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DIGITALISING CITIES: A METHODOLOGY TO MAP EVALUATION REQUIREMENTS INTO ROBUST AND FEASIBLE DATA COLLECTION APPROACHES

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Abstract. The sustainable development of cities relies on the implementation of multi-sectoral actions towards carbon neutrality, reducing the air pollutants emissions. The actions' decision-making process for cities transformation should be supported by lessons learnt from previous interventions and KPIs (Key Performance Indicators). To do so, gathering real data becomes pivotal, complementing simulation tools (currently used), solving the inherent uncertainties due to assumptions. Data collection methodologies are then necessary, being the main driver for digital cities and providing better mechanisms for informed decision-making. Most of the cities still operate in silos and do not always implement the strategic plans supported with a digitalization of the municipal processes. Within this perspective, this paper presents a methodology to support cities in the preparation of monitoring programmes to collect real data in a robust and feasible manner. Taking the KPIs and the Smart Cities urban strategies into account, this paper concludes with some lessons learnt within cities to deploy monitoring approaches. From the city challenges to the review of the plans, all the process is driven by real data and KPIs. The methodology has been applied in the mySMARTLife project (Grant Agreement #731297) and deployed into the cities of Nantes (France), Hamburg (Germany) and Helsinki (Finland).

Keywords: Digitalisation, sustainable cities, KPIs-based assessment, monitoring, decision-making, data.

1. Introduction

Cities population is growing and nowadays, more than two thirds of the European population (the 70.9 % [1]) is living in urban areas [2], where the 29.1 % of people live in rural areas [1] with expectations to increase the statistic in the next years. This is partially because of the perception of cities as centres of economic growth that provide opportunities for study, innovation and employment [2]. Additionally, cities are responsible for more than 60 % of greenhouse gas emissions, a figure that will increase with the population growth. For these reasons, there is a need for a transition, not only from current cities into Smart Cities, but also, as stated in the EU Green Deal and the Horizon Europe Climate-Neutral and Smart Cities mission, towards a more ambitious target that aims at the creation of Climate-Neutral Cities. These are cities that optimize the resources, enhance the citizens' participation, increase the satisfaction of living, as well as quality of live and sustainability [3].

However, the major challenge lies in how to assess the level of smart cities and the achievement of the sustainable goals. Many cities implement subjective criteria to evaluate themselves; hence, objective methodologies and indicators are necessary, with certain level of uniformity [4], so as to be able to determine the strengths and weaknesses of the municipality. These methodologies and indicators should be driven by real data, but cities fail in the definition of proper strategies to collect real data [5, 6]. On the one hand, they lack of expertise in the application of technologies like IoT [5], being usually supported by external parties. On the other hand, cities are split into verticals (e.g. energy or mobility), without relationships between councillorships [6].

Cities are currently working on new urban transformation or regeneration models to transform current practices towards a Smart City [4]. These require the dependency between various perspectives of the city, e.g. impacts on the energy demand due to the electrification of the mobility. Then, Smart Cities of the future are a combination of multiple pillars such as energy, mobility, nature, economy or water management, among others, but always with the citizens at the core. All of these are supported by the integration of the Information and Communication Technologies (ICT) [7].

Within this perspective, mySMARTLife project [8] aims at the transformation of the cities of Nantes, Hamburg and Helsinki into more environmentally friendly, as well as more liveable cities, by reducing greenhouse gas emissions, supported by the digital-

isation process. More than 150 actions have been implemented across the three cities following the concept of "inclusive cities", where citizens play a key role through the Smart People concept. Furthermore, Smart Economy is the driver for the urban transformation, attracting talent and providing goods and offering services accompanied by innovative business models to satisfy the requirements and creates a solid business case. The final impacts of these actions need to be calculated to extract conclusions. Under this objective, mySMARTLife has defined a holistic evaluation procedure [9], where Key Performance Indicators (KPIs) are set to facilitate the impact assessment. The mySMARTLife framework merges multiple pillars (energy, mobility, social, economy, ICT and governance) of the city to provide a holistic analysis of the Smart City.

The implementation and deployment of this procedure relies on data, which is presented as one of the main challenges [5]. To overcome it, this paper presents a methodology that has been applied in Nantes, Hamburg and Helsinki to define robust and feasible monitoring programmes with the aim of collecting real data that support the calculation of the KPIs. It should be noted that the paper is focused on the digitalisation of the cities under the pillars of energy and mobility, whose assessment is based on real data, leaving out of the scope the analysis of qualitative data for other verticals. This is an iterative process for the implementation of Smart City strategic plans, which can be adapted in each step to support better informed evaluation and, thus, decision-making processes. As results, this paper extracts examples and lessons learnt of the cities of Nantes and Helsinki.

The rest of the paper is organised as follows. Section 2 provides a background of current practices. Section 3 presents the methodology that has been proposed within mySMARTLife to approach the urban plans and data-driven evaluation. Finally, section 4 shows the examples for Nantes and Helsinki. Section 5 extracts the conclusions and lessons learnt of the proposed methodology.

2. Background and current practices in Smart Cities

As it was introduced before, the Smart City concept merges multiple pillars, such as energy and environment, sustainable mobility, smart people, smart economy and transparent government, among others. All of them are supported and enabled by the implementation of ICT solutions for digitalisation and data management. However, there is no consensus about standard procedures for assessing the achievement of the city goals within these pillars [4]. For instance, the authors in [10] studied 16 evaluation frameworks, including more than 950 indicators, concluding the lack of sustainability assessment. Also, the ranking of indicators is highly conditioned by the data availability [4], which complicates the application of data-driven approaches for Smart Cities evaluation.

Open initiatives, like the one presented in [11], offer new frameworks under which impact and sustainable evaluation can be carried out. The result of [11] is mainly theoretical, but fosters the open data accessibility to calculate indicators. Nevertheless, the reality of a city is different. The challenge is not the exposition of data, but the collection from field, requiring the definition of robust monitoring programmes to be able to ingest data before being openly shared. This is of special importance when private companies are involved.

Apart from data availability, it should be considered the heterogeneity of cities and its complexity in the governance aspects, being one of the causes the involvement of different actors (i.e. the councillors of the municipality, urban planners, citizens, private companies, investors ...). The convergence is pursued by the methodology that is presented in [12]. Within this analysis, building and district renovation, urban mobility, ICTs and non-technical actions are considered under the umbrella of a data collection approach. The authors in [13] presented a survey, which includes Smart Nature, Smart Living, Smart Mobility, Smart Governance, Smart People and Smart Economy, without a clear data gathering approach to evaluate the aforementioned verticals, similar to the case in [11].

The examples of current initiatives for city impacts assessment converge in the need for KPI-driven evaluation framework. However, no one considers the mature level of the city in terms of digitalization or, in other words, data to calculate the indicators. While some cities are highly digitalised, with a wide deployment of sensors across the city, others that are still using analogue data. This paper then presents a methodology to support cities in the digital transformation to overcome the barriers between data collection and KPI calculation. As far as it is known by the authors, there are not researches regarding this line of work. Literature is focused on the analysis of evaluation frameworks, such as [10], without caring about the procedure to assure real data to apply them.

3. mySMARTLife methodology: Translating KPIs into monitoring

This section provides an overview of the methodology that has been applied within mySMARTLife project, which is depicted in Figure 1. It consists of four stages, described below, which are cyclical and iterative. Cities need to be continuously transforming and adapting to changes; therefore, this methodology allows dynamic and continuous evaluation. The starting point of the approach is the availability of any assessment framework with well-established KPIs, which will be the reference for the city. In this case, mySMARTLife counts on its own framework [9]. The

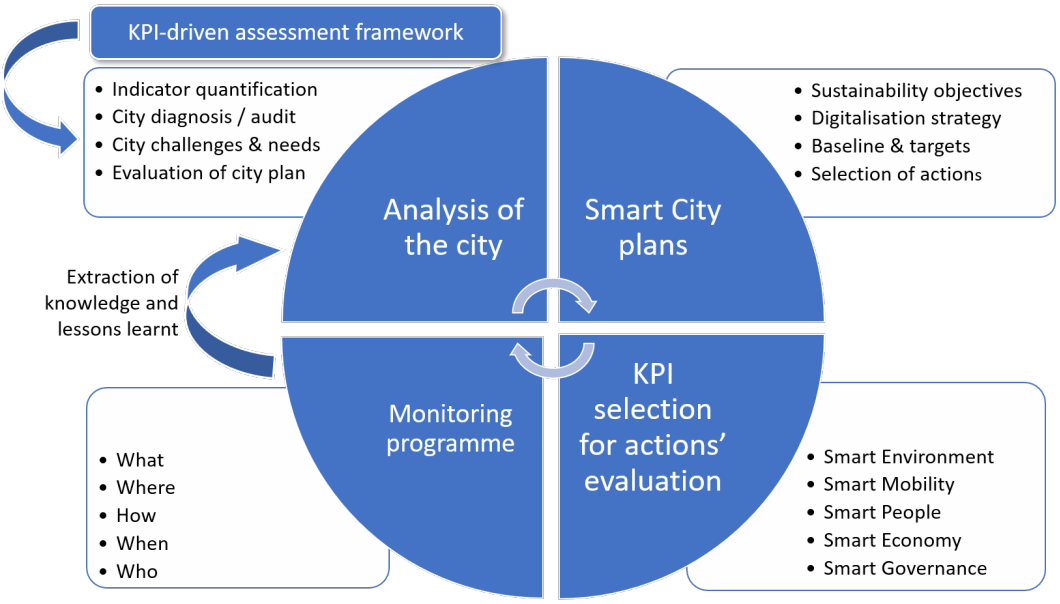

FIGURE 1. Roadmap for a data-driven sustainable environment evaluation.

four stages of the proposed methodology are explained in the next bullets:

(1.) Analysis of the city. Being a cyclic and iterative methodology, this phase represents at the same time the initial and final stage of each one of the iterations. It aims at quantitatively determining the city challenges (i.e. by using the KPIs from the evaluation framework). The outcome of this stage is to obtain the city audit. In the first iteration, this analysis is made at macro level (i.e. city as a whole), meanwhile, in the rest of iterations it is micro level, i.e. evaluating the actions that have been implemented in the Smart City plans. This quantitative analysis, at the end of the iteration, allows planning the next steps by extracting the lessons learnt and knowledge from real data.

(2.) Smart City plans. From the previous analysis of the city, where the challenges and needs are gathered, the actions and interventions for the sustainable transformation are determined in this stage. These actions and interventions contain clear objectives and targets to be achieved, e.g. reducing of energy demand in 30 %. The selection of the most suitable actions is based on benchmarking through estimated values from the indicators, such as the case of the Morgenstadt Initiative [14]. It is normal that the estimations were performed with simulation tools, which make some assumptions that are not representing the real situation. Within the methodology being described in this paper, real data support the estimation thanks to the digitalisation strategy and ICTs. The main advantage or benefit is the capability of selecting actions under quantitative evidences, instead of experiences, which are usually biased by subjective perceptions.

(3.) KPI selection for actions' evaluation. Within this stage, the most suitable KPIs from the framework [9] are extracted according to the objectives of the actions. The framework [9] considers five axes: Smart Environment (that covers energy and greenhouse emissions), Smart Mobility, Smart People, Smart Economy and Smart Governance, as well as ICTs in the form of urban platforms for the digitalisation of the city. More than 150 indicators are available.

(4.) Monitoring stage. This is the main challenge of the cities. Current decisions are based on simulation tools that make some assumptions, introducing errors. Data are crucial to calibrate the models or make data-driven decision-making. This phase establishes the requirements about what to measure according to the KPIs and where to measure (location of sensors), as well as how (e.g. IoT pollution sensors or heat meters), when (frequency) and who (responsible). Many of the studies do not include this crucial stage, which is in charge of the data collection for assuring data-driven strategic plans for sustainable transformation.

This methodology is complemented with the urban data platforms, with the goal of storing data in a persistent way that is defined by the monitoring programmes [15]. The urban data platform makes data available for a later analysis and data-driven decision making. The monitoring programmes are a theoretical definition of the datasets and data-points that are required from the KPIs perspective, but its deployment is not covered by the proposed methodology. In this case, the cities, together with their local innovation ecosystems and through the deployment of sensors and the integration of the related datasets

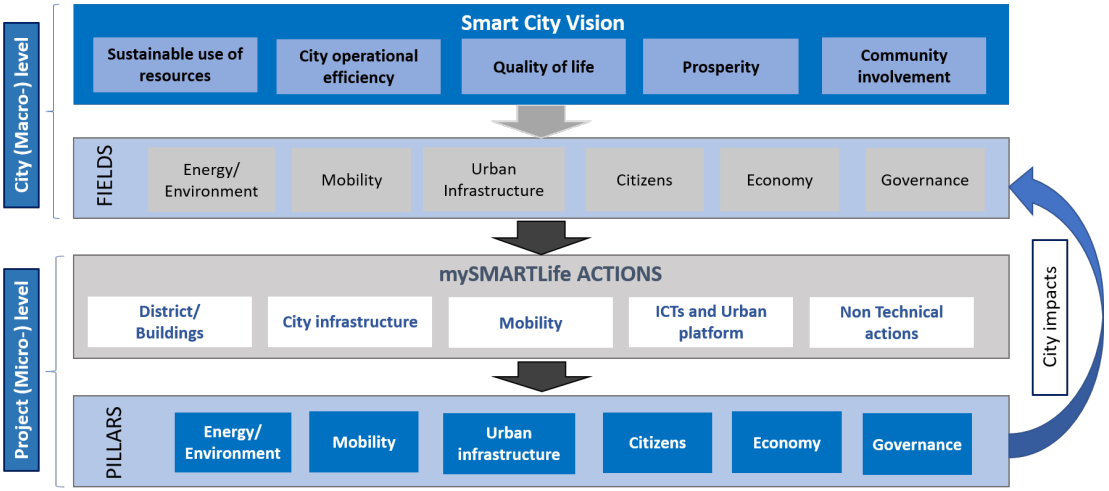

Figure 2. KPI-driven assessment framework.

	Smart Environment	Smart Mobility	Smart People	Smart Economy	Smart Governance
City (Macro-) level	56	22	16	16	15
Project (Micro-) level	32	51	5	22	7

Table 1. Total number of KPIs defined for each of the pillars.

in the data platforms, are the responsible for managing the physical interventions. The main advantage of using the urban data platforms is the availability of data in open formats for further treatment and KPI calculation. The automation of the calculation algorithms and decision-making dashboards is out of scope of this paper, although it is recommended for the analysis [15].

By following the proposed methodology, one of the main benefits is to keep aligned the objectives and challenges of the city, which are driven by quantitative evidences coming from data. Data collection and knowledge extraction support the analysis of the actions impact and lessons learnt to enhance sustainable development based on better-informed decision-making. Data are the complement for the simulation tools in order to calibrate them and extract real performance metrics. In this way, the assumptions taken when creating the simulation models and uncertainties are demonstrated or solved. All in all, this methodology presents a holistic approach for the cities to continuously improve the sustainable transition. on one hand, by updating for each cycle the indicators of sustainable development; on the other hand, by aligning objectives, KPIs and real data.

3.1. KPI-driven assessment framework

The methodology relies on the existing KPI-based evaluation framework. This section summarises the evaluation framework under which the methodology is supported. The concept is represented in Figure 2 [9]. As it can be observed, there are two levels: city (providing the Smart City vision) and project (the mySMARTLife actions). The city level extrapolates the results of the actions to the whole city to determine the benefits under the assumption of implementing these interventions across the city. Both levels cover the same six categories (named fields in the city level and pillars in the project level).

Although the aim of this paper is not the definition of the KPIs, which are available on [9], Table 1 summarises the KPIs account for each pillar, excluding the digitalisation metrics. All are included within the overall framework of the, but only the selected KPIs (as per step 3) will be evaluated in the iterative analysis of the city, being chosen considering the strategic plan objectives and actions.

3.2. Mapping KPIs into monitoring requirements

The key for the success of the application of this data-driven procedure is the capability for collecting real data from the different city resources. Some cities fail in the collection of data so as to achieve a specific objective and they just acquire data [16] that is not exploited. Then, a comprehensive and robust data collection approach needs to be applied. For that end, a common template has been provided to support cities in the mapping of the objectives, KPIs and monitoring requirements. This template is focused on energy and mobility, which require the deployment of physical devices, while social, economic, governance and ICT (digitalisation) aspects do not require such monitoring schemas, although definition of data collection methods like surveys and questionnaires are also used.

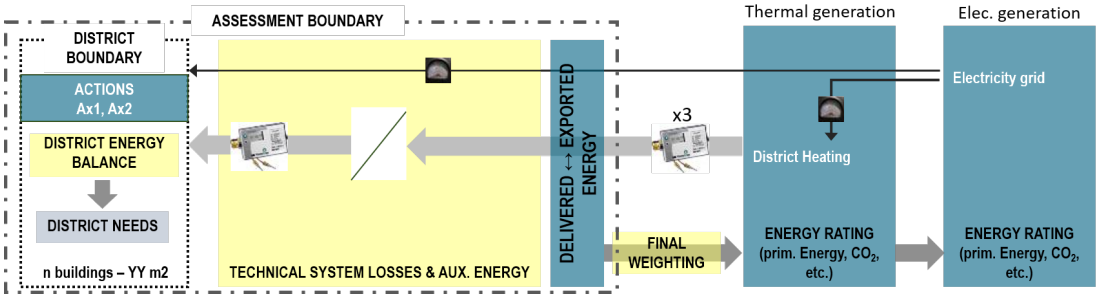

FIGURE 3. Monitoring template schema for energy monitoring in cities.

Figure 3 [17] represents the schematic view for the energy monitoring. On right side, it shows the thermal and electrical generation systems that could be the grid, renewables, district heating or any other supplying energy. In the middle of the schema, there is the assessment boundary, where the interventions apply, which is pivotal to determine the area of intervention [9]. In the example, the boundary covers both the buildings (e.g. retrofitting) and energy distributions elements (e.g. heat exchangers). This virtual boundary is like a geographical or physical one that splits the systems/interventions to be analysed (those that are part of the Smart City plan for sustainability) from the existing elements (e.g. the electricity grid). This boundary is flexible and can be completely adapted to the strategic plan of the city. Finally, on the left side, it is shown the demand side, e.g. the buildings that are retrofitted or new construction, which are the final "users" of the energy.

Also, the monitoring template allows cities to identify the energy flows and the connection between elements. While a grey arrow points the thermal energy flows, a black arrow identifies the electricity flows. In this way, the elements of the physical connections are easily identified and where to measure by placing directly in the schema the icon representing the measurement sensor (e.g. wattmeter). Each of these sensors represents one measurable parameter of the KPIs.

It should be noted that this schematic definition is flexible enough to be adapted to the needs of various cities. It aims at following the same concept of boundaries, energy flows and so on. Nantes and Helsinki have already adapted this concept to their specific contexts. Moreover, it should be remarked that zoom-in is possible to specific interventions, such as district heating details.

4. Examples of application in the cities

This section aims to show direct examples of the application of this methodology to define monitoring schemas in Nantes and Helsinki lighthouse cities within the framework of mySMARTLife project.

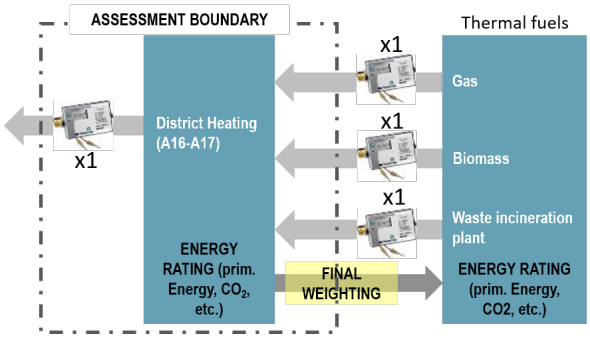

FIGURE 4. Monitoring programme for district heating in Nantes.

4.1. Nantes case

Nantes is a city committed with the sustainable transformation for climate change adaptation. For that end, Sustainable Energy Action Plan (SEAP) and Sustainable Urban Mobility Plans (SUMP) were developed as initial strategic plans based on macro-indicators. These plans have driven the calculation of the city audits and baseline to establish the targets of the actions defined in mySMARTLife [18]. The main interventions defined in the Smart City plans are the renovation of the building stock, renewable district heating, electro-mobility, citizens' involvement and engagement.

Under this perspective, the evaluation framework defined during the first stage of the project was adapted to these plans by selecting the significative KPIs for the Nantes evaluation. Following these KPIs, the monitoring programme was defined as depicted in Figure 4 [17]. It reflects the flexibility of the template, where a zoom is made to the district heating, which has to assure 80 % of renewable contribution, according to the Smart City plans. In this sense, the contribution for each source is measured, both renewable and non-renewable to obtain the final ratio. With the results, at the end of the project, the fulfilment of the plan will be evaluated (by means of the KPIs) to be reviewed.

4.2. Helsinki case

Helsinki started from initial SEAP and SUMP [19], whose baseline and targets were established based on the selected actions. KPIs adapt the evaluation

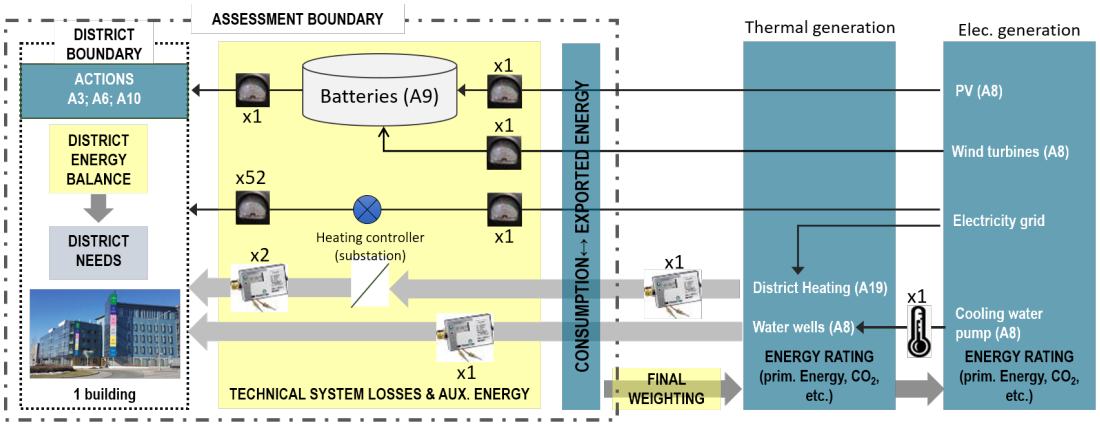

Figure 5. Monitoring example for the Viiki building in Helsinki.

framework to the necessities of these strategic plans. Throughout the process, existing data sources for the KPI calculation were mapped and possible blind spots in terms of monitoring identified and, thus, obtaining the monitoring needs for the impact calculation. By applying this data-driven methodology, the monitoring schema for high-performance office building (equipped with a rather sophisticated energy system consisting of both thermal and electrical grid connections, renewable energy generation and storage) is detailed in Figure 5 [17]. The template is able to encase the core needs for monitoring in terms of final calculation of the KPIs.

5. Conclusions and lessons learnt

In this paper it has been described a methodology to support cities in the digitalisation process to deploy impact assessment frameworks when evaluating sustainable plans for climate change adaptation. The methodology provides guidance in the data collection strategies to supply quantitative evidences in the decision-making processes, while qualitative analysis is out of the scope of this paper. The presented mySMARTLife methodology benefits cities in the capabilities to deploy monitoring programmes focused on well-established KPIs and evaluation frameworks. The iterative nature of the methodology grants an adaptative capacity in the Smart City strategic plans for sustainable transition.

The methodology has been deployed in the cities of Nantes, Hamburg and Helsinki, although this paper presented the cases of Nantes and Helsinki. The main lesson learnt or conclusion, extracted from the cities, is the support provided by a visual tool to determine the monitoring programmes. These help to calculate audits and baselines and apply better-informed decision-making processes. In contrast, another lesson learnt is the complexity in the management of the completion of the schemas because they require the interaction among municipality stakeholders, which is not always easy.

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