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Lessons from Using Indicators to Evaluate a Municipal Climate Action Plan

A Case Study of the City of Gothenburg

Master's Thesis in Industrial Ecology

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Abstract

This thesis aimed to investigate the monitoring and evaluation processes of the City of Gothenburg's ECP, with a particular focus on indicators. Monitoring and evaluation are processes that often fall short, with common challenges being the selection of appropriate indicators or a lack of structures to support their use.
The employed methodologies included a literature review, interviews with employees at the Environmental Administration and a thematic analysis, and an evaluation of the indicators, the indicator system and the data through the use of two frameworks and select data quality criteria.
The first main finding concerns the indicators' limited identification of distributional effects across space and groups. Second, no unified framework for indicator development was identified, and it instead relies on a few guiding principles, for example quantitative measurability and the possibility to follow up indicators over time. The third finding are the challenges and opportunities of indicator use and data structures in the evaluation process of the ECP, as a result of operating as a large organization. Lastly, public participation could be utilized in future iterations of the ECP to ensure that the indicators align with public concerns and values. To tackle these issues, recommendations include the adoption of a formalized framework grounded in the guiding principles, developing a shared data system for better management and collection of data, and increasing public participation by engaging in citizen dialogue.

Keywords: sustainability indicators, climate action plan, municipal sustainability, urban sustainability, sustainability assessment, indicator framework

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Carl Kieksi and Johan Svensson, Gothenburg, June 2025

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis, listed in alphabetical order:

BAF	Biotope Area Factor
CAP	Climate Action Plan
DPSIR	Drivers, Pressures, State, Impact and Response
DQ	Data Quality
ECP	Environmental and Climate Program
FCSM	Federal Committee on Statistical Methodology
IPCC	International Panel on Climate Change
SI	Sustainability Indicator
UN	United Nations

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1
Introduction

Addressing climate change is one of the most urgent challenges of our time, and while the problem is global, the actions required to mitigate it often occur at the local level (Bulkeley, 2013). Urban areas, in particular, are central to this effort, as they are both significant contributors to climate change and centers for innovation and mitigation strategies (Mi et al., 2019; Rosenzweig et al., 2010).

In Sweden, municipalities are responsible for climate and environmental action at the local level. With strong autonomy, they play a central role in formulating and implementing measures to reduce greenhouse gas emissions and promote sustainable development. To guide this work, many municipalities have adopted Climate Action Plans (CAPs), which are strategic frameworks that set out climate goals and the actions or strategies needed to achieve them. (Rosvall et al., 2023)

A central component of CAPs is monitoring and evaluation, typically supported by indicators. These indicators are used to track progress toward goals, identify areas of improvement, and ensure accountability. However, research has shown that despite the widespread adoption of CAPs, their implementation often falls short, especially in relation to monitoring and evaluation (Guyadeen et al., 2019). Challenges include both the selection of appropriate indicators and the practical structures required for using them effectively (Klopp and Petretta, 2017). Poor availability of consistent data and the absence of clear organizational structures for data collection have been identified as contributing factors to these difficulties.

In recent years, several frameworks have been proposed for developing indicators, many of which outline theoretical best practices (Soulé et al., 2021). Yet, these frameworks often fail to address the complex realities of local governance, where contextual constraints, and organizational dynamics can hinder implementation (Michalina et al., 2021). To address these issues, there is a need for more detailed insight into how municipalities work with indicators in practice: how they are selected, what challenges emerge in their application, and how the evaluation processes are structured and maintained.

Through a case study of the Environmental and Climate Program (ECP) in the City of Gothenburg, this thesis will contribute to a further understanding of the challenges with using indicators to monitor and evaluate a municipal CAP (Göteborgs Stad, 2021). With an upcoming revision of the ECP, the city has an opportunity to reflect on how the indicators are currently used and how they can be improved for future evaluations.

1.1 Research Aim

This thesis aims to investigate the monitoring and evaluation processes of the City of Gothenburg's ECP, with a particular focus on indicators. Knowledge and insights regarding these processes will be gathered through a case study on their practical implementation. More specifically, the focus will be on evaluating how effectively the indicators measure progress towards environmental goals and how they can be improved. To ensure that this aim is being met, a number of objectives have been formulated as follows:

- To monitor the evaluation process of the ECP.
- To understand what data is needed for the City of Gothenburg in order to evaluate their progress.
- To investigate if the indicators is of sufficient quality for their purpose.
- To understand the organizational structure, the responsibilities, and the actions that are being taken by involved actors in the evaluation process.

1.2 Research Questions

To further specify the issue that is being investigated and to support the overall aim of the thesis, three research questions have been formulated. These questions serve as a framework to guide the research process and structure the analysis:

1. How does the City of Gothenburg work with evaluating progress towards the indicator targets outlined in their ECP?
2. In what way does indicator and data quality affect the evaluation of progress towards the environmental goals in the ECP?
3. What barriers and opportunities can be identified in the monitoring and evaluation of the ECP?

1.3 Research Scope

The scope of this thesis is subject to several delimitations. First, the study focuses specifically on the City of Gothenburg and its ECP, meaning that the results are closely tied to this context and the conclusions may not be directly transferable to other CAPs or municipalities. Second, only a subset of the environmental goals, and thus the indicators, in the ECP were considered. This delimitation means that the findings do not capture the full range of environmental efforts under the ECP, and some barriers and opportunities related to goals outside the selected subset may therefore be overlooked. Lastly, the thesis does not include an analysis of the goal or sub-goals themselves, but is limited to examining the indicators and their connection to the goals.

1.4 Outline of the Thesis

The structure of the thesis is as follows: Chapter 2 presents the conceptual background and reviews relevant literature on sustainable development, CAPs, indicators, and evaluation frameworks. Chapter 3 introduces the case study of Gothenburg's ECP. Chapter 4 outlines the methodological approach, including data internal documents and collection through interviews, as well as an explanation of how the chosen frameworks have been applied. Chapter 5 presents the results of the empirical investigation. Chapter 6 discusses these findings in relation to the literature, and includes reflections on directions for future research. Finally, Chapter 7 concludes with a summary of the main findings.

2

Literature review

This section will go deeper into the relevant background, highlighting relevant research. The highlighted research topics are *sustainable development*, *climate action plans*, *indicators* and *data quality assurance*.

2.1 Sustainable Development

In 1987, the World Commission on Environment and Development introduced what remains the most widely recognized definition of sustainable development: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). This definition is built on three interconnected dimensions: economic, social, and environmental (see figure 2.1).

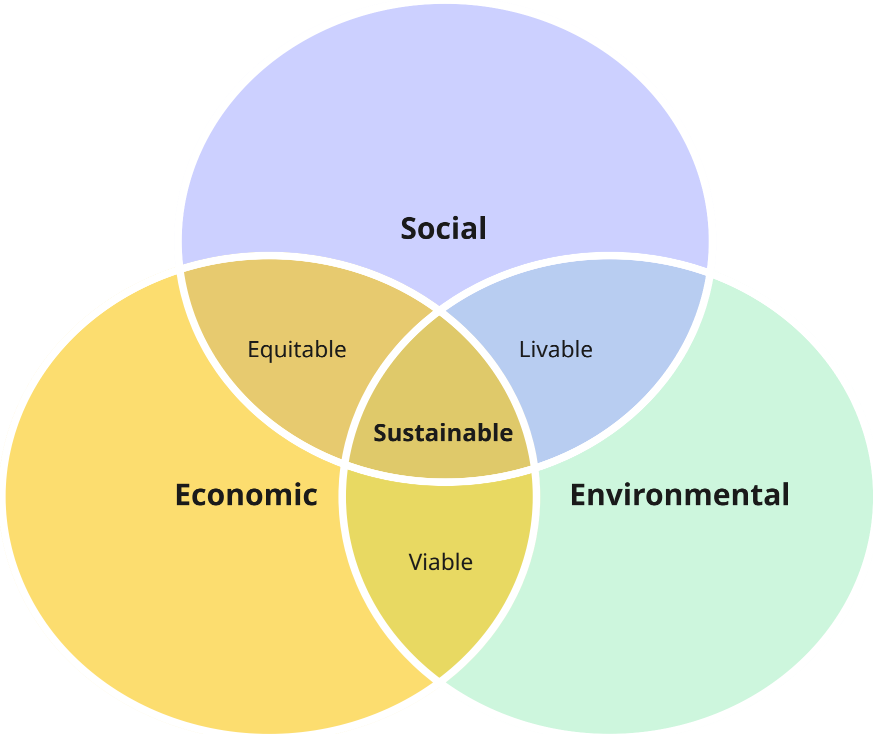

Figure 2.1: The dimensions of sustainable development, adapted from Tanguay et al. (2010).

While each dimension within sustainable development is important in its own respect, it is also essential to account for their interdependent relationships (Cohen, 2017). While there is no universally adopted definition of livability, a common theme is the interaction between humans and their surrounding environment (Bedi et al., 2022). Viability refers to the ability of economic stability to be maintained within the confines of the available environmental resources (Reddy and Thomson, 2014). Equity emphasizes that resources, opportunities, and benefits are fairly distributed between all groups within society (Leach et al., 2018).

Local governments play a central role in sustainable development efforts, particularly through their capacity to address climate change at the urban level (Balaban, 2012). As a result, the institutional dimension has also been recognized in recent years (Michalina et al., 2021). This dimension is specifically relevant for urban sustainable development, as it captures the institutional forces required to deal with complex issues. It includes four categories: environmental management, governance, participation and urban planning. Since every municipality operates within an unique context, Jones (2010) states that sustainable development efforts must be tailored accordingly. According to Cunningham et al. (2010); Mapar et al. (2017) environmental issues have generally received more attention than social issues, resulting in an imbalance that extends to urban and municipal settings. Consequently, the social impacts, including those relating to health and safety issues, induced by climate change, are comparatively underdeveloped.

2.2 Climate Action Plans

CAPs are strategic frameworks that outline policies and programs aimed at reducing a municipality's climate impact or enhancing its resilience to climate change by implementing climate adaptation strategies. They can serve as high-level strategic visions that outline future policy directions and coordination efforts, or be more action-oriented and provide policies, programs and implementation strategies to achieve measurable climate goals. Common focus areas in CAPs include for example greenhouse gas emissions, water conservation, air quality improvement, and ecological processes. In order to successfully implement a CAP, it is necessary that it reflects local conditions. This includes identifying major emission sources, considering geographic and climatic factors, aligning with existing policies, and taking into account local values and traditions. (Boswell et al., 2012)

The focus of CAPs can lie on mitigation, adaptation, or a combination of both (Koski and Siulagi, 2016). Mitigation focuses on addressing the causes of climate change, by for example geoengineering, biofuel expansion, or carbon taxes (IPCC, 2014). Adaptation measures instead focus on responding to changes in actual or expected changes to the climate, with the aim of reducing vulnerabilities to human or ecological systems (Rezvani et al., 2023). Measures include, for example, physical infrastructure like sea walls or flood barriers, ecosystem restoration efforts such as reforestation, and water management strategies like rainwater harvesting. There are opportunities for synergistic effects if mitigation and adaptation measures are implemented simultaneously (Moser, 2012). An example is reforestation, where mitigation is achieved through carbon storage and adaptation through habitat and species protection, flood control and soil preservation. However, there are also potential negative consequences of pursuing both at the same time. Examples of this are for instance the adaptation measures of desalinization and increased use of air conditioning, which increases energy consumption. Depending on the carbon content of the fuel, this might lead to increased greenhouse gas emissions, counteracting mitigation efforts. Adaptation measures are often local and short-term, while mitigation measures are broader in their geographical scale and long term (figure 2.2). The overlap between measures of mitigation and adaptation is restricted, which limits the number of tradeoffs.

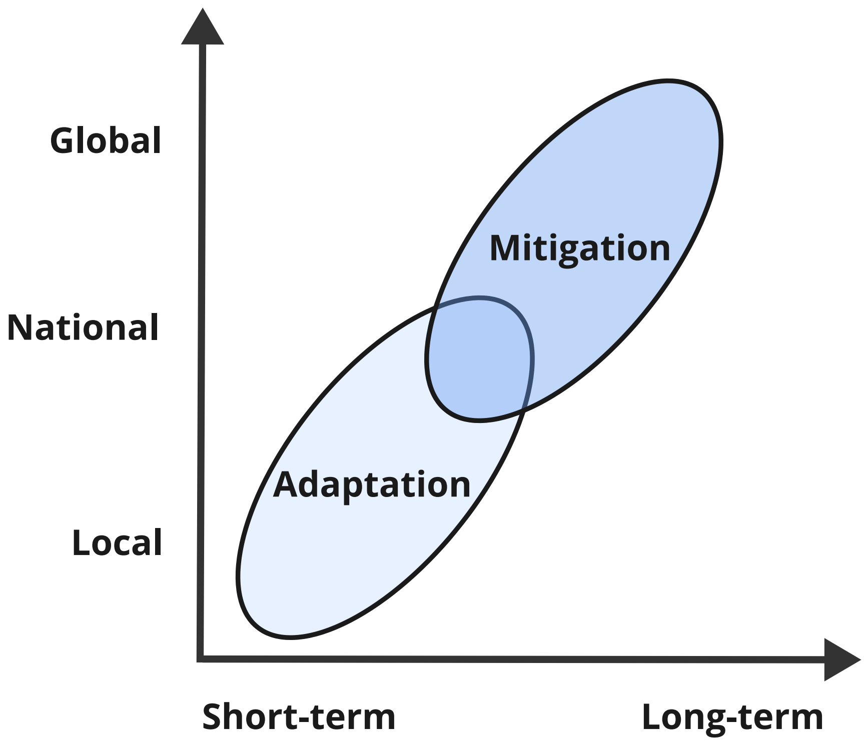

Figure 2.2: The overlap of adaptation and mitigation measures, where the overlapping area represents the set of potential tradeoffs. Adapted from Moser (2012).

The process of implementing a CAP can generally be split into three phases: understanding, planning, and managing. Each phase involves specific subprocesses. In the *understanding* phase, these subprocesses involve problem detection, information gathering and problem definition. The *planning* phase involves option development, option assessment and option selection and the *managing* phase involves option implementation, monitoring, and evaluation. In figure 2.3 a schematic of the phases and their respective subprocesses is presented. (Ekstrom et al., 2011)

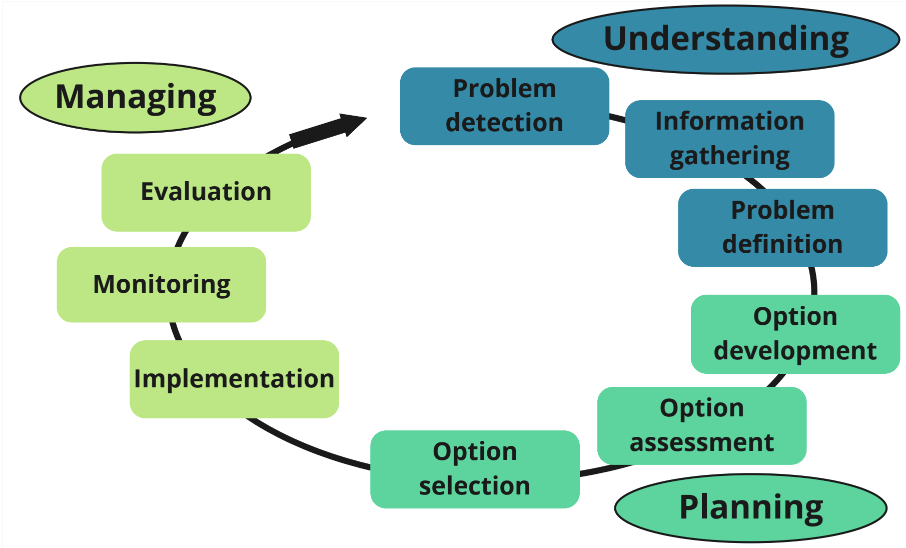

Figure 2.3: CAP implementation process, with phases and their respective sub-processes, adapted from (Ekstrom et al., 2011).

While this schematic might be useful in the sense that it provides a linear and simplistic way of understanding the CAP implementation process, it misses out on feedback loops between the phases, something that is acknowledged by the Intergovernmental Panel on Climate Change (IPCC) through their iterative risk management framework. They also acknowledge that people and knowledge shape the process and its outcomes, see figure 2.4. This framework allows for decision making in complex situations characterized by large potential impacts, uncertainties and trade-offs. Both internal and external factors can be identified within this process. Within the understanding phase, the emphasis is placed on identifying risks, vulnerabilities and objectives in order to establish the decision making criteria. The planning phase is focused on identifying options, assessing risks and evaluating the tradeoffs. The managing phase is comprised of the implementation of the decisions, monitoring as well as reviewing and learning. The internal iterations are found within the planning and managing phases whereas the external factors are present throughout the entire process. This reflexivity allows for the identification of new knowledge, risks, or conditions to alter the process. The iterations can be scheduled, initiated when specific criteria are met or when new information comes to light. (IPCC, 2014) In their critique of CAPs, Hamin and Gurran (2015) recognizes the inherently uncertain nature of climate change and the impact this might have on the effectiveness of overall climate planning. To overcome this problem, they also suggest that cities should include elements of flexibility in their planning processes, allowing for adjustment when new information comes to light or when there are shifting conditions.

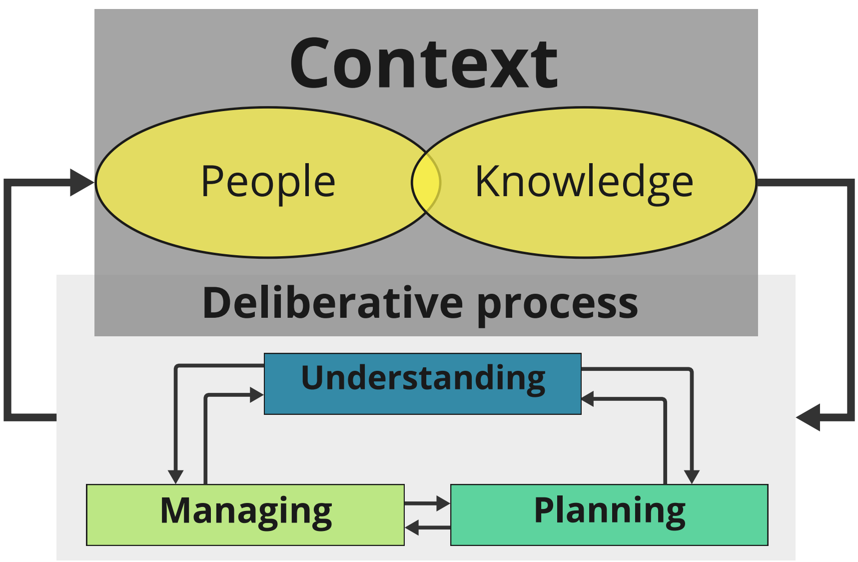

Figure 2.4: Interpretation of IPCCs design of the CAP process, including feedback loops between the phases and the context that helps shape its outcome (IPCC, 2014).

Aboagye and Sharifi (2024) proposed a framework to assess the suitability of CAPs, which they used to assess plans in 257 cities from around the world. They found that many of the plans were insufficient in their implementation and monitoring, but that plans developed in recent years (2018-2022) generally were more suitable. For a CAP to be effective, Meerow and Woodruff (2019) outlines several principles that should guide its development. First, the plan should establish a clear purpose with ambitious yet attainable goal, supported by measurable objectives. It is essential to use the best available data to evaluate current conditions and inform decision making. Public participation is also crucial, not only to enhance transparency, but also to address social inequities and actively engage marginalized communities through participatory methods. Given the complexity of urban governance, involving a wide range of stakeholders and aligning the CAP with existing municipal plans helps ensure coherence and broad support. A well-defined implementation and monitoring framework should be in place, including a timeline, secure funding, and clearly assigned responsibilities. Finally, they also state that the plan must account for uncertainties, which can be addressed through tools such as scenario analysis or adaptive management strategies.

In the guidebook "How to develop a Sustainable Energy and Climate Action Plan (SECAP)", JRC (2018) outline key elements when developing a CAP. Among these steps is the formal adoption of the CAP by the municipal council, to ensure strong political support. The CAP should also include comprehensible mitigation and/or adaptation goal(s) and an assessment of the local situation should be conducted in order to establish baseline values. This assessment should include energy and greenhouse gas emissions, climate hazards, vulnerabilities and the policy sectors that are impacted. Estimates based on national or regional averages are deemed insufficient as they do not reflect the local situation. They also recognize the importance of consistency in both methodology and data sources, emphasizing the need for documentation of how these processes are carried out. The CAP process necessitates that all departments of the municipality view it as internal, and integrate it into their practices. Stakeholder engagement is also of importance, especially during the planning phase, to ensure that needs and perspectives of the public are reflected. Continuous monitoring through the use of suitable indicators together with revisions of the CAP should be performed to measure progress toward the goal(s). This process also allows for correctional measures if the progress is unsatisfactory. They also state that monitoring should involve clearly identifying the data and indicators required to track the progress. It is essential to define the methods of data collection, including the frequency of collection, and specify who will be responsible for gathering and compiling the data. To enhance implementation efficiency, actions can be divided into steps, with each step having its own timeline, budget and designated person in charge. Lack of skills in the field of data management is also recognized as a major barrier.

Several barriers exist for the successful execution of a CAP. For the planning and managing phases, some of these barriers are related to data. The planning phase is hindered by the availability of data to assess options and the overall accessibility or usability of data. If the required data can not be produced, other indicators have to be investigated. The managing phase, and the monitoring subprocess in particular, might be hampered by the ability to retrieve, store, organize, and analyze data. These steps, besides the software and hardware, also require expertise and organizational structure. A set frequency for how often the data should be assessed to evaluate progress is also important. For the subprocess of evaluation the availability of data and evaluation methodology can be significant barriers. If the required data is not available, which often is the case due to insufficient monitoring, information may have to be constructed, which limits the quality of the evaluation. (Ekstrom et al., 2011)

2.3 Indicators

According to Gabrielsen and Bosch (2003) indicators can be defined as observed values representing a phenomenon that is being studied, and their aim is to reveal complex phenomena by simplifying information. The authors also state that the main function of indicators is communication of information regarding the issue they address. Data forms the foundation of indicators, and an indicator can be differentiated from raw data or a variable when it serves an evaluative purpose (Tanguay et al., 2010). Individual indicators can be aggregated into indices,through weighting and normalization, or organized into indicator sets, which group multiple indicators without aggregation and are often developed using a specific framework (Huang et al., 2015). Such sets can be more easily understood, communicated, and interpreted, making them more effective in informing policy decisions than standalone indicators (Sparks et al., 2011).

According to Gabrielsen and Bosch (2003), environmental indicators fulfill four primary functions from a policymaking perspective:

1. Supplying information on environmental problems, to enable the evaluation of their seriousness by policy-makers
2. Identifying key factors pressuring the environment, to support prioritization of issues as well as policy development
3. Monitoring effects and effectiveness of implemented policies
4. Raising public awareness on environmental issues and strengthening the public's support for policies by providing information on the driving forces and impacts of said issues.

Several frameworks have been developed to guide either the development or evaluation of sustainability indicators (SIs), although none are universally applicable (Turcu, 2013). Among the most widely used is the Drivers-Pressures-State-Impact-Response (DPSIR) scheme, originally developed by the European Environment Agency (Smeets and Weterings, 1999). DPSIR is primarily a developmental framework used to structure environmental indicators by tracing causal relationships between human activities and environmental change. The framework includes five components: drivers (e.g., social or economic changes), pressures (e.g., emissions, land use), state (the current condition of the environment), impacts (effects on ecosystems and human health), and responses (policy measures or actions taken). While DPSIR is helpful in organizing and presenting indicators, it is often underused in the actual selection process (Niemeijer and de Groot, 2008). In practice, indicators are often based on separate and context-based criteria rather than their causal relationships.

The PICABUE framework developed by Mitchell et al. (1995) serves as both a developmental and an evaluative tool for sustainability indicators . It guides the creation of indicators through a structured process and includes an evaluative step to assess their quality and performance. It consists of seven steps, where the last step concerns itself with evaluation of sustainability indicators with respect to what the desired indicator characteristics are and how they align with overarching objectives. In other words its focus lies on assessing the quality and performance of the indicator itself, not just the phenomenon that is being studied. This last step is thus relevant for the thesis as it can help assess the indicators in the ECP. More information about the criteria can be found in chapter 4.3.1.

Many frameworks share overlapping criteria for what constitutes a good indicator. For instance, the Organisation for Economic Co-operation and Development suggests that indicators should be policy-relevant, analytically sound, and measurable, while the SMART framework proposes that indicators should be Specific, Measurable, Achievable, Relevant and Time-bound (OECD, 2003; Menon et al., 2009). The BellagioSTAMP principles, is another framework for the design and use of indicators, with the following criteria: Guiding vision, Essential considerations, Adequate scope, Framework and indicators, Transparency, Effective communications, Broad participation, and Continuity and capacity (Pintér et al., 2018). Criteria from these frameworks often overlap with those found in PICABUE, which also incorporates more specific considerations for spatial sensitivity and effectiveness of communication. Despite differences in terminology and minor variability in focus, the core aim across frameworks remains the same, to ensure that indicators are both robust and useful for decision making.

Indicator frameworks for the local level typically follow one of two approaches: bottom-up or top-down. When establishing the goals and selecting indicators, the top-down approach makes use of experts to identify the relevant local conditions and select appropriate indicators. These indicators are often selected by using a list of evaluation criteria, and the data collection and monitoring is performed by experts. With a bottom-down approach, different stakeholders instead come together to discuss conflicting visions or strategies. Possible indicators are then evaluated with community criteria, and the indicators are used by the communities to measure progress toward the sustainability targets that they have agreed upon. (Reed et al., 2006) Another approach for public participation in indicator development at a municipal level was suggested by Tasser et al. (2008), who argued that collaboration with policy makers and local field experts makes the information contained within the indicators accessible to a wider public, who would then have a vested interest in carrying out the surveys to provide data. An example of when public participation improved indicator relevance and clarity is given in a study by Ólafsdóttir (2020), where it is explained that direct input from local citizens led to substantial revisions of the indicators.

Information regarding sustainability can be organized according to a hierarchical structure, referred to as the indicator pyramid, which ranges from raw data at the base to indices at the top, see figure 2.5. At the base level, data consists of unprocessed statistics or measurements, primarily used by researchers and specialists. These data can be transformed into indicators, and be used by policy-makers or planners. At the top of the pyramid are indices, that offer simplified overviews for communication with the general public. (Huang et al., 2015)

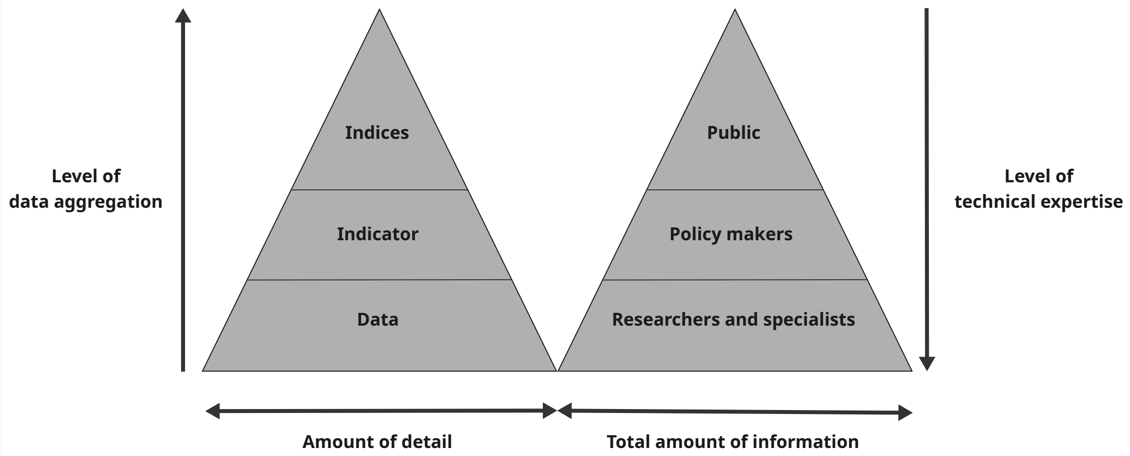

Figure 2.5: Indicator Pyramid.

In recent years, following the adoption of Agenda 2030, SIs have developed to become more locally tuned in their design (Reinar, 2025). Adjusting the SIs to cater to local challenges and needs has been seen as a critical approach for being able to implement the Sustainable Development Goals at the local level, where many of the activities contributing to climate change take place. It has also been shown that SIs can be used to organize local actors in partaking in challenges regarding sustainable development.

Regarding urban SIs, Verma and Raghubanshi (2018) identified a set of internal and external challenges. The internal challenges are related to inherent problems with indicators, for example the choice of methodology used for developing indicators, weighting methods and degree of complexity. External challenges hinder the effective implementation of indicator frameworks. These challenges include data shortages, policy inertia, reluctance to adopt indicators and the absence of standards and mechanisms for comparison. A study by Thomas et al. (2020) of 484 urban SIs found that many failed to measure progress on the 11th sustainable development goal, due to a lack of locally relevant benchmarks, realistic targets and clear evaluation of the distributional effects. Similarly, geographically disaggregated data with high resolution was pointed out as a key consideration in solving these problems (Tanguay et al., 2010).

A conceptual framework for the meta-evaluation of sustainability indicators and indicator systems has been developed by Ramos and Caeiro (2010). Their approach aims to evaluate both the appropriateness of SIs and more generally the activities and results of performance monitoring. The meta-performance evaluation indicators convey three different things. First, they measure the performance of the indicator system by evaluating the activities of the assessment process, which is a distinctive feature of this framework. Second, they show how appropriate the SIs, their methodology, and the outcomes they produce are. Third, they evaluate the measures and actions that are being implemented as a result of the operation and analysis of the indicators.

The meta-evaluation can be seen as a process within an sustainability indicator (SI) system. Its main function is to allow for the revision and modification of the indicators as well as overall system improvement. The performance level is achieved by applying scores to a list of good-practice factors, which are grounded in dependable guidelines for SI development. To prevent the process from becoming overly complex, one can also evaluate the good-practice factors qualitatively. The authors supply a list of key good-practice factors. Information on these factors can be found in table 4.5, in section 4.3.2. (Ramos and Caeiro, 2010)

2.4 Data Quality Assurance

There exists several definitions as to what constitutes the concept of data quality (DQ), which has evolved over time to reflect the progression of the field and the change in the landscape as a whole. Examples of such definitions include:

- *"Fitness for use"* (Wang and Strong, 1996)
- *"Data quality is accomplished when a business uses data that is at a minimum, complete, relevant, and timely. Determination of quality is dynamic, as a certain level of excellence is not universal, not absolute, and not a constant but is assessed to a relative degree. The same applies in the case of data quality."* (Mahanti, 2019)

In 2020, The Federal Committee on Statistical Methodology (FCSM) proposed a unified framework for assessing data quality, which divided the concept of DQ and its evaluation into three distinct dimensions, each housing a number of criteria. The three proposed dimensions are *utility*, *objectivity* and *integrity*. The utility dimension is focused on assessing the extent to which the data can meet the needs of the user and the overall usefulness of the data in the end. The second dimension, objectivity, is focused on whether the data is sufficiently accurate, reliable and unbiased, and whether it is presented in such a way that these criteria are conveyed. The integrity dimension hones in on details on whether the DQ meets scientific standards and whether or not there exists measures to ensure the data and information is protected from manipulation and influence as well as unauthorized access or revision. The dimensions and their corresponding criteria that were proposed in the FCSM framework have been visualized in 2.6. (Dworak-Fisher et al., 2020)

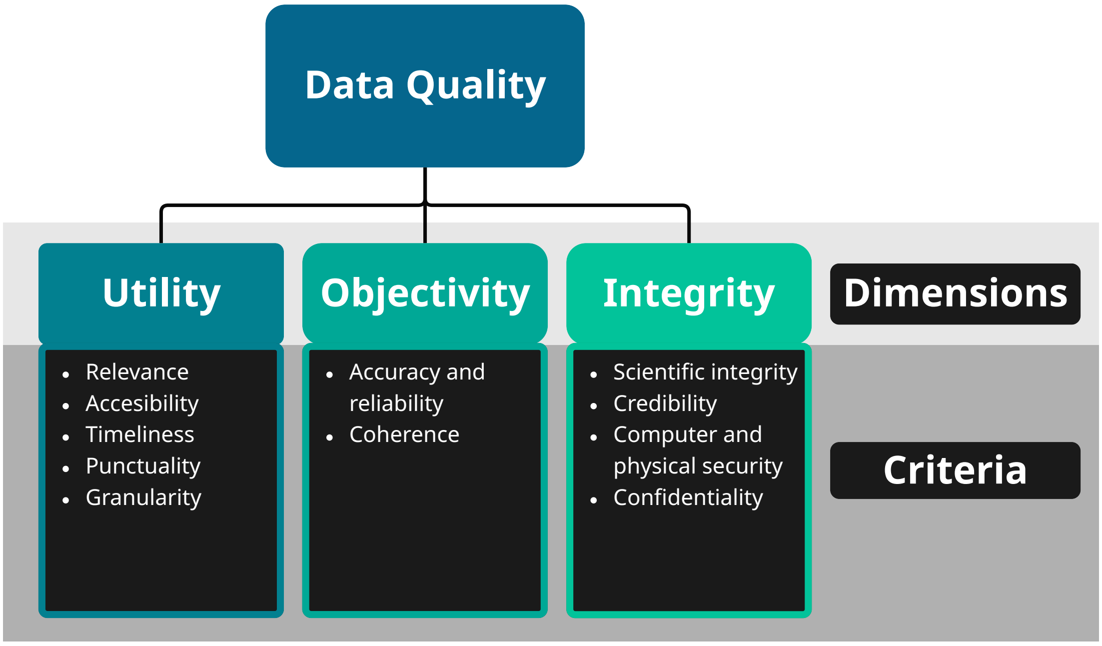

Figure 2.6: FCSM Framework with dimensions and associated criteria. Adapted from Dworak-Fisher et al. (2020).

The United Nations Statistics Division announced in 2017 that a Statistical Quality Assurance Framework were to be adopted across the United Nations' (UN) different agencies. It was developed and introduced with several goals in mind, such as establishing a unified definition of statistical quality across the UN, providing an equivalent framework to the already in use national quality assurance framework along with providing a cohesive understanding of what quality assurance entails and having a common vernacular in place to discuss issues across the UN's different entities. The framework proposed and eventually adopted included three distinct dimensions for quality assurance, which in turn contains a number of criteria. The dimensions outlined in the framework are *output*, *institution* and *process*, which has been visualized in figure 2.7 along with the included criteria. The output dimension deals with criteria relating to assuring that the output of any statistical endeavor is accurate, reliable, relevant, coherent, set within a timely manner along with being accessible and manageable in terms of interpretation. The dimension focused on the process places emphasis on the methodological choices, the systems in place and the associated costs. These two dimensions are quite standard, overlapping with other frameworks (such as the earlier presented FCSM-framework) that aim to improve the quality assurance checks and balances.

However, the final dimension is quite unique and context specific to the operations of the UN entities that use it. The institution dimension deals with challenges such as credibility of data that only comes from its member states, objectivity and impartiality of the statistics when member states try to use their political powers to interfere with agencies fulfilling their mandates. This particular dimension is thus put in place to address very specific challenges that are not universally faced when assuring quality standards. It is important to note that the United Nations Statistics Division decided to make a distinction between data and statistics, where data is considered to be basic elements or singular information pieces, whereas statistics are numerical data that have been put through and organized using mathematical operations. This distinction was made for further clarity, as the two terms are often used inter-changeably, but a statistical quality framework in this case also includes the process and not just the input (data). However, before the final introduction of the framework, it was argued that the concept of data could be considered a more broad scope, with the inclusion of all sources and analytics, ultimately making it a more holistic approach. (Reister et al., 2022)

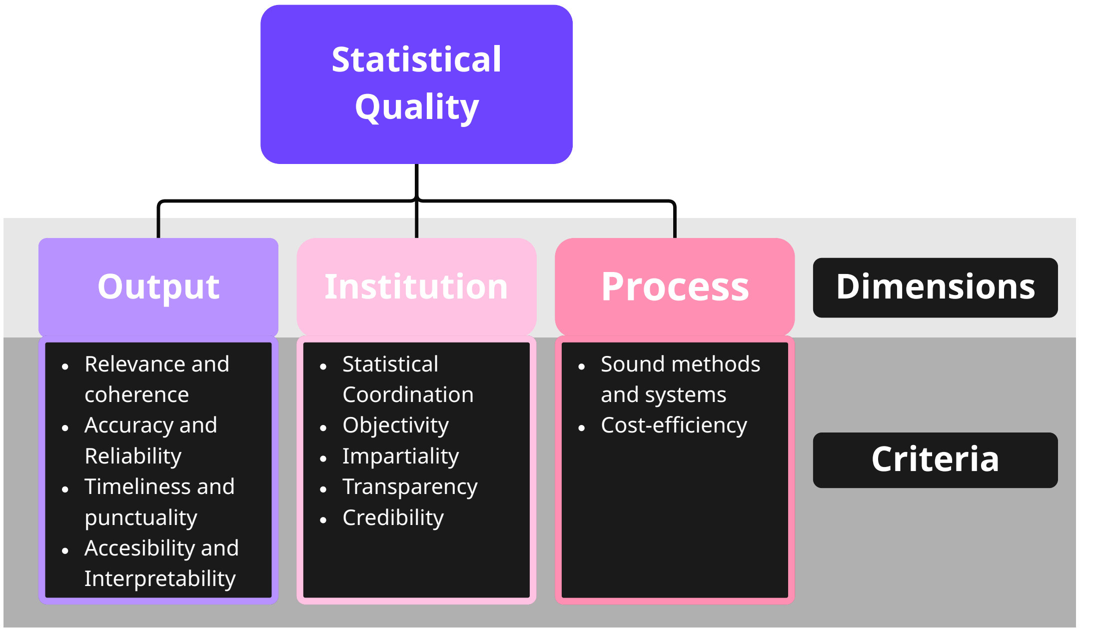

Figure 2.7: Statistical Quality Assurance Framework from the United Nations Statistics Division. Adapted from Reister et al. (2022).

When deciding what approach to take when choosing or developing a DQ-framework, there are several factors which should be taken into consideration. Some of these include the context of the data, the information systems in place and the activity the data will be used for. Cichy and Rass (2019) investigated twelve general purpose DQ-frameworks that applied to the above mentioned factors (although activity was noted as "type of business") as well as looking at frameworks that provided *a definition of relevant data quality attributes*, *data quality assessment steps* and *data quality improvement steps*. When looking at these twelve frameworks and the dimensions of DQ that they contained, it was found that there were three of the dimensions which were mentioned at a more significant frequency. The dimensions, the frequency at which they were part of a framework and their definitions, according to Wang and Strong (1996), can be found in table 2.1.

Although these three were identified as the most frequently used of the dimensions for data quality found in the study, there were 17 additional dimensions that were

Table 2.1: Most common dimensions across frameworks, according to Cichy and Rass (2019).

DQ Dimension	# of Frameworks	Definition
Completeness	10	The extent to which data are of sufficient breadth, depth and scope for the task at hand.
Timeliness	9	The extent to which the age of the data is appropriate for the task at hand.
Accuracy	8	The extent to which data are correct, reliable and certified.

mentioned to have been found in various frameworks are lower frequencies. This highlights that the choice of DQ dimensions which are used in any given framework is highly based on the context of the data which is being analyzed at the time.

In 2020, the Data Management Association in the Netherlands (DAMA NL) published a research paper titled "*Dimensions of Data Quality (DDQ)*" in which the authors compiled and classified 60 different DQ dimensions. The research paper aimed to answer a number of questions in connection to DQ. These questions were:

- What dimensions of data quality can be distinguished?
- What definitions of data quality dimension have been published?
- Which definitions are to be preferred?
- Which set of dimensions are essential?
- How can dimensions be classified?

Although the authors ultimately landed on 60 definitions for DQ dimensions, 127 were considered during the process, meaning that over half were not deemed as essential. As data quality can cover such a wide range of uses and processes, it is not surprising that the final number of dimensions is so high. It is also not surprising, given this information, that there is a lack of universal definitions and agreement on the use of DQ in various information systems.

3

Gothenburg as a Case Study

This chapter introduces the City of Gothenburg as the case study for this thesis. It covers the organizational structure of the municipality, with extra focus on the Environmental Administration, and the ECP.

3.1 The City of Gothenburg's Organizational Structure

The City of Gothenburg is lead by the City Council, which is comprised of elected officials that represent the local elections. The decisions that are made by the City Council is channeled to the City Executive Board, which has the primary responsibility of making sure that these decisions are carried out, reviewed and evaluated. This is done through the City Executive Office, which is the administration that sends out the work that needs to be done out to the plethora administrations that the City of Gothenburg has. Each administration adheres to a committee, which is comprised of political members that reflect the constellation of the City Council members. (Göteborgs Stad, 2016)

The organization of the City of Gothenburg, under the highest decision-making bodies is divided into three distinct categories, the committees (as mentioned earlier) and their corresponding admninistrations, the municipal association and Göteborgs Stadshus AB. In total there are 24 different committees, not counting the City Executive Board. The Municipal association represents coordination and collaboration with 12 other municipalities in the surrounding area, called Greater Gothenburg. Examples of services included under this association is the fire rescue service and interpretation services. Göteborgs Stadshus AB is the parent company of all the companies owned by the City of Gothenburg. As of 2023, there are 90 companies that fall under the umbrella of Göteborgs Stadshus AB, both partially and entirely owned (Göteborgs Stad, 2024b).

3.1.1 The Environmental Administration

Continue

The Environmental Administration is the administration within the city that hosts several different responsibilities in regards to the environment. These responsibilities include services such as monitoring of the housing environment as well as making sure companies and administrations follow regulations related to potentially environmentally hazardous activities. The responsibilities that will be most pertinent to this thesis concerns the strategic work and governance of environmental activities within the City of Gothenburg. This is done both on a daily basis with activities such as monitoring of air- and noise pollution as well as more rigorous evaluations of the state of the environment being performed through ECP. The organizational structure of the Environmental Administration has been visualized in figure 3.1.

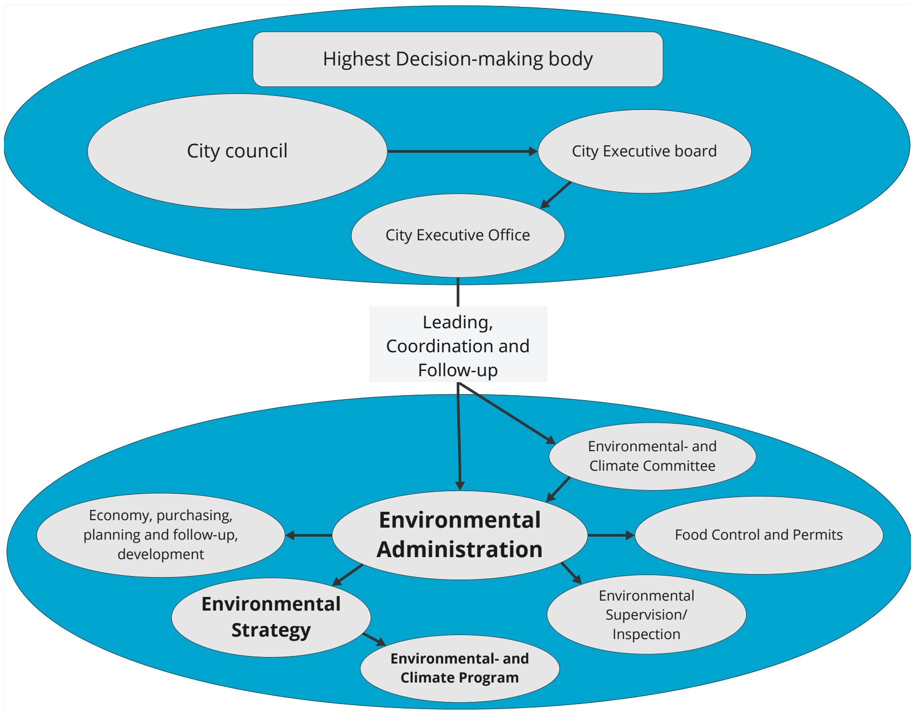

Figure 3.1: The organizational structure of the Environmental Administration

3.2 The Environmental and Climate Program

The ECP outlines the City of Gothenburg's long-term strategic environmental work and is a comprehensive governing document for the ecological dimension of the sustainable development within the city. All of the municipality's committees and boards adheres to the program, which is valid until 2030. It was decided by the city council in 2021 and was developed by the environmental administration together with the City Executive Office, and with the support of employees in the city's administrations and companies. It is based on international agreements such as Agenda 2030 and the Paris agreement, legislation such as directive from the European Union, as well as Sweden's national environmental targets and national legislation in the Swedish Environmental Code. Local challenges have also been considered when developing the ECP, both those that the city faces and those relevant for the City of Gothenburg as an organization. (Göteborgs Stad, 2021)

The program has some delimitations. There are no goals regarding climate adaptation, instead the focus is on mitigation measures that can reduce the need for such interventions. Furthermore, there are no goals for areas that are covered by other governing documents and legislative requirements are not repeated as goals or target values for indicators.

The overarching aim of the ECP is to achieve an ecologically sustainable Gothenburg by 2030. To guide the work towards this aim, three environmental goals have been developed, each further divided into four sub-goals. Table 3.1 provides an overview of the environmental goals, including a short description of their purpose and the associated sub-goals.

Table 3.1: Overview of the environmental goals, their descriptions, and their sub-goals in the ECP

Environmental Goal	Goal Description	Sub-goals
Nature	Gothenburg has a high biodiversity.	• Protect species' habitats to ensure development of natural values. • Work for cleaner oceans, lakes, and watercourses. • Increase biodiversity in the urban environment. • Promote biodiversity in procurement.
Climate	Gothenburg's climate footprint is close to zero.	• Reduce energy consumption in homes and buildings. • Produce energy exclusively from renewable sources. • Reduce environmental impact from transport. • Reduce environmental impact from procurement.
Human	The people of Gothenburg have a healthy living environment.	• Reduce the use of harmful substances. • Ensure good air quality. • Ensure a healthy sound environment. • Ensure access to green spaces and utilize ecosystem services.

While the three environmental goals are comprehensive, with a focus on all activities and processes in Gothenburg, the sub-goals instead focus on the operations of companies and administrations within the municipal organization. The sub-goals themselves also vary with regards to the extent that they can be impacted by the City of Gothenburg's actions. In other words, the City of Gothenburg has different influence on their possibility to achieve the environmental goals and the overarching target to become an ecologically sustainable city by 2030.

In figure 3.2, the structure of the Environmental- and Climate Program has been visualized. In the figure, D1-D4 refers to the direct indicators, I1.1-I1.3 refers to the indicators under sub-goal one, I2.1-I2.4 refers to the indicators under sub-goal two, I3.1-I3.4 to refers to the indicators under sub-goal three, and I4.1-I4.2 refers to the indicators under sub-goal four. The direct indicators and the sub-goals with their associated indicators for the *Nature* and the *Climate* are not included in the figure.

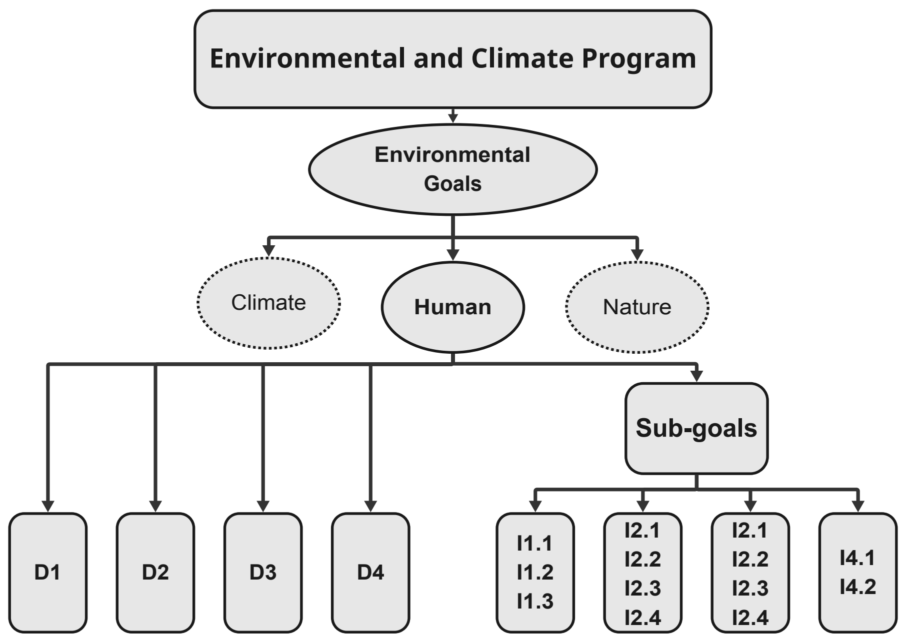

Figure 3.2: A visualization of the structure of the Environmental and Climate Program.

As previously mentioned, this thesis will focus on the direct indicators and the indicators supporting the sub-goals for the *Human*. The four direct indicators (D1-D4), their starting values, and their target values can be seen in table 3.2.

Table 3.2: The four direct indicators supporting the *Human* goal, including their starting and target values.

Indicator	Starting Value	Target Value	Label
Road traffic work, meaning the number of kilometers driven by all types of motorized road vehicles per weekday, in Gothenburg	7 260 000 Vehicle-kilometers (2019)	25 % lower compared to 2019	D1
The share of green and blue spaces in contiguous urban area (or equivalent term in the upcoming overview plan)	55 % (2018)	No decrease compared to starting value	D2
Access to urban cool islands	66 % (2022)	Yearly increase	D3
The share of detailed development plans on municipal land where biotope area factors are set during the consultation	3 % (2019)	100 %	D4

Green spaces are defined here as areas with vegetation, for example trees, parks, forests or grass. Blue spaces as areas with water, for example lakes, the ocean, watercourses or dams. Urban cool islands are defined as an area within the city with a lower surface temperature than the surrounding environment. It is the opposite of urban heat islands, a phenomenon that occurs in urban areas mainly due to the presence of heat-absorbing materials, such as concrete and asphalt. Urban green infrastructure is seen as an effective measure to lower urban temperatures and thereby reduce the risk for health problems during heat waves. The biotope area factor (BAF) measures the level of ecosystem services an area provides, i.e. how well green and blue spaces can improve the local climate and offer recreational opportunities.

The first sub-goal, to reduce the use of harmful substances has the following indicators:

Table 3.3: The three indicators under the first sub-goal, including their starting and target values.

Indicator	Starting Value	Target Value	Label
The number of chemical products containing phasing-out substances used in the city's operations	816 unique products (2021)	Close to zero	I1.1
The number of chemical products containing prioritized risk reduction substances used in the city's operations	1211 unique products (2021)	No decrease compared to starting value	I1.2
The share of building materials and products in the city's logs in the Building Product Assessment that have a total assessment of "recommended" or "accepted"	"Recommended": 14 % "Accepted": 77 %	Yearly increase	I1.3

Phasing-out substances are recognized by the Swedish Chemicals Agency as having particularly hazardous properties, such as carcinogenicity. Risk reduction substances are those recognized by the Swedish Chemicals Agency for their serious properties, which necessitate restricted use, such as toxicity. Building materials and products categorized as "recommended" or "accepted" contain minimal or no harmful substances.

The second sub-goal, to ensure good air quality for the people of Gothenburg is measured by the four indicators in table 3.4. I2.1 and I2.2 previously included dwellings in addition to kindergartens, this part of the indicators has however been removed as it was deemed redundant.

Table 3.4: The four indicators under the second sub-goal, including their starting and target values.

Indicator	Starting Value	Target Value	Label
The share of kindergarten's playgrounds with a nitrogen dioxide (NO_2) concentration below 20 micrograms per cubic meter	Kindergartens: 57 % (2018)	100 %	I2.1
The share of playgrounds in kindergartens with a particulate matter (PM_{10}) concentration below 15 micrograms per cubic meter	Kindergartens: 47 % (2018)	Yearly increase	I2.2
The share of contiguous urban area with an NO2 concentration below 20 micrograms per cubic meter	58 % (2018)	Yearly increase	I2.3
The share of contiguous urban area with a PM10 concentration below 20 micrograms per cubic meter	50 % (2018)	Yearly increase	I2.4

Contiguous urban area is defined in the city's overview plan as the contiguous and densely populated areas of Gothenburg. It includes the city center and the surrounding areas with somewhat lower population density and mixed use areas.

The third sub-goal, to ensure a healthy sound environment also has four indicators, found in table 3.5.

Table 3.5: The four indicators under the third sub-goal, including their starting and target values.

Indicator	Starting Value	Target Value	Labelfier
The share of playgrounds in new kindergartens with an equivalent sound level below 50 dBA	80 % (2020)	100 %	I3.1
The share of playgrounds in old kindergartens with an equivalent sound level below 55 dBA	75 %	100 %	I3.2
The share of dwellings with a façade where the sound level exceeds 60 dBA in equivalent sound level, but where there is access to a sound-dampened side with an equivalent sound level below 50 dBA	60 % (2020)	Yearly increase	I3.3
The share of citizens with access to a green area larger than 0,2 ha within 300 metres, with an equivalent sound level below 50 dBA	75 % (2018)	Yearly increase	I3.4

The A-weighted sound level (dBA) takes into account how hearing perceives sounds at different frequencies.

Lastly, the indicators under the fourth sub-goal, to ensure access to green spaces and utilizing ecosystem services, has two indicators, see table 3.6. Due to lack of data, I4.1 will be removed. It is still included in this report to highlight difficulties in monitoring and the iterative nature of the ECP.

Table 3.6: The two indicators under the fourth sub-goal, including their starting and target values.

Indicator	Starting Value	Target Value	Label
The share of playgrounds in kindergartens with a BAF above 0,45	21 % (2015)	Yearly increase	I4.1
The share of citizens with access to a green area larger than 0,2 ha within 300 metres	93 % (2018)	100 %	I4.2

BAF = Biotope Area Factor

To complement the environmental goals and their sub-goals, there are also seven strategies that in different ways contribute to reaching the environmental goals. Achieving the environmental goals of the program requires cross-sector collaboration. The strategies are coordinated by different committees and companies within the municipal organization. The strategies, a description of their intent and their responsible coordinators are presented in tables A.1 and A.2, which can be found in Appendix A.

3.2.1 Procedures of the evaluation process

Evaluation and analysis of the ECPs goals are performed and reported to the City Council every other year. The purpose of the evaluation is to give politicians, officials and other important stakeholders information regarding goal achievement, actions that are being taken within the city, and what is required to reach the goals. The evaluation should also provide consensus to officials in administrations and companies regarding what is required to reach the goals and divide responsibilities.

The procedure has been divided into different parts. Part one consists of planning and organizing the tasks that are to be carried out. This involves mapping the state of the indicators, including staffing of the role as indicator coordinator, method descriptions and their possible revisions, developing indicators, and creating new indicators or supporting indicators. Supporting indicators can either be variations of existing indicators or have separate methodologies. Their function is to offer analytical nuance, they are however not stated explicitly in the evaluation report. When choosing supporting indicators, personnel are asked to consider whether the required data will be available and relevant throughout the years. Furthermore, they should consider the amount of resources required to evaluate it. As the indicators are not deemed as being able to give a comprehensive answer on whether the goals are achieved, planning for the collection of supplementary information is important.

Part two handles the evaluation of the goals. It involves information collection on what is being done in the City of Gothenburg and the rest of the world. Indicator coordinators collect data for their respective indicators, produce outcomes for and analyze the indicators. This is presented, together with complementary information, to the goal-editor. For the indicators where external data or indicator information is required, providing parties are contacted about the expected delivery date. Indicator coordinators together with their respective goal-editor analyze the outcome of the indicator and the goal achievement. The supporting indicators are used in this analysis to the extent that their inclusion is identified as necessary (i.e. if complementary information is required to assess goal achievement). Additional material is gathered, in meetings and by experts, to a section of the report covering the overall recommendations regarding organizational structures and management in the city.

The evaluation of goal achievement is based on the indicators, supporting indicators, and complementary information on the City of Gothenburg efforts. Recommendations are developed for all three goals and for organizational structures and management. The report is produced by the editor group, where the main editors have the roles of project managers. They are also responsible for ensuring an adequate report and for the overall recommendations. The recommendations should be co-created with other stakeholders within the City of Gothenburg, such as administrations and companies. For the upcoming evaluation, there is also an objective to make the recommendations more clear and to better describe the responsibilities, compared to the previous evaluation. The goal editors are responsible for their respective goals and for contributing to the overall analysis in the report. A list of questions with respective sub-questions exist to guide the writing of the report and ensure that relevant topics are discussed.

Lastly, the evaluation process is also assessed to enable improvements for future evaluations. The editor group structures documentation on e.g. method documents and handles possible needs of development that have been identified during the evaluation process. A report detailing the methodology and assessing the satisfaction of the process is also written.

3.2.2 Organizational structure of the evaluation process

In the evaluation process, tasks are split between several different roles. A schematic of the main roles and the organizational structure of the evaluation process can be seen in figure 3.3.

Figure 3.3: The main roles involved in the evaluation of the ECP.

Indicator coordinators are responsible for following up, compiling, analyzing, and reporting information about one or several indicators. They should also ensure that the method description for the indicator is up to date and, when needed, develop a method and collect data for supporting indicators.

The goal editors are responsible for coordinating the evaluation of their respective goals and their associated sub-goals. They should help compile and develop the analysis of goals and sub-goals, contribute to the overall goal evaluation and contribute to the communication plan of the evaluation regarding who to contact and when. Lastly, they should ensure that indicators, supporting indicators, and information regarding the city's ongoing sustainability work is developed and documented to guarantee an efficient evaluation process.

At the Environmental Administration, there is also an employee responsible for the required Geographical Information System (GIS) operations connected to the evaluation of the *Human* and *Nature* goals. This role is responsible for developing and sustaining the structures that are required for a safe and efficient handling and processing of geodata. They should also carry out the GIS-based analyses and, if necessary, produce the indicator outcomes together with the goal-editor.

The main editors lead the evaluation work to ensure that adequate processes are followed and that the evaluation report is delivered. Their main tasks involve coordinating the group of goal editors and participating in the editorial work of the evaluation report. They are also responsible for the comprehensive analysis and the layout of the entire evaluation. Furthermore, they coordinate the effective communication and involvement of the environmental administrations' departments, ECP-management, those responsible for the environmental management system, strategy coordinators, and communicators. Lastly, they also document lessons learned from the evaluation.

The goal coordination teams' role is under construction, but as of now they should assist the goal editors in their work through discussion and by supporting them with the analysis and the development of recommendations for the respective goals. A steering group is also part of the evaluation process. They support the project management work, allocate resources, make decisions when there are forks in the road, and handle deviations from e.g. the time plan.

4
Methods

This chapter outlines the methodological approach employed to address the research questions and achieve the aim of this thesis. The data collection process included a literature review, analysis of internal data, and an interview study. The analysis included a thematic analysis of the interview data, the application of the evaluation criteria of the PICABUE framework to assess the quality of the indicators, and a meta-evaluation of the indicator system. Additionally, the data quality was analyzed using specific criteria during the literature review. The findings from the literature review provided essential background on the research topics, identified best practices in municipal sustainability reporting, and outlined relevant evaluation frameworks. Internal data offered a detailed understanding of the case study context, including the processes used to evaluate progress toward the ECP's indicator targets, and was used as input to the frameworks for analysis. The data from the interview study contributed similarly to the analysis, with the addition of informing the thematic analysis, to capture insights and patterns that emerged from the respondents' perspectives.

4.1 Literature Review

The literature review aimed to examine the current state of research by systematically reviewing relevant academic articles, books, regulatory documents and standards. Sources were obtained by searching with keywords in academic databases such as Google Scholar and Scopus. For the identification of additional sources, the method of forward snowballing was used. Forward snowballing involves examining newer publications that have cited a given article.

Literature was collected iteratively throughout the project, with topics and areas of interest being added as they emerged as relevant, for instance, when new information came to light through the review of internal documents or the interviews. The keywords used to identify literature for the different research topics are presented in table 4.1.

Table 4.1: Research topics and keywords used in the literature review.

Research Topic	Keywords
Sustainable Development	Urban sustainability, Urban sustainability assessment, Municipal sustainability, Integrated dimensions of sustainability
Climate Action Plans	Municipal climate action plan, Climate programs, Implementation of climate action plans, Municipal sustainabilty management
Indicators	Sustainability indicators, Ecological indicators, Socioecological indicators, Assessment of sustainability indicators, Public participation in indicator development
Data Quality Assurance	Data quality, Sustainability data quality, Data quality frameworks, Municipal data management

4.2 Data from the Case Study

4.2.1 Role-based Interviews

To gain a comprehensive understanding of the evaluation process of the ECP interview participants were selected based on their specific roles and responsibilities within the Environmental Administration. The selected interviewees represent key positions in the evaluation process: indicator coordinators, goal editor, GIS analyst, and main editors. Indicator coordinators were included due to their central role in collecting, analyzing and reporting data related to the indicators, as well as maintaining and updating indicator methodology. The goal editor was interviewed because of their responsibility for coordinating and synthesizing the evaluation of the main goal and its sub-goals, and for their involvement in ensuring that relevant information and documentation is developed. The GIS coordinator provided information on the need for spatial data processing and analysis, which was needed given the spatial nature of several indicators under the *Human* goal. Main editors were included as they lead the overall evaluation process, coordinate communication between stakeholders, and ensure the delivery of the final evaluation report. In addition to these roles, one participant involved in the original development of the goals and indicators was interviewed to provide insight into the rationale and process behind the initial design of the indicator system. Together, these individuals offer a holistic view of both the strategic and operational aspects of the indicator based evaluation system used in the ECP. In total, 11 interviews were conducted, with one interview including both of the main editors. Table 4.2 presents the interviewees, their job title and their role in the monitoring and evaluation processes of ECP.

Table 4.2: Table containing the roles and responsibilities of the interviewees along with their corresponding labels for anonymity.

Role	**Responsibilites**	**Label**
Goal Editor	Coordination and evaluation of main- and sub-goals	R1
Indicator Coordinator 1	Responsible for I1.1, I1.2, I1.3	R2
Indicator Coordinator 2	Responsible for I2.1, I2.2, I2.3, I2.4	R3
Indicator Coordinator 3	Responsible for I3.1, I3.2, I3.3, I3.4	R4
Indicator Coordinator 4	Responsible for I4.1, I4.2, D2, D4	R5
Indicator Coordinator 5	Responsible for D1	R6
Indicator Coordinator 6	Responsible for D3	R7
GIS Analyst	Aids with spatial data processing and analysis	R8
Main Editors	Responsible for overall evaluation process	R9
ECP Developer	Involved in the development of the ECP	R10

ECP = Environmental and Climate Program
GIS = Geographic Information System

The interviews were conducted using a semi-structured approach to balance consistency with flexibility, ensuring that the intended data was collected while allowing space for unexpected insights (Kallio et al., 2016). This format followed a guiding framework of open-ended questions to keep the conversation focused on relevant themes, while still allowing interviewees to elaborate on specific topics or introduce new perspectives. The questions were designed to gain insight into the current practices and processes of the Environmental Administration in relation to the ECP. They were informed by the literature review, internal documents, and aligned with the RQs to ensure their relevance. Furthermore, inclusion of specific questions was tailored to the role of the interviewee. The interview questions can be seen in table 4.3.

Table 4.3: The interview questions and their associated RQs.

RQ 1
Describe your role and responsibilities in the monitoring and evaluation of the ECP?
Explain the organizational structure of the monitoring and evaluation process
What were the incentives for the development of the ECP?
Have the structure and routines developed since the implementation of the ECP?
What information, in addition to the indicators, is included in the analysis of the goal evaluation?
In what way are external actors included in the evaluation process?
RQ 2
Can you describe the data collection process?
Can you describe the indicator method?
How were the target values for the indicators decided?
Can you describe the alignment of the indicator and its goal?
RQ 3
How does the process of revision work and how are indicators developed?
Are specific frameworks or principles used for developing indicators?
Were potential synergies considered during the development of the indicators?
Whose interests were considered during the development of the indicators?
Were the indicators developed in collaboration or consensus with other actors?
Do you have any understanding of how other actors perceive the indicators?
Are there other indicator functions than demonstrating goal achievment?

Microsoft Teams was used for recording the interviews and they were conducted either in person or online. Each interviewee was briefed in advance on the aim and objective of the thesis to provide context and ensure informed participation. One of the authors asked questions while the other took notes. The automatic transcription service in Teams was utilized. After the interview, the transcripts were proofread while listening to the recordings and mistakes were edited manually to ensure their accuracy. The automated transcription could not assign speakers when the interviews were conducted in person, and in that case sentences were also attributed to the correct individual (interviewer or interviewee).

The qualitative data was analyzed using thematic analysis, which is a common method for identifying, analyzing and presenting themes that emerge from qualitative data (Säfsten and Gustavsson, 2024). The approach followed the framework outlined by Säfsten and Gustavsson (2024) and is as follows:

- Familiarize with the data. Transcribe and take notes of interesting passages.
- Create codes and systematically assign them to interesting phenomena in the transcripts.
- Identify themes by gathering codes. Seek similarities and patterns in codes that can be grouped under the same theme.
- Examine the themes and how they relate to the coded extracts and to the entire data material.
- Define and label themes continuously throughout the analysis by refining, defining and labeling the themes.
- Create a report by selecting extracts with themes linked to relevant theory and the RQs.

The coding was performed in the software NVivo 15 (Lumivero, 2024). A table containing all codes can be found in Appendix D. As the interviews, and thus the transcripts, were in Swedish, some of the functions in the software were not available. As a result, subsequent analytical steps were conducted manually, without the software.

4.2.2 Review of internal documents

Access was given to relevant Sharepoint folders where documents containing method descriptions for evaluation of the indicators were located. There were also documents containing detailed description of the indicators, their purposes, limitations, review and development. Other reviewed documents contained information about the analysis of indicator outcomes, organizational structures of the evaluation process, and the routines for follow-up after the evaluation is finished. Information was classified and compiled into relevant sections of the thesis, so that it could be utilized for further analysis.

4.3 Frameworks and criteria for evaluation

The evaluation of the data focused on three aspects: individual indicators, the indicator system, and the quality of the underlying data. These aspects were chosen to capture the performance of indicators on an individual level, how well the system functions overall, and how data quality affects the effectiveness of indicators. The distinction between indicator performance and data quality allowed for the identification of where in the system improvements could be made.

4.3.1 Evaluation of Indicators

To help assess the suitability and evaluate the fit of the indicators, evaluation criteria from the PICABUE framework were utilized (Mitchell et al., 1995). The framework is used within the field of industrial ecology and shares many criteria with other investigated frameworks, as shown in chapter 2. It holds the benefit of including clearly defined criteria for evaluation that address the main considerations for indicator quality identified in the literature review. These criteria clearly includes considerations that are not explicitly stated in other frameworks, such as distributional effects and communicability. The eight evaluation criteria for the acceptability of sustainability indicators can be found in table 4.4.

Table 4.4: Criteria for the PICABUE-framework and associated descriptions.

Criteria	Description
Relevance and scientific validity	Relevant in relation to the goals of the stakeholders. Scientifically valid in the sense that it is technically sound, well founded and grounded in a clear understanding of its relationship to the issue of concern.
Sensitivity to change across space and/or groups	Sensitive to variations across different spatial areas and/or groups. Identifies distributional effects to allow for the identification of at-risk ecological areas or communities.
Sensitivity to change over time	Allows for the identification of trends. The sensitivity should be measurable, and show a graduate response to stress and natural variability.
Consistency of data	Allows for trend identification of trends by utilizing adequate supporting data. The data must exist and the monitoring should be future-proof. The data should be timely enough to allow indicators to signal emerging issues before conditions become unacceptable.
Comprehensibility	The indicator should be understood by relevant stakeholders. It should have a differentiation of desirable and undesirable situations. It should be simple enough to be understood by non-professionals.
Appropriate data transformation	The indicator should accurately represent the area of concern. The data should be transformed in such a way that it increases understanding of the information the indicator is trying to convey.
Measurable data	Measurements should be technically feasible, financially sustainable, and available on time. The data should also be valid and accurate, and collected with appropriate instrumentation. Standardized procedures that minimize measurement errors and promote cost-efficiency are desired.
Possible target or threshold values	The target value of an indicator should identify an outcome that is desirable. It is also preferable if there is one or more threshold values that can help identify unfavorable outcomes.

The indicators are evaluated on how well they fulfill the criteria through a qualitative assessment, based on collected data from the interview study and the internal documents. For visualization and analysis purposes, the indicators were furthermore assessed on how well they fulfill a criteria by utilizing the scale: low (purple), moderate (teal), and high (yellow).

4.3.2 Evaluation of the Indicator System

To evaluate the performance and appropriateness of the indicator system within the ECP, a qualitative meta-evaluation was conducted using the framework proposed by Ramos and Caeiro (2010). The inclusion of such a framework is a rare yet important consideration to ensure the credibility of the indicator system, and it has been used for similar purposes in other studies (Verma and Raghubanshi, 2018; Krank and Wallbaum, 2011). A selected subset of the good-practice factors were applied (see table 4.5), and each factor was evaluated on a qualitative basis, supported by data from internal documents and information from interviews. The good-practice factors that were ultimately selected were the ones which could be analyzed with the collected data and were deemed relevant to the indicators and processes examined in this thesis. As a result, two good-practice factors were excluded: *Technical and educational skills of the staff* and *Cost-benefit analysis*.

Table 4.5: The selected subset of good-practice factors with complementary short summaries, from (Ramos and Caeiro, 2010).

Key Good-Practice Factors	Short Summary
Objective, scope and scale effects	Identification of general and specific objectives for the assessment sustainability. The SI-system should emphasize territorial characteristics and the scope of the analysis. There should be coverage of the main dimensions of sustainable development, while recognizing sustainability principles and limits.
Target audience and type of language	The SI-system should identify the principles of its target audience and assure that said audience be reached in a preferred language. The SI-system should identify whether it intends to reach a majority non-technical audience and adjust accordingly.
Management model and institutional cooperation	The management framework should be clearly defined. Institutions along with their roles and leadership structures are imperative in understanding potential societal influence of the SI-system. Agreements around institutional cooperation should be well understood. The institutions can include other public agencies, NGOs and universities, with academia possibly having an active role.
Indicator organization and structuring	The organization and structuring of the indicators is of vital importance, with several considerations being important to understand. Is the SI-system coherent with a conceptual framework? Are the indicators structured as to optimally achieve objectives, e.g. by theme, by dimension or using causality? Regardless of the answer to these questions, the indicator organization should be motivated clearly.
Regularity issues, revision and updating procedures	Frequency of reporting and reviewing of the SI-system should be identified. In addition to this, the revision process and frequency should be clearly stated, along with the criteria which ought to be used for assessing the effectiveness of the SI-system.
Governance and public participation process	The SI-system should integrate good governance practices. It should also promote dynamic interaction with all stakeholders. Participative and collaborative procedures should play a supporting role in ensuring transparency, credibility and robustness, beyond the technical and scientific dimensions.
Relationships with regional strategies	Initiatives should be connected to strategic tools and instruments for sustainable development. The SI-system could also be used as a template for forming policies,plans and projects by utilizing the SIs.
Intra-territorial asymmetries	The SI-system should make it possible for the evaluation of internal territorial asymmetries. It should allow for analysis of inequities or disparities in the territory within the scope.
Communication and promotion/dissemination	The SI-system should be accompanied by a clearly established communication strategy to ensure that information reaches the end-users. Communication strategies and reporting should aim at improving communication with decision-makers as well as the general public.
Decision-makers' and stakeholders' responses	The translation from sustainability assessment of an SI-system to policy and management decisions is a vital component. Recommendations and measures taken within the city as a result of an evaluation should seek to continually improve the overall sustainability. There should be a clear linkage between the SIs and policy, action and programs.

4.3.3 Evaluation of Data Quality

The core of assessing the data quality lies in the determination of whether the data that is being used fulfills the needs of the consumer based on a set of criteria. These criteria are context based and can vary from case to case, but there are certain that are generally used in most cases for assessing DQ. The context of assessing the DQ from a municipal perspective is important and has been taken into account when selecting the chosen evaluation criteria. The criteria chosen for this case study is based on combination of a few different frameworks, with the starting point being the PICABUE-framework. Within the evaluation step of the PICABUE framework, three of the criteria examined concerns data. These are *consistency of data*, *appropriate data transformation* and *measurable data*. To complement these three, additional criteria have been chosen to clarify certain aspects in terms of DQ and make a distinction between indicator quality and DQ. These criteria along with their definitions can be found in table 4.6.

Table 4.6: DQ Criteria to complement the PICABUE framework.

DQ Criteria	Definition of Criteria
Timeliness	*The extent of which the age of the data is appropriate for the task at hand. (Wang and Strong, 1996)*
Granularity	*Granularity refers to the amount of disaggregation for key data elements. Granularity can be in units of time, level of geographic detail available, or the amount of detail available on any of a number of characteristics (e.g. demographic, socio-economic). (Dworak-Fisher et al., 2020)*
Comparability	*Measurement of the impact of differences in applied statistical concepts, measurement tools and procedures where statistics are compared between geographical areas or over time. (Black and van Nederpelt, 2020)*
Completeness	*The extent to which the data are of sufficient breadth, depth and scope for the task at hand. (Wang and Strong, 1996)*
Accuracy and Reliability	*Accuracy measures the closeness of an estimate from a data product to its true value. A related concept is reliability, which characterizes the consistency of results when the same phenomenon is measured or estimated more than once under similar conditions. (Dworak-Fisher et al., 2020)*
Relevance	*Relevance refers to whether the data product is targeted to meet the current and prospective user needs. (Dworak-Fisher et al., 2020)*

5
Results

In this chapter, results are presented in three sections. First, descriptions of the indicator methods and data are presented. These results are gathered and compiled from internal documents and complemented with information from the interviews. Then, the results from the thematic analysis of the interviews are presented. The identified themes are *The Role and Purpose of Indicators*, *Indicator Functionality*, *Data Quality and Availability*, *Development of indicators and their methodologies*, and *Organizational Complexity and Collaboration*. Finally, results regarding the evaluation of the indicators, the indicator system, and the data quality are presented.

5.1 Insights from Internal Documents of the Environmental Administration

A review of the internal documents of the Environmental Administration was conducted in order to garner an understanding of how the documentation is performed and structured as well as gaining insights regarding indicator methodology and data collection. The documents mainly focused on for this review were the method descriptions for the indicators under the *Human* goal as well as the in-depth method descriptions. Other documents were also reviewed, which supplied complementary information on the internal structure and routines in terms of documentation. The indicator method descriptions followed an established template which contained:

- The approach for producing the indicator outcome. This part included a step-by-step description for how the indicator outcomes were produced. This description then includes data collection, how the producing of the outcome ought to be done as well as any possible data transformation necessary and how the data should be stored in the internal documents.
- A description of how, where and when the data is collected. It also includes possible contact information is needed or if the data is publicly available.
- The update frequency of the data, i.e. how often and when the data is updated.
- A description of the possible delimitations of the method, such as geographical delimititaions and choice of parameters.
- A list of other pertinent information for the indicator, that is not used for producing the indicator outcome, but rather used for the analysis of the indicator.

To complement the above mentioned method descriptions, there are also in-depth method descriptions used to go into greater detail on information around the methodology for the indicators. These in-depth descriptions were designed to create an understanding and a consensus around the function of the indicators in the evaluation and the implementation of the ECP. This documentation was also designed to make certain aspects of the indicators more clear and concrete, such as assumptions and definitions used. These in-depth method descriptions contain:

- A description of the indicator
- Purpose of the indicator
  - Interpretation of the target value
  - The indicators governing function in the implementation of the ECP
- Definitions and delimititations
- Factors that can affect the indicator outcome over time
  - The city's conditions for working towards the target values
  - Relevant governing documents
  - Trends in society, economic incentives and legislation
- Evaluation of the indicator
  - Comments about data and method for producing indicator outcome
  - Supporting information for interpretation of the indicator outcome
  - Link to method for other indicators along with evaluation of the overarching goal in its entirety
  - Additional information around the working method
  - Comments regarding earlier evaluations
- Background and reasoning
- Development of the indicator and its evaluation
- Assessment of the indicator - revision of the ECP 2024-2025

The method descriptions for the indicators have been synthesized and can be found in Appendix B. The goal was to include data requirements, sources, collection procedures, processing, and update frequency for all indicators. This was however not possible for all indicators, as all documents were not complete at the time of the review.

5.2 Thematic Analysis

The identified themes from the interviews, found through the thematic analysis, aim at understanding key dimensions in relation to the evaluation process of the ECP. The themes along with a description of what they include can be seen in figure 5.1.

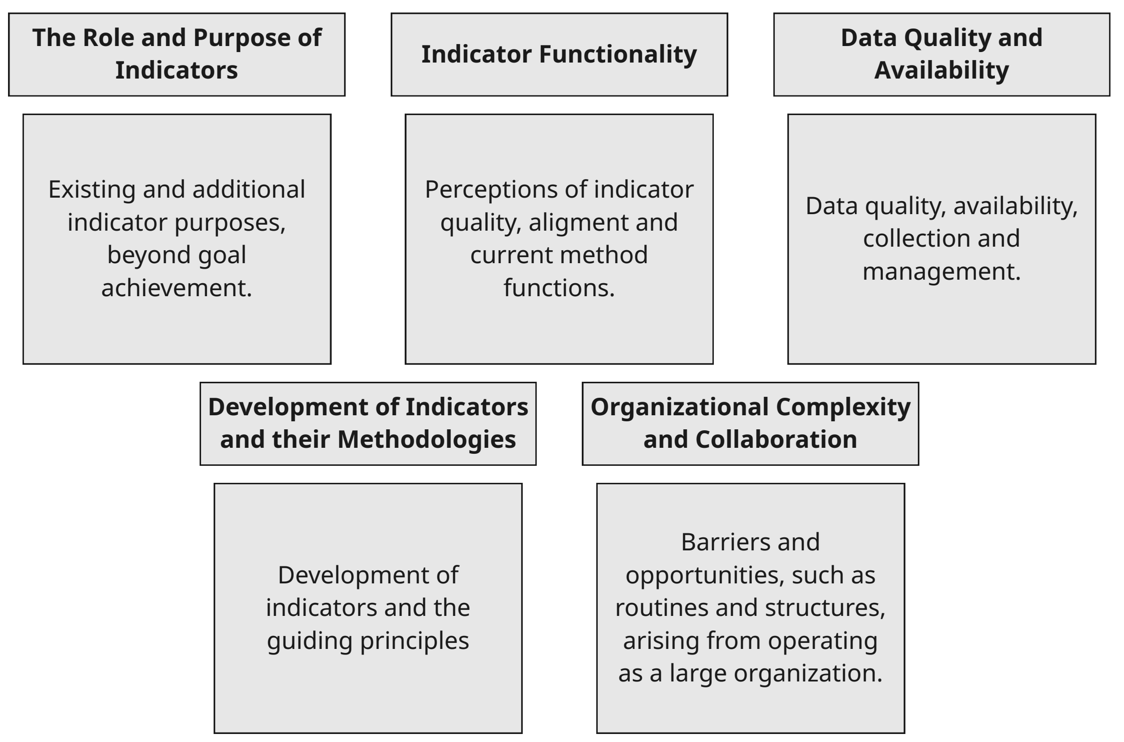

Figure 5.1: Identified themes and their respective descriptions.

5.2.1 The Role and Purpose of Indicators

While the main purpose of the indicators in the ECP is to assess progress towards its goals and sub-goals, respondents emphasized that their function extends beyond evaluation. Indicators also play important strategic, communicative, and motivational roles in the city's environmental efforts. Several respondents noted that the indicators were developed not only to measure, but also to drive action. One described them as intended to "be a driving force and motivate actors within the city that can influence the development", underscoring their role in translating broad environmental goals and ambitions into more concrete and actionable targets. It was understood that by setting clear time frames and target values, indicators can support administrations in operationalizing long-term goals.

Another key function was mentioned to be the symbolic and communicative value indicators hold within the municipal organization. However, one respondent explained that indicators are sometimes misunderstood as the goals themselves, which can result in confusion or disengagement:

> *Indicators are frequently misinterpreted as being the goals. This can lead to misunderstandings, when administrations assume that the goals do not concern them, as their activities are not covered explicitly by any indicator.* [R5]

This statement was used to highlight the need for clearer communication around what the indicators represent and how they relate to broader policy objectives.

Respondents also emphasized the potential of indicators to support municipal decision making and planning processes, suggesting that their utility should extend beyond the Environmental Administration. One respondent hoped that the conveyed information could become more accessible and relevant to other departments, and for instance be used in the review of detailed development plans. Indicators are also seen as important for raising awareness and directing attention to issues within the city. Even when the data or methodology is not fully robust, as was explained to be the case with D3, they can still provide value. As respondent R7 explained, "it still holds potential value... it can help highlight the accessibility of cool islands and direct attention to the issue." From this, it can be understood that indicators can contribute to building knowledge and highlight issues within the city.

According to one respondent, the primary purpose of the indicators is not to achieve perfection in measurement, but rather to support the overall progress towards the environmental goals. Indicators are seen as tools to facilitate this work, rather than as an end in themselves. They continued by stating that goals may be set in cases when the available data and the methods are limited or imperfect. In such instances, the intention is to actively begin working on the issues, using the goals and indicators as tools for stimulating development.

Lastly, supporting indicators were highlighted as a way to increase analytical depth and offer nuance in the evaluation, with the degree of their utilization varying depending on how well the indicators align with their respective goals. For example, the use of supporting indicators have become a central strategy for sub-goal one, as its indicators are deemed insufficient in their alignment. An example of when a supporting indicator provided valuable nuance was provided. It was found that D2 had an almost identical outcome as the outcome from 2023. This was then further investigated using a supporting indicator that revealed that one large area had been developed whereas many smaller areas, equating to the same size, had disappeared.

In sum, the indicators are more than monitoring tools, they are part of the city's broader environmental strategy. They help support cross-administration dialogue, stimulate engagement, and help focus attention on both current progress and areas in need of development. Many respondents also see significant untapped potential in this function and suggest that with better integration, the indicators could become useful tools not only for evaluation, but also for planning, collaboration, and organizational learning.

5.2.2 Indicator Functionality

Under this theme, results are first presented for indicators under each goal or subgoal before more general findings are presented.

Sub-goal One: Reduce the Use of Harmful Substances

Several challenges were raised regarding the quality and reliability of indicators under sub-goal one. A recurring concern was the limited scope of the current indicators. Respondent R1 pointed out that "the overarching goal related to a non-toxic environment lacks indicators that reflect the broader status in the city", since the current indicators only cover the City of Gothenburg's internal use of chemical products and construction materials. Other important product categories such as electronics, clothing, and general consumer goods were mentioned as being entirely absent from the indicator set.

Indicators I1.1 and I1.2 were mentioned as particularly problematic, in the sense that their quality is said to be heavily dependent on whether the city's companies and administrations regularly update their chemical registers. Furthermore, the presence of a shifting baseline was identified as a methodological flaw. It was explained that as substances become classified as risk-related or subject to phase-out, compliance with the target becomes more difficult, regardless if the city has made actual progress with reducing said substances. This was stated to affect the ability to track the progress, and also making it hard to identify long-term trends. Despite these challenges, no improved alternative methodology has been identified.

I1.3 also suffers from significant data quality issues. According to respondents, the data is skewed due to the fact that around 90% comes from a single administration, one that also performs well environmentally. Consequently, the indicator outcome is said to overestimate the overall compliance level. One respondent also noted that the indicator only includes the city's own administrations and companies, excluding private actors entirely.

Together these issues were raised as concerns in connection to how well the indicators align with both the sub-goal of achieving a non-toxic environment. It was understood that while the existing indicators may provide some insight into municipal practices, they offer limited understanding of broader environmental exposure or risks to human health in the city.

Sub-goal Two: Ensure Good Air Quality

The indicators under sub-goal two were widely regarded as high-quality and well-aligned with both its sub-goal and the *Human* goal. Respondents emphasized that the indicator evaluation is closely aligned with day-to-day operations. One respondent also highlighted that they capture population exposure, which was viewed as the key metric for assessing health-related impacts in the city.

One respondent explained that the thresholds used for indicators under sub-goal two are based on national environmental objectives. This was stated to be a contributing factor to their legitimacy. The thresholds are expected to remain relevant despite ongoing revisions to EU legislation. However, the discussion also revealed some uncertainty about their future relevance, if EU further raise the ambitions. One respondent reflected that, in such a case, the indicators might become somewhat redundant.

While the indicators were generally seen as well-functioning, some limitations were acknowledged. One issue was stated to be their sensitivity with regards to the target values. It was explained that, due to the threshold values, small variations in pollution levels can cause notable shifts in results. It was stated that this may give the impression of drastic year-to-year changes, despite there only being minor differences in actual levels of pollution, due to for example weather conditions.

Sub-goal Three: Ensure a Healthy Sound Environment

The noise pollution indicators under sub-goal three generally received a positive assessment with regards to their functionality. Specifically, I3.1 and I3.2 were perceived as successful examples of indicators, with the responsible indicator coordinator stating that they produce outcomes consistent with expectations.

The other two, I3.3 and I3.4, were described as more problematic, as they were noted to have methodological issues that undermine their reliability, making it difficult to draw meaningful conclusions from their outcomes. I3.4, in particular, was singled out due to its reliance on national land cover data. This data source was criticized for giving an imprecise estimate of what constitutes as a green area. Furthermore, it was explained that although the goal alignment is sound, the practical usefulness of the results is limited due to the low resolution of the indicators and the nature of the underlying data.

One respondent explained that, in some cases, indicators were derived from the methodologies of other indicators. I3.4 was given as an example of this, as it follows a similar methodology as I4.2, with the addition of a noise mapping. Furthermore, it was stated that if a supporting indicator is developed for I4.2, I3.4 will likely receive a good foundation for a supporting indicator as well.

Sub-goal Four: Ensure Access to Green Spaces and Utilize Ecosystem Services

I4.1 has been discontinued, as the Facilities Administration no longer maintains the data on BAF, making future follow-up infeasible. In addition to the infeasibility, the indicator was criticized for the lack of qualitative differentiation. As one respondent pointed out, the BAF provides no insight into biodiversity or other potential benefits that an area may provide.

The remaining indicator under sub-goal four, I4.2, is seen as practical and technically feasible to follow up, with established data infrastructures supporting long-term tracking. However, concerns were raised regarding its analytical depth and alignment with the full scope of the sub-goal, particularly in relation to the utilization and quality of ecosystem services. One respondent mentioned that while I4.2 provides a foundational measure of the presence of green areas and associated ecosystem services, these services are difficult to measure. Moreover, it was stated to not fully capture nuanced or qualitative aspects, such as how many people have access to these spaces, the types of green areas available, or their quality. An example was also given on how inaccessible areas, such as traffic islands or roundabouts, is treated the same way as parks. Furthermore, the indicator was explained to fall short in addressing the broader perspective of an equitable access to nature.

The indicator coordinator mentioned that there are challenges in knowing when enough analysis has been done to produce a reliable assessment for the indicators connected to green areas. The slow rate of change in green infrastructure is stated to make annual shifts difficult to detect. As one respondent put it, "If a tree is planted today, it will not have grown fully until 2030", highlighting the need to complement these indicators with longer-term perspectives and perhaps additional qualitative data. The low resolution of the indicator is also mentioned as a concern, as it introduces difficulties in identifying areas in need of intervention. Despite these challenges, I4.2 is still considered to offer a solid foundation for continued development, especially if a more nuanced methodology or supporting indicators can be added to reflect the quality and use of urban green space.

Direct indicators

In the case of D1, respondent R6 described how its methodology has been undergoing refinement. This was stated to have resulted in implications regarding consistency, which was remedied by having earlier outcomes retroactively adjusted to align with the revised methodology. Regarding the methodology and the indicator outcome being produced externally, a respondent stated that trust must be placed on the knowledge of the external actors. The respondent also noted that a dialogue had been initiated between stakeholders to further develop the method, allowing for more frequent and multi-purpose use of the data in the future. Lastly, D1 was mentioned to serve as a link between the *Human* goal and sub-goals two and three, relating to air and noise pollution.

D2 was stated to share a similar methodology to I4.2, with the exception that it does not account for ecosystem services or accessibility. Thus, it mainly relies on national land cover data, which was stated to be problematic due to inconsistencies with the classification green and blue areas.

The direct indicator measuring access to urban cool island, D3, is stated to be weather dependent, as it depends on surface temperature which varies from year to year. Because of this, it is perceived as difficult to determine a threshold of what should be defined as an urban cool island, both in absolute and relative terms. It is stated that this inherent problem makes the indicator quite arbitrary. However, it has been observed that the relative differences in surface temperatures have been stable over time. The observed areas in D3 are also said to show relatively small differences over time, which is a problem as the development it seeks to observe takes a long time to manifest. Furthermore, it is explained that there are difficulties in determining whether the observed cooling is due to meteorological factors or the city's interventions. A desire was expressed for an indicator capable of reflecting municipal action, preparedness and adaptation, rather than just observing the environmental state. The complexity of urban heat exposure was discussed, and the need for urban cool islands was stated to vary depending on where and how people live. Due to this spatial variability, a single, citywide indicator was assessed as insufficient for capturing the nuances of the issue. Instead, there was a suggestion to develop more targeted indicators that focus on vulnerable, or high-need areas, such as inner city neighborhoods or districts where the residents may lack the means to access cooler environments.

The outcome of D4 is said to be a measure of well implemented a work procedure has been, rather than actually measuring the actual effects that green areas might produce. Another issue with D4 is that the outcome can differ substantially from year to year, depending on the number detailed development plans submitted. From the last evaluation, the outcome achieved was 90%, due to the small number of detailed plans submitted. It is mentioned that the indicator could continue to be monitored, as it is easy to follow up and City Planning Office already follow up on it for their internal goals. If used consistently, the inclusion of BAF in detailed development plans is mentioned to possibly result in a greener city. The respondent however expressed a desire for an indicator that could also highlight where ecological losses are occurring, particularly due to urban development.

General Indicator Functionality

Indicators were explained to be a valuable tool for evaluating progress in the city's work with sustainability. However, it was recognized that their helpfulness in assessing the situation depends a lot on the data quality and how they align with goals and sub-goals. One respondent noted that without the indicators, the process of evaluation would likely be more uncertain, relying more on guesswork or rough estimations. However, it was emphasized that solely relying on indicators would not be sufficient for evaluating goal progression. The following example was given goal alignment:

> *There are other plans in the city, such as "we have a goal to electrify trucks to this extent by this year", where the goal and the indicator value are the same. But these goals [in the ECP] are much broader in almost every case, which makes it more challenging.* [R9]

Respondents also stated that the current indicators generally do not capture the full scope of the goal. Therefore, it was explained, a complementary qualitative assessment is performed consisting of insights from strategically relevant actors within city. One respondent stated that these qualitative assessments are necessary to identify how the city is working towards the goals and what needs to be done to reach them.

They added that the complexity of the city and the various perspectives among actors from different areas and sectors poses a challenge for this approach. Another respondent similarly stated that the evaluation also takes into account supporting indicators and other qualitative information, and that the weight given to different types of information depends on how well the indicators align with the goals. An additional difficulty of the evaluation was stated to be the difference in context and available information across assessments.

One interviewee expressed uncertainty about what makes an indicator "good enough". There were questions about whether the evaluation approach might be too simplistic or too complex, or whether the focus is truly aligned with the ECP's goals. Clearer guidance or some kind of framework for quality assurance was desired, especially given the significant time and resources in producing and analyzing the indicators. Respondents also wished for indicators that more clearly defined what the goals actually mean in practice, to make them more actionable and useful in decision-making.

5.2.3 Data Quality and Availability

Uncertainty in data quality was discussed in relation to a number of indicators. For example, multiple respondents highlighted limitations with the national land cover data, which is used for several indicators (I3.4, I4.2, D2). Although the data is generally considered to be reliable, the fact that it is produced externally was stated to introduce challenges. These include delay in data releases, long update intervals (every five years), and methodological inconsistencies between updates. It was stated that even if a method appears ideal in theory, in practice data quality issues often limit the capacity to draw meaningful conclusions. One respondent said:

> *Then there are problems with all the indicators requiring the national land cover data. It is updated every fifth year, which makes it difficult as the evaluation is performed every other year.* [R1]

For indicators I1.1 and I1.2, respondents expressed doubts about the reliability of submitted data from administrations and companies. Issues such as personnel changes, lack of routines, and varying levels of competence among those responsible for data reporting can result in large discrepancies that do not reflect actual changes in the city's use of chemical substances. It was stated that even though companies are required by law to have their lists of chemical products up to date, there is no guarantee that they report it into Chemsoft, which is the system used for logging chemicals in the City of Gothenburg. Similarly for I1.3, the lack of quality assurance in the submitted logbooks and the incomplete implementation of data systems across organizations were mentioned as limitations.

Several respondents also commented on the absence of a centralized system for gathering indicator data. This was explained to complicate the evaluation process, especially as the information must be gathered from a broad range of sources. Overall, while many of the indicators are seen as theoretically adequate, interviewees mentioned that data quality and availability influence their analytical value, as it increases the risk of misinterpretation. From many of the respondents it was however gathered that they are working continuously with improving both the data quality and the structures supporting data collection.

5.2.4 Development of Indicators and their Methodologies

The development of the ECP and the indicators is an iterative process, and potential challenges can be hard to predict. In the interviews, there were several examples of potential improvements. Some of these examples include:

- Under the first sub-goal, which aims to achieve a non-toxic environment, there were several areas suggested by one interviewee that might hold the potential to be useful for future indicators. The areas highlighted were drinking water quality, sewage water and contaminated areas.
- For I1.3, it was mentioned that it might be desirable to include all types of construction work or to develop a supporting indicator to help paint a more nuanced picture.
- There have been discussions around the noise pollution indicators about the possibility of upgrading the current model used for calculating noise levels (from the current model Nord96 to the newer version, Nord2000). The new model is said to include more detailed input data and includes more parameters to tune.
- I3.3 might benefit from a slight methodological change, in which the indicator would focus on the most exposed facade, as opposed to the least exposed. This was said to possibly produce more actionable insights and increase reliability.
- Under sub-goal four, it was suggested by one interviewee that there is a desire to develop an indicator that is focused on how green areas are affected by urban development. Another suggestion under sub-goal four would be to develop an indicator (or supporting indicator) which explores how many inhabitants have access to the same green areas.
- For D3, there are heat maps created by another administration which features the radiant temperatures within the city. It was suggested by a respondent that these might be used in order to further develop D3 as well as creating synergies.

It was suggested by a couple of respondents that there might be value in developing supporting indicators which utilize more granular datasets, focusing more on specific areas of the city. This could make certain indicators more actionable and help highlight local disparities. One such example raised by an interviewee, which was connected to the sub-goal for noise pollution, highlights how there might be value in looking specifically at areas of the inner city, which has a higher population density than the city average.

Another respondent expressed a desire for indicators that more clearly reflect the city's actions in response to climate-related challenges. Rather than only measuring the environmental state, it was stated that such indicators could focus on the implementation of adaptation strategies. One example brought up was the city's efforts regarding climate adaptation for extreme heat. The respondent suggested that indicators could more actively track or encourage adaptation efforts, not only with regards to municipal infrastructure, but also in the built environment managed by private actors.

One interviewee emphasized the limitations of the current indicator set and pointed to the value of more comprehensive, composite indicators that integrate multiple data sources:

> *They had used green space data, like tree canopy coverage, and combined it into an index with indicators on socioeconomics. Seven indicators became one. I hope that we, not for the upcoming follow-up, but eventually, can have that kind of data to support goal management. Because we do not have that, and I have met several people who see it as a shortcoming that we only measure a small part.* [R5]

Several interviewees mentioned that data and methods have changed for many indicators since the implementation of the program. This was expressed to have caused difficulties with establishing trends and providing a fair comparison between indicator outcomes over time. For some of the cases, this has been circumvented by applying the new data or method to produce indicator outcomes for previous years as well, to better identify this development.

Supporting indicators are mentioned as useful tools to support the analysis and often provide the indicator coordinators with invaluable nuance for the indicator outcomes and reports. Supporting indicators were explained to be developed over time in an iterative process to help address emerging challenges. The evaluation process of the ECP was stated to be a testing ground for whether the supporting indicators might be useful as main indicators, or if they should remain in a supporting role for future evaluations.

It was expressed that the indicators under sub-goal two have a significant advantage over many others, in that development of the methodology rarely seems to be needed, and the only changes and improvements which are being considered regard the ambition level of the indicators. The current indicators were explained to be based on national guidelines; however, their target values are even more ambitious. The current guidelines and national targets are due to be updated, after which they are expected to align with those of the City of Gothenburg. One respondent expressed that there is value in Gothenburg maintaining higher ambition levels in order to remain a driving force and continue pushing for further development and action on air quality.

Despite the obvious benefits of continual improvements and iterative development of the indicators, such as covering a broader scope as well as providing a more realistic picture of reality, there were also drawbacks highlighted by the interviews. One stated drawback was the difficulty arising due to method development, as this possibly introduces difficulties with finding previously utilized data and with establishing trends.

Urban Canopy Cover

While there was talk of several different developments and improvements which could be made for different indicators, the most frequently was the possible development and use of urban canopy cover data for various purposes. This data would ideally be of sufficient granularity to be able to monitor how trees are planted and felled over time. It was mentioned that such a dataset could help inform indicator within sub-goal four as well as the D4, as canopy cover can be linked to both green areas and natural regulation of temperatures within an urban environment.

Even though this approach seems to show great potential and was mentioned during interviews as being actively investigated, there have been reservations mentioned which have to be resolved in order to properly implement it into the ECP. One such reservation is regarding the scale and scope of the dataset, as one interviewee noted:

> *It is good if we have a cohesive knowledge-basis, since so far the journey has revolved around that "this might solve a lot of problems". But the question remains around how we should divide the work. What geographical scale would be statistically correct? There currently exists maplayers from another administration, but is it possible to follow up on? So as it stands, there remains technical considerations about where the data would come from and whether the Environmental Administration should be in charge of it. How we want to process the data is also something which needs to be decided upon before it can be properly implemented."*
> [R5]

It was also mentioned by a respondent that it was initially thought that the data for canopy cover would be relatively easy to obtain. However, upon further investigation, it was found that questions regarding update frequency and management of data was not as straightforward as originally posited.

Guiding Principles in Development

When developing new indicators and their associated methodologies, interviewees offered varying perspectives on what should be prioritized. On a general level, there were two principles which were said to be explicitly adhered to in the development process. The first of these included that the indicators should be possible to monitor over time. Second, there was a clear preference for quantitative over qualitative data, to enable objective tracking and comparison. One respondent stated that these two principles in combination meant that during the initial development of indicators under the Human area, emphasis was placed upon being able to set a target value, a starting value, and to consistently produce outcomes for each indicator.

Another element lifted as an integral piece in the initial development of the indicators and sub-goals was the 2017 report from the Public Health Agency of Sweden and Karolinska Institutet (Folkhälsomyndigheten and Karolinska Institutet, 2017). This report details the environmental health risks in Sweden, and was used as a basis for deciding which environmental factors to include in the ECP. In the creation of the ECP, it was highlighted by a respondent that a guiding principle, playing a major role in what goals, sub-goals and indicators to include, was the avoidance of repeated governance. This helped focus on what was currently being addressed within the city to avoid superfluous work as well as identifying gaps in governance. Furthermore, it was stated that the ECP was designed to solely address the ecological dimension of sustainable development, and that indicators therefore were developed in accordance with this.

Inclusion of the public was mentioned to not be a part of the development process of the ECP, primarily due to time constraints. When asked whether public participation would have resulted in different goals or indicators, it was stated that:

> *I do not believe that the program itself would have looked very different, but there would have been a stronger anchoring. People would have felt as if it was their environmental- and climate program. Now it became more of the environmental administrations program.* [R10]

When examining how the Environmental Administration is currently working with updating and developing the indicators in the ECP, there were several different examples that highlighted how different employees approach the development and revision process. In one such example, an employee states that they first start thinking about the purpose of the indicator in question, and whether a new indicator might better align with the goal. Following this, they ponder whether the methodology should be more quantitative, qualitative or a combination of the two. This is then complemented by reaching out to other municipalities and other relevant network actors to get inspiration and further details on the subject area. This is then finally complemented by assessing the data availability, where the data might come from and whether the data demands would be realistic. A couple of interviewees highlighted the importance of creating indicators that are maintainable over time and that they should be formulated using data which already exists within the City of Gothenburg. There has for example been talks about developing an indicator that highlights the presence of PFAS in drinking waters. This data should theoretically be readily available and the chance of the monitoring of such data being discontinued is very small due to regulations around PFAS already being in place within the city. An inverse example, in where data previously used became unavailable, was brought up in connection to I4.1. Part of the dataset that was being used in order to perform an evaluation of the indicator became obsolete to the administration from which it was requested, thus they stopped producing it, leading to I4.1 being discontinued.

5.2.5 Organizational Complexity and Collaboration

Collaboration

Several of the indicators in the ECP are dependent on data from external actors across the city's organization. To be able to facilitate the collection of this data, a recurring sentiment brought up during the interviews was the role that collaboration holds for the Environmental Administration. One barrier associated with collaboration is that the indicator coordinators have to rely on the competence and expertise of employees at other administrations. An example of this was illustrated in connection to I1.1 and I1.2, where data on chemical substances is reported by the companies and administration themselves. It was expressed by the indicator coordinator that this type of reporting makes it difficult and time consuming to verify the quality of this data.

Another barrier, expressed by a few respondents, was the absence of formal agreements with other administrations in terms of data demands. Furthermore it was stated that the data is collected in various ways and that there is no shared system for data management. When the Environmental Administration relies on data from an external source, it was stated that data supply can become unreliable if the required data suddenly becomes redundant for the external actor. In these cases, the indicator coordinators are left without their required data with little or no way of replicating the data production. Additionally, it was expressed by one interviewee that this lack of formal procedures can affect the efficiency of the evaluation process.

Routines and Structures

It was expressed in several interviews that there had been issues in the previous evaluation process, mainly surrounding the routines and structures. Many of the encountered challenges stem from the fact that the previous evaluation was the first of its nature for the ECP, and thus routines and structures were not properly formalized. Since this evaluation, which was conducted in 2023, respondents mentioned several areas which have been improved and formalized for the 2025 evaluation:

- Method descriptions for the indicator were explicitly documented with a template being created for indicator coordinators to adhere to.
- Similar documentation and templates were also created for in-depth method descriptions (which delves deeper into details on the indicator methods) and indicator reports.
- Goal coordination teams were instated, to assist the goal-editors with analysis and development of recommendations for the goals.

However, problems with certain indicators due to insufficient documentation and change in personnel since the last evaluation was expressed. This was explained to have led to difficulties with reconstructing previous methodologies, thus requiring extra time and effort for understanding what had been done previously.

Organizational Complexity

One respondent stated that a great challenge the City of Gothenburg faces in process of trying to accomplish all the goals in the ECP, as well as working with its corresponding indicators is the problem of complexity. It is a large organization, with a multitude of different associated actors, administrations and companies. It was explained that these stakeholders in turn have different challenges, goals and initiatives they are trying to drive forward. This makes grasping and understanding the full picture of the City's operations incredibly challenging, and even more challenging is trying to address the various challenges at hand. It was understood that Environmental Administration's work with the indicators is a balance act between what is feasible, what should be prioritized and finding what areas the City of Gothenburg actually has the possibility of exerting its influence upon.

Even within the Environmental Administration itself, it was expressed by the goal editor that it is a challenge to audit and support the work being done by the various indicator coordinators, since the scope of the *Human* area covers such a wide array of challenges through its goal and sub-goals.

Synergies

The concept of utilizing synergies with the indicators and their associated data was brought up a few times. The indicators within the ECP heavily relies on data from a wide range of different organizations within the City of Gothenburg, meaning that both time and resources can be saved if the supplied data can server multiple purposes. With this in mind, it was suggested by one interviewee that there exist two main approaches for developing the indicators to promote synergies. The first mentioned approach involves the Environmental Administration developing something which other administrations can make use of or take part of. The second approach would be to build upon data and practices that are already in place at other administrations.

One interviewee emphasized that communication and synergies can be a catalyst for development. They noted that by aligning with other administrations and their existing initiatives and plans, a more coordinated and effective effort can be achieved. However, it was also cautioned that this type of coordination must be handled carefully to avoid repeated governance. An example of such dialogue was shared by a respondent, in relation to D1.

> *"I have opened up a dialogue between the consultants, the City Planning Authority, the Traffic Administration Office, and possibly us here at the Environmental Administration about developing the method to perform evaluations more often if the need arises and finding alternate uses for the numbers produced and used." [R6]*

The beneficial nature of synergies was highlighted by several respondents. However, it was also highlighted that when synergies break down, it can be a cause of major problems for certain indicators. One such example comes from I4.1, in which the BAF data for kindergarten playgrounds used for the indicator was produced by another administration. When this administration stopped producing the data, I4.1 disappeared and became resource-inefficient to maintain.

5.3 Evaluation Results

The data evaluation was performed, with a focus on three different aspects, as mentioned in the method (see 4.3). The results are thus highlighted in three sections: *Evaluation of Indicators*, *Evaluation of the Indicator System* and *Evaluation of Data Quality*.

5.3.1 Evaluation of Indicators

The studied indicators have been individually assessed by using the evaluation step in the PICABUE framework. The performance levels are color-coded as low (purple), moderate (teal), and high (yellow), see figure 5.2. Each indicator was evaluated according to the eight criteria laid fourth in the method section, see 4.3.1. The complementary explanations for how the indicators have been graded can be found in appendix C.

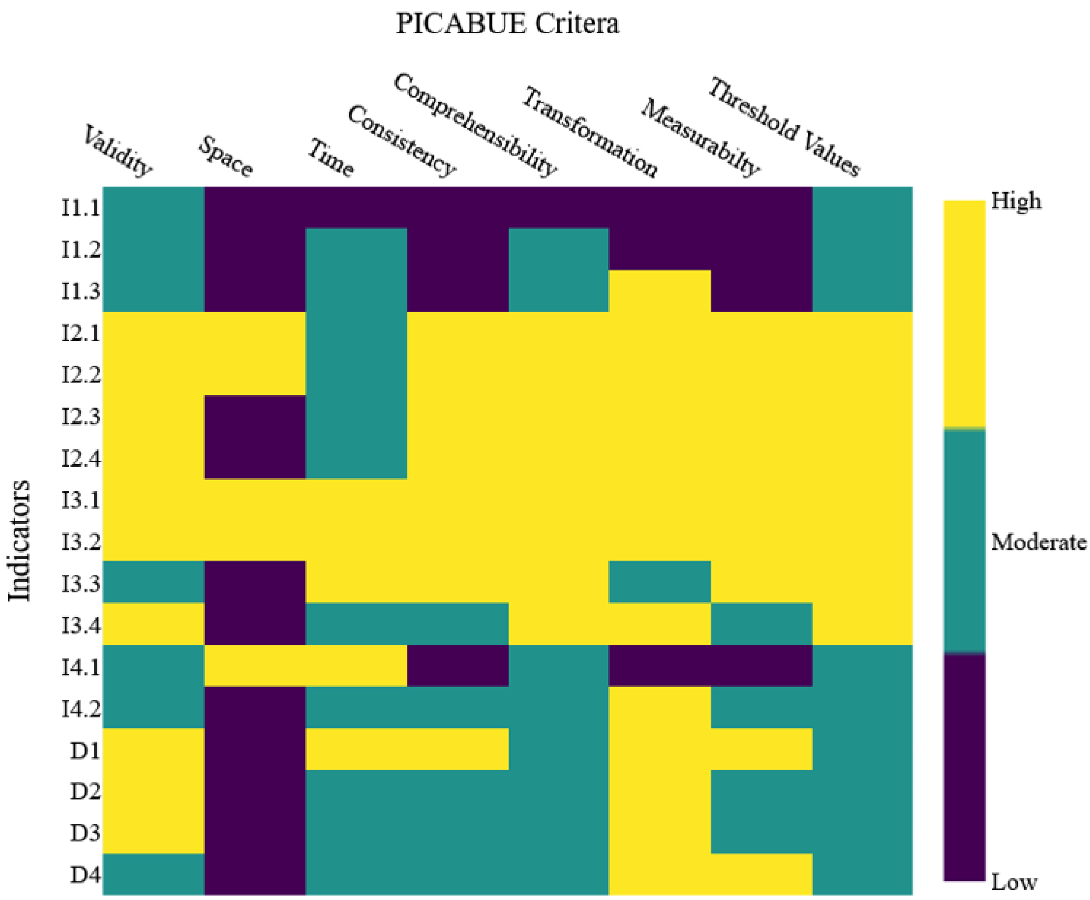

Figure 5.2: Assessment of how well the indicators meet the evaluation criteria defined in the PICABUE framework (Mitchell et al., 1995). Performance levels are color-coded as low (purple), moderate (teal), and high (yellow).

It can be seen that many indicators fulfill the criteria, at least moderately. For *relevance and scientific validity* as well as *possible targets and threshold values*, no indicator has been identified to have a low performance level. Furthermore, for *appropriate data transformation*, a majority of the indicators fulfill the criteria completely. Conversely, for *sensitivity to change across space and/or groups*, only five indicators have been assessed to have a high performance level, while the remaining twelve lack in this aspect. All of the indicators fulfilling this criteria concern kindergarten playgrounds, specifically targeting a vulnerable group.

For sub-goal one, I1.1 and I1.2 fail to fulfill a majority of the criteria. I1.3 also has issues, having been assessed with a high performance level for only the *appropriate data transformation* criteria. Indicators under sub-goal two and three fulfill many or all of the criteria. However, the indicators under sub-goal two do not show a graduate response to natural variability, compromising their sensitivity to change over time. Furthermore, I3.4 relies on national land cover data, which hampers its ability to fulfill criteria *sensitivity to change over time*, *consistency of data*, and *measurable data*. Partially relying on the same data, I4.2 and D2 have similar issues with the aforementioned criteria. Out of the direct indicators, D1 fulfills the most criteria with a high performance level. D3 and D4 share many assessments, with the exception that D3 is seen as performing well with regards to *relevance and scientific validity* while D3 performs well in the criteria for *possible target or threshold values*.

5.3.2 Evaluation of the Indicator System

Objective, Scope and Scale Effects

Regarding the sustainability dimensions it is clear that the ECP has a focus on the ecological dimension, as this is explicitly stated in the program. The indicators also address the specific needs and characteristics of the city, aligning with the scope of the ECP. The possibility of vertical integration among the studied indicators varies, with some being comparable and easily scalable to e.g. indicators on a national scale, such as the indicators for air quality, noise pollution, road traffic work, and urban cool islands. Others, such as the indicators focusing on chemical use and BAF in kindergartens are more specific to the City of Gothenburg.

Target audience and type of language

The target audience is identified as all committees and boards in the City of Gothenburg's organization. However, there is no clarification if the indicator system is intended to reach a broader audience and be understandable for people without the adequate expertise.

Management Model and Institutional Cooperation

The management structure for the ECP and the indicator system is clearly defined and established. Documents explaining the organizational structure, including role responsibilities and job descriptions, are available. Institutional cooperation is established through the ECP's strategies as well as meetings and work-shops with different stakeholders. Furthermore, there are indicators that rely on data or calculations from other actors within the city. In the implementation and evaluation of the ECP, the Environmental Administration is supported by the Environmental Council, consisting of researchers acting as unbiased experts.

Indicator Organization and Structuring

The structure of the indicator system in the ECP is well founded with indicators grouped under sub-goals, which in turn relates to the main goal. There also indicators which directly relate to the main goal. The organization of the indicator system is explained, along with reasoning behind its structure. However, no clear framework is utilized in this structuring. The indicators do not fully capture the scope of the goals, and some have difficulties in implementation.

Regularity Issues, Revision and Updating Processes

The ECP will undergo one major revision during its period of validity, which will take place during the fall of 2025. In this revision, the possibility exists to reselect or replace indicators. Additionally, both the program and the indicator system is continuously being developed. Indicator outcomes are updated and reported every other year.

Governance and Public Participation Process

Participative processes were part of when the indicator systems was developed, as the program was sent out on for review to external actors. During the managing phase, there are little signs of such processes in connection to the development of indicators. Overall, there are no formalized structures for facilitating participative processes for this purpose. There are however several indicators which require cooperation with other municipal administrations and companies during the managing phase. In no phase, any existence of public participation could be identified.

Relationship With Regional Strategies

The ECP and the indicator system is associated with several strategic documents, both on a municipal and a regional level. It is also associated with national and international legislation, goals, and guidelines. Some examples for the different spatial scales include The City of Gothenburgs meal policy, Regional environmental goals for Västra Götaland County, The Swedish environmental code, and Agenda 2030. Furthermore, the indicators under the *Human* were largely based on the 2017 report by the Public Health Agency of Sweden and Karolinska Institutet.

Intra-territorial Asymmetries

The indicators generally do not provide information allowing for the assessment of territorial asymmetries within the city. Some exceptions are the indicators relating to air pollution, noise pollution and BAF as they take into account vulnerable children through the inclusion of kindergarten playgrounds.

Communication and Promotion/Dissemination

There is an established communication strategy, where the evaluation is sent to all committees and boards within the organization. With the exception of this line of communication, there are no other formalized strategies for dissemination. There are however ideas for how the evaluation could reach a broader audience. For example, outreach activities are planned in which the evaluation will be presented to various stakeholders with a focus on specific content that is relevant to them. A presentation will also be held for those involved in the evaluation, and there are plans for a webinar where interested individuals can participate. In addition to this, there have been discussions about creating presentation material that can be distributed to employees working with sustainability in other administrations and companies.

Decisions-makers' and Stakeholders' Responses

The current responses to the sustainability assessment provided by the indicators is currently somewhat limited. While the indicators provide information on a city-wide level, action to reverse or prevent negative trends have been mentioned to require more granular indicators that can inform targeted measures. Furthermore, there is a shortage of policy monitoring indicators, resulting in a lack of clear linkages between assessments and actions.

5.3.3 Evaluation of Data Quality

Timeliness

When analyzing the utilized datasets for certain indicators within the ECP, it was found that the update frequency of some external data sources can affect the overall quality. One such example is the national land cover data which is utilized for several different indicators relating to green areas (I3.4, I4.2, D2). This data is updated every five years which means that it can skew certain results since it can remain the same across evaluations. However, it can also be argued that green urban infrastructure and vegetation evolve slowly over time and, therefore, is not as negatively affected by these infrequent data updates. The data on surface temperatures (D3) from the Swedish Civil Contingencies Agency (SCCA) shares similar issues. SCCA update this dataset continuously over a three year period. With the exception of these examples, the data is assessed to be adequate in terms of timeliness.

Granularity

Large parts of the datasets utilized within the ECP contain data that is granular enough to illustrate specific areas or sub-groups within the population that are affected. There are also instances where the use of supporting indicators, which utilize even more granular data, help paint a more nuanced picture of the outcomes. For instance, the resolution of datasets regarding the built environment (I2.1-D3), address points (I2.3, I2.4, I3.3, I3.4, I4.2, D3), land cover (I3.4, I4.2, D2), air pollution (I2.1-I2.4), noise pollution (I3.1-I3.4) are all sufficiently granular to possibly include distributional effects within the indicators. Datasets for I1.1-I1.3 and D4 do not offer the possibility to showcase distributional effects.

Comparability

As the methods and data sources of the indicators evolve over time, it has been found that the introduction of approaches to calculate indicator outcomes can present issues when it comes to establishing overall trends for the indicators. When a new method or dataset is used, there has to be considerations whether there exists data to recalculate the outcomes for previous evaluations as well as a starting value. This is something which has previously been done. However, it must be reflected upon if the extra effort and time spent performing these retrospective calculations are worth the potential benefits that a new method or dataset would offer. This can be exemplified by the introduction of a new dataset on surface temperatures for D3, where recalculations were made as the new dataset was not comparable to the previous one.

Completeness

The depth, breadth, and scope of the data used within the the ECP can generally be deemed as sufficient to calculate the indicator outcomes. One exception is the data for I1.3, which lacks in breadth, as a majority of the input data comes from a single administration. A more complete dataset would ideally contain data from all administrations and companies within the city to fully capture the scope. For the indicators that focus on access to green areas (I3.4, I4.2), the national land cover data is of insufficient depth, as it does not accurately portray points of access to green areas.

Accuracy and Reliability

Overall, the accuracy of the utilized data is accurate, with some exceptions. First, the indicators regarding a non-toxic environment (I1.1-I1.3) have issues with accuracy. This is due to the lack of quality assurance making it hard to verify if the collected data reflects reality. The national land cover data (I3.4, I4.2) also has inefficiencies in the sense that qualitative aspects regarding the classification of green areas is not explicitly defined. For instance, some included areas are inaccessible to the public, and other areas are hard to define in terms of what recreational value or ecosystem services they offer. The BAF data suffers from a similar lack in accuracy, as it does not fully account for recreational values or biodiversity.

In terms of reliability, sub-goal one (I1.1-I1.3) is affected by the dependency of the employees reporting the data. In the case of employee turnover, the contents reported might differ, even though conditions are similar. Weather dependent data, i.e. air pollution data (I2.1-I2.4) and surface temperature data (D3), was noted to be reliable as it effectively takes fluctuation into account while remaining consistent under similar conditions.

Relevance

The data being used for the indicators is relevant for meeting the current internal needs for the ECP. For the indicators to better align with their respective goals, additional relevant data would however be required. To improve the alignment of the indicators under sub-goal one (I1.1-I1.3), on a more comprehensive list of products would be relevant. Another example can be highlighted in connection to I4.2, which would require complementary data to better capture the utilization of ecosystem services, as it currently lacks in this regard.

In order to work proactively, prospective needs would need to be identified to ensure data relevancy. One example is the potential use of PFAS data, which could improve the alignment under sub-goal one. Another prospective user need is a dataset containing urban canopy cover. This dataset has been identified as having the potential to develop indicators that increase the alignment towards several goals and sub-goals (sub-goal four, D3).

6

Discussion

6.1 Reflections on Indicator Characteristics

After being implemented for four years, the ECP is soon due for its only revision during its lifetime. In this revision, there is a possibility of removing unsatisfactory indicators and introducing new ones. From both the interview results and the indicator evaluation, it is clear that the best functioning indicators are those under sub-goal two and three (I2.1-I3.4). These indicators share characteristics that contribute to their robustness. First, they align with the core responsibilities of the involved unit. This alignment means that methods and routines are already in place, and the employees are experienced in both data collection and interpretation. Furthermore, the benefits of indicators being integrated with everyday operations include long-term continuity and less time spent on developing new methods and creating structures for data collection. In contrast, the indicators under sub-goal one (I1.1-I1.3) rely on data input from other municipal administrations and companies. This dependency complicates interpretation and introduces challenges in verifying data quality, often requiring substantial time and effort to collect, validate, and assess the information.

Another beneficial characteristic can be identified in the internal ownership of data and methodology. This enables the indicator outcomes to be produced in a timely manner, as the calculations and data transformations is performed by employees at the Environmental Administration. It also facilitates a deeper understanding of how outcomes are produced, which aids analysis and reduces the risk of miscommunication and misinterpretation. Since the indicators cover a wide array of areas, it would be unrealistic to require ownership of all data and indicator outcomes. D1 exemplifies a case where an externally produced outcome is well-functioning.

The alignment of an indicator in relation to its goal reduces the need for supporting indicators or complementary qualitative analyses to interpret goal achievement. Even partial misalignment, as with I4.2, can introduce uncertainties in the assessment. Although this indicator reveals access to green areas, it is flawed with regards to conveying information about the utilization of ecosystem services. On a similar note, indicators based on legislation or established guidelines have been identified as easier to interpret, as they clearly differentiate between acceptable and unacceptable conditions. Furthermore, it can aid in the development, as it becomes easier to set a target value, and can favor long-term monitoring, as data is unlikely to become redundant. As an example, data provision for I4.1 was discontinued when the responsible administration no longer required it for their internal operations.

6.2 Actionable Indicators

A majority of the indicators are formulated to provide information on a citywide level, which is appropriate in scope in relation to the goals and sub-goals. However, a recurring point raised by interviewees was the need for more actionable indicators, capable of guiding targeted interventions and better represent the lived realities of Gothenburg's communities. This was reflected in the desire to see distributional effects integrated into indicator development, for instance by integrating other dimensions of sustainable development when developing indicators.

While the ECP is deliberately focused on the ecological dimension of sustainable development, it was understood from several respondents that this scope may limit the relevance and usefulness of the indicators in practice. The *Human* goal aims to ensure a healthy living environment for the citizens of Gothenburg, however the indicators, with some exceptions (I2.1, I2.2, I3.1, I3.2, I4.1), largely exclude socioeconomic factors, making it difficult to determine which communities are most affected by environmental health risks or most in need of targeted interventions. This exclusion can be deemed as problematic since sustainable development is inherently multidimensional, and isolating dimensions may weaken the overall effectiveness of the indicators (Cohen, 2017). As several others have argued, one-dimensional approaches to sustainability risk ignoring crucial systemic interactions, including those related to equity, viability, and livability (Michalina et al., 2021; Tanguay et al., 2010).

In the ECP, five out of seventeen indicators are deemed to be sensitive to change across space, revealing at risk communities in the form of children. The indicator system is thus limited with regards to its potential in assessing the experiences of environmental benefits or harms for different groups. In many cases, data of sufficient granularity exists to support the inclusion of distributional effects for the indicators. The usefulness of a more granular indicator must however be weighed against the time and resources required to develop and maintain it. Furthermore, practical and organizational constraints can impact the feasibility of such implementation, even if the data is available.

From literature, it can be understood that ecological indicators are prevalent in urban sustainability assessment, and the exclusion of socioeconomic aspects remains a known issue. According to Sharifi (2021), a majority of indicator frameworks still fail to fully integrate the social dimension. The ECP's indicators, as currently formulated, also reflect this imbalance. Despite this absence of distributional effects being part of the intended design, it can also represent a potential shortcoming.

6.3 Towards a Unified Framework

Another identified barrier, highlighted in the results, was that no explicit or shared framework has been used in the development of indicators. Instead, reliance has been placed on certain principles, or rules of thumb. During the development of the ECP, the three main followed principles were that the indicators should be measurable (i.e. quantitative), possible to follow up (i.e. based on accessible data), and that they should avoid repeated governance. Other principles and preferable characteristics mentioned by different employees included that indicators should be developed to follow repeatable methodologies, be multifunctional, utilize internal data, and be grounded in legislation or guidelines. With regards to utilizing internal data, it should here be understood as data produced by the Environmental Administration itself. Such data should be the primary option for producing indicator outcomes, as it increases the reliability, compared to data from other administrations or companies within the organization. This is supported by the results, which indicate that indicators utilizing internal data and aligning with existing operational routines tend to function more effectively and consistently over time.

Many of the aforementioned informal principles have been derived through the employees' continuous management of the indicators, and they often align with established criteria found in the literature. For instance, Mori and Christodoulou (2012) mentions that evaluation methodology "should rely on absolute criteria as far as possible, considering scientific thresholds, global standards based on international agreements, and local standards." This highlights the role of learning as an important part of developing and managing indicators. Similar findings have been made by Elmqvist et al. (2013), who describes how learning can occur at the organizational level, in addition to the individual level. In the context of the ECP, these learning processes have for example manifested through iterative improvements in indicator method and design, which has led to a more robust indicator system over the course of the program's implementation.

While these informal principles aid in guiding the development of the indicators, the absence of a formalized framework may hinder the alignment of the indicators with the goal and sub-goals of the ECP (Tanguay et al., 2010). The authors also highlight that there is no universally accepted framework for indicator development at the municipal level, which makes it problematic to recommend a specific one. However, the adoption of a framework could offer a shared structure for indicator design, even if not all criteria can be fully met due to limitations in data availability or other practical constraints. After all, as evident from the results, the goal is not to achieve perfection in indicator quality, but rather for indicators to be sufficiently aligned with the goals and act as a driving force. Therefore, rather than serving as a checklist, a framework can act as a guiding tool.

While the absence of a framework can be a barrier, it also represents an opportunity. The Environmental Administration has already identified principles which can serve as the foundation for a tailored framework that reflects their unique goals, challenges, and organizational structure of the City of Gothenburg. These principles could be complemented with additional criteria from existing frameworks that fit the local context and the scope of the ECP. The adoption of a framework can foster greater cohesion and improve transparency by making the rationale behind indicator selection more visible to both internal and external stakeholders. Furthermore, it can also serve the purpose of institutionalizing knowledge which in turn can be utilized for future revisions. While the development of a framework would benefit from input across the Environmental Administration, it could be particularly relevant to assign this responsibility to the goal coordination team. Their emerging role already involves supporting goal editors by facilitating discussion and helping to develop recommendations for the various goals, which positions them well to lead the effort of creating a cohesive framework.

Another issue with some indicators, particularly those related to urban green spaces, is their inability to track long-term responses. This becomes a challenge due to the time lag between efforts and observable outcomes. While the temporal dimensions of environmental impacts is often neglected, a cause-effect framework such as DPSIR (or one of its derivatives, e.g. eDPSIR) can help to address this challenge by illustrating the causal pathways between human activities and environmental changes (Chandrakumar and McLaren, 2018). By using such a framework, delays or bottlenecks can be identified. For instance, by recognizing that planting a tree (a Response) may not immediately alter the urban environment (a State) or biodiversity (an Impact), more realistic expectations of observable change can be created. Furthermore, even if the framework is merely used to classify the indicators, it can still inform whether they address the underlying activities or their consequent effects.

6.4 Collaborative Challenges and Evolving Practices

The reliance on collaboration across administrations and with other municipal actors emerged as both a necessity and a vulnerability. The decentralized nature of data ownership for some of the indicators, where critical data is collected by other actors, creates challenges around accountability, consistency, and data quality. Regarding consistency, another related challenge is the lack of a shared system for data management, with data being collected in diverse ways across different administrations. The current approach can lead to inefficiencies and a potential loss of data. The absence of formal agreements exacerbates this issue. Without predefined routines and division of responsibilities, these activities become contingent on the continued participation of external actors, which has been shown to vary over time. This is a significant risk in long-term strategic work such as the evaluation of a CAP.

Lessons from the previous evaluation appear to have informed several improvements to routines and documentation practices. The standardization of indicator method descriptions through the introduction of templates represent important steps towards institutionalizing knowledge. These efforts can be seen as a form of institutional work, in which actors adapt in response to past challenges and learning (Oseland, 2019). These measures help mitigate the risk posed by employee turnover, which has previously led to the loss of knowledge and challenges in reconstructing methodologies. This iterative process of refinement illustrates the importance of reflexivity within a CAP, and urban sustainability assessment in general. However, the fact that some challenges, such as unclear past methodologies, still persisted in 2025 shows that the process of establishing routines takes time and that these efforts must be continuous and proactive.

Another identified barrier concerns the evolution of data sources and methods for indicators over time. While methodological development can be seen as a positive sign and generally should be encouraged, it also introduces problems for longitudinal analysis. In response this issue, new methods have retroactively been applied to earlier data for some indicators. In other cases, improved data has been utilized for existing methods instead. This form of backcasting reflects a practical workaround which allows for iterative development while managing to establish trends. While maintaining consistency in methods and data is preferable, improvements are a natural part of the process. To maintain transparency and allow stakeholders to interpret and trust the indicator outcomes, a restatement of the previous method or data can be provided in cases where changes have been made (Global Reporting Initiative, 2021).

Furthermore, while climate action planning is often described as an iterative process where shortcomings can be improved upon, there appears to be some uncertainty around how certain improvements should be made without creating conflict or redundancy with respect to other governing documents. The issue of repeated governance was mentioned, though it is unclear whether this constitutes a real obstacle. In fact, if other municipal strategies already address adaptation or socio-economic issues, it could be argued that relevant data should already be available and can be integrated into the ECP, particularly if the indicators are used for evaluation rather than direct governance. Furthermore, the absence of a comprehensive sustainability program may lead to gaps in indicator coverage, where integrated dimensions are either omitted or insufficiently addressed, as they are fragmented across multiple governing documents.

6.5 Public Participation

While the development of the ECP involved consultation with other municipalities and internal stakeholders, public participation was deliberately excluded due to time constraints. However, the merits of utilizing public participation in indicator development should not be underestimated. The current form of the ECP is based on a top-down approach, in which the goals and indicators were developed and selected in accordance with experts (some of which were employees at the Environmental Administration).

As of now, the indicators are meant to provide information to policy makers. In order to be used for communication with the public, simplified indices might be an alternative to complement the existing indicators. Involving citizens earlier in the indicator design process could also ensure that the aggregation and communication strategies are aligned with public understanding. Such participation might also highlight qualitative dimensions or community priorities that otherwise can be overlooked.

In future iterations of the ECP, the incorporation of participatory procedures for indicator design could also support indicators that are more effective for communication with the public. Tying in to the earlier discussion regarding the inclusion of the social dimension in the indicators, O'Regan and Moles (2008) found that when citizens are invited to assist in indicator development, they placed comparatively greater emphasis on the social dimension. This divergence from top-down priorities should be considered if the indicators and goal progression are to be made more relatable to the public.

Since participatory procedures can be time-consuming, it could be advisable to employ a citizens' assembly, since that has previously been used within the city (Göteborgs Stad, 2024a). In such an assembly, citizens would be allowed to express areas of interest and concern to relevant actors. The statements could be further leveraged into the Q-method, which is a method that combines a top-down and a bottom-up approach, and has previously been used for the development and selection of indicators (Doody et al., 2009).

6.6 Methodology and Limitations

One important methodological consideration is the choice of framework used to assess the indicators and the data. In this thesis, the evaluation criteria from the PICABUE framework were helpful in assessing the indicators in terms of their performance and relevance. However, this may have constrained the analysis to certain dimensions, such as practicality and communicability. It might also underemphasize sustainable development dimensions and public participation.

Alternative frameworks, such as DPSIR or the Bellagio STAMP principles might have led to different emphases, insights, and conclusions. For instance, DPSIR focuses more on causal linkages and could have revealed different insights into the systemic relationships between human activities and environmental outcomes. It is however mostly used for classification, and not evaluation of indicators. The Bellagio STAMP principles place greater emphasis on transparency, participation, learning, and a holistic systems approach. In contrast to PICABUE's more operational perspective, the Bellagio STAMP principles promote a vision of indicators not just as management tools, but as drivers for dialogue and sustainability learning. These aspects were however covered to various degrees by the complementary framework and the interview study.

Thus, the selection of a particular framework is not a neutral step, it shapes what is considered important, what is measured, and ultimately how performance is assessed. Therefore, while the evaluation criteria from PICABUE provided structure and clarity, acknowledging that other frameworks might have highlighted different barriers and opportunities is important for a nuanced understanding of the indicators in the ECP.

The thesis design involved semi-structured interviews with municipal employees who were directly involved in the evaluation and coordination of the ECP. While this provided valuable insights into the internal workings, challenges, and learning processes, the limited number of interviews, and the exclusive focus on internal actors, also constrains the breadth of captured perspectives. No interviews were conducted with external stakeholders, such as the public, experts, or representatives from other administrations involved in the ECP. As a result, the thesis does not capture external viewpoints on how indicators are perceived, whether they are seen as legitimate, understandable, or representative of community concerns. This is particularly relevant given the emphasis in the literature on participatory approaches and communicability of the indicators.

The thesis was conducted during an ongoing evaluation of the ECP, which presents both a strength and a limitation. On one hand, examining the program in real time allowed for identification of emerging challenges and adjustments, making the analysis more timely and relevant. On the other hand, the continuous changes means that some minor developments may have been missed or not fully accounted for, potentially affecting the completeness of the findings.

Lastly, the research began with an open-ended inquiry, but was limited to data, indicators and processes under the *Human* goal. This approach allowed for unexpected issues to surface and helped to identify and focus on areas of particular concern for practitioners, such as collaboration, and the quality as well as actionability of indicators. As key problems became evident, the scope of the study naturally narrowed to enable deeper investigation.

6.7 Further Research

This thesis identified the lack of a shared data system as a barrier for the evaluation process. Further research, of a more operational nature, could further explore data pathways and demands to inform the creation of such a system. The implementation of a shared system would possibly allow for a more cohesive, transparent and streamlined process, both regarding the collection and utilization of the data. Additionally, it could be pertinent to investigate how such a system would affect the experience of collecting data from external actors and what opportunities it could bring forth in terms of collaboration and synergies.

Furthermore, the focus was on a subset of the indicators in one municipality. Further research could broaden the scope to include a wider array of indicators, either in the ECP, or across different municipalities. Such comparative studies could help identify common patterns and barriers, thereby supporting generalization and offer more robust guidance for urban sustainability assessments.

As the City of Gothenburg is a large municipality by Swedish standards, it would also be valuable to investigate whether the challenges identified here are of a similar nature in smaller municipalities. Furthermore, this thesis reflects the perspectives of employees directly involved in the ECP. Incorporating the views of additional stakeholders would provide a more comprehensive understanding of the barriers and opportunities in municipal indicator development and use.

From literature, it was identified that indicators covering isolated dimensions may weaken their effectiveness, and that the inclusion of social impacts such as health and safety is underdeveloped. Further research could explore how to better integrate the social dimension into ecological indicators, to more fully capture the interactions between these dimensions.

7
Conclusion

This thesis aimed to investigate the monitoring and evaluation processes of the City of Gothenburg's ECP, with a particular focus on indicators. Additionally, it investigated how effectively the indicators measure progress towards the ECP's environmental goals and how they can be improved. This was achieved by examining the evaluation process, assessing indicator and data quality, and by identifying barriers and opportunities of indicator use. By interviewing eleven employees at the Environmental Administration, and evaluating indicator performance, data quality, and the indicator system, the assessment resulted in the identification of the following barriers and opportunities.

First, a majority of the indicators do not capture distributional effects, making it harder to identify communities or areas in need of targeted interventions. In many cases, sufficiently granular data exists. However, integrating these aspects would require balancing the benefits of more nuanced indicators against the time and resources needed to develop and maintain them. This reflects a broader challenge seen in urban sustainability assessments: the lack of integration between the ecological and the social dimension of sustainability.

Another key finding was the absence of a framework for indicator development, which instead has relied on informal principles. Many of these principles align with best practices found in the literature and can contribute to more consistent indicators. These principles could serve as a foundation for a tailored approach. The goal coordination team is well placed to lead this effort. The potential benefits of adopting a shared framework are clearer structure, improved transparency, and institutionalization of knowledge.

The third finding to be highlighted is the challenge emerging from the Environmental Administration being part of a large and complex organization. Despite the identified challenges of collaboration, accountability and consistency, it remains essential as the indicators require data and information from a multitude of administrations and companies in order to measure the progress of the City of Gothenburg. If properly implemented, it can also provide benefits, with formal agreements aiding in securing data provision and quality, along with providing indicators with long-term stability, as the risk of data no longer being produced or supplied decreases.

Although the ECP's development included input from other municipalities and internal stakeholders, it excluded public participation due to time constraints. However, public involvement could enhance indicator relevance and communication by reflecting community priorities. Future iterations of the ECP could benefit from participatory processes, such as citizens' assemblies, which can help ensure indicators are better aligned with social concerns and public understanding. Methods such as the Q-method could combine top-down expertise with bottom-up input, fostering more inclusive and effective indicator design.

This thesis highlights several directions for further research. First, within the City of Gothenburg, a more detailed exploration of data pathways and demands could help inform the development of a shared data system. Second, broader comparative studies across municipalities and a wider range of indicators would also provide insights into common challenges and opportunities for generalization. Finally, there is a need for further research focusing on better reflecting socioecological interactions for indicators.

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A

Strategies in the ECP

Table A.1: Strategies in the ECP, their intent, and the responsible coordinator (1).

Strategy	**Intent**	**Coordinator**
We act as forerunners	Driving the transition to an ecologically sustainable society and become one of the world's most progressive cities in preventing and addressing environmental and climate issues.	The Environmental- and Climate Committee
We create conditions for living sustainably	The city of Gothenburg, through its committees and boards, will create conditions for those who visit, live, and work in Gothenburg to live sustainably. The city will use all ithe tools and instruments at its disposal to enable a sustainable lifestyle where it is easy to make environmentally smart choices.	The Committee for Democracy and Citizen-service
We drive the development of a circular economy	To reduce resource depletion, emissions, and the spread of toxins, the City of Gothenburg aims to shift to circular economy principles in its own operations. This includes reducing consumption, improving effciency amd promoting reuse, non-toxic materials, and shared products.	Göteborgs Stad Leasing AB
We work strategically with financing to accelerate the transition	To cover investments and operations that accelerate the transition, funds will be sought from the EU as well as the nation. Sustainable investments should support environmental and social transitions and harmful lock-ins must be avoided.	The Environmental- and Climate Committe

Table A.2: Strategies in the ECP, their intent, and the responsible coordinator (2).

Strategy	Intent	Coordinator
We drive the development of sustainable conctruction	All construction in the city will focus on people's needs for quality of life, good health, and resource efficiency. The strategy covers new construction, renovation, and adaptations of buildings and facilities.	Förvaltnings AB Framtiden
We plan for a green and robust/resilient city	Green infrastructure should be viewed as a foundational element and a natural part of urban planning in the city, both in strategic and early planning stages. Urban greenery, blue structures, and ecosystem services should be integrated in planning and management. Building a resilient city also includes planning for the impacts of climate change, with green infrastructure playing a role in the climate adaptation.	Real Estate Committee
We drive the development of sustainable transports	The City of Gothenburg strives for a modern transport system with minimal environmental and health impacts. Urban planning should prioritize proximity, density, and mixed-use. Gothenburg Port offers the opportunity for the city to become a leader in the climate transition of transport system in Northern Europe.	Traffic Administration Committee

B
Indicator Method Descriptions

Sub-goal One

I1.1 & I1.2
Data on the number of chemical products containing phase-out substances used in the city's operations is collected in the software Chemsoft. For the administrations and companies not using the software, an inquiry is instead sent by mail, asking for the required information on the chemical products. A list of the actors not using Chemsoft exists and is updated regularly. This indicator is monitored on a yearly basis. For the actors using Chemsoft, the evaluation is performed based on the list that is automatically saved in the system at the end of every year. For those who do not, a request for information is sent in January every year. For I1.2 the same method is used, with the sole distinction being that the list of substances from the Swedish Chemicals Agency and ChemSec's SIN-list now contains risk reduction substances instead of phase-out substances.

I1.3
A form is created where relevant administrations and companies fill out their use of construction products and materials. The affected parties compile their data in project folders in a logging system, which the environmental administration do not have access to. The evaluation is performed annually, with the form being sent during autumn. The share of building materials and products in the city's logs in the Building Product Assessment that have a total assessment of "recommended" or "accepted".

Sub-goal Two

I2.1
Values are calculated by combining map layers for NO_2 concentrations with map layers for preschools, resulting in the total number of kindergartens with an annual average concentration below 20 micrograms per cubic meter . The measurements of air quality are performed by the environmental administration independently from the indicator itself, and the latest available measurement is used for the calculation. The map layer containing preschools comes from Serviceguiden with an unknown update frequency. The calculations are performed on a yearly basis, with possible deviations.

I2.2
The same method is used as for I2.1, with the slight difference that the maplayer for NO_2 is replaced with the equivalent for PM_{10}.

I2.3
Maplayers of the NO_2 concentrations are combined with maplayers for the contiguous urban areas. With these combined, it can be calculated how much of the contiguous urban area in Gothenburg that has NO_2 concentrations above 20 micrograms per cubic meter.

I2.4
The same method is used as for I2.3 except that PM_{10} maplayers replace the NO_2 maplayers.

Sub-goal Three

I3.1 and I3.2
Four different datasets are required to calculate the indicator value for I3.1 and I3.2. First a noise mapping that is performed by the environmental administration and performed every five years, with smaller updates more regularly. SoundPlan software. Second, a map layer containing preschool playgrounds, divided into old and new. Old preschools are defined as those built before 2017, and new as those built in 2017 or after. For I3.1 the new preschools playgrounds are used together with the noise mapping, to see how many clear the threshold of 50 or less dBA. The same is done for I3.2, but the threshold is 55 dBA.

I3.3
A noise mapping modeled in SoundPLAN is utilized. This noise mapping is produced independently of the indicator itself, and is performed every five years with smaller updates in between. It is complemented with a continuously updated map layer containing the spread of settlements. With these datasets, the noise level at facades can be calculated. New buildings are then identified by subtracting the previous map layer with the spread of settlements with the new one. The evaluation of exposure is done with a python script in QGIS.

I3.4
I3.4 utilizes the outcome on access to green areas produced in I4.2 (see below) and combines it with the modelled noise mapping. The outcome is then produced by cropping and identifying which areas meet the threshold of <50 dBA.

Sub-goal Four

I4.1
Data on the Biotope Area Factor (BAF) is required. This data has previously been collected by the Property Management Administration through inspecting the

share of vegetation at preschool playgrounds. This indicator will be removed from the ECP as the data required for its evaluation is no longer collected. Thus, little information on the method exists. The discussion is ongoing for possible indicators to replace this one.

I4.2

The calculations uses three datasets. The first dataset is a map layer of the green areas within Gothenburg, which is accessed from a database containing national land cover data from the Swedish EPA and the overview plan of Gothenburg. The national land cover data is updated every five years. The second dataset is the transport network data, specifically concerning walking and biking. This data is collected from Gothenburg's City Planning Authority, and was updated in 2018 and in 2023. The third and final dataset is the population data of Gothenburg. This is also supplied by the City Planning Authority and is continuously updated. The map layers containing population data, transportation network data, and national land cover data are added to a QGIS-project where the distance between two points (in this case the distance between an address point and a point on the perimeter of a green space, along a given transport network) are calculated using an add-on Place Syntax Tool. The number of people with more than 300 meters to a green space bigger than 0.2 hectares, are then calculated in FME.

Direct Indicators

D1

D1 measures the yearly road traffic work, which is is a measure on the amount of traffic on the transport network. It is estimated by utilizing data from 71 cameras for congestion fees and fixed measurement points for traffic. These datasets are used in a method developed by SMF together with the consulting firm WSP, together with data on the traffic network from WSP. The method involves performing traffic counts at the same stratums as during the start year and the calculations are performed through a combination of the transport modeling software EMME and a Python script. The road traffic work is calculated and compared to the start year per stratum before the result is summarized. Since cameras for congestion fees are used as a data source, the method doesn't take into account the travel that is being done within, and outside the area where cameras are located. The result from this is the amount of driven kilometers with motorized road vehicles in the City of Gothenburg. The data is updated on an annual basis, and the indicator outcome is submitted to the Environmental Administration by the City Planning Authority, where it is calculated by traffic analysts.

D2

The shares of green- and blue spaces in contiguous urban areas is produced by combining map layers in FME of the green- and blue spaces within the City of Gothenburg with a map layer of the contiguous urban area. The first dataset comes from the Swedish EPA's national land over database, and is updated every fifth year. The second set of data comes from the City Planning Office with unknown update frequency. The result of this is the share of blue and green spaces that overlap with the contiguous urban area.

D3

D3 is the indicator measuring the access to urban cool islands and is calculated in two steps, the first of which includes using data on green spaces within the geographical area and heatmaps of urban surface temperatures. These datasets are combined in QGIS to map the temperatures of the green areas. The data on green spaces is collected from a national database of land cover from the Swedish EPA (which is updated every five years) and the overview plan of the City of Gothenburg. The heatmaps are extracted from the Swedish Civil Contingencies Agency and are updated every year. In the second step transport network data and population data is added and the Place Syntax Tool is utilized to calculate inhabitants' access to urban cool islands. Both the population data and the transport network data is supplied by the City Planning Authority, the first of which is updated on a continuous basis, whereas the latter has been updated in 2018 and 2023.

D4

D4 is used to gauge the share of detail development plans set on municipal grounds that include the BAF in its consultation. A list of detail development plans that have been out on consultation is collected for the relevant year, and the share containing calculated and weighted BAFs are compiled using the project portfolio management tool Antura. This compiled list is then sent to the Environmental administration from the City Planning Authority. The share of detail development plans containing calculated and weighted BAFs is calculated on a yearly basis, however the list is compiled every other year during the evaluation of the ECP.

C

PICABUE Evaluation

Table C.1: Complementary explanations for the evaluation of indicators using the PICABUE framework. Criteria A1 and A2.

Indicator	Relevance & scientific validity	Sensitivity to change across space
I1.1	Aligns with the sub-goal, but not the main goal. Lists of substances are from the Swedish Chemicals Agency and ChemSec's SIN-list.	Does not identify distributional effects.
I1.2	Aligns with the sub-goal, but not the main goal. Lists of substances are from the Swedish Chemicals Agency and ChemSec's SIN-list.	Does not identify distributional effects.
I1.3	Aligns with the sub-goal, but not the main goal. List of recommended and accepted building materials from Byggvarubedömningen.	Does not identify distributional effects.
I2.1	Aligns with both sub-goal and main goal. Scientifically valid.	Identifies distributional effects through the inclusion of a vulnerable population.
I2.2	Aligns with both sub-goal and main goal. Scientifically valid.	Identifies distributional effects through the inclusion of a vulnerable population.
I2.3	Aligns with both sub-goal and main goal. Scientifically valid.	Does not identify distributional effects.
I2.4	Aligns with both sub-goal and main goal. Scientifically valid.	Does not identify distributional effects.
I3.1	Aligns with both sub-goal and main goal. Scientifically valid.	Identifies distributional effects through the inclusion of a vulnerable population.
I3.2	Aligns with both sub-goal and main goal. Scientifically valid.	Identifies distributional effects through the inclusion of a vulnerable population.
I3.3	Aligns with both sub-goal and main goal. Technical validity hampered by software.	Does not identify distributional effects.
I3.4	Aligns with both sub-goal and main goal. Scientifically valid.	Does not identify distributional effects.
I4.1	Aligns partially with sub-goal and main goal. Weak relationship to the issue of concern	Identifies distributional effects through the inclusion of a vulnerable population.
I4.2	Aligns partially with sub-goal and main goal. Weak relationship to the issue of concern	Does not identify distributional effects.
D1	Aligns with main goal. Scientifically valid.	Does not identify distributional effects.
D2	Aligns with main goal. Scientifically valid.	Does not identify distributional effects.
D3	Aligns with main goal. Scientifically valid.	Does not identify distributional effects.
D4	Aligns partially with main goal. Weak relationship to the issue of concern.	Does not identify distributional effects.

Table C.2: Complementary explanations for the evaluation of indicators using the PICABUE framework. Criteria A3 and A4.

Indicator	Sensitivity to change over time	Consistency of data
I1.1	Identification of trends is not possible due to a shifting baseline.	Inconsistent data collection, due to not all actors having the required expertise or software.
I1.2	Identification of trends is not possible due to a shifting baseline.	Inconsistent data collection, due to not all actors having the required expertise or software.
I1.3	Reference value allows for easier trend identification. Shifting baseline?	Incosistent data collection, due to ot all actors having log books.
I2.1	Identification of trends is possible, however affected by natural variability.	Supported by adequate data, allows for trend identification and monitoring is future proof.
I2.2	Identification of trends is possible, however affected by natural variability.	Supported by adequate data, allows for trend identification and monitoring is future proof.
I2.3	Identification of trends is possible, however affected by natural variability.	Supported by adequate data, allows for trend identification and monitoring is future proof.
I2.4	Identification of trends is possible, however affected by natural variability.	Supported by adequate data, allows for trend identification and monitoring is future proof.
I3.1	Identification of trends is possible.	Supported by adequate data, allows for trend identification and monitoring is future proof.
I3.2	Identification of trends is possible.	Supported by adequate data, allows for trend identification and monitoring is future proof.
I3.3	Identification of trends is possible.	Supported by adequate data, allows for trend identification and monitoring is future proof.
I3.4	Identification of trends is possible, however national land cover data hampers results due to infrequent updates.	Partially supported by adequate data and monitoring is future proof.
I4.1	Identification of trends is possible.	Discontinuation of data collection made the evaluation impossible.
I4.2	Identification of trends is possible. Infrequent updates of national land cover data and slow rate of change complicates assessment.	Partially supported by adequate data and monitoring is future proof.
D1	Identification of trends is possible.	Supported by adequate data, allows for trend identification and monitoring is future proof.
D2	Identification of trends is possible. Infrequent updates of national land cover data and slow rate of change complicates assessment.	Partially supported by adequate data and monitoring is future proof.
D3	Identification of trends is possible, however affected by natural variability.	Partially supported by adequate data and monitoring is future proof.
D4	Identification of trends is possible, however affected by variance in collected data.	Partially supported by adequate data and monitoring is future proof.

Table C.3: Complementary explanations for the evaluation of indicators using the PICABUE framework. Criteria A5 and A6.

Indicator	Comprehensibility	Appropriate data transformation
I1.1	Shifting baseline hinders the differentiation of desirable and undesirable conditions.	Data is not transformed in a way that enhances understanding.
I1.2	Shifting baseline hinders the differentiation of desirable and undesirable conditions.	Data is not transformed in a way that enhances understanding.
I1.3	Easily understandable but no clear differentiation of desirable and undesirable conditions.	Data transformation increases the understanding through the inclusion of a reference value.
I2.1	Clear threshold values allows for the differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.
I2.2	Clear threshold values allows for the differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.
I2.3	Clear threshold values allows for the differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.
I2.4	Clear threshold values allows for the differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.
I3.1	Clear threshold values allows for the differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.
I3.2	Clear threshold values allows for the differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.
I3.3	Clear threshold values allows for the differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information, however software limitations can skew results.
I3.4	Clear threshold values allows for the differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.
I4.1	Unclear threshold value, no clear differentiation of desirable and undesirable conditions.	Data is not transformed in a way that enhances understanding.
I4.2	Easily understandable but no clear differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.
D1	Easily understandable but no clear differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.
D2	Easily understandable but no clear differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.
D3	Easily understandable but no clear differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.
D4	Easily understandable but no clear differentiation of desirable and undesirable conditions.	Data transformation helps to clearly convey indicator information.

Table C.4: Complementary explanations for the evaluation of indicators using the PICABUE framework. Criteria A7 and A8.

Indicator	Measurable data	Possible target/threshold values
I1.1	Not all data is collected with approprate instrumentation. Lack of quality assurance.	The target value represents a desirable outcome, however unfavorable outcomes are difficult to identify.
I1.2	Not all data is collected with approprate instrumentation. Lack of quality assurance.	The target value represents a desirable outcome, however unfavorable outcomes are difficult to identify.
I1.3	Not all data is collected with approprate instrumentation. Lack of quality assurance.	The target value represents a desirable outcome, however unfavorable outcomes are difficult to identify.
I2.1	Methodologically relevant, appropriate instrumentation, standardized procedure. Removal of redundant information has been done.	The indicator identifies both desirable and unfavorable outcomes.
I2.2	Methodologically relevant, appropriate instrumentation, standardized procedure. Removal of redundant information has been done.	The indicator identifies both desirable and unfavorable outcomes.
I2.3	Methodologically relevant, appropriate instrumentation, standardized procedure.	The indicator identifies both desirable and unfavorable outcomes.
I2.4	Methodologically relevant, appropriate instrumentation, standardized procedure.	The indicator identifies both desirable and unfavorable outcomes.
I3.1	Methodologically relevant, appropriate instrumentation, standardized procedure.	The indicator identifies both desirable and unfavorable outcomes.
I3.2	Methodologically relevant, appropriate instrumentation, standardized procedure.	The indicator identifies both desirable and unfavorable outcomes.
I3.3	Methodologically relevant, appropriate instrumentation, standardized procedure.	The indicator identifies both desirable and unfavorable outcomes.
I3.4	Methodologically relevant, appropriate instrumentation, standardized procedure. Data is partially valid, accurate and available on time.	The indicator identifies both desirable and unfavorable outcomes.
I4.1	Measurements are not technically and financially sustainable. Lack of quality assurance.	The target value represents a desirable outcome, however unfavorable outcomes are difficult to identify.
I4.2	Methodologically relevant, appropriate instrumentation, standardized procedure. Data is partially valid, accurate and available on time.	The target value represents a desirable outcome, however unfavorable outcomes are difficult to identify.
D1	Methodologically relevant, appropriate instrumentation, standardized procedure.	The target value represents a desirable outcome, however unfavorable outcomes are difficult to identify.
D2	Methodologically relevant, appropriate instrumentation, standardized procedure. Data is partially valid, accurate and available on time.	The target value represents a desirable outcome, however unfavorable outcomes are difficult to identify.
D3	Methodologically relevant, appropriate instrumentation, standardized procedure. Data is partially valid, accurate and available on time.	The target value represents a desirable outcome, however unfavorable outcomes are difficult to identify.
D4	Methodologically relevant, appropriate instrumentation, standardized procedure.	The target value represents a desirable outcome, however unfavorable outcomes are difficult to identify.

D
Codes from Thematic Analysis

Table D.1: Codes and frequency of occurrence from the thematic analysis.

Code	Frequency
Data Quality	38
Indicator Quality	51
Method	62
Goal Alignment	38
Framework or Principles	26
Supporting Indicators	18
Additional Indicator Functions	10
Data Collection	32
Environmental Management System	3
External Communication	47
External Competence	23
Internal Communication	12
Internal Competence	16
Complexity	15
Revision	12
Routines and Structures	54
Synergies	21
Development	48

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