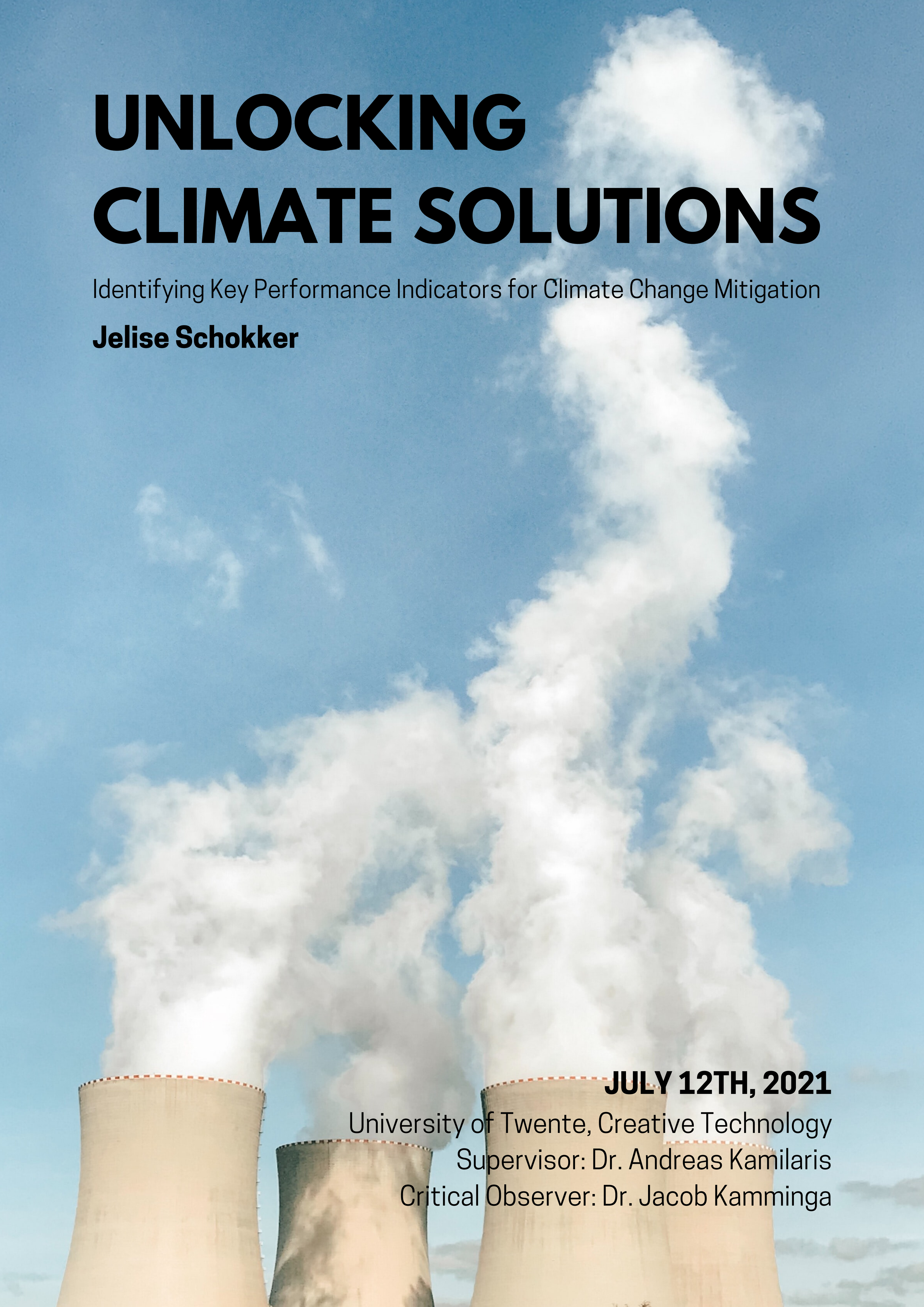

UNLOCKING CLIMATE SOLUTIONS

Identifying Key Performance Indicators for Climate Change Mitigation

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Abstract

Human caused climate change has become an undeniable problem. Monitoring and mitigating this climate change is a priority for many countries and cities. Key performance Indicators (KPIs) related to climate change can be used to develop appropriate climate change mitigation policies. This study aims to identify useful KPIs and determine their units, values and use. 63 KPIs across eight main topics are presented in this study. These topics are pollution, resource use, climate hazards, biodiversity, transport, land use, health, and others. The use of these KPIs in 193 countries is evaluated and visualized. Together, the KPIs that are selected provide a step in the right direction towards a consistent and comparable index of global, well-defined metrics that can be used to monitor and mitigate climate change.

Contents

1 Introduction

1.1 Background

In the past couple of years, climate change has become an undeniable problem. The year 2020 was tied with 2016 as the warmest year on record. The average temperature of the earth has risen over 1.2 degrees Celsius since the late nineteenth century. [1] Climate change and the environmental issues it causes affect life for many people around the world. As temperatures keep rising, an increasing amount of climate-related issues arise. It is important that cities and countries form appropriate policies to combat climate change and the problems that ensue.

Key Performance Indicators (KPIs) can be used to formulate policies and to reach climate goals. According to Lo-Iacono-Ferreira et al. [2], KPIs are measures that are used to assess essential factors related to a given objective, such as reducing the effects of climate change. The effectiveness of a country or organization in achieving these objectives can be determined by these factors. Because KPIs are always tied to a certain objective [3], they are very important in developing useful policies.

Having a comprehensive index of KPIs is important because it would provide a method for policymakers to consistently monitor their performance and take appropriate actions based on that. This would in turn lead to a more straightforward way of policy-making, where policies can easily be developed based on current performance. The importance of globally defined KPIs lies in the ability to compare performance across countries and cities. This would give not only an absolute performance, but also relative to the achievements of other regions.

1.2 Research Questions

The main objective is giving insight into which Key Performance Indicators can be used to form policies on climate change. Relevant KPIs can be used by policymakers to set and achieve clear goals, therefore it is important to focus on the correct KPIs. Previous research has resulted in useful lists, but the goal of this thesis is to fill gaps in the literature by creating a more comprehensive index that includes all relevant KPIs. This done by listing, describing and understanding important KPIs related to climate change. As a result, the main research question may be stated as follows:

Which KPIs can be used by countries or cities to monitor and mitigate climate change?

In order to answer the main research question, the following sub-questions must be answered:

1. *What are the KPIs that relate to climate change?*
2. *Which units and values are associated with these KPIs?*

3. *Which countries use these KPIs to monitor their environmental impact and set climate change mitigation goals?*

1.3 Outline

First, an overview of related work is given in section 2. Section 3 discusses a review of the existing literature and the methods used to answer the research questions. Section 4 presents the results that were obtained. In section 5, a discussion of the results is given based on the formulated research questions. In the discussion, limitations and possibilities for future work are also identified. Finally, section 6 presents a conclusion of the research.

2 Related Work

In this section, an overview will be given of existing work similar to what will be done in this project. First, the Carbon Disclosure Project is discussed. Next, three efforts on sustainability are addressed: Hristov and Chirico, Angelakoglou et al. and Amrina and Yusof. Then, the Sustainable Development Goals presented by the United Nations are considered. Finally, the Climate Change Performance Index is discussed.

2.1 Carbon Disclosure Project

Each year, thousands of cities, businesses and regions submit data on their environmental impacts to the Carbon Disclosure Project (CDP), a non-profit organization with the goal of building the world's most comprehensive data set on environmental action [4]. The framework that they have developed has resulted in unprecedented global engagement on environmental issues. In order to reduce emissions, improve resilience, and to protect themselves against a changing climate, over 810 cities provide information on their environmental impact to the CDP [5]. This data can be very useful in developing KPIs related to a city's environmental impact and to climate change. For their data collection, the CDP uses a set list of questions and indicators that make comparing performance across cities possible.

The CDP questionnaire for disclosing cities is divided into eleven categories: governance and data management, climate hazards and vulnerability, adaptation, city-wide emissions, emissions reduction, opportunities, energy, transport, food, waste, and water security [6]. Together, these categories cover a wide range of climate change related topics and can provide useful comparisons between cities.

2.2 Hristov and Chirico

One effort to identify KPIs related to climate and sustainability is [7]. This paper aims to identify KPIs that measure a company's performance, and proposes a way in which sustainability can be integrated in company strategies. Out of all KPIs found in the study, 24 were related to environmental targets. These KPIs were grouped according to 4 goals: reducing gas emissions, improving the use of renewables, reducing natural resources consumption, and reducing waste and improving *green-ness*.

2.3 Angelakoglou et al.

Another study that investigates KPIs related to sustainability is [8]. This paper primarily focuses on monitoring and evaluating Smart City Solutions though the proposed indicators. 75 KPIs are identified across six topics and include technical, environmental, economic, social, ICT and legal KPIs.

2.4 Amrina and Yusof

A third study that investigates KPIs related to climate change is [9]. This study focuses on sustainability in the automotive industry. 41 KPIs are presented, 10 of which relate to environmental performance. These indicators are grouped into the following categories: emissions, resource utilization, and waste.

2.5 Sustainable Development Goals

The United Nations' 2030 Agenda for Sustainable Development [10] is a roadmap for prosperity, peace and stability for humanity and for the planet. It consists of 17 Sustainable Development Goals (SDGs), 169 targets and 231 unique indicators that can be used to achieve sustainable development. Three categories are presented: economic, social and environmental sustainable development. The indicators in the latter category in particular are of relevance to this research.

Goal 13, "Take urgent action to combat climate change and its impacts," is one of the most relevant SDGs. Eight indicators are associated with this goal. These indicators are shown in table 1. Additionally, there are also other goals that focus on climate change mitigation and sustainability in a more indirect manner, and several of the indicators overlap with goal 13. These are the following goals:

2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
6. Ensure availability and sustainable management of water and sanitation for all.
7. Ensure access to affordable, reliable, sustainable and modern energy for all.
9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
11. Make cities and human settlements inclusive, safe, resilient and sustainable.
12. Ensure sustainable consumption and production patterns .
14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development.

15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

#	**Indicator [11]**
13.1.1	Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population
13.1.2	Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015-2030
13.1.3	Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies
13.2.1	Number of countries with nationally determined contributions, long-term strategies, national adaptation plans and adaptation communications, as reported to the secretariat of the United Nations Framework Convention on Climate Change
13.2.2	Total greenhouse gas emissions per year
13.3.1	Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment
13.a.1	Amounts provided and mobilized in United States dollars per year in relation to the continued existing collective mobilization goal of the $100 billion commitment through to 2025
13.b.1	Number of least developed countries and small island developing States with nationally determined contributions, long-term strategies, national adaptation plans and adaptation communications, as reported to the secretariat of the United Nations Framework Convention on Climate Change

Table 1: List of indicators used for goal 13 of the SDGs.

2.6 Climate Change Performance Index

The final effort to introduce KPIs related to climate change is the Climate Change Performance Index (CCPI) [12] proposed by the organization Germanwatch. Currently, the CCPI assesses and analyses the climate change mitigation performance of 57 countries and the European Union (EU), which collectively account for over 90 percent of global GHG emissions. The CCPI seeks to improve transparency in international climate politics by allowing comparisons between efforts and progress on climate protection between countries. It measures countries' performance based on four categories: GHG emissions, renewable energy, energy use, and climate policy. The indicators that are used in the CCPI are shown in table 2.

#	**CCPI indicator [12]**
1	Current Level of GHG Emissions per Capita
2	Past Trend of GHG Emissions per Capita
3	Current Level of GHG Emissions per Capita compared to a well- below-2°C compatible pathway

4	GHG Emissions Reduction 2030 Target compared to a well- below-2°C compatible pathway
5	Current Share of Renewables per Total Primary Energy Supply (TPES)
6	Development of Energy Supply from Renewable Energy Sources
7	Current Share of Renewables per TPES compared to a well-below-2°C compatible pathway
8	Renewable Energy 2030 Target compared to a well-below-2°C compatible pathway
9	Current Level of Energy Use (TPES/Capita)
10	Past Trend of TPES/Capita
11	Current Level of TPES/Capita compared to a well-below-2°C compatible pathway
12	TPES/Capita 2039 Target compared to a well-below-2°C compatible pathway
13	National Climate Policy
14	International Climate Policy

Table 2: List of indicators used in the CCPI.

2.7 Conclusion

Many KPIs have already been proposed to address elements of sustainability and sustainable development in corporations and organizations, as well as smart cities. Some of these efforts, such as Hristov and Chirico and Amrina and Yusof, do not address the performance of cities and countries in regard to climate change, but that of companies. The CCPI, SDGs, and the CDP do focus on countries or cities and cover a wide range of topics related to climate change and sustainability.

3 Methodology

This section will discuss the methods that were used to obtain the results in section 4. First, a literature review is given to establish the important aspects of climate change. Next, the methodology and the criteria for the selection of the KPIs are given. Finally, the methods that were used to visualize the KPIs and their use are described.

3.1 Theoretical Framework

In order to answer the research question, it is important to have the necessary information on climate change. The theoretical framework will discuss what information can be discovered in existing literature that can be used to aid in answering the research question. A literature review is presented on the major areas of climate change. Its aim is to give an overview of the causes and consequences of climate change. Eight important aspects are described and their different aspects are defined and evaluated.

The literature review includes 51 sources that were found using *Google Scholar* and *Scopus*. First, a general search for relevant topics was performed, using the search terms:

["Climate Change" OR "Climate Crisis" OR "Environment"] AND ["Causes" OR "Effects"]

Papers and reports that were found using this query were filtered based on their relevance and year of publication. As climate change is an ever evolving process, it is important to make sure the sources are up to date. Therefore, mainly recent papers and reports published after 2010 were selected. In order to find more specific information on the causes and effects of climate change, the main topics of the sources were used in a second query:

["Topic"] AND ["Climate Change" OR "Climate Crisis" OR "Environment"] AND ["Causes" OR "Effects"]

In this query, "Topic" was replaced with relevant topics found in the previous search results. Based on the papers and reports that were found using the query, the literature review was performed, highlighting the most important causes and effects of climatic change.

3.1.1 Pollution

3.1.1.1 Air Pollution

The term "air pollution" refers to a combination of particulate matter and gases in the air. Particle matter (PM), also known as particle pollution, is made up of small particles of solids or liquids in the air [13]. There are two types of particulate matter: PM_{10} and $PM_{2.5}$. These are particles with a size between 2.5 and 10 μm, and particles measuring less than 2.5 μm, respectively. For PM_{10}, the recommended maximum annual mean is 20 $\mu g/m^3$, and for $PM_{2.5}$ it is 10 $\mu g/m^3$ [14].

3.1.1.2 Greenhouse Gases

One of the most widely known types of emission is greenhouse gases (GHG), which are gases that absorb and emit infrared radiation. Water vapor, carbon dioxide, methane, nitrous oxide, and ozone are the greenhouse gases present in the Earth's atmosphere [15]. These gases are responsible for the natural greenhouse effect of the earth. This effect, unlike the enhanced greenhouse effect, is not caused by human activity [16]. The earth's greenhouse effect has increased significantly since the industrial revolution. Therefore, human activity is also a key element in reducing major greenhouse gas emissions [17].

GHG emissions can be generated both inside and beyond city boundaries as a result of such activities taking place within the city. The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) categorizes emissions into three separate groups based on where they occur: scope 1, scope 2, and scope 3 emissions [18]. Emissions from sources located within the city boundary are part of scope 1. Scope 2 includes GHG emissions resulting from the use of grid-supplied power, heat, steam, and cooling inside the city limits. Scope 3 includes any additional GHG emissions that occur beyond the city border as a consequence of activities that occur inside the city. Emissions are also categorized based on by whom they are produced. A distinction can be made between those produced by government operations and those by community activities [19].

3.1.1.3 Plastic Pollution

Plastics and microplastics that harm marine ecosystems are another form of pollution. Plastic particles have been discovered in the intestines of dead aquatic animals, demonstrating that plastic has caused catastrophic damage to living organisms [20]. The production of plastic has been growing rapidly in the past and is expected to increase further in upcoming years [21]. It is important to properly manage this plastic in order to prevent it from ending up in the oceans.

3.1.1.4 Solid Waste

In many affluent, urban areas, consumption is relatively high. Individuals discard many products on a daily basis, resulting in a considerable amount of solid waste. Because of inappropriate treatment and transportation, solid waste can cause pollution of the air, water, and soil, causing numerous environmental repercussions and health risks. Thus, solid waste management is critical since it aids in the reduction of solid waste pollution and contributes to a pollution-free and healthy environment [22].

There are several ways of waste disposal, some of them are more harmful than others. Solid waste disposal into landfills is still a common method of disposal, despite the health hazards and pollution that are linked to this way of waste disposal [23]. Other ways of waste disposal, such as recycling, incineration, or pyrolysis, are used to manage solid waste pollution and its harmful consequences [22].

3.1.1.5 Recycling

Recycling is also a popular method of waste disposal. It entails reusing certain waste components and it therefore saves resources, reduces the manufacturing of new resources, and minimizes pollution [22]. However, recycling is not yet a sufficiently widespread practice, as a considerable amount of waste still ends up in landfills or in nature. Since 1950, only nine percent of plastic waste has been properly recycled [24].

3.1.1.6 Soil Pollution

Additional chemicals are frequently introduced into the soil as a result of how land is used [25]. This soil contamination can have major effects on biodiversity. Because of the toxicity produced by the pollutants, the number of organisms present in an ecosystem can decrease. However, there can also be changes at the community level, with tolerant or resistant species benefiting over those susceptible to the contaminants [26].

3.1.1.7 Water Pollution

As a consequence of increased industrialization and urbanization, the stress on our water sources is growing rapidly, decreasing the clean water availability. Polluted water is harmful to marine life, plants, humans, and the environment [27]. While companies and treatment plants make use of different wastewater treatment procedures, some industries continue to dispose of untreated wastewater into bodies of water. This causes pollutants such as heavy metals and organic pollutants to enter the water.

In the 1979s and 1980s, heavy metal concentrations in rivers and lakes were relatively low. However, they have been higher since the 1990s up until now. The predominant sources of heavy metal contamination in water bodies around the world have shifted over time from mining and production to metal waste disposal. Metal pollution can have negative impacts on people through the food chain, drinking water, air inhalation, or skin absorption [28]. The second type of pollutants found in water, organic pollutants, come in a wide range of types and toxicity levels [27]. Dyes, pharmaceuticals, product waste, and petroleum organic pollutants are several of the organic pollutants that have posed a significant threat to aquatic species, plants, and people.

3.1.2 Resource Use

3.1.2.1 Water

Water is a natural resource that is a necessity for every person on earth. However, according to the World Health Organization, over 700 million people do not have access to basic drinking-water services. On top of that, half of the world's population is expected to be living in water-stressed areas by 2025 [29]. A crucial aspect of climate change mitigation is to ensure that everyone will have access to reliable water services. Soto-Montes and Herrera-Pantoja [30] state that the implementation of a water resource management strategy can, especially in developing countries, lead to an increased resilience against the impacts of climate change. Furthermore, it is important that countries and cities are aware of current and future risks to their water security. Threats can include increased water stress or scarcity, droughts, water-borne diseases and other events that affect the available water supply [6].

3.1.2.2 Energy

People often correctly link energy and climate change because the fossil fuels, such as gas, oil, and coal, that have driven the global economy have also changed the environment and caused climate change [31]. The consumption of fossil fuels has grown substantially during the last 50 years. Between 1980 and 2019, global fossil fuel consumption almost doubled [32]. However, sixteen percent of primary energy came from low-carbon sources in 2019. These sources include hydro, nuclear, wind and solar power, bio-fuels, and other renewables.

In order to reduce GHG emissions caused by energy use, it is important to further increase the share of renewable and low-carbon energy sources. Many countries and organizations are setting goals to decrease their use of fossil fuels. The European Union, for example, has set a target for the share of renewable energy sources. In 2030, they plan to have a renewable energy share of at least 32 percent [33]. Furthermore, they do not only focus on renewable energy, but also on energy efficiency. Using energy in a more efficient way can help reduce climate change and its consequences [34]. The aim of the EU is an energy efficiency of 32.5 percent in 2030.

3.1.2.3 Food

Reducing the amount of food that is wasted is of great importance. In many regions around the world, it is expected that these reductions can result in a considerable gain in water and food security [35]. According to a report of the Food and Agriculture Organization of the United Nations (FAO), the world is currently not on course to achieve the hunger and malnutrition targets that had been set for 2030 [36]. Although the number of people suffering from hunger had been declining for decades, this is not the case anymore. The number has been slowly increasing since 2014. The projections for 2030 are not optimistic, and that is without taking into account the possible effects of the COVID-19 pandemic on world hunger.

Human demand as well as the availability of natural resources are dispersed unevenly across the world [37]. The ecological footprint of consumption shows the amount of production and waste per person. These levels vary across the world as a result of differences in lifestyle and consumption habits. The target level of the ecological footprint also varies, as hunger and malnutrition are still an important problem. Certain countries can benefit from increasing their carbon footprint, if this means their food security and quality of food can increase as well [36].

3.1.3 Climate Hazards

3.1.3.1 Climate Hazards

Climate hazards are an important aspect of climate change. Extreme events will most likely change in frequency and severity as the environment changes as a result of climate change [38]. One example is North America, where there are increasingly more and worse wildfires [39]. Alternatively, climate change can also cause changes in precipitation. This in turn can result in more precipitation-induced flooding [40]. It is important for cities and countries to know what climate hazards may pose a threat, either today or in the future.

3.1.4 Biodiversity

3.1.4.1 Biodiversity Intactness

Climate change is speeding up as a result of increased greenhouse gas emissions, which has an impact on both people and ecosystems [41]. Because even a minor shift in the climate can result in the extinction of some of the world's most vulnerable species, it is important to ensure that they are monitored and protected. The Biodiversity Intactness Index (BII) shows how native terrestrial species' average abundance compares to their abundance before human intervention [42]. It is necessary to use this index to comprehend the interactions between plants, animals, and biodiversity, and implement strategies to improve biodiversity based on that understanding.

3.1.4.2 Threatened Species

Climate change currently threatens 19 percent of the IUCN Red List's endangered species, increasing their chances of extinction [43]. This can have harmful effects on humans too, as species have important functions in ecosystems that provide essential benefits to people. Therefore it is crucial to not only keep track of threatened animals, but to also try to protect them.

3.1.4.3 Protected Land

Protected areas are the most common method of preserving vulnerable species and protecting biodiversity across the world [44]. It is important that in these protected areas, all threats to threatened animals are removed, in order to prevent their extinction. Adequate funding, careful design, and proper organization are all important when it comes to protected areas to preserve biodiversity.

3.1.5 Transport

3.1.5.1 Public and Private Transport

Transport is an important part of everyday life and it also has a significant impact on the environment. Over sixteen percent of all GHG emissions in 2016 can be attributed to transportation [45]. Especially in urban areas, a lot of energy is used in transportation services. One way to reduce transport emissions is the implementation of a good public transit network [46], [47]. If this network is of good quality and accessible to as many people as possible, it can reduce the use of private transport methods [47]. One example is New York, where private car ownership and emissions are much lower than in the rest of the United States, due to the extensive public transport system in the city [48].

3.1.5.2 Electric Vehicles

In 2016, almost twelve percent of global GHG emissions were caused by road transport alone [45]. This is quite a high percentage, as the total transport sector accounts for 16 percent, which means that electrification of road transport could make a significant impact on GHG emissions. Nanaki and Koroneos also supports this claim, stating that the implementation of alternative fuels can lead to low carbon cities, and positively impact the environment [49].

3.1.5.3 Aviation

Aviation is one of the fastest-growing emitters of greenhouse gases [50]. Carbon dioxide and water vapor are among the most significant emissions of airplanes [51]. However, it is difficult to measure the emissions caused by aviation of an individual country or city, because of disagreements on where the emissions should be allocated [48]. This mainly poses a problem for international flights, as it is not clear if the country of origin or the country of destination should be held responsible.

3.1.6 Land Use

3.1.6.1 Deforestation

One important aspect to consider when it comes to land use is deforestation. Forests and rain forests all around the world are threatened by increasing rates of deforestation [52]. Brazil, for example, saw 40,000 hectares of forest cut down in just fifteen years, from 1990 to 2005. However, Brazil managed to reduce deforestation rates by 84 percent in 2012, relative to historically high levels in 2004 [53]. But rates have begun to rise again in recent years, with 2020 reaching the highest rate in the past decade.

3.1.6.2 Agriculture

Food often goes a long way before it is consumed. It is produced, processed, packed, shipped, and prepared. Every step causes GHG emissions to be released into the earth's atmosphere [54]. Agriculture emits an especially high amount of greenhouse gases. It contributes 17 percent directly through agricultural operations and 7-14 percent indirectly via land use changes [55]. However, agriculture not only contributes to climate change, but is also particularly vulnerable to it. Most of the risks associated with agriculture are caused by adverse climatic conditions and climate variability, with climate change posing an additional concern [56].

3.1.7 Health

3.1.7.1 Public Health

Public health and good health systems are crucial for a city, but they can face several risks related to climate change. These risks include diseases as a result of climate change, the disruption of health services, threats to food security, and many more [6]. The CDP asks cities to indicate whether they are aware of such threats, in order to be prepared and provide an early response.

3.1.7.2 Illnesses and Mortality

Climate change has a wide range of effects on human health. It has the potential to exacerbate current health hazards while also introducing new risks [57]. One common way in which this happens is through air pollution. Reduced lung function, increased hospital admissions for asthma, and an increase in premature mortality have all been linked to air pollution [58].

The effects of climate change can also lead to excess mortality, especially in vulnerable groups. One cause that is linked to climate change is the occurrence of heatwaves. Heatwaves can increase the death risk of especially elderly people, according to Can et al. [59]. Moreover, since 1950, the frequency and intensity of heat waves has increased, and with it the threat to vulnerable people [60].

3.1.8 Others

3.1.8.1 Global Temperature

The mean global temperature is an important measure when it comes to climate change, as the increasing temperature can negatively affect the environment. Temperature rises may have a variety of negative consequences, including an increase in the likelihood of flooding, droughts, and heat waves, so it is an important indicator to consider [61].

3.1.8.2 Sea Level

Sea-level rise is a worldwide phenomenon with potentially massive consequences, including coastal erosion and marine habitat destruction [62]. Countries in low-lying areas and small islands, in particular, are concerned that coastal erosion and floods will decrease their land areas.

3.1.9 Conclusion

There are eight important topics that should be considered when developing KPIs to monitor and mitigate climate change. These topics are pollution, resource use, climate hazards, biodiversity, transport, land use, health, and others. The latter includes information that cannot be categorized in any of the other topics, namely the global temperature and the sea level.

3.2 Identification of KPIs

After establishing the relevant background information in section 3.1, this research was used to find and select KPIs. First, the eight clusters and the research described in section 3.1 were used to find research papers, reports and databases on climate change related indicators. Relevant KPIs in these sources were identified and subsequently selected based on the criteria in the section 3.1.1.

The papers, reports and databases were found using the following query:

["Topic"] AND ["Key Performance Indicators" OR "Metrics" OR "Units"] AND ["Climate" OR "Climate change" OR "Environment]

In place of *"Topic"*, the title of the corresponding topic was used, e.g. *air pollution* or *greenhouse gases*. The search engines that were used are *Google Scholar* and *Scopus*. Finally, *Google Search* was also used, mainly to find databases.

Several KPIs are also based on the CDP questionnaire of disclosing cities [6] that was discussed in section 2.1.

3.2.1 Selection of KPIs

The KPIs that were found were then filtered according to three criteria. The first criterion is that the KPI should be adopted by some country or city. This means that at least one country or city uses the indicator to measure their performance on climate change. Secondly, the KPI should be measurable. It should have a quantitative or qualitative metric that can be used to establish benchmarks. Finally, the KPI should have a value in some country or city.

3.2.2 Definition of KPIs

After selecting the KPIs, they are defined based on a set of principles [63], to ensure the KPI captures the important aspects of the topic. The first principle is comprehensiveness. This entails that for every topic, the KPIs combined should give a clear understanding of every facet of the topic. Secondly, the KPIs should be defined in such a way that they can be compared across different cities or countries, but also over time. The third, independence, entails that the KPIs should be independent and overlap as little as possible with the other indicators. Each KPI should be a separate indicator. Finally, the KPIs must be straightforward and simple to comprehend.

3.2.2.1 Unit and Benchmarks

After defining the KPIs, a search was conducted to find the appropriate units of measurement for the KPIs. This data was found using the sources of the KPIs and *Google Search*. Both qualitative and quantitative units are used. For some indicators, multiple possible units of measurement exist. In these cases, either the unit that is used in the available data is chosen, or the unit that is used most frequently. Using the same sources that were used to find the KPIs, benchmarks were established. Two categories are provided, "+" for values that represent good performance, and "-" for values that represent bad performance.

3.3 Visualizing the KPIs

In order to give an indication of which KPIs are used in which country, a categorical heatmap is created. The heatmap displays all KPIs that are used by countries and have both recent data and data for individual countries. To define recent data, the time period of 2010-present was used. KPIs that are based on more regional data or global data were not included in the heatmap, as these cannot be compared across countries.

In the heatmap, the 193 member states of the United Nations are visualized. These nations were chosen in order to present a consistent comparison in the graph.

Data was found using the sources of the KPIs and *Google Search*. This data was preprocessed using *Tableau Prep Builder 2021.1* and *Microsoft Excel*. After preprocessing the data, the heatmap was created using *Tableau 2020.4*.

4 Results

4.1 Table of KPIs

Using the methods described in section 3, 63 KPIs were selected. These KPIs can be found in table 3, along with a topic, a unique name, a brief description, the most common unit of measurement, and the established benchmarks, ranging from a bad performance (-) to a good performance (+).

Category	Topic	#	KPI	Unit	Description	+	-
1 Pollution	1.1 Air Pollution	**1**	Air Quality Index	#	Ranking of cities based on annual average PM2.5 concentration ($\mu g/m^3$)	0-50	>100
	1.2 Greenhouse Gases	**2**	Existence of emissions inventory system	yes/no	Inventory which includes emissions that are within the city boundary	yes	no
		3	Existence of GHG emissions reduction target	yes/no	Existence of a target to reduce greenhouse gas emissions	yes	no
		4	Emissions generated by government operations	tCO2e	Scope 1, 2 and 3 emissions as a result of government operations	0	-
		5	Emissions generated by community activities	tCO2e	Scope 1, 2 and 3 emissions as a result of community activities	0	-
	1.3 Plastic Pollution	**6**	Existence of plastic policies	yes/no	Existence of regulations on the use and disposal of (single-use) plastics	yes	no
		7	Percentage of mismanaged plastic waste	%	The percentage of total waste that is not properly disposed of	0%	100%
		8	Amount of plastics currently in the oceans	metric tonnes	Amount of macro- and micro-plastics currently in the oceans	0	-
	1.4 Solid waste	**9**	Annual solid waste generation	tonnes/yr	Total solid waste generation per year	0	-
		10	Solid waste disposed to landfill or incineration	tonnes/yr	Solid waste that is disposed of in landfills or that is incinerated	-	-

	1.5 Recycling	**11**	Solid waste diverted away from landfill or incineration	%	Solid waste that does not end up in landfills or incineration because of recycling	100%	0%
		12	Percentage of population with access to recycling	%	Percentage of the population that have access to a recycling point	100%	0%
	1.6 Soil Pollution	**13**	Percentage of land that is polluted	%	Percentage of surface area that is affected by soil pollution	0%	-
	1.7 Water Pollution	**14**	Percentage of heavy metal concentration in river and lake water bodies	%	Heavy metal concentration in global river and lake water bodies as a cause of water pollution	0%	100%
		15	Biochemical Oxygen Demand	mg/L	Measurement of non toxic organics in water	<1 mg/L	>8 mg/L
		16	Chemical Oxygen Demand	mg/L	Measurement of total toxic and non toxic organics in water	-	-
2 Resource Use	2.1 Water	**17**	Water consumption	L/person/day	The average liters of water used by one person in one day	-	-
		18	Water stress level	low-high	The ability to meet a region's demand for water	low	high
		19	Existence of a public Water Resource Management strategy	yes/no	Existence of a plan for dealing with water use and resources	yes	no
		20	Existence of any current or future risks to the city's water security	yes/no	Existence of (climate change related) risks that will decrease the city's water security	no	yes
		21	Percentage of population with access to potable water supply	%	Percentage of people that have access to clean and safe drinkwater	100%	0%
	2.2 Energy	**22**	Energy consumption	kWh/household/yr	The average amount of energy consumed by one household per year	0 kWh	-

		23	Share of renewable energy sources	%	The share of a city's energy mix that consists of renewable sources	100%	0%
		24	Existence of renewable energy or electricity target	yes/no	Existence of a target to increase the use of renewable energy	yes	no
		25	Existence of target to increase energy efficiency	yes/no	Existence of a target to use energy more efficiently and eliminating energy waste	yes	no
		26	Percentage of energy grid that is zero carbon	%	Zero carbon includes solar, wind, hydro, biomass and geothermal as the source to produce electricity	100%	0%
	2.3 Food	**27**	Annual food waste	tonnes/yr	Amount of food that is wasted each year	0 tonnes/yr	-
		28	Ecological footprint of consumption per person	gha/person	The Ecological Footprint per person is a measure of the rates of consumption and the total population of a country	<1.6	>5
3 Climate Hazards	3.1 Climate Hazards	**29**	Global Climate Risk Index	#	The Global Climate Risk Index shows the level of exposure and vulnerability to extreme weather events	>100	0-50
		30	Existence of inventory of relevant climate hazards	yes/no	Existence of an inventory to keep track of relevant current or future climate hazards in a city	yes	no
		31	Most significant climate hazards faced by the city	n/a	Identification of the most important climate hazard a city faces or will face	no risks	many risks or no identification
		32	Existence of a climate change risk and vulnerability assessment	yes/no	Existence of an assessment of current or future risks and the city's vulnerability	yes	no

4 Biodiversity	4.1 Biodiversity Intactness	**33**	Biodiversity intactness index	%	The Biodiversity Intactness Index (BII) shows how native terrestrial species' average abundance compares to their abundance before human intervention	100%	>60%
	4.2 Terrestrial Animal Diversity	**34**	Percentage of known terrestrial species that are threatened	%	Percentage of terrestrial species that are threatened according to the IUCN Red List	0%	100%
		35	Terrestrial protected land area as percentage of total land area	%	Percentage of land surface area that is protected	-	0%
	4.3 Marine Animal Diversity	**36**	Percentage of known marine species that are threatened	%	Percentage of marine species that are threatened according to the IUCN Red List	0%	100%
		37	Marine protected land area as percentage of total land area	%	Percentage of marine surface area that is protected	-	0%
		38	Existence of policies for commercial fishing	yes/no	Existence of policies to curb commercial fishing rates	yes	no
		39	Commercial fishing rates	nr	The amount of fish caught for commercial purposes	low	high
		40	Bycatch rates	nr	The amount of marine animals that are caught unintentionally while fishing for other animals	high	low
5 Transport	5.1 Public Transport	**41**	Percentage of population living within 500m of a mass transit station	%	The amount of people that live within 500 m of a mass transit station and have access to public transportation	100%	0%
		42	Quality of public transport	%	The quality rating given by inhabitants to a city's public transport system	100%	0%

		43	GHG emissions caused by public transport	tCO2e	The total amount of GHG emissions caused by public transport	0	-
	5.2 Private Transport	**44**	Percentage of population that owns a private car	%	Describes how many people own a private car	0%	100%
		45	GHG emissions caused by private transport	tCO2e	The amount of GHG emissions caused by private transport	0	-
		46	Existence of a zero- or low-emission in the city	yes/no	The existence of an area in the city where only zero- or low-emission vehicles are allowed	yes	no
	5.3 Electric Vehicles	**47**	Percentage of private cars that are electric	%	The percentage of total private cars that are electric	100%	0%
		48	Public access EV charging points per capita	nr	The number of charging points for electric vehicles per capita	>1	0
	5.4 Aviation	**49**	GHG emissions caused by aviation	tCO2e	The amount of GHG emissions caused by air travel	0	-
		50	Per capita emissions from domestic and international flights	kg	The total combined emissions caused by domestic and international flights per capita	0	>500
6 Land Use	6.1 Deforestation	**51**	Deforestation rate	Mha/yr	The total forest surface area that is cut down each year	0	-
		52	Percentage of global land cover that is tree cover	%	The percentage of total land area that is covered by trees	>30	0
	6.2 Agriculture	**53**	GHG emissions caused by agriculture	tCO2e	The amount of GHG emissions caused by agriculture	0	-
		54	Percentage of land used for agriculture	%	The percentage of total land area used for agriculture	-	-

		55	Surface area of potential agricultural spaces in a city	km2	The total land area that has the potential to be turned into agricultural space	-	-
		56	Vulnerability to climate change related agricultural risks	n/a	The vulnerability to climate related agricultural risks such as droughts	not vulnerable	very vulnerable
7 Health	7.1 Public Health	**57**	Identification of risks to public health or health systems associated with climate change	yes/no	Identification of risks to the public health or health systems of a city	no risks	many risks or no identification
	7.2 Mortality	**58**	Excess mortality caused by extreme heat	%	Addresses the number of people that die from extreme heat	0%	100%
		59	Deaths caused by air pollution	deaths per 100.000 people	Mortality rate linked to household and ambient air pollution	0	>1
	7.3 Illnesses	**60**	Number of heat related illnesses	nr	Identifies the amount of illnesses that were caused by extreme heat	0	>1
		61	Number of respiratory diseases caused by increased air pollution	nr	Identifies the amount of respiratory diseases that were caused by an increase in air pollution	0	>1
8 Other	8.1 Global Temperature	**62**	Annual rise in global temperature	°C/yr	The rise in global temperature per year	<1.5	>2
	8.2 Sea Level	**63**	Annual sea level rise	mm/yr	The rise of the sea level per year	0	3

Table 3: List of Key Performance Indicators related to climate change, as recorded through this study.

4.2 Definition KPIs

4.2.1 Pollution

4.2.1.1 Air Pollution

1. Air Quality Index

The Air Quality Index is a ranking of countries based on their 'annual average PM2.5 concentration weighted by population' [64]. PM2.5 was chosen since it is generally considered to be the most hazardous pollution to human health.

4.2.1.2 Greenhouse Gases

2. Existence of emissions inventory system

3. Existence of GHG emissions reduction target

4. Emissions generated by government operations

5. Emissions generated by community activities

The first indicator on greenhouse gases is the existence of an emissions inventory system [6]. This is essential because without such an inventory, cities likely do not have data available for the other indicators in this category. The next indicator is the existence of a reduction target of GHG emissions [6]. Then there are two indicators focusing on emission generation. Emissions are separated into those generated by government operations and those caused by community activities [19].

4.2.1.3 Plastic Pollution

6. Existence of plastic policies

7. Percentage of mismanaged plastic waste

8. Amount of plastics currently in the oceans

An indicator that is especially important when it comes to plastic pollution is whether cities or countries have any policies in place on plastic use and disposal. Another relevant KPIs is the amount of mismanaged plastic waste. This KPI is especially relevant in coastal cities or cities directly connected to the ocean in some other way, for example by rivers. Mismanaged plastics can directly lead to pollution of bodies of water. Furthermore, the amount of macro and microplastics currently in the oceans is also an important KPI to consider, as this can have damaging effects on marine ecosystems.

4.2.1.4 Solid Waste

9. Annual solid waste generation

10. Annual solid waste generation

It is important to both look into how much waste is generated and the way it is disposed of, to get a full understanding of solid waste pollution. Therefore, the first KPI in this category is the annual solid waste generation of a city or country. This is the total amount of waste that is generated in a country or city in tonnes per year. As stated in section 3.1, disposal to controlled landfills is one of the most common methods, followed by incineration and recycling. The second KPI for solid waste is the amount of solid waste that is disposed of in landfills is incinerated. Recycling is not taken into account here, because it is covered in the next section.

4.2.1.5 Recycling

11. Solid waste diverted away from landfill or incineration

12. Percentage of population with access to recycling

As mentioned above, waste can be disposed of in landfills or through incineration. However, another important metric is how much waste is diverted away from landfills and incineration and is recycled instead. This KPI is measured as the percentage of total waste that is recycled. The higher this percentage, the smaller the amount of waste that ends up polluting the environment. In order to increase this percentage, it is important to look at the next KPI in this category, the percentage of people with access to recycling.

4.2.1.6 Soil Pollution

13. Percentage of land that is polluted

4.2.1.7 Water Pollution

14. Percentage of heavy metal concentration in river and lake water bodies

15. Biochemical Oxygen Demand

16. Chemical Oxygen Demand

The two types of pollutants found in water are heavy metal and organic pollutants [27], [28]. The former can be described by the percentage of heavy metal concentration in water [65]. The Biological Oxygen Demand (BOD) and the Chemical Oxygen Demand (COD) are two water quality indicators that show the degree of organic pollution of water [66]. COD refers to the measurement of total organics, including both toxic and non toxic organics, which means it is an indirect measure of organic waste. BOD, on the other hand, is solely a measure for non toxic organics.

4.2.2 Resource Use

4.2.2.1 Water

17. Water consumption
18. Water stress level
19. Existence of a public Water Resource Management strategy
20. Existence of any current or future risks to the city's water security
21. Percentage of population with access to potable water supply

There are many areas important to the use of water. The first KPI that can be considered is the water consumption. This refers to the total amount of water that is used by the inhabitants of a country or city over a specific time period. Another important KPI related to water use is the water stress level of a country, which is a region's ability to satisfy the water demand. The ratio between all freshwater withdrawals and total available freshwater resources is used to determine the level of water stress. Additionally, the percentage of people that have access to potable water supplies is a key metric to consider, as there are still many people that do not have access to drinking water [29].

When it comes to cities in particular, there are two more KPIs based on the data collected by the CDP. The first is the existence of a public Water Resource Management strategy. This is a plan cities make for dealing with water use and resources. The second KPI is the existence of any current and future risks to the city's water security. This is important because when cities are aware of potential risks, they can take actions to mitigate this.

4.2.2.2 Energy

22. Energy consumption
23. Share of renewable energy sources
24. Existence of renewable energy or electricity target
25. Existence of target to increase energy efficiency
26. Percentage of energy grid that is zero carbon

Energy consumption also includes a wide range of KPIs that are relevant to the topic. The first KPI is energy consumption, which is the average amount of energy consumed by one household per year. Secondly, the share of renewable energy sources in a city or country is a key metric. This KPI measures the percentage of the energy mix that consists of renewable sources. Related to this is the percentage of the energy grid that is zero carbon, which takes into account sources such as wind, nuclear, hydro and solar power [34].

Two other KPIs in this topic aim to reduce energy use, especially that of non renewable resources. The amount of energy needed to generate one unit of economic output is referred to as energy intensity. That is why the next KPI is the existence of a target to increase energy efficiency. This metric also relates to target 7.3 of the SDGs [67]. Additionally, the existence of a target for renewable energy or electricity is important. The more renewable energy is consumed, the less non-renewable energy is used, causing a decrease in CO2 emissions [68].

4.2.2.3 Food

27. Annual Food Waste
28. Ecological footprint of consumption per person

Based on the research in section 3.1, there are two important indicators related to food. The first KPI is the annual food waste of a country or city. This is mainly relevant because a reduction in food waste can improve water and food security [35]. Furthermore, the ecological footprint of consumption per person should also be considered. This is an indicator based on consumption rates and a country's total population.

4.2.3 Climate Hazards

4.2.3.1 Climate Hazards

29. Global Climate Risk Index
30. Existence of inventory of relevant climate hazards
31. Most significant climate hazards faced by the city
32. Existence of a climate change risk and vulnerability assessment

For climate hazards, one main indicator is the Global Climate Risk Index (CRI) [69]. The Global Climate Risk Index indicates the extent to which countries are exposed to and vulnerable to extreme weather occurrences. Storms, floods, and heat waves are among the extreme weather occurrences covered, and a ranking is given of the most affected countries.

The following indicators focus on a wider range of climate hazards. The first KPI is the existence of an inventory of relevant climate hazards. Identifying current or future hazards is important for the next KPI, which describes the most significant climate hazards that are faced by a city or country. Keeping track of relevant climate hazards may teach countries a lot about how to reduce susceptibility and increase resilience in the face of future climate-related disasters [70]. The last indicator is the existence of a climate change risk and vulnerability assessment. This assessment is based on various aspects: the projected climate threat, the geographic setting, and the sectors and systems that are affected by the risks [71].

4.2.4 Biodiversity

4.2.4.1 Biodiversity Intactness

33. Biodiversity Intactness Index

One KPI that gives a clear indication of the biodiversity in a region is the Biodiversity Intactness Index (BII). The BII compares the average abundance of native terrestrial species to their abundance prior to human involvement.

4.2.4.2 Terrestrial Animal Diversity

34. Percentage of known terrestrial species that are threatened

35. Terrestrial protected land area as percentage of total land area

For terrestrial animal diversity, there are two relevant KPIs. The first is the percentage of known terrestrial species that are threatened. Threatened species include those that are classified as critically endangered, endangered, or vulnerable [72]. Apart from the species that are threatened, it is also important to look at what is being done to preserve biodiversity. That is why the next indicator is the percentage of total terrestrial land area that is protected.

4.2.4.3 Marine Animal Diversity

36. Percentage of known marine species that are threatened

37. Marine protected land area as percentage of total land area

38. Existence of policies for commercial fishing

39. Commercial fishing rates

40. Bycatch rates

The first two KPIs in this category are very similar to those in the previous category for terrestrial animals. These indicators include the percentage of known marina species that are threatened and the percentage of total marine areas that are protected.

Further indicators cover a more specific aspect of marine life. The first is the existence of policies for commercial fishing. Policies such as limiting overfishing, outlawing harmful fishing methods, and controlling unlawful fishing can all help to improve biodiversity protection [73]. It is also important to consider the commercial fishing rates, and the bycatch rates, to give a clear indication of the state of marine biodiversity.

4.2.5 Transport

4.2.5.1 Public Transport

41. Percentage of population living within 500m of a mass transit station
42. Quality of public transport
43. GHG emissions caused by public transport

For public transport, it is important to look into the accessibility and quality, but also the impact it has on greenhouse gas emissions. Therefore, the first KPI is the percentage of people living within 500 meters of a mass transit station. This indicator is also used by the CDP in their questionnaire for cities [6]. The next indicator is the quality of public transport. This is relevant because high-quality public transport can lead to a decrease in the use of private modes of transportation [74]. Finally, an indicator that covers the influence that public transport has on emissions is the GHG emissions caused by public transport.

4.2.5.2 Private Transport

44. Percentage of population that owns a private car
45. GHG emissions caused by private transport
46. Existence of a zero- or low-emission zone in the city

There are three important KPIs that cover the topic of private transportation. The first is the percentage of the population that owns a private car. Similarly to public transport, the emissions should also be taken into account. That is why the next indicator is the GHG emissions caused by private transport. The last KPI in this category, the existence of a zero- or low-emission zone in a city, focuses on the aim to reduce emissions. This is an area in a city where only vehicles that cause very little to zero emissions are allowed, such as electric cars.

4.2.5.3 Electric Vehicles

47. Percentage of private cars that are electric

48. Public access EV charging points per capita

Two indicators cover the important aspects of electric vehicles. First of all, the percentage of private cars that are electric should be taken into account. Alternative fuels can lead to lower emissions, as stated in section 3.1, so the higher this percentage, the larger the positive impact on the environment. Secondly, the accessibility of electric vehicles can be looked at. That is why the next indicator is the number of public access charging points for electric vehicles, per capita.

4.2.5.4 Aviation

49. GHG emissions caused by aviation

50. Per capita emissions from domestic and international flights

The final topic in the category of transport is aviation. One way in which air travel contributes to climate change is through CO2 emissions [75]. That is why the first indicator describes the GHG emissions caused by aviation. The second indicator also relates to emissions, but compares it based on a country's population. The emissions from domestic and international flights per capita can differ a lot per country. One reason for this is that there are many countries where a large portion of the population does not fly at all [76].

4.2.6 Land Use

4.2.6.1 Deforestation

51. Deforestation rate

52. Percentage of global land cover that is tree cover

Deforestation can be measured by two KPIs. The first is the deforestation rate. This is the total forest surface area that is cut down per year. Secondly, the total percentage of global land cover that is covered by trees is also an important indicator to take into account, in order to give a clear indication of the current status of deforestation.

4.2.6.2 Agriculture

53. GHG emissions caused by agriculture

54. Percentage of land used for agriculture

55. Surface area of potential agricultural spaces in a city

56. Vulnerability to climate change related agricultural risks

One KPI that can be used to measure the impacts of agriculture on climate change is the GHG emissions caused by agricultural activities. Additionally, two relevant indicators are the percentage of land that is used for agriculture, and the surface area of potential agricultural spaces in a region. A balance between these indicators is important because agriculture provides food security, but also contributes to climate change. Finally, the vulnerability to climate change related agricultural risks, such as droughts, should be considered.

4.2.7 Health

4.2.7.1 Public Health

57. Identification of risks to public health or health systems associated with climate change

To get a clear indication of the public health in relation to climatic change, the identification of risks to public health or health systems associated with climate change is an important KPI. This indicator is also used in the CDP questionnaire [6], and it makes cities aware of potential threats so that they can be prepared.

4.2.7.2 Mortality

58. Excess mortality caused by extreme heat

59. Deaths caused by air pollution

Two climate change related mortality KPIs are important to consider. The first is the excess mortality caused by extreme heat. As stated in section 3.1, climate change can increase the frequency and intensity of heat waves, which in turn can lead to an increased death risk for vulnerable groups of people. Secondly, the number of deaths caused by air pollution, both household and ambient air pollution, is an important indicator. It directly relates to goal 3.9 of the SDGs [67]. This states that in 2030, the number of deaths and diseases from hazardous chemicals and pollution should be reduced.

4.2.7.3 Illnesses

60. Number of heat related illnesses

61. Number of respiratory diseases caused by increased air pollution

There are also two indicators when it comes to climate change related illnesses. The first is the number of heat related illnesses. Section 3.1 states that heat waves have increased in frequency and intensity, which can bring about illnesses such as heat stroke or heat exhaustion [77]. Furthermore, air pollution can also cause illnesses, which is why the second KPI in this category is the number of respiratory diseases caused by increased air pollution. These illnesses can include asthma, lung cancer, and other serious diseases [78].

4.2.8 Others

4.2.8.1 Global Temperature

62. Annual rise in global temperature

The annual rise in global temperature is an important KPI for climate change. The speed, intensity, and duration of global warming determine future climate-related hazards [79]. Some consequences, such as ecosystem loss, may be long-term or permanent. This makes the rise in the earth's temperature a very relevant metric.

4.2.8.2 Sea Level

63. Annual sea level rise

The final KPI is the annual sea level rise. Sea levels are projected to keep rising for years to come, which makes it important to monitor and decelerate the rise [79]. Small islands, low-lying coastal regions, and deltas in particular benefit from a slower pace of sea level rise.

4.3 Visualizing KPIs

In figure 1, the categorical heatmap which depicts the use of several KPIs can be seen. 25 KPIs and 193 countries were included in the heatmap. The countries in the heatmap are separated into two parts to make it legible, but both parts show the same KPIs.

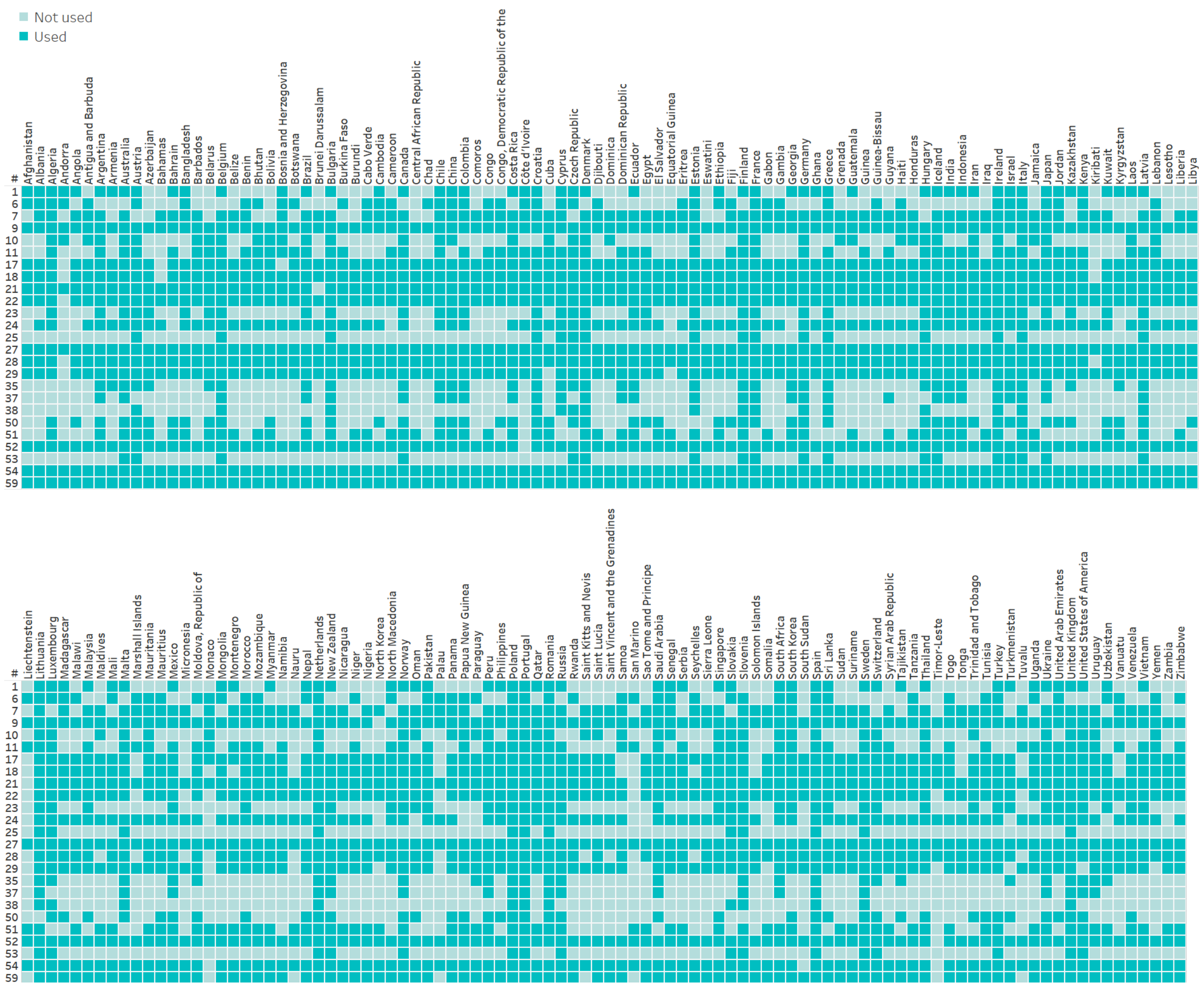

Figure 1: Categorical heatmap showing the use of KPIs per country [69], [80]–[98]

5 Discussion

5.0.1 KPIs Related to Climate Change

The aim of this study was to investigate which KPIs can be used by countries or cities to monitor and mitigate climate change. The first sub-question was "What are the KPIs that relate to climate change?" This study found a total of 63 KPIs across eight main categories. All of these KPIs are used to measure the performance of some country or city in relation to climate change. Together, the eight clusters give a clear and complete picture of the current status of climate change, and what can be changed based on these indicators.

These clusters build upon existing efforts described in section 2. While Hristov and Chirico, Angelakoglou et al. and Amrina and Yusof focus on smart cities and organizations, this study has found KPIs that can be used by cities and countries. Furthermore, the index covers more areas of climate change than the aforementioned lists of KPIs. While all efforts discussed in section 2 cover a varied range of topics related to sustainability and climate change, these topics are not consistent over the different indexes, and often lack several of the important categories discussed in section 3.1. Although some of the efforts may cover the most essential KPIs for businesses, the lists are insufficient for countries or cities to utilize.

With regards to cities in particular, the CDP is a promising effort. Many useful topics are covered and data is available directly from the source, namely from the cities themselves. This research built upon the efforts of the CDP by including more topics, and expanding it to countries as well.

As part of the related work in section 2, the SDGs are also discussed. Nine out of those goals relate to climate change in some way, but one goal in particular: "Take urgent action to combat climate change and its impacts" (goal 13). In table 4, a comparison between these indicators and the KPIs found in this thesis can be seen. Only four of the KPIs defined in this thesis are also covered by the indicators of goal 13, as can be seen the table. These KPIs are number 4, 5, 29 and 32 (Emissions generated by government operations, Emissions generated by community activities, Global Climate Risk Index, Existence of a climate change risk and vulnerability assessment). Thus, it can be concluded that the great majority of indicators are not utilized in the SDG that addresses climate change.

Additionally, there are also indicators used for goal 13 that are not covered in this thesis. Some indicators of the SDGs are very specific towards one of the targets set for 2030 and have therefore not been found using the methods in this research. Others,

Another effort that is similar to this research is that of the CCPI. However, more aspects of climate change have been covered in this study. Where the CCPI focuses on four topics, the index presented in this thesis covers eight. There are five topics that are not associated with KPIs in the CCPI. These are climate hazards, biodiversity, transport, land use, and health. As was established in section 3.1, these are all important aspects to consider when it comes to climate change. Therefore, including these topics helps make the presented index more complete.

A more thorough comparison is shown in table 5. The table lists the CCPI indicators and the corresponding KPIs presented in this thesis. One insight that can be concluded from this is that only six KPIs are also covered in the CCPI, namely number 3, 4, 5, 22, 23, and 24 (Existence of GHG emissions reduction target, Emissions generated by government operations, Emissions generated by community activities, Energy consumption, Share of renewable energy sources, Existence of renewable energy or electricity target). This means that the vast majority of the KPIs are not included in the CCPI.

However, as can be seen in table 5 there are also several indicators in the CCPI that are not included in the index of KPIs. The CCPI uses indicators that compare a metric to a "well-below-2°C compatible pathway" [12]. These metrics show the absolute difference between the current performance and country-specific benchmarks for reaching the targets set for 2030. The list of KPIs in this thesis does not include such comparisons in the indicators, but solely defines the indicators that could be used for comparisons. Additionally, the CCPI uses separate indicators for current and future performance, while in the KPIs in this thesis, no such distinction is made. Additional metrics such as time can be used to compare the KPIs over time.

SDG indicator for goal 13 [11]	Corresponding KPI(s)	Comparison with the presented index
Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population	Global Climate Risk Index (29)	Although this indicator is not directly covered by the index, the number of deaths is included in the Global Climate Risk Index.
Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015-2030	Existence of a climate change risk and vulnerability assessment (32)	A similar but slightly less specific indicator is included in the index.
Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies	Existence of a climate change risk and vulnerability assessment (32)	The same indicator is used for countries and local governments.
Number of countries with nationally determined contributions, long-term strategies, national adaptation plans and adaptation communications, as reported to the secretariat of the United Nations Framework Convention on Climate Change	n/a	No specific indicator on the general contribution and strategies of countries is included in the index.
Total greenhouse gas emissions per year	Emissions generated by government operations (4) and emissions generated by community activities (5)	The SDGs focus on GHG emissions in general, while this index separates it into government and community emissions.
Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment	n/a	No indicators for education are included in the index.
Amounts provided and mobilized in United States dollars per year in relation to the continued existing collective mobilization goal of the $100 billion commitment through to 2025	n/a	No indicators for financial help for developing countries are included in the index.
Number of least developed countries and small island developing States with nationally determined contributions, long-term strategies, national adaptation plans and adaptation communications, as reported to the secretariat of the United Nations Framework Convention on Climate Change	n/a	The indicators in the index make no distinction between developing and developed countries.

Table 4: Comparison of the SDGs for goal 13 and the KPIs presented in this thesis.

CCPI indicator [12]	Corresponding KPI(s)	Comparison with the presented index
Current Level of GHG Emissions per Capita	Emissions generated by government operations (4) and emissions generated by community activities (5)	The CCPI focuses on GHG emissions in general, while this index separates it into government and community emissions.
Past Trend of GHG Emissions per Capita	Emissions generated by government operations (4) and emissions generated by community activities (5)	Unlike the CCPI, this index does not have separate indicators for current and past emissions.
Current Level of GHG Emissions per Capita compared to a well- below-2°C compatible pathway	n/a	This index does not include comparisons in the KPIs, it solely states the KPIs that can be used for comparisons.
GHG Emissions Reduction 2030 Target compared to a well- below-2°C compatible pathway	Existence of GHG emissions reduction target (3)	This index does not include comparisons in the KPIs, it solely states the KPIs that can be used for comparisons. However, targets for GHG emissions are covered in the index.
Current Share of Renewables per Total Primary Energy Supply (TPES)	Share of renewable energy sources (23)	Both indexes include a similar KPI on the share of renewables.
Development of Energy Supply from Renewable Energy Sources	n/a	No specific KPI on the development of renewables is included in the index.
Current Share of Renewables per TPES compared to a well-below-2°C compatible pathway	n/a	This index does not include comparisons in the KPIs, it solely states the KPIs that can be used for comparisons.
Renewable Energy 2030 Target compared to a well-below-2°C compatible pathway	Existence of renewable energy or electricity target (24)	This index does not include comparisons in the KPIs, it solely states the KPIs that can be used for comparisons. However, targets for renewable energy are covered in the index.
Current Level of Energy Use (TPES/Capita)	Energy consumption (22)	Both indexes include a similar KPI on energy use.
Past Trend of TPES/Capita	Energy consumption (22)	Unlike the CCPI, this index does not have separate indicators for current and past emissions.
Current Level of TPES/Capita compared to a well-below-2°C compatible pathway	n/a	This index does not include comparisons in the KPIs, it solely states the KPIs that can be used for comparisons.
TPES/Capita 2039 Target compared to a well-below-2°C compatible pathway	n/a	This index does not include comparisons in the KPIs, it solely states the KPIs that can be used for comparisons.
National Climate Policy	n/a	No KPI for general climate policy is included in this index.
International Climate Policy	n/a	No KPI for general climate policy is included in this index.

Table 5: Comparison of the CCPI and the KPIs presented in this thesis.

5.0.2 Units and Values

The information in table 3 helps to answer the second sub-question "Which units and values are associated with these KPIs?" The table shows a qualitative or quantitative unit for each KPI that was found. Alongside the units, two benchmarks are given for many KPIs. These benchmarks, based either on theoretical data or on current use in policies, give an indication of what values the KPIs can take. It also shows when a country or city performs well on a specific KPI, or when countries should take extra actions.

5.0.3 Use of the KPIs

The heatmap presented in figure 1 provides insight into the final sub-question, "Which countries use these KPIs to monitor their environmental impact and set climate change mitigation goals?" There are six countries that use all of the KPIs included in the heatmap. These countries are Ireland, Italy, the Netherlands, Poland, Portugal, and Spain. Additionally, there are seven more countries that use all KPIs but one. These countries include Denmark, Estonia, France, Lithuania, Romania, Sweden, and the United Kingdom. It is worth noting that these are all European countries.

Furthermore, out of the 25 KPIs used in the heatmap, twelve are used by more than 150 out of 193 countries included in the heatmap. These indicators are number 9, 17, 18, 21, 22, 24, 27, 28, 29, 52, 54, and 59 (Annual solid waste generation, Water consumption, Water stress level, Percentage of population with access to potable water supply, Energy consumption, Existence of renewable energy or electricity target, Annual Food Waste, Ecological footprint of consumption per person, Global Climate Risk Index, Percentage of global land cover that is tree cover, Percentage of land used for agriculture, Deaths caused by air pollution). The only KPI that is used by all countries and also has available data for each of them is number 27, the annual food waste in the countries. One reason for this could be that food waste is a universal problem. Therefore, it is understandable that each country aims to measure and monitor their food waste.

Overall, these results indicate that although there are several countries that make use of almost all of the established KPIs, there are still many more that do not use them all. Additionally, the majority of the KPIs are not yet used by many countries.

5.1 Limitations

One important limitation of this study is the available data. As stated before, all countries that use every KPI are European. Data for other countries might not be available in the languages that were used to search for the data. This can affect the accuracy of the information presented in the heatmap, and thereby the answer to the question of which KPIs are used by countries to monitor their environmental impact and set climate change mitigation goals.

Another limitation is the fact that all KPIs that were documented and included in this thesis are based upon the criterion that they have been adopted by a country or city. This may leave out certain important KPIs that have yet to be implemented. One such KPI is the "number of living organisms lost per square kilometer of cut-down forest" [99]. This is an example of an indicator that can be impactful, but is not currently used by countries or cities to establish policies. Moreover, this study does not include the development of new KPIs that are not already covered by the selected indicators, as this is outside the scope of this research.

One final limitation of this study was the lack of results KPIs related to economy and climate policy. First of all, using the methods described in section 3, no economy related indicators were found. Such indicators could be of importance, as climate change can have harmful effect on economies and economic stability [100]. Secondly, the comparison with the CCPI in table 5 showed that there is no KPI that covers general climate policies in the presented index. Indicators similar to the ones in the CCPI could be added in order to make the index more complete.

5.2 Future Work

For future work, the heatmap could be expanded by including not only whether a country uses a KPI or not, but also how that country performs on a particular KPIs. For performance measurements, the benchmarks proposed in table 3 can be used. This could give a clear indication of what KPIs countries perform well on, and for which KPIs it is necessary to take additional actions.

Moreover, the heatmap that was was developed for countries can also be made for cities. As certain KPIs are mainly relevant for cities, such an additional heatmap could provide more insight into the use of KPIs in cities. However, making this was outside the scope of this study, because it would take a lot of time and data to develop. Furthermore, an indicator can be developed that combines all or almost all of the KPIs included in this thesis. This indicator can be based on the benchmarks in table 3, and it can provide a method to easily compare the overall performance of countries

6 Conclusion

This study was performed to answer the research question "Which KPIs can be used by countries or cities to monitor and mitigate climate change?" After conducting a thorough literature research of relevant papers, 63 KPIs were identified and selected, across eight main topics: pollution, resource use, climate hazards, biodiversity, transport, land use, health, and other.

Looking at the results in section 4, it can be concluded that although there already are many KPIs that are used to measure climate change performance, many are not yet used on a large scale. While individual policies can lead to specific desirable results, what is important is that the KPIs found in this study are all used in unison to give a complete and comprehensive representation of countries' efforts to mitigate climatic change. When implemented in a majority of countries, the indicators can be used to monitor and mitigate climate change by providing a consistent and comparable measure across countries and cities. The benchmarks give a clear indication of whether a country or city performs well or not. When the performance is not sufficient, the appropriate action would be for governments and policymakers to develop strategies to improve the performance. Therefore, monitoring the individual KPIs and corresponding data is very important for giving insight into where intervention is necessary.

This is why the KPIs aim to cover each important aspect of climate change and its consequences. Although certain topics, such as economy and climate policy, are not yet included in the list presented in this research, it does provide a more complete index than was found in related work. More topics are covered and the indicators are aimed specifically at cities and countries. A more complete index can be useful to develop in the future, but this research provides a good step in the right direction.

7 Bibliography

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