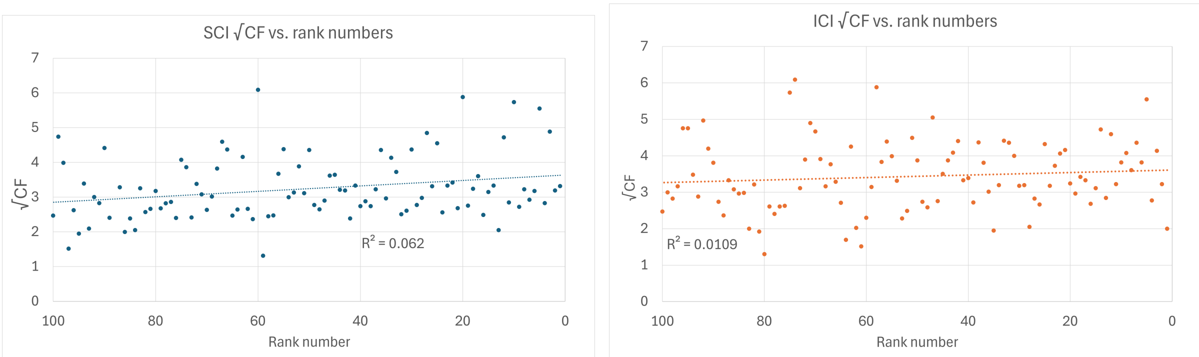
F Appendix - Other statistical relationships between CF and smartness

In this appendix, an overview of tested correlations between CF and smartness is presented.



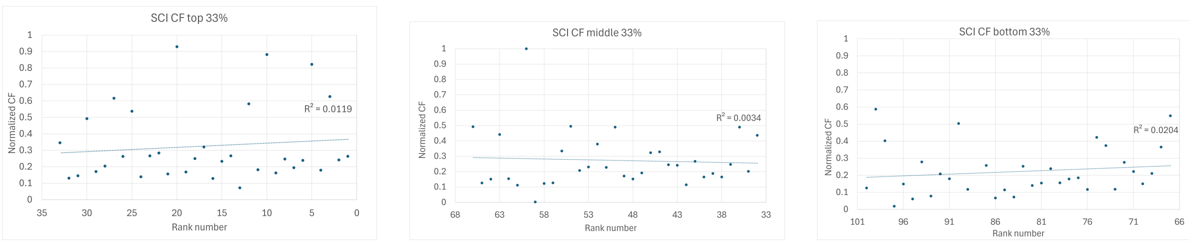
(a) SCI *(b) ICI*

Figure F.1: Logarithmic relationship between CF and rank numbers for both indexes.



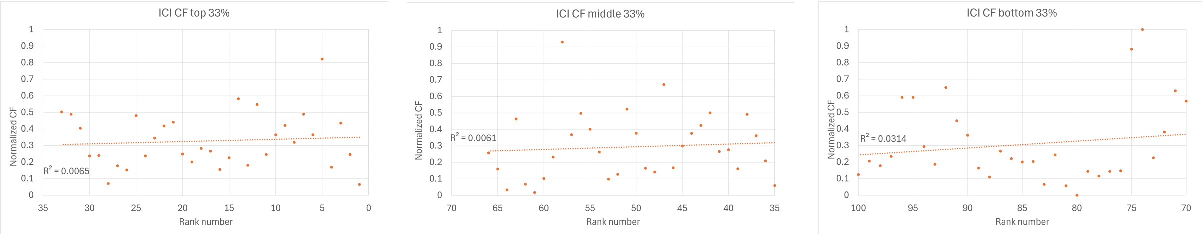
(a) SCI *(b) ICI*

Figure F.2: Square root-relationship between CF and rank numbers for both indexes.



(a) SCI top 33% cities *(b) SCI middle 33% cities* *(c) SCI bottom 33% cities*

Figure F.3: The relationships between the CFs and the SCI groups' smartness, divided by rank numbers.



(a) ICI top 33% cities *(b) ICI middle 33% cities* *(c) ICI bottom 33% cities*

Figure F.4: The relationships between the CFs and the ICI groups' smartness, divided by rank numbers.

G Appendix - Energy mixes for countries and cities

Country	Renewable	Nuclear	Fossil fuels	Total kWh/capita	% Renewable	% Nuclear	% Fossil fuels
Brazil	8431	169	8700	17300	49 %	1 %	50 %
Belgium	6240,0186	9386,54	42769,266	58395,8246	11 %	16 %	73 %
Canada	3128,535	5636,829	65239,92	74005,284	4 %	8 %	88 %
China	4974,1704	733,05255	25344,26	31051,48295	16 %	2 %	82 %
Czechia	3284,8643	7395,684	33561,6	44242,1483	7 %	17 %	76 %
Denmark	13858,966	0	18338,973	32197,939	43 %	0 %	57 %
Estonia	7099,013	0	39405,848	46504,861	15 %	0 %	85 %
Finland	22700,47	11396,982	24848,705	58946,157	39 %	19 %	42 %
France	5270,6436	11409,492	19371,66	36051,7956	15 %	32 %	54 %
Germany	8710,929	1041,2916	31225,268	40977,4886	21 %	3 %	76 %
Hong Kong	111,411865	0	29040,893	29152,30487	0 %	0 %	100 %
Hungary	2430,8186	3968,923	20260,748	26660,4896	9 %	15 %	76 %
Iceland	139521,33	0	0	139521,33	100 %	0 %	0 %
Ireland	7601,9966	0	30159,404	37761,4006	20 %	0 %	80 %
Israel	2175,225	0	31467,791	33643,016	6 %	0 %	94 %
Italy	4798	0	24111,465	28909,465	17 %	0 %	83 %
Japan	5003,856	1044,9875	33936,066	39984,9095	13 %	3 %	85 %
Latvia	6546,746	0	15667,594	22214,34	29 %	0 %	71 %
Lithuania	2891,2927	0	20259,76	23151,0527	12 %	0 %	88 %
Luxembourg	6546,746	0	53787,58	60334,326	11 %	0 %	89 %
Mexico	1702	213	17094	19009	9 %	1 %	90 %
Malaysia	3226,491	0	36360,508	39586,999	8 %	0 %	92 %
Netherlands	8051,7456	592,2688	47356,742	56000,7564	14 %	1 %	85 %
New Zealand	19355,164	0	25584,105	44939,269	43 %	0 %	57 %
Norway	69426,695	0	27499,533	96926,228	72 %	0 %	28 %
Oman	0	0	89850,02	89850,02	0 %	0 %	100 %
Portugal	7269	0	17825	25094	29 %	0 %	71 %
Poland	2817,1733	0	7248,246	10065,4193	28 %	0 %	72 %
Qatar	0	0	193665,31	193665,31	0 %	0 %	100 %
Russia	3722	3867	47871	55460	7 %	7 %	86 %
Romania	3321,3687	1411,162	13614,338	18346,8687	18 %	8 %	74 %
Saudi Arabia	0	0	87647,36	87647,36	0 %	0 %	100 %
Singapore	0	0	146257,7	146257,7	0 %	0 %	100 %
Slovakia	3491,5803	7046,819	23349,29	33887,6893	10 %	21 %	69 %
Slovenia	5347,2437	6615,506	22428,342	34391,0917	16 %	19 %	65 %
South Korea	2939,291	8500,325	56686,57	68126,186	4 %	12 %	83 %
Spain	7070,7124	3082,4805	23462,137	33615,3299	21 %	9 %	70 %
Sweden	31948,436	12223,56	15754,809	59926,805	53 %	20 %	26 %
Switzerland	11031,041	6615,6626	15704,048	33350,7516	33 %	20 %	47 %
Taiwan	2452,8599	2487,2866	50666,402	55606,5485	4 %	4 %	91 %
Thailand	1437,4113	0	18179,367	19616,7783	7 %	0 %	93 %
Turkey	4301,231	0	18522,918	22824,149	19 %	0 %	81 %
UAE	0	5327,5034	141325,73	146653,2334	0 %	4 %	96 %
Greece	6049	0	24361	30410	20 %	0 %	80 %
GBR	5820,2104	1768,5579	22509,117	30097,8853	19 %	6 %	75 %
USA	8912,268	6006,1494	63835,86	78754,2774	11 %	8 %	81 %
Vietnam	3473,4663	0	9509,55	12983,0163	27 %	0 %	73 %
Argentina	2819	411	18765	21995	13 %	2 %	85 %
Australia	9172,81	0	54286	63458,81	14 %	0 %	86 %
Austria	15626,23	0	27059	42685,23	37 %	0 %	63 %
Total	**493679,4616**	**118182,0629**	**1923075,803**	**2534937,327**	**19 %**	**5 %**	**76 %**

Figure G.1: Full overview of the energy mixes in the countries represented in the study.

Figure G.2: Full overview of the energy mixes for the smart cities for both indexes.

(a) SCI

IMD SMART CITY INDEX				
City, smartness	Renewable %	Nuclear %	Fossil fules %	Footprint (normalized)
Zurich, 1	33 %	20 %	47 %	0,264166902
Oslo, 2	72 %	0 %	28 %	0,24161263
Canberra, 3	14 %	0 %	86 %	0,62700874
Geneva, 4	33 %	20 %	47 %	0,179306456
Singapore, 5	0 %	0 %	100 %	0,822385114
Copenhagen, 6	43 %	0 %	57 %	0,238793346
Lausanne, 7	33 %	20 %	47 %	0,195094446
London, 8	19 %	6 %	75 %	0,247251198
Helsinki, 9	39 %	19 %	42 %	0,162672681
Abu Dhabi, 10	0 %	4 %	96 %	0,881590076
Stockholm, 11	53 %	20 %	26 %	0,182407668
Dubai, 12	0 %	4 %	96 %	0,582745983
Beijing, 13	16 %	2 %	82 %	0,072455596
Hamburg, 14	21 %	3 %	76 %	0,266986186
Prague, 15	7 %	17 %	76 %	0,233154779
Taipei City, 16	4 %	4 %	91 %	0,128841274
Seoul, 17	4 %	12 %	83 %	0,32055258
Amsterdam, 18	14 %	1 %	85 %	0,250070482
Shanghai, 19	16 %	2 %	82 %	0,168311249
Hong Kong, 20	0 %	0 %	100 %	0,929517902
Munich, 21	21 %	3 %	76 %	0,157034113
Sydney, 22	14 %	0 %	86 %	0,283901889
Vienna, 23	37 %	0 %	63 %	0,266986186
Tallinn, 24	0 %	0 %	100 %	0,139272625
Riyadh, 25	0 %	0 %	100 %	0,53763744
Reykjavik, 26	100 %	0 %	0 %	0,263321116
Luxemburg, 27	11 %	0 %	89 %	0,616295461
Wellington, 28	43 %	0 %	57 %	0,204398083
Bilbao, 29	21 %	9 %	70 %	0,171130533
Brisbane, 30	53 %	20 %	26 %	0,492528898
Auckland, 31	28 %	0 %	72 %	0,145756978
Ljubliana,32	16 %	19 %	65 %	0,131096701
Melbourne, 33	18 %	8 %	74 %	0,345926135
New York, 34	11 %	8 %	81 %	0,43614322
Madrid, 35	21 %	9 %	70 %	0,202142656
Boston, 36	14 %	0 %	86 %	0,489709614
Berlin, 37	21 %	3 %	76 %	0,247251198
Warsaw, 38	28 %	0 %	72 %	0,165491965
Gothenburg, 39	53 %	20 %	26 %	0,188328165
Brussels, 40	11 %	16 %	73 %	0,165491965
Rotterdam, 41	14 %	1 %	85 %	0,266986186
The Hague, 42	14 %	1 %	85 %	0,114744855
Vancouver, 43	4 %	8 %	88 %	0,24161263
Dusseldorf, 44	21 %	3 %	76 %	0,244995771
Busan, 45	4 %	12 %	83 %	0,328728503
Ottawa, 46	4 %	8 %	88 %	0,323371864
Vilnius, 47	15 %	0 %	85 %	0,191711305
Doha, 48	0 %	0 %	100 %	0,151677474
Paris, 49	15 %	32 %	54 %	0,171130533
Washington D.C. , 50	11 %	8 %	81 %	0,489709614
Toronto, 51	4 %	8 %	88 %	0,227516211
Mecca, 52	0 %	0 %	100 %	0,379757542
Hannover, 53	21 %	3 %	76 %	0,230617423
Tianjin, 54	16 %	2 %	82 %	0,207781224
Jeddah, 55	0 %	0 %	100 %	0,495348182
Bratislava, 56	10 %	21 %	69 %	0,334367071
Zaragoza, 57	21 %	9 %	70 %	0,126867776
Zhuhai, 58	16 %	2 %	82 %	0,123202707
Riga, 59	29 %	0 %	71 %	0,002819284
Shenzhen, 60	16 %	2 %	82 %	1
Lyon, 61	15 %	32 %	54 %	0,111925571
Nanjing, 62	16 %	2 %	82 %	0,154214829
Seattle, 63	11 %	8 %	88 %	0,441781787
Hangzho, 64	16 %	2 %	82 %	0,151395546
Guangzhou, 65	16 %	2 %	82 %	0,12602199
Denver, 66	11 %	8 %	88 %	0,492528898
Chicago, 67	11 %	8 %	88 %	0,548914576
Los Angeles, 68	11 %	8 %	88 %	0,365661122
Dublin, 69	20 %	0 %	80 %	0,210600507
Bordeaux, 70	15 %	32 %	54 %	0,149985904
Manchester, 71	19 %	6 %	75 %	0,221877643
Leeds, 72	19 %	6 %	75 %	0,276007894
Kuala Lumpur, 73	8 %	0 %	92 %	0,118409924
Medina, 74	0 %	0 %	100 %	0,374118974
San Francisco, 75	11 %	8 %	88 %	0,422610657
Krakow, 76	9 %	0 %	91 %	0,116718354
Newcastle, 77	19 %	6 %	75 %	0,185226952
Bologna, 78	17 %	0 %	83 %	0,178460671
Kiel, 79	21 %	3 %	76 %	0,1559064
Montreal, 80	4 %	8 %	88 %	0,238793346
Barcelona, 81	21 %	9 %	70 %	0,154214829
Chongqing, 82	16 %	2 %	82 %	0,14011841
Birmingham, 83	16 %	6 %	75 %	0,252889766
Bangkok, 84	7 %	0 %	93 %	0,072455596
Lille, 85	15 %	32 %	54 %	0,114744855
Tokyo, 86	13 %	3 %	85 %	0,066817028
Glasgow, 87	19 %	6 %	75 %	0,257964477
Muscat, 88	0 %	0 %	100 %	-0,045954328
Budapest, 89	9 %	15 %	76 %	0,117564139
Philadelphia, 90	11 %	8 %	88 %	0,503806033
Milan, 91	17 %	0 %	83 %	0,179588385
Cardiff, 92	19 %	6 %	75 %	0,208627009
Chengdu, 93	16 %	2 %	82 %	0,078094164
Tel Aviv, 94	6 %	0 %	94 %	0,278263321
Osaka, 95	13 %	3 %	85 %	0,061178461
Ankara, 96	19 %	0 %	81 %	0,148576262
Hanoi, 97	27 %	0 %	73 %	0,018889202
Phoenix, 98	11 %	8 %	88 %	0,402311813
Al-Khobar, 99	0 %	0 %	100 %	0,587538765
Bucharest, 100	18 %	8 %	74 %	0,12602199

INNOVATION CITIES INDEX				
City, smartness	Renewable %	Nuclear %	Fossil fules %	Footprint (normalized)
Tokyo, 1	13 %	3 %	85 %	0,064971751
London, 2	19 %	6 %	75 %	0,245762712
New York, 3	11 %	8 %	88 %	0,435028249
Paris, 4	15 %	32 %	54 %	0,169491525
Singapore, 5	0 %	0 %	100 %	0,822033898
Los Angeles, 6	11 %	8 %	88 %	0,36440678
Boston, 7	11 %	8 %	88 %	0,488700565
Seoul, 8	4 %	12 %	83 %	0,31920904
San Francisco, 9	11 %	8 %	88 %	0,421468927
Houston, 10	11 %	8 %	88 %	0,36440678
Berlin, 11	21 %	3 %	76 %	0,245762712
Chicago, 12	11 %	8 %	88 %	0,548022599
Stockholm, 13	53 %	20 %	26 %	0,18079096
Dubai, 14	0 %	4 %	96 %	0,581920904
Toronto, 15	4 %	8 %	88 %	0,225988701
Munich, 16	21 %	3 %	76 %	0,155367232
Vienna, 17	37 %	0 %	63 %	0,265536723
Sydney, 18	18 %	8 %	74 %	0,282485876
Madrid, 19	21 %	9 %	70 %	0,200564972
Amsterdam, 20	14 %	1 %	85 %	0,248587571
Seattle, 21	11 %	8 %	88 %	0,440677966
Dallas, 22	11 %	8 %	88 %	0,418079096
Melbourne, 23	18 %	8 %	74 %	0,344632768
Montreal, 24	4 %	8 %	88 %	0,237288136
Atlanta, 25	11 %	8 %	88 %	0,480225989
Barcelona, 26	21 %	9 %	70 %	0,152542373
Milan, 27	17 %	0 %	83 %	0,177966102
Beijing, 28	16 %	2 %	82 %	0,070621469
Vancouver, 29	4 %	8 %	88 %	0,240112994
Copenhagen, 30	43 %	0 %	57 %	0,237288136
Miami, 31	11 %	8 %	88 %	0,403954802
Washington DC, 32	11 %	8 %	88 %	0,488700565
Philadelphoa, 33	11 %	8 %	88 %	0,502824859
Oslo, 34	72 %	0 %	28 %	0,240112994
Osaka, 35	13 %	3 %	85 %	0,059322034
Dublin, 36	20 %	0 %	80 %	0,209039548
San Diego, 37	11 %	8 %	88 %	0,361581921
Brisbane, 38	18 %	8 %	74 %	0,491525424
Helsinki, 39	39 %	19 %	42 %	0,161016949
Tel Aviv, 40	6 %	0 %	94 %	0,276836158
Hamburg, 41	21 %	3 %	76 %	0,265536723
Denver, 42	11 %	8 %	88 %	0,5
Portland, 43	11 %	8 %	88 %	0,423728814
Austin, 44	11 %	8 %	88 %	0,375706215
Las Vegas, 45	11 %	8 %	88 %	0,299435028
Shanghai, 46	16 %	2 %	82 %	0,166666667
Detroit, 47	11 %	8 %	88 %	0,672316384
Rome, 48	17 %	0 %	83 %	0,141242938
Brussels, 49	11 %	16 %	73 %	0,163841808
Newark, 50	11 %	8 %	88 %	0,376271186
Baltimore, 51	11 %	8 %	88 %	0,52259887
Taipei, 52	4 %	4 %	91 %	0,127118644
Istanbul, 53	19 %	0 %	81 %	0,098870056
Zürich, 54	33 %	20 %	47 %	0,262711864
Phoenix, 55	11 %	8 %	88 %	0,401129944
Oakland, 56	11 %	8 %	88 %	0,497175141
Orlando, 57	11 %	8 %	88 %	0,367231638
Hong Kong, 58	0 %	0 %	100 %	0,929378531
Prague, 59	7 %	17 %	76 %	0,231638418
Lisbon, 60	29 %	0 %	71 %	0,101694915
Mexico City, 61	9 %	1 %	90 %	0,016949153
Buenos Aires, 62	13 %	2 %	85 %	0,06779661
Perth, 63	18 %	8 %	74 %	0,46299435
Kyoto, 64	13 %	3 %	85 %	0,033050847
Basel, 65	33 %	20 %	47 %	0,15960452
Athens, 66	20 %	0 %	80 %	0,257062147
Sacramento, 67	11 %	8 %	88 %	0,353107345
Frankfurt, 68	21 %	3 %	76 %	0,234463277
Tampa, 69	11 %	8 %	88 %	0,384180791
Minneapolis, 70	11 %	8 %	88 %	0,56779661
Pittsburgh, 71	11 %	8 %	88 %	0,629943503
San Antonio, 72	11 %	8 %	88 %	0,381355932
Riverside, 73	11 %	8 %	88 %	0,225706215
Shenzhen, 74	16 %	2 %	82 %	1
Abu Dhabi, 75	0 %	4 %	96 %	0,881355932
Moscow, 76	7 %	7 %	86 %	0,146892655
Auckland, 77	28 %	0 %	72 %	0,144067797
Budapest, 78	9 %	15 %	76 %	0,115819209
Oporto, 79	29 %	0 %	71 %	0,144067797
Sao Paulo, 80	49 %	1 %	50 %	0
Nagoya, 81	13 %	3 %	85 %	0,056497175
Düsseldorf, 82	21 %	3 %	76 %	0,243502825
Yokohama, 83	13 %	3 %	85 %	0,064971751
Quebéc, 84	4 %	8 %	88 %	0,203389831
Stuttgart, 85	21 %	3 %	76 %	0,200564972
Manchester, 86	19 %	6 %	75 %	0,220338983
Rotterdam, 87	14 %	1 %	85 %	0,265536723
Lyon, 88	15 %	32 %	54 %	0,110169492
Warsaw, 89	28 %	0 %	72 %	0,163841808
Charlotte, 90	11 %	8 %	88 %	0,361581921
Nashville, 91	11 %	8 %	88 %	0,449152542
Cleveland, 92	11 %	8 %	88 %	0,649717514
Gothenburg, 93	53 %	20 %	26 %	0,186723164
Santa Ana, 94	11 %	8 %	88 %	0,294067797
Cincinnati, 95	11 %	8 %	88 %	0,59039548
Kansas City, 96	11 %	8 %	88 %	0,59039548
Cologne, 97	21 %	3 %	76 %	0,234463277
Geneva, 98	33 %	20 %	47 %	0,177683616
Fort Lauderdale, 99	11 %	8 %	88 %	0,205932203
Guangzhou, 100	16 %	2 %	82 %	0,124293785

(a) ICI

H Appendix - Collection of MVRAs

Figure H.1 shows the main findings for the MVRAs done, with an additional summarizing comment for each dependent variable. In total, 50 analysis has been executed, 25 for each index. Every analyzed variable in this study has been tested as the dependent variable for both indexes, with each independent variable being excluded once for ever case. The excluded variables are marked with a cross. The following list clarifies the meaning of each abbreviation used:

- GDP: Gross domestic product (USD per capita)
- CF: Carbon footprint (tons CO_2 per capita)
- S: Rank of smartness from 1-100
- E: Education level from 0-1
- T: Temperature (degrees Celsius)

Index	Dependent variable	Independent variables					Adjusted R-squared	Significance-F	Significant variables	P-value	Comment
SCI	GDP in USD	GDP	CF	S	E	T	0,31127209	2,00663E-06	CF E	0,012185 0,0030256	The R-squared values are about the same for both indexes. The Signiffance-F is within the cut-off limit for all cases. For the SCI, CF and E are frequent significant variables. For the ICI, S and E are more frequent. This makes E a frequent sicnifigant variable for both indexes.
		GDP	~~CF~~	S	E	T	0,25980786	1,11858E-05	E	0,00013313	
		GDP	CF	~~S~~	E	T	0,30169278	1,34E-06	CF E	0,006739 0,002334	
		GDP	CF	S	~~E~~	T	0,23411599	3,85991E-05	CF T	0,0005167 0,004354	
		GDP	CF	S	E	~~T~~	0,31532047	6,50E-07	CF E	0,015524 0,000049	
ICI		GDP	CF	S	E	T	0,3188833	1,35586E-06	S E	0,033228 0,00013	
		GDP	~~CF~~	S	E	T	0,30586013	1,07E-06	S E	0,03081796 0,00000916	
		GDP	CF	~~S~~	E	T	0,28520659	3,14E-06	E	0,00009413	
		GDP	CF	S	~~E~~	T	0,17987064	0,000454868	CF S T	0,007086 0,025235 0,002783	
		GDP	CF	S	E	~~T~~	0,30477721	1,14E-06	S E	0,03567 0,000004	
SCI	Carbon Footprint in tCO2 per capita	GDP	CF	S	E	T	0,19871221	0,0003878	GDP T	0,012185 0,00069	The R-squared values are generally higher for the SCI. For both indexes, the R-squared values are very low and the Significance-F are generally higher when T is excluded. For the ICI, it is too high to look at the p-values. GDP and T are the most frequent significant variables.
		~~GDP~~	CF	S	E	T	0,1388371	0,002590833	E T	0,0027277 0,000836	
		GDP	CF	~~S~~	E	T	0,202972	0,0001629	GDP T	0,00674 0,00087	
		GDP	CF	S	~~E~~	T	0,17363186	0,000596676	GDT T	0,0005167 0,003768	
		GDP	CF	S	E	~~T~~	0,07531111	0,031045427	GDP	0,0155243	
ICI		GDP	CF	S	E	T	0,14423582	0,003565452	T	0,0014863	
		~~GDP~~	CF	S	E	T	0,12787334	0,004050888	E T	0,003911 0,002760	
		GDP	CF	~~S~~	E	T	0,15551294	0,001294007	T	0,00138658	
		GDP	CF	S	~~E~~	T	0,11521289	0,006723991	GDP T	0,0070860 0,0044724	
		GDP	CF	S	E	~~T~~	0,03134118	0,146946741	-	-	
SCI	Level of smartness from 1-100	GDP	CF	S	E	T	0,0195353	0,246220387	-	-	The R-squared values are extreamly low for every case, and negative for the ICI with the GDP excluded. The only significant variable is T for the SCI when E is excluded. Elsewise, the Significance-F values falls outside the cut-off limit for most ICI-cases.
		~~GDP~~	CF	S	E	T	0,08228401	0,023943913	-	-	
		GDP	~~CF~~	S	E	T	0,09968553	0,0123458	-	-	
		GDP	CF	S	~~E~~	T	0,10685848	0,009342085	T	0,0355433	
		GDP	CF	S	E	~~T~~	0,06945886	0,038507233	-	-	
ICI		GDP	CF	S	E	T	0,09487315	0,002590833	-	-	
		~~GDP~~	CF	S	E	T	-0,0289422	0,847787545	-	-	
		GDP	~~CF~~	S	E	T	0,0324557	0,141550122	-	-	
		GDP	CF	S	~~E~~	T	0,03157069	0,145820239	-	-	
		GDP	CF	S	E	~~T~~	0,03020003	0,152666749	-	-	
SCI	Education level from 0-1	GDP	CF	S	E	T	0,43674707	1,55E-09	GDP T	0,0030256 0,000002	The R-squared values are higher for the SCI, and all of the Significance-F values are within the cut-off level for both indexes. GDP is a frequent significant variable for all cases where it is considered for both indexed. The same goes for T when looking at the SCI.
		~~GDP~~	CF	S	E	T	0,37364756	2,48E-08	CF T	0,002727 0,00000003	
		GDP	~~CF~~	S	E	T	0,41911723	1,54E-09	GDP T	0,00013313 0,000009	
		GDP	CF	~~S~~	E	T	0,44420544	3,02E-10	GDP T	0,00233 0,0000008	
		GDP	CF	S	E	~~T~~	0,24347925	2,47115E-05	GDP	4,9134E-05	
ICI		GDP	CF	S	E	T	0,30605915	2,62E-06	GDP T	0,0001301 0,022389	
		~~GDP~~	CF	S	E	T	0,16442915	0,000886382	CF T	0,0039105 0,00062	
		GDP	~~CF~~	S	E	T	0,28252441	3,59E-06	GDP	9,1575E-06	
		GDP	CF	~~S~~	E	T	0,31457742	6,77E-07	GDP T	0,000094 0,02043	
		GDP	CF	S	E	~~T~~	0,26496654	8,67E-06	GDP	4,02E-06	

Figure H.1: Overview of all conducted MVRAs.

I Appendix - Complete Data Collection for both Indexes

Figure I.1 and I.2 presents every value that is used in this study to conduct the analysis for both indexes. Every method used to extract the values are explained in Section 4.

SCI						
City	Smartness rank	CF per capita (t CO2)	CF for country (t CO2)	Average temperature	Education level from 0-1	GDP per capita (USD)
Zurich, 1	1	11	4,74	9,7	0,902	76319
Oslo, 2	2	10,2	8,3	5,9	0,912	130942,8599
Canberra, 3	3	23,87	17,15	12,8	0,896	58623
Geneva, 4	4	7,99	4,74	10	0,902	77386
Singapore, 5	5	30,8	8,47	26,7	0,771	-
Copenhagen, 6	6	10,1	6,66	8,9	0,909	62132
Lausanne, 7	7	8,55	4,74	11,1	0,902	54977
London, 8	8	10,4	5,6	10,8	0,901	60927
Helsinki, 9	9	7,4	9,31	6,1	0,907	56831
Abu Dhabi, 10	10	32,9	24,33	27,9	0,751	-
Stockholm, 11	11	8,1	4,49	7,3	0,885	68720
Dubai, 12	12	22,3	24,33	28,2	0,751	-
Beijing, 13	13	4,2	7,44	12,7	0,573	30178
Hamburg, 14	14	11,1	9,42	9,8	0,917	57359
Prague, 15	15	9,9	10,62	9,8	0,868	60032
Taipei City, 16	16	6,2	11,73	21,1	0,573	-
Seoul, 17	17	13	11,77	11,3	0,799	-
Amsterdam, 18	18	10,5	9,54	10,7	0,875	67167
Shanghai, 19	19	7,6	7,44	16,6	0,573	23373
Hong Kong, 20	20	34,6	6,33	22,6	0,802	-
Munich, 21	21	7,2	9,42	8,8	0,917	79635
Sydney, 22	22	11,7	17,15	18	0,896	46320
Vienna, 23	23	11,1	8,44	9,9	0,832	51275
Tallinn, 24	24	6,57	17,02	6,5	0,876	46295
Riyadh, 25	25	20,7	15,47	26,2	0,676	-
Reykjavik, 26	26	10,97	11,69	4,3	0,938	-
Luxemburg, 27	27	23,49	17,39	9,7	0,794	107261
Wellington, 28	28	8,88	7,13	12,5	0,914	46078
Bilbao, 29	29	7,7	5,42	13,5	0,717	39646
Brisbane, 30	30	19,1	17,15	20	0,896	41153
Auckland, 31	31	6,8	7,13	15,5	0,914	43839
Ljubliana,32	32	6,28	7,04	10,2	0,898	-
Melbourne, 33	33	13,9	17,15	14,8	0,896	41736
New York, 34	34	17,1	15,32	11,9	0,883	85563
Madrid, 35	35	8,8	5,42	14,5	0,717	45013
Boston, 36	36	19	15,32	10,1	0,883	93663
Berlin, 37	37	10,4	9,42	10,1	0,917	46299
Warsaw, 38	38	7,5	7,7	9,3	0,845	66746
Gothenburg, 39	39	8,31	4,49	8,1	0,885	46808
Brussels, 40	40	7,5	8,37	10,7	0,859	57258
Rotterdam, 41	41	11,1	9,54	10,8	0,875	52518
The Hague, 42	42	5,7	9,54	10,9	0,875	-
Vancouver, 43	43	10,2	18,72	9,5	0,893	45071
Dusseldorf, 44	44	10,32	9,42	10,9	0,917	68028
Busan, 45	45	13,29	11,77	13,8	0,799	-
Ottawa, 46	46	13,1	18,72	6,9	0,893	43274
Vilnius, 47	47	8,43	4,66	7,2	0,87	50541
Doha, 48	48	7,01	38,14	27,5	0,607	-
Paris, 49	49	7,7	5,18	11,7	0,762	71346
Washington D.C., 50	50	19	15,32	13,7	0,883	77580
Toronto, 51	51	9,7	18,72	8,7	0,893	44095
Mecca, 52	52	15,1	15,47	28,6	0,676	-
Hannover, 53	53	9,81	9,42	10,3	0,917	53154
Tianjin, 54	54	9	7,44	13,3	0,573	275
Jeddah, 55	55	19,2	15,47	28,1	0,676	-
Bratislava, 56	56	13,49	6,78	10,8	0,819	74562
Zaragoza, 57	57	6,13	5,42	15,6	0,717	37358
Zhuhai, 58	58	6	7,44	22,9	0,573	23033
Riga, 59	59	1,73	4,13	7,6	0,872	38701
Shenzhen, 60	60	37,1	7,44	22,4	0,573	22994
Lyon, 61	61	5,6	5,18	12	0,762	54225
Nanjing, 62	62	7,1	7,44	16,1	0,573	28407
Seattle, 63	63	17,3	15,32	10,8	0,883	98051
Hangzho, 64	64	7	7,44	17,1	0,573	25256
Guangzhou, 65	65	6,1	7,44	22,4	0,573	22504
Denver, 66	66	19,1	15,32	9	0,883	68836
Chicago, 67	67	21,1	15,32	10,2	0,883	67733
Los Angeles, 68	68	14,6	15,32	17,6	0,883	61920
Dublin, 69	69	9,1	8,29	9,4	0,856	102486
Bordeaux, 70	70	6,95	5,18	13,8	0,762	42454
Manchester, 71	71	9,5	5,6	9,4	0,901	36565
Leeds, 72	72	11,42	5,6	9,4	0,901	33231
Kuala Lumpur, 73	73	5,83	8,45	25,8	0,638	-
Medina, 74	74	14,9	15,47	18,7	0,676	-
San Francisco, 75	75	16,62	15,32	19,6	0,883	130744
Krakow, 76	76	5,77	7,7	9	0,845	39379
Newcastle, 77	77	8,2	5,6	9,3	0,901	29010
Bologna, 78	78	7,96	5,96	14,3	0,727	49609
Kiel, 79	79	7,16	9,42	9,5	0,917	44668
Montreal, 80	80	10,1	18,72	7,1	0,893	38491
Barcelona, 81	81	7,1	5,42	15,5	0,717	39459
Chongqing, 82	82	6,6	7,44	18,3	0,573	2721
Birmingham, 83	83	10,6	5,6	9,7	0,901	31105
Bangkok, 84	84	4,2	3,84	27,7	0,608	-
Lille, 85	85	5,7	5,18	11	0,762	36812
Tokyo, 86	86	4	9,76	15,2	0,829	51143
Glasgow, 87	87	10,78	7,59	8,1	0,901	34758
Muscat, 88	88	-	19,97	27,3	0,698	46774
Budapest, 89	89	5,8	5,2	11,1	0,802	67868
Philadelphia, 90	90	19,5	15,32	18,1	0,883	56822
Milan, 91	91	8	5,96	13	0,727	31515
Cardiff, 92	92	9,03	5,6	10,4	0,883	18997
Chengdu, 93	93	4,4	7,44	17,3	0,573	-
Tel Aviv, 94	94	11,5	7,99	20,5	0,835	41250
Osaka, 95	95	3,8	9,76	15,8	0,829	40009
Ankara, 96	96	6,9	4,54	11,5	0,68	-
Hanoi, 97	97	2,3	2,21	23,6	0,541	51395
Phoenix, 98	98	15,9	15,32	23,2	0,883	-
Al-Khobar, 99	99	22,47	15,47	26,5	0,676	61718
Bucharest, 100	100	6,1	3,98	12,2	0,729	-

Figure I.1: All values used for the SCI.

ICI						
City	Smartness rank	CF per capita (t CO2)	CF for country (t CO2)	Average temperature	Education level from 0-1	GDP per capita (USD)
Tokyo, 1	1	4	9,76	15,2	0,829	51143
London, 2	2	10,4	5,6	10,8	0,901	60927
New York, 3	3	17,1	15,32	11,9	0,883	85563
Paris, 4	4	7,7	5,18	11,7	0,762	71346
Singapore, 5	5	30,8	8,47	26,7	0,771	-
Los Angeles, 6	6	14,6	15,32	17,6	0,883	61920
Boston, 7	7	19	15,32	10,1	0,883	93663
Seoul, 8	8	13	11,77	11,3	0,799	-
San Francisco, 9	9	16,62	15,32	19,6	0,883	130744
Houston, 10	10	14,6	15,32	20,9	0,883	62443
Berlin, 11	11	10,4	9,42	10,1	0,917	46299
Chicago, 12	12	21,1	15,32	10,2	0,883	67733
Stockholm, 13	13	8,1	4,49	7,3	0,885	68720
Dubai, 14	14	22,3	24,33	28,2	0,751	-
Toronto, 15	15	9,7	18,72	8,7	0,893	44095
Munich, 16	16	7,2	9,42	8,8	0,917	79635
Vienna, 17	17	11,1	8,44	9,9	0,832	51275
Sydney, 18	18	11,7	17,15	18	0,896	46320
Madrid, 19	19	8,8	5,42	14,5	0,717	45013
Amsterdam, 20	20	10,5	9,54	10,7	0,875	67167
Seattle, 21	21	17,3	15,32	10,8	0,883	98051
Dallas, 22	22	16,5	15,32	19,3	0,883	63338
Melbourne, 23	23	13,9	17,15	14,8	0,896	41736
Montreal, 24	24	10,1	18,72	7,1	0,893	38491
Atlanta, 25	25	18,7	15,32	16,7	0,883	66439
Barcelona, 26	26	7,1	5,42	15,5	0,717	39459
Milan, 27	27	8	5,96	13	0,727	56822
Beijing, 28	28	4,2	7,44	12,7	0,573	30178
Vancouver, 29	29	10,2	18,72	9,5	0,893	45071
Copenhagen, 30	30	10,1	6,66	8,9	0,909	62132
Miami, 31	31	16	15,32	24,6	0,883	54262
Washington DC, 32	32	19	15,32	13,7	0,883	77580
Philadelphoa, 33	33	19,5	15,32	18,1	0,883	67868
Oslo, 34	34	10,2	8,3	5,9	0,912	130943
Osaka, 35	35	3,8	9,76	15,8	0,829	41250
Dublin, 36	36	9,1	8,29	9,4	0,856	102486
San Diego, 37	37	14,5	15,32	16,7	0,883	66417
Brisbane, 38	38	19,1	17,15	20	0,896	41153
Helsinki, 39	39	7,4	9,31	6,1	0,907	56831
Tel Aviv, 40	40	11,5	7,99	20,5	0,835	-
Hamburg, 41	41	11,1	9,42	9,8	0,917	57359
Denver, 42	42	19,4	15,32	9	0,883	68836
Portland, 43	43	16,7	15,32	11,3	0,883	63124
Austin, 44	44	15	15,32	20,4	0,883	67884
Las Vegas, 45	45	12,3	15,32	20,3	0,883	47385
Shanghai, 46	46	7,6	7,44	16,6	0,573	23373
Detroit, 47	47	25,5	15,32	10	0,883	54376
Rome, 48	48	6,7	5,96	15,8	0,727	45343
Brussels, 49	49	7,5	8,37	10,7	0,859	57258
Newark, 50	50	15,02	15,32	11,8	0,883	-
Baltimore, 51	51	20,2	15,32	13	0,883	-
Taipei, 52	52	6,2	11,73	21,1	-	-
Istanbul, 53	53	5,2	4,54	14,9	0,68	46104
Zürich, 54	54	11	4,74	9,7	0,902	76319
Phoenix, 55	55	15,9	15,32	23,2	0,883	51395
Oakland, 56	56	19,3	15,32	14,1	0,883	-
Orlando, 57	57	14,7	15,32	22,1	0,883	-
Hong Kong, 58	58	34,6	6,33	22,6	0,802	-
Prague, 59	59	9,9	10,62	9,8	0,868	60032
Lisbon, 60	60	5,3	4,85	16,7	0,685	38343
Mexico City, 61	61	2,3	3,63	16	0,623	23213
Buenos Aires, 62	62	4,1	4,6	24,2	0,818	-
Perth, 63	63	18,09	17,15	18,6	0,896	77950
Kyoto, 64	64	2,87	9,76	14,1	0,829	-
Basel, 65	65	7,35	4,74	10,5	0,902	91046
Athens, 66	66	10,8	6,31	17,5	0,777	35192
Sacramento, 67	67	14,2	15,32	16,8	0,883	56428
Frankfurt, 68	68	10	9,42	10,7	0,917	65198
Tampa, 69	69	15,3	15,32	22,5	0,883	59727
Minneapolis, 70	70	21,8	15,32	7,9	0,883	68478
Pittsburgh, 71	71	24	15,32	10,9	0,883	73601
San Antonio, 72	72	15,2	15,32	21	0,883	47070
Riverside, 73	73	9,69	15,32	17,9	0,883	-
Shenzhen, 74	74	37,1	7,44	22,4	0,573	22994
Abu Dhabi, 75	75	32,9	24,33	27,9	0,751	-
Moscow, 76	76	6,9	11,45	5,7	0,846	-
Auckland, 77	77	6,8	7,13	15,5	0,914	43839
Budapest, 78	78	5,8	5,2	11,1	0,802	46774
Oporto, 79	79	6,8	4,85	15,1	0,685	28897
Sao Paulo, 80	80	1,7	2,24	14,7	0,594	-
Nagoya, 81	81	3,7	9,76	14,7	0,829	49054
Düsseldorf, 82	82	10,32	9,42	10,9	0,917	68028
Yokohama, 83	83	4	9,76	15,3	0,829	-
Quebéc, 84	84	8,9	18,72	5,4	0,893	39568
Stuttgart, 85	85	8,8	9,42	10	0,917	64556
Manchester, 86	86	9,5	5,6	9,4	0,901	36565
Rotterdam, 87	87	11,1	9,54	10,8	0,875	52518
Lyon, 88	88	5,6	5,18	12	0,762	54225
Warsaw, 89	89	7,5	7,7	9,3	0,845	66746
Charlotte, 90	90	14,5	15,32	16,1	0,883	70095
Nashville, 91	91	17,6	15,32	15,5	0,883	46861
Cleveland, 92	92	24,7	15,32	10,5	0,883	-
Gothenburg, 93	93	8,31	4,49	8,1	0,885	46808
Santa Ana, 94	94	12,11	15,32	16,9	0,883	-
Cincinnati, 95	95	22,6	15,32	12,7	0,883	64430
Kansas City, 96	96	22,6	15,32	13,3	0,883	-
Cologne, 97	97	10	9,42	10,7	0,917	54138
Geneva, 98	98	7,99	4,74	10	0,902	77386
Fort Lauderdale, 99	99	8,99	15,32	24,3	0,883	-
Guangzhou, 100	100	6,1	7,44	22,4	0,573	22504

Figure I.2: All values used for the ICI.

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