A Review on Key Performance Indicators for Climate Change

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Savvas Karatsiolis
University of Cyprus

A review on Key Performance Indicators for Climate Change

Jelise Schokker[1], Andreas Kamilaris[12], and Savvas Karatsiolis[2]

[1] Dept. of Computer Science, University of Twente, Enschede, The Netherlands
n.j.schokker@student.utwente.nl, a.kamilaris@utwente.nl
[2] CYENS Center of Excellence, Nicosia, Cyprus
a.kamilaris@cyens.org.cy, s.karatsiolis@cyens.org.cy

Abstract. Climate change is one of the biggest threats to humanity in the near future. Almost all different scenarios of climate change involve large-scale disasters and hazards. In order to define goals to cities, regions and countries in regards to mitigating climatic change, we first need to understand which the important key performance indicators (KPIs) are, how they can be measured and which values they take. Then, each country can calculate its performance based on these KPIs, setting realistic goals for better performance in the near future. This paper performs a large survey to identify and list 63 relevant KPIs, together with suggested units and metrics associated with them, divided in eight different thematic areas. It can be considered as an important contribution in the global efforts to understand climatic change, shaping policies and setting goals associated with it.

Keywords: Climate change, Key performance indicators, Metrics, Units, Countries, Performance.

1 Introduction

In the past decades, climate change has been recognized as an undeniable high-risk problem for humanity and its future on this planet. The year 2020 was tied with 2016 as the warmest years on record [1]. The average temperature of the earth has risen over 1.2 degrees Celsius since the late nineteenth century. Climate change and the environmental issues it causes affect the life of humans around the world significantly. As temperatures keep rising, an increasing amount of climate-related risks arise. Up to now, natural ecosystems have proven to be extremely resilient to change [2]. However, we do not know where the tipping point is and we definitely do not want to find out.

To define realistic and measurable goals for different cities, regions and countries around the world for avoiding or at least mitigating climatic change, we first need to understand which the important *key performance indicators* (KPIs) are, how they can be measured and which values they take. KPIs are defined as measures that are used to assess essential factors related to a given objective, such as reducing the effects of climate change [3]. The effectiveness of a country or city in achieving these objectives can be determined by these factors. Each country can thus calculate its performance based on these KPIs, setting realistic goals for better performance in the near future, empowering its citizens to work collaboratively in this direction, shaping environmental policies accordingly.

The contribution of this paper is to perform a survey to identify and list relevant, important and measurable KPIs, together with units and metrics associated with them. These KPIs and measurement units are based on how different countries around the world have been measuring those KPIs to date. Although some efforts have already been made in this direction (e.g. [4], [5], [6] - see Section 2), we argue that they do not capture the complete spectrum of important and relevant KPIs, which should be included in such estimations and calculations (see Sections 3 and 4), nor they link those KPIs with their actual use by countries around the world (see Section 5). Our goal is to stimulate the discussion and motivate more effort in quantifying climatic change, environmental performance and sustainability at local and global level in a more *complete, inclusive, transparent and fair manner*. The rest of the paper is organized as follows: Section 2 lists related work, Section 3 describes the methodology used, Section 4 presents our findings, Section 5 discusses the overall results and finally, Section 6 concludes this paper.

2 Related work

Only few research works tried to compile lists of KPIs related to the protection of the environment, environmental sustainability and performance at local level (i.e. city, country) in relation to climatic change. We describe these few efforts here. An effort to link sustainability aspects and company strategies via an appropriate set of KPIs is studied in [3]. The study identifies suitable KPIs that affect company performance, based on 82 papers identified, and proposes a new perspective on how to integrate sustainability issues in company strategies. KPIs are defined as environmental performance indicators (EPIs) in [7], used to measure an organization's impact on the environment, including ecosystems, land, air and water.

Moreover, a methodological framework for the selection of KPIs to assess smart city solutions is proposed in [8]. The framework proposed led to the development of a repository of 75 KPIs categorized in six dimensions: technical, environmental, economic, social, ICT and legal. To help cities in their choice, the work in [9] compared seven recently published indicator standards for smart sustainable cities, identifying 413 indicators which were classified based on the following taxonomy: five conceptual urban focuses (types of urban sustainability and smartness), ten sectoral application domains (energy, transport, ICT, economy, etc.) and five indicator types (input, process, output, outcome, impact). From the 413 indicators, only 45% were typical for sustainability assessment.

It seems that numerous KPIs have been proposed to deal with aspects of sustainability and sustainable development in relation to companies and organizations [3], [7] or smart cities [8], [9]. However, these proposals do not directly relate to the performance of cities and countries in relation to climate change.

Worth mentioning is the effort of the Intergovernmental Panel on Climate Change (IPCC), the United Nations group tasked with assessing climate science for policy makers, which proposed ways to measure and monitor emissions [5], as well as land use [10]. Further, the European Environment Agency (EEA) analyzed trends and projections of around 40 indicators, with a focus on key climate variables and on impacts of climate change on health, environment and economy [4]. Moreover, the performance of EU Member States on environmental innovations is measured by the *Eco-Innovation index*[3], which is a composite indicator obtained by taking an unweighted average of 16 indicators included in the measurement framework adopted by the European Commission.

This absence of relevant metrics and criteria motivated organizations such as Germanwatch, to propose relevant indexes, like the *Global Climate Risk Index* (GCRI) [11] and the *Climate Change Performance Index* (CCPI) [6]. GCRI analyses to what extent countries and regions have been affected by impacts of weather-related loss events (storms, floods, heat waves etc.). On the other hand, CCPI acts as an independent monitoring tool for tracking the climate protection performance of 57 countries and the EU. The CCPI aims to enhance transparency in international climate politics and it enables comparison of individual countries' climate protection efforts and progress. CCPI assesses countries based on the following: a) GHG Emissions (40% of overall score), b) Renewable Energy (20% of overall score), c) Energy Use (20% of overall score) and d) Climate Policy (20% of overall score). It is remarkable that still no country has made it to the top three ranks, based on CCPI.

Finally, the United Nations' 2030 Agenda for Sustainable Development [12] is an effort worth mentioning. The agenda 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. Economic, social and environmental sustainable development are the three main groups of indicators. The latter group, in particular, is the one more relevant to our study.

3 Methodology

This paper aims to fill the aforementioned gaps in the literature, by addressing the following research questions:

1. Which are the KPIs used by different countries and cities around the world to measure climate change?
2. Which units, metrics and ranges of values are associated with these KPIs?
3. Which countries actually use these KPIs, assigning values and setting goals for mitigating climate change based on these KPIs?

It is important first to properly define *climate change*, in the context of this survey. Many people relate climate change to changes in climate that result from

[3] European Commission, Eco-innovation index. https://ec.europa.eu/environment/ecoap/indicators/index_en

greenhouse gas forcing of the climate system [13]. Under the FCCC, the term is defined as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods. On the other hand, the IPCC states that climate change is any change in climate over time whether due to natural variability or as a result of human activity [14]. We adopt the IPCC definition of climate change here.

Search for related work was performed through the Web scientific indexing services *Web of Science* and *Google Scholar*. The following query was used:

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

Twenty three (23) scientific papers and reports were found via this approach. To increase the range of our bibliography, a search of the related work as appeared in these 23 papers was also performed. This effort allowed to increase the number of papers discovered to 52. Each of these papers was studied in detail, aiming to address the research questions as listed above. We tried to record KPIs, understand their semantics and how they have been used in different regions of the world. From the 83 KPIs identified, 63 KPIs were included to our survey, based on the following criteria:

- This KPI has been adopted by some city or country.
- This KPI is measurable based on some quantitative metric.
- This KPI has some unique value based on the quantitative metric associated with it.

4 Results

Based on the 63 KPIs selected, eight general clusters were created, placing the KPIs inside those clusters. These clusters are the following: a) pollution; b) resource use; c) climate hazards; d) biodiversity; e) transport; f) land use; g) health and h) other. These clusters are described in Section 4.1 below, while the KPIs discovered, associated with these clusters, are listed in Section 4.2.

4.1 Clusters of KPIs

The 8 general clusters are described as follows:

Pollution Pollution includes air pollution and emissions, plastic pollution, waste, especially solid waste, water and soil contamination, as well as aspects of recycling. One of the most popular types of emissions recorded is greenhouse gases (GHG), which are gases that absorb and emit infrared radiation. Water vapor, carbon dioxide, methane, nitrous oxide and ozone are the GHG present in the Earth's atmosphere [15]. The earth's greenhouse effect has increased significantly since the industrial revolution [16]. Therefore, human activity is a key element in reducing major greenhouse gas emissions [17].

Plastics and micro-plastics 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 [18]. The production of plastic has been growing rapidly in the past and is expected to increase further in upcoming years [19]. It is important to properly manage this plastic to prevent it from ending up in the oceans.

Regarding waste, because of inappropriate treatment and transportation, it can cause pollution of the air, water, and soil, causing numerous environmental and health risks. Thus, solid waste management is critical [20]. Solid waste disposal into landfills is still a common method of disposal, despite the health and pollution hazards linked to this disposal method [21]. Other ways of waste disposal, such as recycling, incineration, or pyrolysis, are used to manage solid waste pollution and its harmful consequences [20]. Recycling is 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 [20]. 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 [22].

Finally, in respect to water and soil contamination, this occurs as a consequence of increased industrialisation and urbanisation. Polluted soil is harmful to humans and animals, since contaminating materials enter their body through the food chain [23]. Polluted water is harmful to marine life, plants, humans and the environment [24]. While companies and treatment plants make use of different wastewater treatment procedures, some industries continue to dispose untreated wastewater into water bodies and nearby soils. This causes pollutants such as heavy metals and organic pollutants to penetrate the soil and the water. 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.

Resource Use Human demand as well as the availability of natural resources are dispersed unevenly across the world [25]. Water is a critical resource for every person on earth. However, 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 [26]. A crucial aspect of climate change mitigation is to ensure that everyone will have access to reliable water services. 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 [27]. The implementation of smart water resource management strategies can lead to an increased resilience against the impacts of climate change, especially in developing countries [28].

Regarding energy as a resource, the consumption of fossil fuels has grown substantially during the last 50 years [29]. Between 1980 and 2019, global fossil fuel consumption almost doubled [30], despite the fact that 16% percent of primary energy came from low-carbon sources in 2019.

Moreover, reducing the amount of food 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 [31]. According to [32], the world is currently not on course to achieve the hunger and malnutrition targets that had been set for 2030. Although the number of people suffering from hunger had been declining for decades, this is not the case anymore.

Climate Hazards Climate hazards are an important aspect of climate change. Extreme events will most likely change in frequency and severity as a result of climate change [33]. One example is North America, where there are increasingly more and worse wildfires [34]. Alternatively, climate change can also cause changes in precipitation. This in turn can result in more precipitation-induced flooding [35]. It is important for cities and countries to know what climate hazards may pose a threat, either today or in the future.

Moreover, public health systems are crucial for the quality of living of citizens, but they can also face several risks related to climate change. These risks include diseases and pandemics as a result of climate change, threats to food security and safety, and many more [27].

Biodiversity Climate change has an impact not only on people but also on physical ecosystems [36]. Even a minor shift in climate can result in the extinction of some vulnerable and endangered animal species, as well as birds and fish. The Biodiversity Intactness Index (BII) shows how native terrestrial species' average abundance compares to their abundance before human intervention [37]. It is necessary to use such indexes to comprehend the interactions between plants, animals and biodiversity, implementing strategies to improve biodiversity based on that understanding.

Transport Transport is an important part of everyday life of billions of people. Over 16% of all GHG emissions in 2016 can be attributed to transportation [38]. Almost 12% of emissions were caused by road transport [38]. This means that the electrification of road transport could make a significant impact on GHG emissions, combined with alternative ways to produce electricity [39]. The implementation of good public transit networks is also important [40], [41]. If these networks are of good quality, being accessible to as many people as possible, they can reduce the use of private transport [41].

Land Use An important metric related to land use is the deforestation rate. This is critical in the earth's largest natural reserves, such as the Amazon rainforest. Brazil has large deforestation rates, which are rising [42]. Related to biodiversity as well, a relevant metric here is the number of living organisms lost per square kilometer of cut-down forest [43].

Further, agriculture emits an especially high amount of GHG. It contributes 17% to global emissions directly through agricultural operations and 7-14% indirectly via land use changes [44]. Agriculture not only contributes to climate change, but it 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 [45], The food chain contributes largely to emissions too. 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 [46].

Health Health relates mostly to humans, especially in terms of mortality rates and illnesses caused by or being correlated to climatic change. It seems that a large percentage of such illnesses relates to respiratory diseases caused by air pollution. Finally, public health seems to constitute a critical indicator, since climate change might stress the public health systems in case of climatic disasters occurring.

Others Finally, a more general cluster involves metrics relating to global temperature and sea level, which are hard to be attributed to different countries and regions, but relate to the whole planet. The mean global temperature increase may have a variety of negative consequences, including an increase in the likelihood of flooding, droughts, and heat waves [47]. Sea-level rise is associated with global warming, and constitutes a global phenomenon with potentially massive consequences, including coastal erosion and marine habitat destruction [48]. Countries in low-elevation areas, and small islands in particular, are expected to suffer from significant losses of land or even disappear, e.g. the case of Maldives.

4.2 List of KPIs

Table 1 lists the KPIs identified and recorded through this study, organized into the 8 clusters introduce in Section 4.1. Each KPI is associated with a topic, a unique name, a short description, the unit mostly used to measure it, as well as the range of values it takes, from a negative/bad/low value (-) to a positive/good/high one (+). The column *SDG target* shows the corresponding SDG and SDG target for each KPI, wherever available. The first number refers to the SDG, and the second shows the specific target. For example, the KPI #1 falls under the general SDG goal 11 (i.e. *"Make cities and human settlements inclusive, safe, resilient and sustainable"*) and target 11.6 (i.e. *"By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management"*). All SDGs and SDG targets are described in the United Nations' 2030 Agenda for Sustainable Development [12], for the reader's reference.

Category	Topic	#	KPI	Unit	Description	SDG target	+	-
1 Pollution	1.1 Air Pollution	1	Air Quality Index	#	Ranking of cities/countries based on annual average PM2.5 concentration (μg/m^3)	11.6	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	13.2	yes	no
		3	Existence of GHG emissions reduction target	yes/no	Existence of a target to reduce greenhouse gas emissions	13.2	yes	no
		4	Emissions generated by government operations	tCO2e	Scope 1, 2 and 3 emissions as a result of government operations	13.2	0	-
		5	Emissions generated by community activities	tCO2e	Scope 1, 2 and 3 emissions as a result of community activities	13.2	0	-
	1.3 Plastic Pollution	6	Existence of plastic policies	yes/no	Existence of regulations on the use and disposal of (single-use) plastics	n/a	yes	no
		7	Percentage of mismanaged plastic waste	%	The percentage of total waste that is not properly disposed of	14.1	0%	100%
		8	Amount of plastics currently in the oceans	metric tonnes	Amount of macro- and micro-plastics currently in the oceans	14.1	0	-
	1.4 Solid Waste	9	Annual solid waste generation	tonnes/yr	Total solid waste generation per year	11.6	0	-
		10	Solid waste disposed to landfill or incineration	tonnes/yr	Solid waste that is disposed of in landfills or that is incinerated	11.6	-	-
	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	12.5	100%	0%
		12	Percentage of population with access to recycling	%	Percentage of the population that have access to a recycling point	12.5	100%	0%
	1.6 Soil Pollution	13	Percentage of land that is polluted	%	Percentage of surface area that is affected by soil pollution	15.3	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	6.3	0%	100%
		15	Biochemical Oxygen Demand	mg/L	Measurement of non toxic organics in water	6.3	<1 mg/L	>8 mg/L
		16	Chemical Oxygen Demand	mg/L	Measurement of total toxic and non toxic organics in water	6.3	-	-
2 Resource Use	2.1 Water	17	Water consumption	L/person/day	The average liters of water used by one person in one day	6.4	-	-
		18	Water stress level	low-high	The ability to meet a region's demand for water	6.4	low	high
		19	Existence of a public Water Resource Management strategy	yes/no	Existence of a plan for dealing with water use and resources	6.5	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	n/a	no	yes
		21	Percentage of population with access to potable water supply	%	Percentage of people that have access to clean and safe drinkwater	1.4	100%	0%

	2.2 Energy	22	Energy consumption	kWh/household/yr	The average amount of energy consumed by one household per year	7.3	0 kWh	-
		23	Share of renewable energy sources	%	The share of a city's energy mix that consists of renewable sources	7.2	100%	0%
		24	Existence of renewable energy or electricity target	yes/no	Existence of a target to increase the use of renewable energy	n/a	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	7.3	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	n/a	100%	0%
	2.3 Food	27	Annual food waste	tonnes/yr	Amount of food that is wasted each year	12.3	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	12.2	<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	13.1	>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	13.1	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	13.1	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	13.1	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	15.5	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	15.5	0%	100%
		35	Terrestrial protected land area as percentage of total land area	%	Percentage of land surface area that is protected	15.1	-	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	15.5	0%	100%
		37	Marine protected land area as percentage of total land area	%	Percentage of marine surface area that is protected	14.5	-	0%
		38	Existence of policies for commercial fishing	yes/no	Existence of policies to curb commercial fishing rates	14.4	yes	no
		39	Commercial fishing rates	nr	The amount of fish caught for commercial purposes	14.4	low	high

		40	Bycatch rates	nr	The amount of marine animals that are caught unintentionally while fishing for other animals	14.4	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	9.1	100%	0%
		42	Quality of public transport	%	The quality rating given by inhabitants to a city's public transport system	9.1	100%	0%
		43	GHG emissions caused by public transport	tCO2e	The total amount of GHG emissions caused by public transport	9.4	0	-
	5.2 Private Transport	44	Percentage of population that owns a private car	%	Describes how many people own a private car	n/a	0%	100%
		45	GHG emissions caused by private transport	tCO2e	The amount of GHG emissions caused by private transport	n/a	0	-
		46	Existence of a zero- or low-emission zone in the city	yes/no	The existence of an area in the city where only zero- or low-emission vehicles are allowed	9.4	yes	no
	5.3 Electric Vehicles	47	Percentage of private cars that are electric	%	The percentage of total private cars that are electric	n/a	100%	0%
		48	Public access EV charging points per capita	nr	The number of charging points for electric vehicles per capita	n/a	>1	0
	5.4 Aviation	49	GHG emissions caused by aviation	tCO2e	The amount of GHG emissions caused by air travel	n/a	0	-
		50	Per capita emissions from domestic and international flights	kg	The total combined emissions caused by domestic and international flights per capita	n/a	0	>500
6 Land Use	6.1 Deforestation	51	Deforestation rate	Mha/yr	The total forest surface area that is cut down each year	15.2	0	-
		52	Percentage of global land cover that is tree covered	%	The percentage of total land area that is covered by trees	15.1	>30	0
	6.2 Agriculture	53	GHG emissions caused by agriculture	tCO2e	The amount of GHG emissions caused by agriculture	n/a	0	-
		54	Percentage of land used for agriculture	%	The percentage of total land area used for agriculture	n/a	-	-
		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	n/a	-	-
		56	Vulnerability to climate change related agricultural risks	n/a	The vulnerability to climate related agricultural risks such as droughts	1.5	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	11.5	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	n/a	0%	100%

		59	Deaths caused by air pollution	deaths per 100.000 people	Mortality rate linked to household and ambient air pollution	3.9	0	>1
	7.3 Illnesses	60	Number of heat related illnesses	nr	Identifies the amount of illnesses that were caused by extreme heat	n/a	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	3.9	0	>1
8 Other	8.1 Global Temperature	62	Annual rise in global temperature	°C/yr	The rise in global temperature per year	n/a	<1.5	>2
	8.2 Sea Level	63	Annual sea level rise	mm/yr	The rise of the sea level per year	n/a	0	3

Table 1: List of Key Performance Indicators related to climate change.

5 Discussion

As illustrated in Section 4, a large number of KPIs is used to measure a country's or city's performance in relation to climate change. We have identified 63 such KPIs, dividing them into eight categories, based on the criteria set in Section 3.

Some of the KPIs mentioned above (e.g. #1, 2, 5, 6, 12, 17, 22-26, 27, 28, 32, 44, 45, 47, 48 - Table 1) have already been used to measure and quantify sustainability and environmental performance, as well as to set targets in organizational settings [3], [7] or in smart city solutions [8], [9]. However, many other KPIs (e.g. those relating to climate hazards, biodiversity, land use, other - Table 1) have not directly been linked to companies and smart cities yet.

Moreover, some of the most prominent global efforts to define and measure climate change through various KPIs, such as IPCC [5], [10] and EEA [4], focus only on a subset of the indicators/KPIs identified and proposed in this study. We have counted 35 KPIs discussed by IPCC and 40 indicators proposed by EEA. While the KPIs of IPCC relate mostly to pollution, resource use, biodiversity and land use, the indicators of EEA focus on impacts of climate change on health, environment and economy. Here, it is worth mentioning that through our study we have not identified any economy-related KPIs which have been adopted by any city or country around the world and have been somehow measured.

One of the most mature and complete efforts to date in the direction of measuring the climate change-related performance of countries, based on various KPIs proposed, is the work of Germanwatch and the proposed Climate Change Performance Index (CCPI) [6]. CCPI embraces a wide list of KPIs, but we argue that this list could have been extended with additional ones (e.g. ones related to biodiversity, transport, land use - Table 1).

A more thorough comparison is shown in Table 2. The table lists the CCPI indicators and the corresponding KPIs presented in this paper. One insight that can be concluded from this is that only six KPIs are also covered in the CCPI, namely numbers 3 (Existence of GHG emissions reduction target), 4 (Emissions generated by government operations), 5 (Emissions generated by community activities), 22 (Energy consumption), 23 (Share of renewable energy sources), and 24 (Existence of renewable energy or electricity target). This means that the large majority of the KPIs listed in this paper are not included in the CCPI.

CCPI indicator [49]	**Corresponding KPI(s)**	**Comparison with this paper**
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 2:Comparison of the CCPI index vs. the KPIs listed in this paper.

As stated in Section 2, the United Nations' 2030 Agenda for Sustainable Development is also an important effort to consider. Many of the KPIs in Table 1 have a corresponding SDG target. However, when comparing the findings of this paper with the UN SDGs, two categories are notably not sufficiently covered by the targets: transport and agriculture.

We are very much in favour of a globally accepted index, which combines a wealthy and diverse list of KPIs, comparing the performance of cities and countries in respect to climate change. On one hand, this can trigger a healthy competition, creating public pressure to governments and local actors to act and, on the other hand, it will facilitate the work of policy-makers in terms of creating environmentally friendly laws, policies and directives. While individual policies focusing on specific KPIs can lead to better monitored and assessed results, at the same time, embracing a diverse list of KPIs in unison can also give a complete and comprehensive representation of countries' efforts to mitigate climatic change.

The European Union seems to work towards the right direction in some clusters, e.g. resource use and energy [50], land use and forestry [51], as well as biodiversity [52]. For example, in relation to the share of renewable energy sources, EU plans to have a renewable energy share of at least 32%, plus using energy more efficiently [53], with a target of 32.5% savings by 2030, in comparison to 2020. In relation to biodiversity and land use, EU builds strategies to protect nature and reverse the degradation of ecosystems. We expect and hope that these strategies and initiatives will be complete, realistic, fair for member countries, with proper incentives and aids in order to reach the goals proposed. The EU initiatives could become exemplar for the rest of the world.

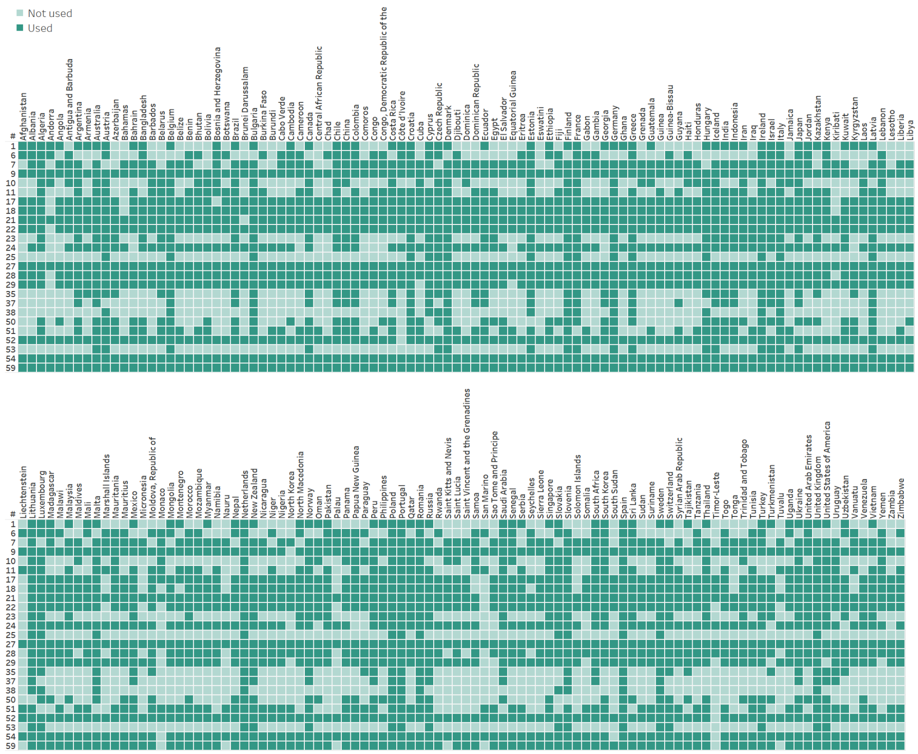

Fig. 1. Heatmap showing the use of KPIs per country [54–73]

5.1 Countries and use of KPIs

In Figure 1, the use of the 63 KPIs in 193 countries is displayed as a categorical heatmap. The KPIs that were used for the graph are those that are implemented at a country level and have recent data available (#1, 6, 7, 9, 10, 11, 17, 18, 21, 22, 23, 24, 25, 27, 28, 29, 35, 37, 38, 50, 51, 52, 53, 54, 59 - Table 1). This means that a maximum number of 25 (KPIs) can be scored by each country. These 25 KPIs cover the whole spectrum of categories as defined in this paper, except from transport (i.e. only aviation is included). 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: 9 (Annual solid waste generation), 17 (Water consumption), 18 (Water stress level), 21 (Percentage of population with access to potable water supply), 22 (Energy consumption), 24 (Existence of renewable energy or electricity target), 27 (Annual Food Waste), 28 (Ecological footprint of consumption per person), 29 (Global Climate Risk Index), 52 (Percentage of global land cover that is tree covered), 54 (Percentage of land used for agriculture) and 59 (Deaths caused by air pollution). The only KPI that is used by all countries and also has available data for each of them is 27 (Annual food waste). The countries that employ all 25 KPIs are all European ones. Six countries use all KPIs: Ireland, Italy, the Netherlands, Poland, Por-

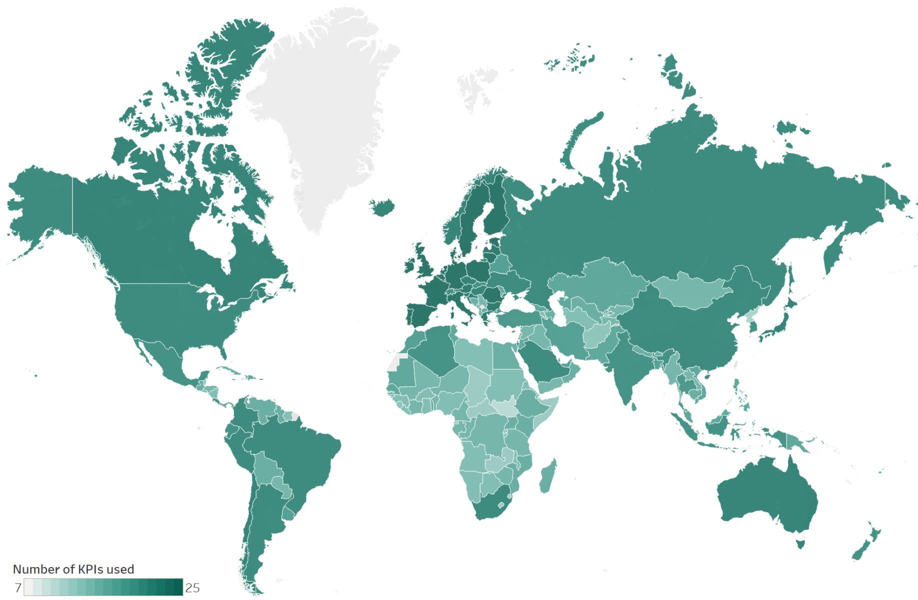

Fig. 2. Choropleth map showing the use of KPIs per country [54–73]

tugal and Spain. Additionally, there are seven countries that use all KPIs but one. These countries include: Denmark, Estonia, France, Lithuania, Romania, Sweden and the United Kingdom. Figure 2 depicts the aggregated number of KPIs adopted by countries around the world. As can be seen in the map, there are some clear regional differences in the use of the KPIs. Many countries in Africa and some countries in central Asia use significantly fewer KPIs than the European ones. There is a clear gap between developed and developing countries in respect to the use of KPIs to measure climate change. Both visualizations, presented in Figures 1 and 2, can be better viewed via this link[4].

5.2 Limitations and future work

As a limitation of this work, we note again that the KPIs recorded and listed in our survey are based on the criterion that they have been adopted by a country or city around the world. This might leave out some relevant KPIs which have not yet been in use (e.g. circular economy, eco-innovations, biodiversity of insects and plants, burned areas due to wildfires). Further, identifying and developing new KPIs that are presently not covered by the survey is outside the scope of this research. Another important limitation of this study is the data available. As stated before, all countries that adopt all KPIs are European ones. Data for other countries might still exist, but not be available in English (i.e. main

[4] Visualizations of this project: https://superworld.cyens.org.cy/demo2.html

language used during bibliography review). This can affect the accuracy of the information presented in Figure 2.

As future work, we are preparing a complete, elaborate climate change index, similar to the CCPI [6], which includes all the KPIs listed in Table 1. We aim to examine how cities and countries perform, in relation to an index that combines all or at least a large percentage of these KPIs, giving a unique score to each country, facilitating and promoting comparisons and competitions. Further, we aim to improve our results considering the limitations mentioned in the previous paragraph. It is important to observe whether countries located in different parts of the world give priority or focus only on specific KPIs, which are linked to their most significant and/or urgent climate change risks.

6 Conclusion

This paper performed a large survey to identify and list key performance indicators, used by different cities and countries around the world to measure and quantify climate change. Sixty three different KPIs have been identified, listed together with suggested units and metrics associated with them, divided in eight different thematic areas: pollution, resource use, climate hazards, biodiversity, transport, land use, health and other. As climate change is one of the biggest threats to humanity, we need to understand, embrace and use such KPIs, in order to define tangible and fair goals for cities, regions and countries around the world, in regards to mitigating climatic change. Each country can calculate its performance based on these KPIs, setting realistic objectives for better performance in the near future, exchanging knowledge and best practices with other countries and regions. This paper can be considered a small but important contribution in the global efforts to understand and measure climatic change, to define properly and fairly policies and to set goals associated with it. It is of crucial importance that countries form appropriate policies to combat climate change and the problems that arise, as the clock is ticking against us as species.

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