Monitoring Cities’ Environmental Sustainability: Lisbon’s Case Study

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<u>This is the final, accepted version of the conference contribution published by *IEEE*</u>

Pacheco, P. M. E., & Neto, M. D. C. (2022). Monitoring Cities’ Environmental Sustainability: Lisbon’s Case Study. In 2022 17th Iberian Conference on Information Systems and Technologies (CISTI): proceedings (pp. 1-7). (CISTI 2022. 17th Iberian Conference on Information Systems and Technologies, 22-25 June 2022, Madrid, Spain). IEEE. ISBN: 978-9-8933-3436-2. https://doi.org/10.23919/CISTI54924.2022.9820501

Monitoring Cities' Environmental Sustainability

Lisbon's Case Study

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Abstract —**In a world of increasing urbanization and where climate change is a growing concern, data presents itself as way to measure the established efforts and forecast future needs and policies as Lisbon finds means to solve some of the major problems that come with being a large city such as air quality and pollution, waste management, mobility, and overall quality of life for its residents. As such, this project developed a dashboard in a BI visualization tool comprised of metrics and indicators based on a tailored framework from the city derived from pre-existing frameworks and conversations with Lisbon's city experts. The result is a prototypical dashboard that can be built upon in the future, once the city invests in a stronger ICT infrastructure that allows for the collection of data to support a project of this nature, something that, currently, is lacking.**

Keywords - Lisbon, sustainability, dashboard, data-driven decisions, data.

I. Introduction

A. Problem Identification

The Brundtland Report (1987), devised by the World Commission on Environment and Development (WCED) first defined the concept of "sustainable development" as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". In recent years, many international institutions such as the United Nations (UN) and the European Union (EU) have devised plans and frameworks to tackle this issue. This is not surprising, considering that, as of 2007, more than 50% of the global population lives in urban areas which are, in turn, responsible for 70% of carbon emissions and 60% of resource consumption while occupying only 3% of the world's landmass [1]. It is within this context that the following research is presented: given the growing efforts for sustainable development, with special emphasis on environmental challenges, and the relevant role urban areas play in these areas, it is important to delineate and develop a framework that measures cities' environmental sustainability.

B. Research Question and Objectives

With this background, the research question is thus: *what are the necessary metrics and indicators to develop a relevant framework to measure cities' environmental sustainability?*
A few objectives can be determined to ultimately help answer the research question:

1. Identify the existing sustainability frameworks and assess their relevancy towards environmental sustainability.
2. Analyze the needs of city officials and the information they need to make data-driven decisions regarding the city's environmental sustainability.
3. Determine the relevant metrics and key performance indicators (KPIs) as well as the raw data necessary to measure them.
4. Design a data-architecture and respective dashboard to convey the information.

II. Literature Review

A. Cities, Smart Cities, and their context within Environmental Sustainability

The link between cities and the environment is one that has made global institutions such as the Organisation for Economic Co-operation and Development (OECD) and the UN worried about the future. By 2050, it is expected that the world's population will grow from 7 to 9 billion people, an almost 30% increase that will be completely absorbed by cities and urban areas. This growth will have severe impacts on air pollution, transportation, waste, and water management, etc. [2].

It is, thus, not surprising to see the term "sustainability" applied to cities and urban areas. One of the most common terms when one is looking at sustainability within urban areas is that of "smart cities" or, more specifically, "smart sustainable cities" [3]. Much like the term "sustainability", "smart cities" has been the victim of a series of attempts at defining it and, to this day, there still isn't any clear-cut, universally accepted clarification of the concept [3,4,5,6]. Nonetheless, one of the most widely accepted definitions of the term is offered by reference [7]: "A city [is] smart when investment in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance." [3].

Regardless, one shared element across all definitions, strategies, and approaches towards the concept of "smart cities" is that of ICT [3]. Reference [8] shows how ICT can be used towards a more sustainable future through several applications aimed at monitoring and analyzing the environment (databases, research, planning, modelling, etc.) which can, in turn, lead to strategies and policies that emerge out of the shared data. By supplying and using open data to track urban sustainable development progress, open data for smart cities play a crucial role in monitoring city sustainability [9]. Additionally, ICT can be used to substitute, improve, and optimize processes through technological improvements. Hence why, even though "smart cities" do not necessarily require sustainability, through the usage of ICT – which is a requirement – they can help the cause of sustainability. Therefore, cities aiming to become environmentally sustainable must turn towards ICT as a supporting – and essential – framework that underlies the complex urban systems so as to provide a better quality of life for its citizens while improving the environment [3,10].

B. Policies, Deals, and Agreements affecting the Portuguese Context

Following the assessment regarding the importance of measuring the progress towards sustainability through metrics and KPIs calculated using data provided by ICT in cities, it becomes relevant to understand which metrics and KPIs should be calculated.

One of the first major sets of international policies and plans came with the Rio Summit in 1992, also known as the Earth Summit, from which two major documents were produced: the "Agenda 21" – signed by more than 178 governments, outlining an action plan to tackle human impact on the environment – and the "United Nations Convention on Climate Change" (UNFCCC) – an agreement on climate change convention signed by 154 nations [11,12].

The "Agenda 21" was so called because it outlined a set of actions to achieve global sustainability by the beginning of the 21st century. It was not legally binding, instead encouraging local, national, regional and international governments to adopt their own "Agenda 21", and it did not contain specific targets or goals, instead delineating general objectives that should be taken into consideration and achieved, with a special focus on the environment and its protection. It gave way to the Millennium Goals in the year 2000 and then to the Sustainable Development Goals (SDGs) in 2015 [13,14].

As for the UNFCCC, it is a non-legally binding treaty with the goal of stabilizing greenhouse gas (GHG) emissions to prevent anthropogenic influences in the climate within a reasonable period that would allow for ecosystems to adapt to climate change.

Despite also not containing specific targets, the UNFCCC set out a series of commitments and objectives that paved the path to future protocols and agreements, with the signatory parties convening every year to assess the progress being made [11,15,16]. In fact, the UNFCCC set the precedent for the Kyoto Protocol, one of the most important documents in international climate change awareness and action. The Kyoto Protocol, signed in 1997 in Kyoto, Japan, entered into force in 2005 and is an internationally legally binding document regarding the reduction of GHG emissions. Thus, the Protocol sets clear targets, divided in two time periods: from 2005 to 2012, which aimed to reduce GHG 5% below 1990 levels; and from 2013 to 2020 (the Doha Amendment), which aimed to reduce GHG 18% below 1990 levels [11,17,18]. The implementation and success – or lack thereof - of the Kyoto Protocol are widely controversial and criticized [19,20] Regardless, one of the major successes of the Kyoto Protocol is, indeed, the international cooperation to tackle the climate change issue, as well as the focus it attributed to the problem, which helped set the stage for the next major agreement in this area: the Paris Agreement.

As per reference [16], "the Paris Agreement is a legally binding international treaty on climate change. It was adopted by 196 Parties at COP 21 in Paris, on 12 December 2015 and entered into force on 4 November 2016. Its goal is to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels" (para. 1-2). However, unlike the Kyoto Protocol, the Paris Agreement does not have specific targets beyond the proposed global warming limit. Instead, each country is responsible for presenting a set of measures and policies in 5-year cycles that should be more ambitious with each cycle [16].

The Portuguese commitment to the Agreement comes through a series of policies and targets set by the Portuguese Government and by the European Union. For the most part, under the "Quadro Estratégico para a Política Climática" (QEPiC), which includes the "Plano Nacional para as Alterações Climáticas 2020/2030" (PNAC 2020/20230 or just PNAC) and the "Plano Nacional de Energia e Clima" (PNEC). Other targets are observed under the EU's "2030 climate & energy framework".

Additionally, the Portuguese Government also approved the "Compromisso para o Crescimento Verde" (CCV) with 14 other targets to be attained between 2020 and 2030 [21] and the "Roteiro para a Neutralidade Carbónica 2050" (RNC) which aims to attain full decarbonization of the economy by 2050 [22] and goes in line with the EU's target of achieving a net-zero GHG emissions economy by the same year [23]. The "European Green Deal" is the EU's response to the Paris Agreement, a set of policies aiming at achieving the goals set out by the Agreement and also expanding them to more ambitious targets and longer time periods [24].

C. Existing Frameworks

As explained, the very concept of sustainability beseeches the need for measurement and tracking as it requires a comparison between a base state and changed state to determine whether positive or negative developments towards sustainability were made. At the intersection of these concepts – sustainability, smart cities, and measurement –, we can find a plethora of frameworks aiming at judging if cities are, in fact, implementing smart solutions and whether those are contributing towards solving the problems facing urban areas today – sustainability just one among them.

One such examples of frameworks designed to measure the effects of smart cities concepts and respective implementations can be found in reference [25] European Smart Cities Ranking. However, other frameworks designed to measure sustainability within smart cities have been developed and are summarized in reference [26] study where they analyzed seven standardized indicator frameworks and developed a taxonomy to organize them and help city managers determine which indicators to use and when. This study will guide most of this section.

In reference [26] study, 7 standardized frameworks issued by international agencies (the International Organization for Standardization [ISO], the International Telecommunication Union [ITU], the European Committee for Electrotechnical Standardization [CENELEC], the European Committee for Standardization [CEN] and the European Telecommunications Standards Institute [ETSI]) are evaluated. Some of these frameworks focus on sustainability, others on smartness, others on city services and quality of life. Connecting them, however, is the fact that they all take the concept of sustainability as a foundational support.

The study then analyses the indicators proposed by the frameworks and classifies them according to 3 categories (City Sector, Indicator Type and Urban Focus) which then subdivide into more specific categories.

This taxonomy and its respective indicators will serve as the basis for indicator selection in this project. However, constructing a framework of urban sustainability is not without its problems and challenges, chief among them the difficulty of choosing universally applicable and relevant indicators that can be used in any city [26,27,28]. On the one hand, standardized frameworks allow data comparison and consolidation of complex problems which help guide policy and decision-making; on the other, standardized indicators might miss important and contextual-dependent problems, misguide debate and are presented as a universal solution when, in fact, such thing is not possible [27]. Therefore, many authors argue in favor of specific and adapted frameworks with indicators adapted to each city's needs.

III. Methodology

The methodology used for this project is an adaptation of the steps presented by reference [28], each linked with a minor goal, which can be seen on Table 1. As evident, this adapted methodology omits certain steps from the original presented in the study. Namely: second and fifth steps, "Choosing Outcomes/Goals" and "Selecting Targets", which are incorporated in the first step; fourth step, "Set performance Baseline", which is included in the third step; and steps seven to ten, which require follow-up after the implementation of the framework and, once again, go beyond the project's timeline and scope. The only data collected throughout this methodology – other than the one already presented throughout the literature review – comes with the second sub-phase of the second step, where interviews with city officials from Lisbon will provide qualitative and quantitative data which will allow the adaptation of the general framework to the city's specific needs.

A. Step 1 - Preliminary Assessment

Going over the policies, deals, and agreements related to environmental sustainability affecting the Portuguese context, we can derive 5 general areas to measure if Portuguese cities wish to comply with the proposed targets set by the policies:

1. Reduce GHG emissions
2. Energy efficiency
3. Renewable energy
4. Urban areas
5. Air and water

Table 1 - Adapted methodology from Reference [28] to help guide the construction of the framework and set clear goals for each step of the process.

Step	**Description**	**Goal**
Preliminmary Assessment	This step is realized by going over the current policies, deals, and agreements related to environmental sustainability affecting the Portuguese context. Despite most of the targets and guidelines presented in these policies, deals, and agreements being too broad and vague for individual cities to put into practice or measure, they still present a basis for what we should focus on.	Understand the general needs and areas to be measured, general goals to be achieved and the context surrounding the framework
Selecting Performance Indicators and Targets	By looking at the already existing frameworks, this step will consist of two sub-phases: 1) indicator selection from the standard frameworks based on the taxonomy developed [26] to create a preliminary, general framework and 2) indicator selection from the preliminary framework alongside city officials from Lisbon to create a tailored framework.	Create an initial, general framework and a second, tailored framework for Lisbon's case study
Application	Applicating the framework to the real-world case of Lisbon, with open data as the input, starting with the baseline data and then the current state data.	Develop a data model based on open data and a dashboard using a Business Intelligence (BI) tool; identify lacking data and show the importance of ICT for sustainability

B. Step 2 – Selecting Performance Indicators and Targets

With this preliminary assessment, we can then look at the indicators analyzed by reference [26] and select the ones related to each Goal. A summary of this process can be found in Figure 1. To do this, we can filter the indicators to only consider those with, at least, 1 point in the Planet aspect of Sustainability as attributed by the authors in accordance with their scoring system so we consider only the indicators related to environmental sustainability. Then, we can map the indicators to the 5 Goals mentioned previously based on their scores in the other categories of the taxonomy, as well as on the metadata provided by the technical documentation, similar to what the authors of the study did.

Following this initial, broad selection, we can look at the remaining indicators for each goal. To further streamline the pool of indicators, we looked, first, at the ones categorized as being of the "Impact" type by reference [26] following their description of this type of indicators: "Impact indicators measure the state with regard to a set city target (impact of policy), e.g. city's energy consumption, and can be used to evaluate for example the sustainability impacts of smart solutions".

Table 2 - The 18 chosen indicators and the targets they relate to.

Goals	Policy	Targe	Indicator	Standard
Reduce GHG emissions	PNAC	30% to 40% compared to 2005 levels	Greenhouse gas emissions measured in tons per capita	ISO 37120:2018
	2030 climate & energy framework	40% compared to 1990 levels		
	RNC	85% to 90% compared to 2005 levels [a]		
	CCV	Cap CO2 emissions between 52.7-61.5 Mt	CO2 emissions	ETSI TS 103 463 (2017)
Energy efficiency	PNEC	35% improvement in energy efficiency	Total end-use energy consumption per capita (GJ/year)	ISO 37120:2018
	2030 climate & energy framework	32.5% improvement in energy efficiency	Final energy consumption of public buildings per year (GJ/m2)	
	CCV	101 toe/€m GDP	Energy intensity [b]	-
Renewable Energy	PNEC	47% share of renewable energy	Percentage of total end-use energy derived from renewable sources (breakdown by source and sector)	ISO 37120:2018
	2030 climate & energy framework	32% share of renewable energy		
	CCV	40% share of renewable energy		
	PNEC	20% share of renewable energy in transportation		
Urban Areas	CCV[b]	23% urban renewal in total construction	Percentage of urban renewal [b]	-
		15.296 million public transport passengers	Number of public transport passengers [b] Percentage of population living within 0,5km of public transit running at least every 20 min Annual number of public transport trips per capita	- ISO 37120:2018 ISO 37120:2018
	SDG – Goal 11	100% proportion of population with access to public transport	Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities.	UN IAEG SDG 11+ (2016)
		Increase proportion of solid and water waste collected and properly discharged	Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities. Municipal solid waste	UN IAEG SDG 11+ (2016) ETSI TS 103 463 (2017)
Air and Water	CCV	Reduce to 20% water loss in the network	Water losses	ETSI TS 103 463 (2017)
		100% bodies of water with "Good or Better" rating	% of bodies of water with "Good or Better" rating [b]	-
		Average of 2 days with Air Quality Index "poor" or "bad"	Average of days with Air Quality Index "poor" or "bad" [b] Air quality index	- ETSI TS 103 463 (2017)
	SDG – Goal 11	Decrease annual mean levels of fine particulate matter	Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted).	UN IAEG SDG 11+ (2016)

a. The RNC has an intermediate target for 2030; however, only the target for 2050 is shown here.
b. These targets do not have any corresponding indicator in the analyzed frameworks.

These indicators are, thus, more appropriate to measure whether a city is on track to reach a certain target or goal, which is in line with the objective of this project, given the aforementioned context of the policies, deals, and agreements. When no suitable indicators can be found after applying this filter, indicators of other types were selected.

Considering that these frameworks often overlap, some indicators can be found in more than one framework, often with different names but measuring the same thing – sometimes changing the measurement units, other times slightly changing the methodology. When this occurs, the choice defaulted to the frameworks developed by ISO, which have, for the most part, the most detailed definitions and methodologies, thus allowing for a better understanding of the indicators. It is also worth mentioning that not all targets have a corresponding indicator in these frameworks.

Following this selection process, a set of 18 core indicators was chosen and can be found on Table 2.

After the initial selection of indicators based on the frameworks analyzed by reference [26] and the policies and targets in place for Portugal and the city of Lisbon, it is necessary to bring some more specificity to the framework so it can be applied to the context of the project. As was seen before, debates around standardized frameworks for sustainability in cities highlight the need for city-specific indicators that answer the city's needs [26,27,29]. To tackle this challenge, an interview with a sustainability expert working for Lisbon's municipality and its executive body (Câmara Municipal de Lisboa, henceforth CML) was held with the goal of understanding the work that is already being done, as well as any new initiatives or existing frameworks that the city officials are already working with. This interview was informal and unstructured, with the goal of understanding the overall necessities of city officials, as well as the current state of technologies that might allow for the collection of data.

From this conversation, we were able to derive that CML is currently working on a proposal for sustainability targets to be presented sometime in 2021 through their own "Climate Action Plan 2030" [30]. There is already some overlap between these targets and the indicators selected in the previous chapter. This is not surprising, as the framework presented in Table 2 was built based on the policies and targets set in place for Portugal which, by extension, also apply to Lisbon. However, the city itself as its own goals, with some not completely aligning with the scope of this project, which is focused mainly on environmental sustainability. Thus, targets such as "Energy Poverty" or "Noise" will not be considered thenceforth.

By combining these two, we can derive a Lisbon specific framework, as presented in Table 3.

C. *Step 3 – Application*

The data used was provided by the previously mentioned city official through Excel files that can also be obtained through the "Observatórios Lisboa", an open data portal reporting data related to the "Climate Action Plan 2030" [30]. This data is, in turn, provided by several city partners, such as Lisbon's water company, the Portuguese energy providers, etc. By the definition of "open data", these files are not considered as such since they are reported by private companies and not produced through public funding. However, it is publicly available and published by a public entity and it is also the most accurate and complete data regarding these themes that is currently available.

The data was thus imported into the BI tool and arranged following a star-schema, which can be found in Figure 1. The

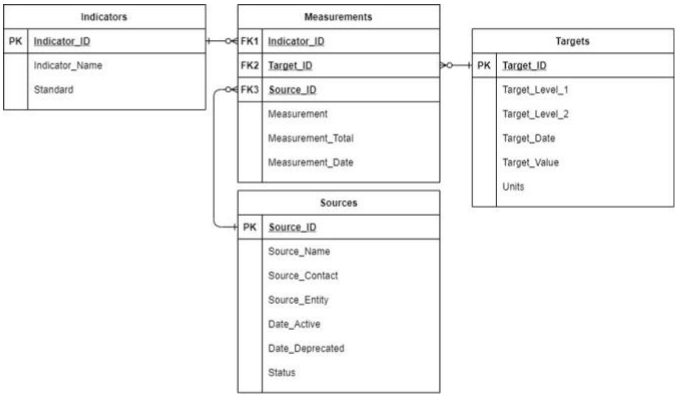

Figure 1 - Final star-schema

table "Measurements" acts as the Fact Table in the schema, housing the data that allows for the calculation of the metrics and KPIs; it has 3 dimensions:

- **Indicator_ID**: identifies the indicator used for the measurement and connects to the "Indicators" dimension table.
- **Target_ID**: identifies the target the entry aims to measure and connects to the "Targets" dimension table.
- **Source_ID**: identifies the source of the measurement and connects to the "Sources" dimension table.

IV. Results, Conclusions, And Discussion

The research question of this project was: "*what are the necessary metrics and indicators to develop a relevant framework to measure cities' environmental sustainability?*". In summation, there is no single relevant framework to measure a city's environmental sustainability. As was reiterated throughout the literature review, the topic of sustainability and its intersection with modern cities is plagued with questions, indecisions, and doubts. Simply put, each city is a specific case and requires a specific and uniquely tailored approached.

The results can be found in the dashboard developed using Power BI published here. Examples of it can be seen in Figures 2 and 3 In Figure 2, the "Target Overview" page is shown, with gauge charts to measure which targets have been achieved, and which haven't, as well as the latest measurements for each and their respective target values. Through this page, anyone can quickly determine the progress that has been made, as well as how much there is still left to do, understand which targets are

Figure 2 - Overview page.

Table 3 - Lisbon's sustainability targets.

Target	Sub Target	Indicator	Standard	Target Year
Reduce GHG emissions	Carbon neutrality	CO2 emissions	ETSI TS 103 463 (2017)	2050
	2,3 tCO2e	Greenhouse gas emissions measured in tonnes per capita	ISO 37120:2018	2030
	-70% GHG emissions compared to 2002			
Renewable energy	100 MW of solar power installed	Percentage of total enduse energy derived from renewable sources (breakdown by source and sector)	ISO 37120:2018	
	100% renewable energy on CML buildings			2021/25
Mobility	34% commute in individual cars and 66% in other alternative means	Number of public transport passengers **	-	2030
Water	-30% water consumption in CML buildings compared to 2018	Water consumption	-	
Municipal Solid Waste and Recycling	-15% waste per capita	Municipal solid waste	ETSI TS 103 463 (2017)	
	50% selective retrieval	Proportion of urban solid waste regularly collected and with adequate final discharge out of total urban solid waste generated, by cities.	UN IAEG SDG 11+ (2016)	
	60% recycled waste			
Air Quality	Comply with WHO reference values	Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted).	UN IAEG SDG 11+ (2016)	2025
	Better air quality	Air quality index	ETSI TS 103 463 (2017)	

far from completion and require more attention, and which are on track.

In Figure 3, an example of a page deep diving into a specific target is shown. Each of the five targets has a page like this, with a small description of the relevance of the target and the data sources, as well as their respective sub-targets.

For each sub-target, the latest measurement and the target values are shown, as well as year-over-year (YoY) percentual changes and absolute volumes with, again, an indication of the target value. Finally, at the bottom, the target year for each sub-target is shown, accompanied by the predicted year it will be achieved if the latest YoY% change is kept (i.e.: for the "Reduce GHG -70% compared to 2002 levels" sub-target, the latest YoY% was -5%: if this pace is kept for the next years, the target will be reached in 2036). These "predicted years" turn red if higher than the target year and green if lower.

As is apparent, the prototype dashboard is somewhat limited due to the lack of good quality data. The available data only

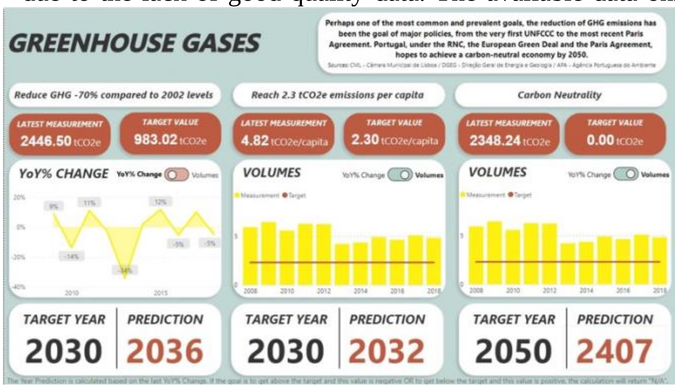

Figure 3 - Example of goal deep-dive page.

contained values up to 2018 (3 years before the development of this project) and was only updated annually. Its most granular level was city-wide, and some wasn't even available and had to be made up in order to show some visuals.

The city of Lisbon has defined targets and goals it hopes to achieve in the near future, often guided by policies at the national and European levels, but these targets become irrelevant when faced with the lack of data to measure them. How can the city hope to achieve 64% of commuters using alternative means if it doesn't have the infrastructure to know how many currently use them? How can the city officials make decisions for the near future, if the only data available has a 3-year lag? How can a dashboard whose purpose is to show data be constructed, if there's still no infrastructure to even measure the data?

V. Limitations and Recommendations for Future Works

As previously mentioned, the main limitation with this project lies in the data, or lack thereof. Ideally, the data would be collected and stored through automatic processes using sensors, cameras, machine learning and the like to measure and, if necessary, calculate the required data points, storing them in a properly structured DataMart which would then allow for the proper ETL processes. In summation, the city requires a well-developed, well-structured ICT network to collect, measure and store the necessary data.

Instead, the current situation leaves CML officials reliant on third parties to provide the data, which often comes with years of delay and without the necessary granularity levels, in Excel files that require manual handling to transform the data into a workable state. In some cases, data wasn't even available in the development of this project, which makes the drafting of their respective targets irrelevant (how can the city determine whether it's on the path towards achieving said target if it cannot know its current state?).

The city of Lisbon has not officially set out to become a smart, sustainable city. However, recent efforts towards sustainability (such as the "Climate Action Plan 2030") show that the city is on a tangential path and, if its goals align with those of smart cities, so must its methods. As chapter 2.2. highlighted, ICT are paramount for cities paving a more sustainable future and, unfortunately, Lisbon is currently far from having the necessary infrastructure to achieve these goals. That said, this project aims to provide a prototype of what can be achieved if said infrastructure is present by showing what is possible with the current situation. In the future, if the city starts collecting more and better-quality data, dashboards such as the one presented here could be improved upon to provide even more insights and metrics, feeding into data-driven decisions that allow for more flexibility and faster policy changes to tackle the issue of sustainability.

Future works should, thus, wait for this data and ICT infrastructure to be implemented first, before implementing dashboards such as these. After all, a dashboard requires data to work and, if said data is not available, said dashboard is unusable. Additionally, dashboards should be updated frequently with the latest available data: dashboards updated yearly with data from 3 years past is, simply put, useless.

VI. ACKNOWLEDGEMENTS

Work developed as a contribution to Project C-TECH — Climate Driven Technologies for Low Carbon Cities (reference 045919), co-financed by the ERDF — European Regional Development Fund through the Operational Program for Competitiveness and Internationalisation — COMPETE 2020, the North Portugal Regional Operational Program — NORTE 2020 and by the Portuguese Foundation for Science and Technology — FCT under MIT Portugal.

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