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Design of a digital solution for monitoring of climate change in communities

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A. INTRODUCTION & SUMMARY

Context

With climate change posing significant challenges to communities worldwide, the current trends in climate change research extend the development of green solutions to the promotion, design, and uptake of resilient measures. For communities in Central Europe extreme weather events have become commonplace, especially flooding and heat waves. The accelerating impacts of climate change require communities to enhance their resilience through timely access to reliable information and adaptive solutions. This report presents the design of a digital solution for monitoring climate change in communities, with a focus on a modular dashboard that integrates diverse data sources and addresses the needs of both citizens and experts.

Designing resilience measures for above mentioned events requires effective data-driven decision-making to enable rapid response and targeted impact. This document addresses this need by presenting a framework for designing and integrating data-driven solutions that enable resilient communities to climate change in the region. Building on the Quadruple Helix and Co-Creation approaches, a methodology is outlined for developing and evaluating dashboards that address key stakeholder needs, particularly those of municipalities and their service providers. By reviewing existing work and identifying key criteria for dashboard development and integration (UX/UI, data quality, AI/ML adoption, business models), this paper provides a structured approach to assessing and tailoring dashboards for specific community contexts. The findings highlight best practices for selected municipalities in Central Europe, demonstrating the potential of our framework to enhance resilience to climate change through effective data-driven decision making.

Summary & Objective

The objective of this deliverable is to develop a concept of a digital solution rather than the implementation of the tool itself. The proposed concept leverages Earth Observation data (e.g., Copernicus), local sensor networks, and citizen science contributions—collected via IoT infrastructures such as LoRaWAN—to provide accurate, localised, and real-time climate indicators. A dual-dashboard approach ensures that citizens receive accessible and engaging tools for awareness-raising and informed decision-making, while experts gain advanced features for natural hazard management, scenario analysis, and climate risk assessment.
The design emphasises participatory approaches, aligning with community-specific user needs through a participation matrix and defined use cases. Its modular architecture supports scalability, adaptability to different contexts, and interoperability with existing climate data systems.

The technical implementation discusses data integration strategies, interface design principles (UI/UX considerations), and system performance requirements to ensure usability and sustainability. Practical examples and good practices are highlighted to demonstrate potential benefits, while a promotion and dissemination strategy is outlined to foster community engagement and long-term adoption.A methodology for best practices of digital solutions within the Mission CE Climate’s context, including the project’s case studies of digital solutions and assessment templates concludes this report.

This deliverable provides an in-depth exploration of the diverse requirements involved in developing such solutions. It begins by outlining the purpose and context, emphasizing the pressing climate challenges facing Central Europe, the relevance of quadruple and quintuple helix frameworks, the importance of citizen involvement, and the landscape of existing climate-information services. It then addresses requirements derived from regional climate models, including technical aspects such as the role of UI/UX in creating dashboards that are both practical and engaging. Building on this foundation, the document introduced several design approaches, focusing on modular dashboard development, overarching design objectives, a participation matrix connecting data granularity to levels of citizen engagement, and a technical overview of potential enabling technologies.

The user-needs analysis identified key stakeholder and user groups, highlighted climate indicators essential for resilience, and summarised insights from the consortium survey. The study also reviewed selected publicly accessible EU data sources and compiled good practices contributed by consortium partners. Taken together, these findings show that creating effective modular dashboards demands not only technological innovation but also cross-sector collaboration and ongoing community participation to genuinely advance climate-resilient futures.

Approach & Methodoloy

The document adopts a design- and user-centred methodology that combines conceptual framework development, requirements analysis, and modular technical design to create digital dashboards for climate-resilient communities. It starts by framing the problem in terms of Central Europe’s climate risks and then positions the work within quadruple and quintuple helix approaches, emphasising co-creation with citizens, public authorities, academia, and industry. On this basis, it defines key questions, reviews existing climate information services and regional climate model requirements, and derives functional, data, and UI/UX requirements for dashboards. A modular architecture is then proposed, including a participation matrix that links data granularity and functionality to different user groups and engagement levels, as well as an outline of data integration and processing pipelines combining Earth observation data, local sensors, and citizen science. Exemplary technological tools are presented and compared.

Building on these conceptual and technical foundations, the methodology uses a user needs analysis and real-world examples to iteratively refine and validate the approach. Stakeholder and target groups are identified, relevant climate indicators and additional information needs are specified, and use cases are collected from project partners to capture practical requirements and constraints. The methodology is operationalised through the collection of best practice templates applied to three municipal examples (Pforzheim, Košice, Dornbirn), where each case documents the local context, digital solution, technology stack, implementation details, impacts, and use cases. Insights from these cases are then synthesised into design principles and assessment criteria that can be reused to replicate modular climate dashboards for other communities.

Outline

Overall, the document explains the need for digital, data-driven tools to strengthen community resilience against climate-related hazards such as floods and heatwaves in Central Europe. It presents the deliverable’s objective as the design of a concept (as opposed to a technical description of a full implementation) for a modular dashboard that integrates Earth observation data, local sensors, and citizen science, targeting both citizens and experts through dashboard approaches.

In total, this document consists of seven parts; part A consists of an introduction, part B sets the context towards climate resilience, part C focuses on dashboard design, and part D looks at existing tools and initiatives of digital solutions. Parts E, F, and G describe good practices.

In the section on the contribution of digital solutions and the dashboard design (part B, page 9), the document outlines the overall purpose and context, including the climate challenges, the relevance of quadruple and quintuple helix frameworks, and the role of citizen participation. It then sets out requirements derived from regional climate models, key questions to be addressed, and the landscape of existing climate information services, followed by a modular design approach with design goals, a participation matrix, and a technical overview of data integration and processing architectures (chapter 2, page 23).

In the user-needs part (chapter 3, page 31), the document describes how to identify stakeholder and target groups, defines climate indicators and complementary climate information needed for dashboards, and summarises user needs and use cases gathered from the project consortium (based on survery across project partners), extending them with relevant approaches towards awareness-raising for citizens. In the section on existing tools and initiatives (chapter 4, page 42), it reviews relevant digital tools and supporting initiatives, highlighting resources such as Copernicus and other Earth observation data services, as well as enabling technologies like FIWARE.

Afterwards, the document describes three good practices: Pforzheim, Košice, and Dornbirn.

In the Pforzheim good practice chapters (part E, page 48), the document provides general information about the city’s context, describes the local digital solution and target groups, and outlines expected impacts, technical implementation, and an implementation overview illustrated with screenshots. It then details a broad set of concrete use cases, ranging from school air monitoring and citizen-led soil and flood monitoring to urban heat mapping, smart logistics, AI-based analysis, infrastructure management, and smart building energy management.

In the Košice good practice chapters (part F, page 74), the document likewise presents general information, describes the digital solution, its target groups, and patterns of stakeholder collaboration, and assesses qualitative and quantitative impacts. It also specifies technical implementation details including data sources and data types, provides an implementation overview with screenshots, and elaborates use cases such as educational dashboards, community engagement via linked apps, and strategic use by school management and municipal governance through open data portals.

In the Dornbirn good practice chapters (part G, page 86), the document offers general information and a description of the digital solution, including the technology stack, monitored climate indicators, geographical coverage, target groups, and expected impacts. It further outlines implementation aspects, presents illustrative screenshots, and lists use cases that demonstrate how modular climate dashboards support local climate monitoring and decision-making.

In the concluding part, the document ends with references and an appendix containing a best-practice template for documenting and assessing digital solutions within the project’s context.

B. THE CONTRIBUTION OF DIGITAL SOLUTIONS IN ENHANCING CLIMATE RESILIENCE IN COMMUNITIES

As the world struggles with the escalating impacts of climate change, the need for robust climate resilience strategies has become increasingly evident. Central Europe, with its unique blend of developed urban centres, rich agricultural lands, and diverse ecosystems, is particularly vulnerable to the adverse effects of climate change. This region faces numerous challenges, including more frequent and severe weather events, changing precipitation patterns, sea level rise, and rising temperatures. These changes threaten not only the environment but also the socio-economic stability of Central European communities. The economic costs of these impacts are substantial: according to a study by the European Environment Agency, between 1980 and 2022, weather- and climate-related extremes caused economic losses of assets estimated at EUR 650 billion in the EU Member States (European Environment Agency, 2023). Without adequate resilience measures, these costs are expected to rise significantly, placing further strain on national and local economies and potentially exacerbating social inequalities. Together with these impacts, climate change threatens Central Europe's diverse ecosystems, disrupting species distribution and increasing vulnerability to invasive species; the degradation of wetlands and forests diminishes natural flood buffering and biodiversity, increasing the risk of flooding in downstream communities. The malfunction of these ecosystems not only diminishes their ability to provide critical services but also undermines the cultural and recreational value they offer to local communities.

Given the diverse and interconnected impacts of climate change on Central Europe, the development and implementation of comprehensive climate resilience strategies are essential. These strategies must be multifaceted, encompassing a range of measures aimed at reducing vulnerability, enhancing adaptive capacity, and building resilience across different sectors and governance levels. One key component of such strategies is the integration of climate considerations into urban planning and development (designing and retrofitting infrastructure to withstand extreme weather events, implementing Nature-based Solutions such as green roofs and permeable pavements to manage stormwater, and enhancing green spaces to mitigate urban heat islands and provide cooling benefits). In the agricultural sector, resilience strategies may include adopting climate-smart agricultural practices (i.e. crop diversification, conservation tillage, and improved irrigation techniques). Furthermore, protecting and restoring natural ecosystems is a crucial aspect of climate resilience. This includes measures to conserve biodiversity, restore degraded habitats, and enhance the connectivity of natural landscapes to facilitate species migration and adaptation: reforestation and afforestation initiatives can sequester carbon, improve soil and water quality, and provide critical habitat for wildlife, contributing to both climate mitigation and adaptation goals.

Effective climate resilience strategies also require robust policy frameworks and active community engagement. Governments at all levels must prioritise climate resilience in their policy agendas, allocating resources, and providing incentives for resilience-building initiatives. This includes developing and enforcing regulations that promote sustainable land use, reduce greenhouse gas emissions, and enhance disaster preparedness and response capabilities. Community involvement is equally important. Building climate resilience is not just the responsibility of governments and experts; it requires the active participation of local communities, businesses, and civil society organizations. Public awareness campaigns, educational programs, and participatory planning processes can empower communities to understand their vulnerabilities, identify resilience-building opportunities, and take proactive measures to protect themselves and their livelihoods.

Therefore, developing and implementing effective climate resilience strategies is imperative to safeguard these communities and ensure their sustainable development. The path to resilience requires collaborative efforts, innovative solutions, and a long-term commitment to safeguarding the environment and the well-being of present and future generations. Digital solutions, especially (modular) dashboards, can help in implementing these strategies.

Digital solutions play a role in enhancing climate resilience by providing communities with the tools to better anticipate, monitor, and respond to climate-related risks. Advanced data analytics, satellite monitoring, and climate modelling enable more accurate forecasting of extreme weather events, allowing local authorities and residents to take timely preventive actions. Early warning systems powered by digital technologies can disseminate real-time alerts through mobile applications, social media platforms, or community-based communication networks, ensuring that vulnerable populations receive critical information quickly. At the same time, digital platforms facilitate the integration of diverse datasets (such as land use, hydrological conditions, and socio-economic indicators) into comprehensive risk assessments that inform evidence-based decision-making at both municipal and regional scales. By making climate information more accessible and actionable, digital tools strengthen preparedness and reduce the long-term costs of climate impacts.

The integration of citizen science can further help in implementing resilience strategies by not only harnessing data but also contributing to the mindset in a region or community. Similarly, participatory digital platforms allow communities to engage directly in resilience planning, share local knowledge, and co-design adaptive measures that suit their specific needs. These solutions not only improve technical capacity but also foster inclusive governance, empowering citizens to actively shape climate resilience strategies and ensuring that no group is left behind in the face of growing climate challenges.

C. DASHBOARD DESIGN

1. Purpose and Context

Due to global warming and climate change, communities around the world face increasing challenges not only in mitigating but also in adapting to climate change. In its Synthesis Report for Policymakers of the Sixth Assessment Report (2023), the Intergovernmental Panel on Climate Change (IPCC) summarizes key findings on the current and projected impacts of climate change in various sectors and regions (Calvin et al., 2023). The extent of these impacts depends on the pathways of climate-resistant development which integrate greenhouse gas (GHG) mitigation and adaption strategies to address climate change consequences. (Calvin et al., 2023). Monitoring, assessing, and implementing climate-resilient development transitions are crucial for reducing greenhouse gas emissions while strengthening social, economic, and ecological resilience in communities (Calvin et al., 2023).

One of the key measures for effective climate adaptation strategies is building community knowledge through capacity development and accessible information services, such as climate services (Biesbroek et al., 2010; Calvin et al., 2023). Climate services play an important role in providing localized and user-oriented climate information, which improves climate literacy and supports informed decision making. However, for these services to be truly effective, they must be appropriately designed to ensure that climate information is accessible, actionable, and tailored to the specific needs of users (Riach & Glaser, 2024).

As an effective way to translate climate data into actionable insights, climate dashboards can serve as an information platform to support decision-making and other user purposes. Effective dashboard design is essential to ensure that climate information is user-friendly, actionable, and aligned with stakeholder needs. Well-designed dashboards not only facilitate the communication and application of climate data but also empower individuals and organizations to make evidence-based decisions, which consequently enhance adaptation planning and implementation (Brasseur & Gallardo, 2016).

This work examines how effective dashboard design enhances climate resilience in communities. By integrating climate data, supporting evidence-based decision-making, and aligning with key criteria such as UX/UI design, data quality, AI/ML integration, and sustainable business models, the framework should help to better support communities in their climate adaptation efforts. These criteria will be framed within the Quadruple Helix Model, ensuring active and effective integration of the four key actors: academia, industry, government, and civil society. The framework aims to promote agile software development, based on collaborative and user-centred dashboard design, to effectively meet stakeholder needs.

Digital tools play a pivotal role in meeting these needs by transforming climate data into actionable insights. Dashboard serve as critical enablers by integrating diverse data sources—including Earth Observation Systems (EOS), IoT sensors, and local datasets—and presenting them through user-friendly interfaces. These tools empower stakeholders to assess vulnerabilities, design adaptive measures, and coordinate crisis responses effectively (Giuliani et al., 2017; Lehmann et al., 2021; Schumann et al., 2018).

Dashboards can be powerful tools in a climate resilient development of communities. They enable data-driven decision making and can help in understanding climate change and the resulting risks in a comprehensive way. Some important characteristics of climate change related dashboard are the following:

- Real-time data integration: For example, the *Heatalyzer* monitors live temperature data, offering communities actionable insights into heatwave conditions (Capol et al., 2024).
- Early warning systems: Real-time alerts facilitate proactive disaster preparedness (Giuliani et al., 2017; Schumann et al., 2018).
- Resilience planning: GIS-based dashboards can map vulnerabilities, assess risks, and simulate resilience strategies tailored to specific regions (Giuliani et al., 2017; Paranunzio & Marra, 2024).
- Community engagement: Participatory dashboards leverage citizen-generated data, ensuring local relevance and fostering collaboration (Lock et al., 2020).
- Making informed decisions: By aggregating climate and socio-economic data, dashboards support evidence-based policies and efficient resource allocation (Aguiar et al., 2024; Contreras et al., 2022; Lehmann et al., 2021).

By combining advanced analytics, participatory design, and real-time data processing, dashboards bridge the gap between complex climate information and practical solutions.

1.1. Quadruple and Quintuple Helix Approaches

Traditional models of innovation have largely focused on interactions between academia, industry, and government, known as the Triple Helix model. This approach has long been regarded as a foundation for knowledge production and technological advancement. However, as modern innovation systems have become more complex and decentralized, the need for greater public engagement and real-time data access has led to the emergence of the Quadruple Helix model. The Quadruple Helix (QH) model expands the Triple Helix framework by integrating civil society alongside the three other dimension. The QH framework highlights the growing role of civil society as an essential actor in innovation, particularly in addressing social, environmental, and economic challenges (Roman et al., 2020; Stephens, 2025). Rather than viewing innovation as a top-down process driven by governments and businesses, the QH model envisions a more participatory approach, where the public collaborates directly with research institutions, policymakers, and the private sector in a so-called co-creation process (Stephens, 2025).

At the policy level, the QH framework has been widely adopted within European innovation strategies, with the European Union (EU) placing the QH model at the forefront of its innovation agenda, particularly within Research and Innovation Strategies for Smart Specialization (RIS3) (Roman et al., 2020).

The implementation of the QH model varies across different contexts. In urban settings, cities are often the epicentres of innovation, where interactions between stakeholders are facilitated through digital tools, participatory platforms, and community-driven initiatives. Co-creation in cities has been particularly effective in tackling complex social and environmental challenges by fostering direct engagement between governments, businesses, and civil society (Roman et al., 2020; Stephens, 2025).

Due to the density, as well as the frequency and variety of activities, urban regions are predestined for QH co-creation processes. In contrast, its implementation in regional innovation strategies has been more challenging. A major issue in regional implementation is that governments and industries often dominate innovation processes, leaving limited room for meaningful community participation. This is particularly problematic in climate adaptation planning, where local knowledge and real-time data integration are crucial for developing effective regional responses to climate change. In this regard, climate dashboards could serve as a potential solution, allowing regional policymakers and civil society to access real-time environmental data, climate risk projections, and localized mitigation strategies. By making data more accessible and transparent, these platforms can strengthen evidence-based decision-making in regional innovation strategies.

Although the QH model presents a compelling framework for sustainable innovation, its implementation faces several barriers that need to be addressed. One of the primary challenges is defining the role of civil society in innovation processes, as the literature is not giving clearly defined indicators to the concept of co-creation (Stephens, 2025).

Institutional resistance presents another significant barrier. Many public and private sector actors struggle to integrate bottom-up participation into established governance structures. Without fostering accessible collaboration spaces to ensure meaningful participation, co-creation risks becoming a top-down process, contradicting the very essence of the QH model (Stephens, 2025).

Creating digital participation platforms, such as climate dashboards, can enhance to tackle this problem. By ensuring transparency and facilitating citizen-driven innovation, climate dashboards can serve as platforms for multi-stakeholder collaboration between government, academia, industry, and civil society. Furthermore, as climate adaptation and innovation continue to evolve, leveraging the Quadruple Helix approach with real-time climate monitoring tools could significantly enhance the effectiveness of sustainability initiatives worldwide.

1.2. Key Questions to be Addressed

Based on the needs of data-driven decision-making and the potential to enhance climate resilience in Central European communities, as outlined in sections 1.1. Quadruple and Quintuple Helix Approach and 3. User Needs, this work proposes a Dashboard Design Framework that integrates the Quadruple Helix approach. It aligns the needs, roles, and engagement strategies of academia, government, industry, and civil society with key software development principles—including data quality, user experience (UX), user interface (UI), artificial intelligence (AI) and machine learning (ML), and sustainable business models (BM).

By fostering data transparency and co-creation, the framework is aiming for a user-centred approach that empowers informed decision-making. To achieve this, we define the following main key question:

- How can dashboards be designed to enhance urban climate resilience in Central European communities based on a Quadruple/Quintuple Helix approach?
- What are the current limitations of existing dashboards for urban climate resilience in terms of usability, information accessibility, and business model approaches, including co-creation processes with civil society?
- What design principles and development approaches (e.g., visualization techniques, participatory methods, and machine learning) are most effective for creating user-centric dashboards tailored to diverse stakeholder needs?
- How can a scalable dashboard framework be developed and evaluated to ensure its practical applicability in supporting data-driven decision-making for climate adaptation?

1.3. Existing Climate Change Information Services

Climate change presents one of the most urgent global challenges, requiring innovative solutions to monitor, assess, and respond to its impacts. The increasing availability of environmental data has led to the development of climate dashboards—sophisticated digital platforms designed to provide insights into climate trends, risks, and policy strategies. These dashboards serve as crucial tools for researchers, policymakers, businesses, and communities to make informed decisions and take proactive measures in climate adaptation and mitigation.

By consolidating large datasets, climate dashboards enhance the accessibility and usability of climate-related information. They integrate various data sources, including satellite imagery, meteorological observations, and climate models, transforming raw data into meaningful visualizations. Many dashboards cater to specific regions or topics, ranging from global climate monitoring to localized adaptation strategies.

As climate change poses increasingly complex challenges, the need for robust, data-driven dashboards has grown significantly. These platforms serve as essential tools for monitoring, analysing, and planning climate change adaptation and mitigation strategies. Below, we explore prominent climate dashboards, highlighting their features, operational areas, data visualization methods, and target audiences.

Table 1 provides a comparative overview of nine climate dashboards designed for monitoring and adaptation. Overall, these platforms share several common features, such as interactive visualization tools and data analysis capabilities, while differing in geographic focus and user interface design.

For instance, the European Environment Agency’s Climate-ADAPT Platform (European Environment Agency, 2025) and Copernicus Climate Change Service (Copernicus, 2025) both offer extensive resources for data-driven decision making and policy support in Europe. These platforms are characterized by their interactive visualizations and tools for assessing vulnerabilities, making them particularly useful for local and regional governments.

Similarly, the platforms European Climate Assessment & Dataset (ECAD, 2025) and ZAMG Climate Data Hub (ZAMG, 2025) emphasize detailed climate trend analyses and localized data, targeting researchers and policymakers with visually rich interfaces.

In contrast, ClimateEU (Marchi et al., 2020) offers Europe-wide climate data that can be queried to support impact assessments and adaptation planning.

At a broader scale, global platforms like the European Space Agency's Climate Change Initiative (ESA, 2025) and NOAA Climate Dashboard (NOAA, 2025) focus on delivering worldwide climate indicators through satellite data and highly interactive tools, respectively. Additionally, the World Resources Institute's Climate Watch Europe (WRI, 2025) combines policy visualization with greenhouse gas tracking to monitor national climate targets.

Overall, the table highlights how these dashboards incorporate similar core functions, such as data aggregation and interactive user interfaces, while tailoring their features to suit specific regional needs and use cases. The selection of the most suitable platform for individual purposes differs due to diverse user needs and can range from localized adaptation strategies to global climate research.

Table 1: Overview of Different Climate Services and Dashboards

Platform	Features	Scope	User Interaction	Use Cases	Accessibility	Access
European Environment Agency – Climate-ADAPT Platform	Adaptation resources; Vulnerability tools	Europe (Regional level)	Interactive visualizations	Local & regional; policy	Open-source; Direct access	EEA Adaptation Dashboard
Copernicus Climate Change Service (C3S)	Extensive datasets; Analysis tools	Europe; Global support	Intuitive customization	Research; Policy	Open-source; Direct access	Copernicus Atlas
European Climate Assessment & Dataset (ECA&D)	Extreme weather analysis; Trend visualization	Europe	Visual-rich interface	Policymaking	Open-source; Direct access	ECA&D Dashboard
Geosphere Austria	Climate database; Downloadable datasets	Austria	Intuitive	Local adaptation Climate research	Selection of climate; indicators via datasets	Geosphere Austria
ClimateEU	Queryable data; Historical & projection data	Europe	User-friendly	Impact assessment; Adaptation planning	Downloadable software	ClimateEU
World Resources Institute – Climate Watch Europe	GHG tracking; Policy visualization	Europe	Interactive visuals	Policy evaluation; Policymaking	Selection of country data	Climate Watch Europe
European Space Agency – Climate Change Initiative (CCI)	Satellite data; Global climate trends	Global	Basic interface	Research; Modeling	Open-source; Direct access	ESA CCI Dashboard
NOAA Climate Dashboard	Global indicators; Climate metrics	Global	Highly interactive	Public awareness; Research; Policy	Selection of different data	NOAA Climate Dashboard

1.4. Regional Climate Model Requirements

In the following we give an overview of common prerequisites for modelling requirements of climate models to be used in digital solutions.

Support via Risk and Vulnerability Assessments
We suggest that to efficiently include the region-specific requirements regarding climatic and socioeconomic conditions, it is of high importance of conducting a risk and vulnerability assessment at regional level and adapt the integration of data types into the climate resilience dashboard. This allows the design of dashboards that meet communities' needs. However, this brings an increase in complexity in the process of dashboard development, as it requires an adaptable and interactive dashboard approach. We argue that this increase in complexity is worth being considered as useful in terms of a significant increase in value for the users, leading to enhance climate resilience on community-level.

Climate Data Resolution
The resolution needed is dependent on the climate model approach (global or regional model), with regional climate models requiring a much higher grid resolution when it comes to earth observation data for example. Higher resolution, however, comes with higher computational costs. One efficient way to improve resolution for improved details at reasonable costs is dynamical downscaling, which is taking a global model with lateral boundary conditions and sea surface conditions from a global climate model, and applying a regional climate model at higher resolution for the specific area defined.

Use of model projections
Climate model projections are projections of how the Earth´s climate may change in different assumed scenarios. These can be helpful in different climate-related forecasting applications. As model projections are the highlight the applicability of models.

Data quality
Data quality plays a critical role in the effectiveness of climate resilience dashboards, which rely on high-quality, real-time data for decision-making. Ensuring accurate, complete, and consistent data allows municipalities and stakeholders to develop targeted adaptation and mitigation strategies. This section outlines the key dimensions of data quality, associated challenges, and methods for ensuring high data integrity.

According to ISO/IEC 25012[1], data quality is defined as "the capability of data to satisfy stated and implied needs when used under specified conditions".

Several dimensions contribute to high-quality data, which can be categorized into two perspectives: inherent data quality and system-dependent data quality. Inherent data quality refers to characteristics intrinsic to the data itself, independent of any system processing or management. It includes accuracy (syntactic as well as semantic), completeness, consistency, credibility, and currentness. On the other hand, system-dependent data quality refers to the extent to which data quality is achieved and

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[1] https://www.iso.org/standard/35736.html

maintained within a (computer) system. This includes availability, portability, and recoverability. Some dimensions rely both on the inherent properties of the data and the system managing it. These include accessibility, compliance, confidentiality, efficiency, precision, traceability, and understandability. (Batini & Scannapieca, 2006; Fenner et al., 2021; Otto & Österle, 2016; Vetrò et al., 2016; Vuckovic & Schmidt, 2023).

Ensuring high data quality is crucial for effective decision-making, particularly in contexts such as climate resilience dashboards, where real-time, accurate data plays a vital role. Several strategies can be employed to maintain data integrity, including validation techniques, quality assessment frameworks, and metadata management. One fundamental approach to ensuring data quality is validation and error detection. Quality control frameworks, such as the CrowdQC+ package, have been developed to filter and remove faulty data from crowdsourced sources. These methodologies utilize statistical techniques to identify anomalies and inconsistencies in datasets before they are used for analysis (Fenner et al., 2021).

Another critical aspect of maintaining data quality is assessing the reliability of sources. Studies have shown that crowdsourced meteorological data, while valuable, often contain errors that must be corrected before use. Methods such as cross-referencing with authoritative sources, as demonstrated in research on personal weather stations (PWS), can enhance data accuracy by comparing collected data with validated meteorological records. (Vetrò et al., 2016).

UX/UI

To effectively support climate resilient development in communities via climate services, a user-centred design approach is essential (Calvo et al., 2022; Morelli et al., 2021). Following Hansen´s User Engineering Principles, the first principle is to ‘know the user’ (Hansen, 1971). This requires building a profile of intended users that help making design decisions. The profile should include education, experience, interests, available time, and any specific constraints relevant to the problem at hand (Hansen, 1971; Young et al., 2021).

The design of the dashboard should be data- and task-dependent. A key requirement is to evaluate different design variants to assess their effectiveness and quality (Reinwald et al., 2023). Visualizations must be clear and informative, enhancing users' knowledge and supporting task completion and informed decision-making (Grainger et al., 2016). Due to the diversity of user needs, it is of great importance to adapt the interface and visualisation techniques in the dashboard design process to the target audiences (Contreras et al., 2022).

A user-centred design approach helps in achieving adaptation in an efficient and effective way. User-centred design is an iterative process, in which user feedback is integrated throughout the entire design process (Calvo et al., 2022; Contreras et al., 2022; Morelli et al., 2021). A user-centred approach ensures optimized data visualizations (including shape, size, and colour adjustments for clarity), minimised information overload (limiting information categories to the essential ones), and reduced cognitive and graphical complexity. Such a co-design approach ensures that climate data visualizations are accessible, clear, and usable for diverse target audiences, including policymakers, international organizations, media, communities, and citizens (Calvo et al., 2022; Terrado et al., 2022). A user-centred design process, including co-designing of climate services such as dashboards for improving climate resilience, enables the integration of all sectors described in the Quadruple Helix Approach (see section 1.1.: Quadruple and Quintuple Helix Approach).

To achieve this, participatory approaches such as interviews, workshops, learning labs, and user forums should be used. Ideally, stakeholders are involved from the beginning and throughout all stages of visualization co-development (Terrado et al., 2022). A co-design approach ensures that climate data visualizations are accessible, clear, and usable for diverse target audiences, including policymakers, international organisations, media, communities, and citizens (Morelli et al., 2021).

Going beyond co-design efforts, it is also required to continuously evaluate usability to identify potential gaps between user needs and the way information is presented. Identifying usability gaps requires comparing end-user needs with the dashboard's purpose, information structure, and visual format to ensure clarity and effectiveness (Raaphorst et al., 2020).

To integrate these principles, the following recommendations can help as a guidance in designing and implementing a successful dashboard:

- **Using the right Visualisation Techniques**: The selection of appropriate visualization techniques is a crucial factor in the development of climate dashboards. Data visualization should enable effective decision making by reducing complexity and extracting information from the raw data. This requires visualization techniques with an appropriate level of complexity to optimize the effectiveness of decision support and interpretation of information, and can be achieved by analysing characteristics of the end-users (Contreras et al., 2022).

- **User-Centred Design and Co-Creation Approach**: Ensure that the dashboard is designed iteratively with continuous user involvement, considering diverse user needs, skills, and accessibility requirements (Calvo et al., 2022; Hansen, 1971; Morelli et al., 2021; Terrado et al., 2022).

- **Ensure Clarity**: Present climate data in a structured format with clear terminology, intuitive navigation, and well-labelled visual elements to enhance comprehension (Grainger et al., 2016; Terrado et al., 2022).

- **Use Visuals Appropriately:** Choose visualisation types based on data characteristics and user tasks and apply colour, size, and shape in a way that reduces complexity without overwhelming the user (Morelli et al., 2021; Terrado et al., 2022).

- **Organize Information Hierarchically**: Implement a logical layout that prioritizes key insights while providing additional details progressively (Calvo et al., 2022; Hansen, 1971).
- **Avoid Cognitive Overload and Distractions**: Limiting the number of categories displayed at once, as well as using consistent terminology and graphical elements

helps to minimise confusion. Adapting terminology and language to the context of the user and providing a help documentation should also be considered (Terrado et al., 2022).

- **Maintain Consistency and Accessibility:** Use uniform design elements, colour palettes, and reference icons throughout the dashboard and chose them in colour-blind-friendly schemes and assistive technologies (Terrado et al., 2022).

- **Test for Usability and Effectiveness**: Conduct user testing at multiple stages of development to refine interactions, assess comprehension, and enhance decision-support capabilities based on real-world feedback. Ideally, this process should be iterative to ensure continuous improvement (Calvo et al., 2022; Terrado et al., 2022).

Use of AI and ML

Dashboards with integrated Artificial Intelligence (AI) and Machine Learning (ML) provide transformative benefits for climate adaptation. They not only help in visualising data but also serve as powerful tools for risk analysis and management, allowing real-time monitoring and proactive decision making that improve urban resilience (Mehryar et al., 2024; Štěpán Machovský, 2023).

AI techniques are useful for assessing climate risks, estimating exposure, and supporting decision-making. By processing large historical and real-time environmental datasets, these systems improve risk management and guide urban policy decisions (Mehryar et al., 2024). Furthermore, integrating ML into dashboards allows for interactive data analysis. For example, one-click solutions and embedded Jupyter Notebooks enable both non-expert and expert users to explore and visualize complex datasets in real time (Štěpán Machovský, 2023).

ML models can also predict extreme events, such as lightning occurrence, using commonly available meteorological parameters. A nowcasting approach based on MeteoSwiss data provides lightning warnings up to 30 minutes in advance (Mostajabi et al., 2019). Furthermore, ML algorithms detect unusual patterns in environmental data that act as early warning signals for potential risks, while clustering techniques group similar risk profiles to support targeted interventions and decision-making in climate adaptation (Bochenek & Ustrnul, 2022).

However, challenges remain. As described in the section on data quality, data quality is a major issue, as sensor degradation and fragmented sources can lead to unreliable or outdated data. Moreover, high technical requirements, such as significant computational resources and smooth integration into existing data flows, increase cost and complexity. Robust data governance, ML-based validation, and advanced computing infrastructures are needed to address these problems (Shalu & Gurjeet Singh, 2023).

Looking ahead, risk-based decision support and data-driven analysis are expected to advance further, continuously optimizing dashboards. This progress will lead to more efficient decision making and improved climate adaptation strategies (Ramya & Singh, 2024).

Business Models for Climate Resilience Dashboard Development

In today's economy, business models are critical for organizations to create, deliver, and capture value. A business model describes how a firm's internal processes create value through services or production and capture value through marketing strategies and increased sales. These processes are vulnerable to external changes, including market shifts, regulatory adjustments, and environmental changes (DiBella, 2020).

Climate services are defined as the production, translation, and delivery of useful climate data, information, and knowledge (Larosa & Mysiak, 2020; National Academies Press, 2001). These are used by decision-makers, which includes all users of the provided climate services with a broad spectrum of different needs (National Academies Press, 2001). Climate services encompass climate records, extreme event catalogues, reanalyses, forecasts, projections, and indices used in vulnerability and risk assessments, as well as linkages to the sectors affected by climate indicators (e.g. energy demand depending on temperature) (Larosa & Mysiak, 2020; National Academies Press, 2001).

To effectively develop and offer climate resilience dashboards, serving as a key component of climate services, specific requirements for business models must be met:

- **User-centred activities and elements**: Climate services must adapt to the needs and culture of their users by recognizing diverse potential users and their specific requirements (Brasseur & Gallardo, 2016).

- **Co-creation process**: A co-creation approach is a key component of climate services BMs. Collaboration among various stakeholders, including enables the exchange of knowledge and competencies, as well as the development of user-friendly services (Brasseur & Gallardo, 2016; Larosa & Mysiak, 2020). This collaboration can occur both offline through workshops and conferences and online through web-based products (Larosa & Mysiak, 2020).

- **Value Network**: An interaction space in which climate services operate can be essential for up-scaling climate services successfully. Using subscriptions to create an online-based infrastructure is one of the most common ways to build partnerships and organizations. Value networks have a huge effect on the innovation process and can create mutual learning opportunities (Larosa & Mysiak, 2020).

- **Financial Structure**: Balancing financial aspects is essential for the long-term viability of climate services. Public providers mainly focus on value proposition and value network, while private firms focus on financial compensation and the value-driven character of their services. As a third provider´s group to be mentioned, research institutions very often receive external research fundings, aiming for structured research projects with legal rules that are not aligning with the corporates request on receiving retribution (Brasseur & Gallardo, 2016; Larosa & Mysiak, 2020; Swart et al., 2017).

Specific Business Models for Climate Resilience Dashboards

One concrete application of climate services is the development of climate dashboards. To ensure effective delivery and user engagement, following the key requirements identified in this section, key components of an effective BM include the following:

- **Tailor-made Services**: Climate dashboards should provide tailor-made services to meet the specific needs of public and private actors. This customization enhances the utility and relevance of the information provided (Brasseur & Gallardo, 2016; Larosa & Mysiak, 2020).
- **Data Integration**: Climate dashboards should integrate various data sources such as the Copernicus Climate Change Service (C3S) and the Climate Data Store to provide free access to data and post-processed information (Larosa & Mysiak, 2020).
- **Targeted Sectors**: Focus on sectors such as energy, water management, and disaster risk reduction, where co-creation and tailor-made approaches are more effective (Larosa & Mysiak, 2020; National Academies Press, 2001).
- **User-Centric Design**: A user-centric approach is essential for a cost-effective and comprehensive linking of knowledge and its use for decision-making and other purposes. This includes mutual information exchange and feedback, communication and accessibility of information, and continuing evaluation and assessment by users and providers (Brasseur & Gallardo, 2016; Larosa & Mysiak, 2020).
- **Hybrid Approach**: Climate services can be private, public, or hybrid goods (Larosa & Mysiak, 2020; Perrels, 2020; Swart et al., 2017). This has consequences for evaluating the propagation of value added from climate services because the cost coverage and price observation differs across these types of goods (Perrels, 2020). It is requested to aim for a hybrid model, with the main objective to design climate services as public goods, mainly funded by taxes and with free access to any citizens. The hybrid model, however, allows financial retribution, but only for specific needs that are requested for exclusive uses (Larosa & Mysiak, 2020).
- **Transparency**: Lack of information on climate risk exposure for certain should be avoided through climate services data transparency (Perrels, 2020).
- **Community Resilience**: It is important to build a sustainable European climate service community that includes users, providers, intermediaries, innovators, and researchers to make the market more sustainable. This requires forums where trust can be built and the credibility and quality of services can be demonstrated (Street, 2016).
- **IT Infrastructure**: Building a solid IT infrastructure is crucial to support data flow and address the challenges associated with big data (Hanelt et al., 2021).

By considering these aspects, business models for climate services can effectively contribute to climate change adaptation while ensuring sustainable value creation. The development of climate services should be viewed as a continuous process, adapting to the changing needs of users and technological advancements, as well as to the changing climate affecting the users' needs.

2. Modular (Dashboard) Design Approach

2.1. Design & Goals

A modular dashboard design approach in climate resilience enables communities to monitor, analyse, and respond to climate risks through integrated, adaptable systems composed of distinct, reusable modules.

Modular dashboards are built from self-contained, reusable components, allowing developers to mix, match, and customize elements such as sidebars, charts, and data tables according to specific needs. This modular structure promotes scalability, flexibility, and maintainability; enabling updates, upgrades, or the addition of new features without disrupting the overall system. Modules can be reused across multiple dashboards and projects, facilitating parallel development and efficient collaboration. In contrast, non-modular dashboards are designed as unified, monolithic systems where the interface and functionality are tightly integrated. Altering or expanding these dashboards often requires significant redevelopment, as changes are less isolated and typically affect the entire system. Non-modular dashboards are less adaptable and more difficult to customise, with limited reusability and reduced long-term efficiency. As a result, modular dashboards are considered better for adaptability, maintenance, and futureproofing, while non-modular dashboards may offer simplicity but lack the versatility required for evolving user needs.

Modular dashboards are structured as collections of self-contained components (modules) such as data visualisations, near-real-time indicators, scenario models, or alert systems. Each module is dedicated to a key functionality, for example:

- Geo-intelligence for mapping hazards
- Climate outlook and trend visualization
- Monitoring & evaluation tools
- Citizen feedback or reporting portals

This approach allows for customisation according to local needs, rapid iteration, and future scalability. It also supports interoperability by enabling the integration of new data sources and modules without disrupting the overall system.

An effective modular dashboard architecture depends on establishing a logical structure that clearly distinguishes between global dashboards and those tailored to local or community-specific contexts. The inclusion of intuitive navigation and well-organised hierarchical elements ensures that users—both citizens seeking alerts and experts managing data models—can readily access the tools and information most relevant to their needs. Thoughtful grouping and precise labelling make modules such as hazard visualisation, adaptation catalogues, and project trackers easy to identify and use. Additionally, robust filtering and customisation options enable users to focus on the metrics, risks, or locations most pertinent to their objectives.

Development best practices include clean folder hierarchies, reusable UI components, and clear separation of logic and style. Continuous user feedback loops and co-creation with stakeholders ensure ongoing relevance and utility.

Modularity equips dashboards with the ability to respond swiftly to evolving climate events and shifting stakeholder needs. Integrated modules, such as those for scenario analysis and investment planning, enable targeted decision-making, while features like project trackers enable communities to effectively monitor and advance climate adaptation initiatives. Insights from case studies using both urban and rural dashboards illustrate how these platforms can enhance overall community resilience, facilitate informed policymaking, and foster robust collaboration among diverse stakeholders.

2.2. Modular Dashboard Design - Participation Matrix

The matrix presented below outlines the relationship between citizen involvement and data availability, segmented into nine distinct categories. It illustrates the relationship between citizen involvement and the amount of data available in a community or organizational context. This framework aims to clarify the varying impacts of different levels of citizen involvement and data availability on data governance and community engagement.

Each category represents a specific combination of citizen engagement and the extent of data accessibility, ranging from minimal interaction to comprehensive participation and co-creation. It is divided into a 3x3 grid with two axes. The vertical axis represents the Amount of Data, ranging from Low at the bottom, through Medium in the middle, to High at the top. The horizontal axis represents Citizen Involvement, progressing from Low on the left, through Medium in the center, to High on the right.

How to use the matrix
This matrix serves as a framework to assess and plan the relationship between data availability and citizen involvement in any data governance or community engagement initiative. The matrix can be used in the following steps:

- **Step 1: Assessment** - Identify the current state of the project or community by locating which cell best describes the existing interaction level between citizen involvement and data volume. This helps clarify current capabilities and engagement.
- **Step 2: Goal Setting** - Use the matrix to define desired progress. For example, a community currently at 'Data Sharing' (medium data, low citizen involvement) may aim to move towards 'Data Collaborator' or 'Co-Creation' by increasing citizen participation.
- **Step 3: Strategy Development** - Tailor strategies to increase data collection methods, citizen engagement activities, or both. The matrix highlights the trade-off and opportunity zones for improving transparency, collaboration, and governance.
- **Step 4: Monitoring Progress** - Track advancement over time by mapping changes in citizen involvement and data availability; use this to refine engagement methods and data initiatives.
- **Step 5: Encouraging Inclusivity** - The matrix can be used to design solutions enabling balancing of data richness with active citizen participation to foster trust, accountability, and shared ownership of data-driven decisions.

Figure 1: Participation Matrix for Use Case Derivation

Participation Matrix Quadrant Details

1. Information Only - Low Data, Low Citizen Involvement

In this quadrant, citizens have minimal involvement and access to very limited data. They primarily receive basic information without interactive engagement or access to dynamic dashboards. For example, a municipality might send a newsletter informing residents about upcoming climate workshops or show basic climate data like average live temperatures. The goal here is awareness and not active participation. However, this approach is considered the least ideal because it offers minimal citizen engagement and insufficient data for addressing the complexity of climate challenges. Within the Mission CE Climate context, this passive information delivery contradicts the project's priority of

fostering active local participation and community empowerment in climate adaptation strategies.
Related projects:

- ENES-CE Initiative; project, which raised awareness on energy efficiency and CO_2 reduction but with minimal interaction from citizens.
- Climate-ADAPT

2. Information/Data Provider - Low Data, Medium Citizen Involvement
Here, citizens have a moderate level of involvement and access to limited data. They contribute to data collection or provide information but lack significant control or ownership of the data. An example could be local governments asking residents to report extreme weather events, such as flood occurrences or heatwaves, via simple online forms. The data collected is controlled centrally, typically by government agencies, to support adaptation planning. This quadrant marks a transition from solely receiving information to active citizen contributions, though without full collaborative control.

3. Co-Ownership - Low Data, High Citizen Involvement
Citizens in this quadrant have high involvement and share ownership over the available data, despite the data volume being limited. They take on significant responsibility and decision-making roles related to data. For example, a small community managing a local flood defense system collects real-time precipitation and water level data and collectively decides how to mitigate flood risks using this locally governed information. This quadrant symbolizes empowerment through shared control, fostering stronger community trust and climate resilience.

4. Data Sharing - Medium Data, Low Citizen Involvement
This quadrant is characterized by citizens having access to a moderate amount of data but with primarily passive involvement. While citizens can view and download climate-related datasets, such as open data portals offering projections or historic flood data, their role is often limited to information consumption rather than active analysis or decision-making. This setting supports transparency but lacks deeper citizen engagement in planning or adaptation processes.

5. Data Collaborator - Medium Data, Medium Citizen Involvement
Citizens actively collaborate with data providers, engaging more deeply with a moderate volume of data. They assist in data collection, share insights, and jointly use the data for community benefit. An example includes citizens measuring urban heat islands using distributed temperature sensors and sharing results with city planners, who then use this data to develop mitigation strategies like creating urban green spaces. Projects like the Municipality of Koper Pilot exemplify this quadrant, where citizens play an active role in data gathering and collaborative use. This stage enhances shared responsibility and knowledge co-production.

Related projects:

- Municipality of Koper – Pilot; actively involved citizens in gathering climate-related data.

6. Co-Creation - Medium Data, High Citizen Involvement

In this quadrant, citizens are deeply involved in both creating and using a moderate amount of data. They partner closely with data providers, researchers, and policymakers to co-create climate solutions and interventions. For instance, in a city-wide initiative, citizens and planners collaborate on urban green infrastructure designs using data on water management and flood risk to develop features like rain gardens. This level emphasizes joint problem-solving, innovation, and localized adaptation strategies reflecting community priorities.

7. Data Transparency - High Data, Low Citizen Involvement

This quadrant has high data availability ensuring broad transparency, but citizen involvement remains low. The public can freely access comprehensive datasets, such as dashboards showcasing regional climate resilience metrics, CO_2 emissions, and detailed risk maps. Although transparency is high, citizen participation in interpreting the data or influencing strategy decisions is limited. This model serves as a baseline for openness but does not fully leverage citizen input for adaptive governance.

8. Data Partnership - High Data, Medium Citizen Involvement

Citizens engage actively with a large volume of data, working in close partnership with data providers and decision-makers. They contribute to data analysis, share insights, and influence data use in policymaking. For example, in a regional resilience platform, citizens collaborate with policymakers to analyze flood risk datasets and co-develop infrastructure projects like flood defenses. This quadrant fosters shared governance, allowing citizens a tangible role in shaping climate strategies and enhancing trust through partnership.

9. Full Participation - High Data, High Citizen Involvement

The ideal quadrant combines full citizen engagement with comprehensive data availability, creating a highly participatory, data-rich environment. For example, in a Smart City climate project, citizens participate in real-time data collection via IoT sensors and are actively involved in analyzing data on energy use, transportation, and climate impacts. They help guide planning, monitoring, and management decisions, ensuring solutions are grounded in community needs. This approach is the best practice because it integrates extensive data resources with meaningful citizen empowerment, fostering innovation, cross-sector collaboration, and adaptive capacity.

Related projects:
Copenhagen's CPH 2025 Climate Plan and Climate Adapted Cities, where strong citizen involvement complements broad data access to drive climate adaptation.

- The CPH 2025 Climate Plan + Climate Adapted Cities (Copenhagen); not 100% full participation but citizens were/are highly involved.

2.3. Modular Dashboard Design - Technical Descripiton

Whilst a detailed technical description must be discussed and agreed upon together with relevant experts or software providers, we give a short overview of a streamlined, classic software development process for a modular dashboard as well as list key technologies which are relevant to its development.

Software Process

The process normally consists of phases for (a) *Planning & Requirement Analysis*, (b) *Design & Software Architecture*, (c) *Development*, (c) *Testing*, (d) *Deployment*. This process is iterative and might use agile software development approaches in each of the phases. Certain phases might be repeated if the need arises or are concluded with a (e) *Maintenance* phase. It is advisable to plan to integration into the project management of a dashboard project, as the deployment / rollout of the solution might need to be accompanied by integration, marketing, or similar measures, especially if the dashboard is intended to be used for citizen science.

A software design process for a modular dashboard usually begins with planning and requirement analysis, where the project's goals, user needs, data sources such as IoT and citizen science sensors, and technical feasibility are defined. This phase sets the foundation by clarifying functionalities like real-time data visualisation and stakeholder roles. Next, the design phase develops a high-level and detailed architectural plan focused on a modular structure, defining reusable UI components, data flows, system interfaces, and integration points. Prototypes or wireframes are created to visualise the user interface and workflows, incorporating security and performance criteria. During development, backend services and frontend modules are implemented independently to promote scalability and reuse, with integration of real-time data ingestion using streaming protocols such as MQTT. User authentication and access control are also established. Testing follows, including unit testing of modules, integration testing of the full system, and user acceptance testing with target groups to ensure data accuracy and usability. The deployment phase involves releasing the dashboard on production infrastructure, often using containerisation and orchestration tools for modular updates and scalability. Finally, maintenance and improvement continue post-deployment, utilising agile methods to incorporate user feedback, add features, and adapt to evolving requirements, thus ensuring a sustainable, flexible, and user-centred modular dashboard aligned with climate resilience goals.

List of potential key technologies

In general, key technologies are to be chosen for frontend and backend development, as well as data storage. Specifically, key technology choices pertaining to IoT and sensor data integration, data processing and analytics, as well as use case specific technologies are relevant to modular dashboard design. Together, these technologies form the foundation for flexible, scalable, and user-centred modular dashboards that effectively integrate IoT and citizen science sensor data to support climate resilience monitoring and community engagement.

Key technologies used for a modular dashboard design, especially when integrating IoT and citizen science sensors as data sources, include the following:

Frontend Technologies

- *Modular UI Frameworks and Libraries:* React, Angular, and Vue.js are popular choices for building modular components, such as reusable cards, charts, tables, navbars, and widgets. They enable scalable, maintainable, and customizable user interfaces.
- *Component-Based Architecture:* Dashboards are constructed from self-contained, reusable components with clear separation of presentation and logic. Techniques like React hooks or Angular services manage shared logic cleanly.
- *Utility-First CSS Frameworks:* TailwindCSS or Bootstrap facilitate consistent styling with minimal effort, supporting responsive and adaptive design for multiple devices.

Backend and Data Integration

- *APIs and Web Services:* RESTful APIs or GraphQL endpoints enable real-time or batch communication with data sources, including IoT platforms or sensor networks.
- *Data Streaming and Messaging*: MQTT, WebSockets, or Kafka are commonly used to stream real-time sensor data from IoT devices into the dashboard backend for processing and visualization.

IoT and Sensor Data Integration

- *IoT Protocols:* LoRaWAN, NB-IoT, Zigbee, and MQTT protocols support low-power, long-range sensor networks gathering environmental, climate, or citizen-contributed data.
- *Sensor Networks and Gateways:* Local sensor stations, citizen science devices, or smart meters collect data shared via IoT gateways to centralized or cloud-based data platforms.
- *Data Aggregation Platforms*: Cloud services like Microsoft Azure IoT Hub, AWS IoT Core, or Google Cloud IoT provide scalable ingestion, storage, and processing infrastructure.

Data Processing & Analytics

- *Databases:* Time-series databases (e.g., InfluxDB, TimescaleDB), NoSQL (e.g., MongoDB), and relational databases (e.g., PostgreSQL) store sensor and citizen science data for efficient querying.
- *Data Visualisation and BI Tools:* Libraries such as D3.js, Chart.js, or integrated tools like Power BI and Tableau visualise climate data dynamically.
- *AI/ML Components:* Machine learning models for anomaly detection, forecasting, or scenario modelling are increasingly integrated to enhance decision support.

Additional Technologies

- *Citizen Science Platforms and APIs:* Tools and protocols supporting citizen data contributions, validation, and quality assurance integrate with dashboards.
- Security and Authentication: OAuth, JWT, and role-based access control protect sensitive data and ensure authorized usage.
- *Modular Architecture Patterns:* Microservices or serverless functions often implement modular backend services corresponding to frontend modules for scalability and maintainability.

2.4. Data Integration and Processing Architecture for Modular Climate Dashboards

Figure 2 provides a high-level architecture diagram tailored for a modular digital dashboard design, specifically aligned with the integration and processing needs of climate data within city infrastructures. It demonstrates a layered, component-based solution that supports scalability and interoperability, ideal for evaluation by city ICT departments aiming to test the feasibility of integrating such solutions within existing municipal ICT environments. This architecture is intentionally modular and technology-agnostic, designed to lower integration barriers for city IT teams. Each layer and service can be leveraged independently or integrated stepwise, enabling cities to adopt dashboard capabilities that fit their specific legacy systems, security standards, and scalability requirements. This flexibility supports gradual adoption and pilot testing within the constraints and requirements of municipal digital ecosystems.

At the top, the architecture features a (web-)driven user interface encompassing modules like User View & AAA (Authentication, Authorisation, Accounting), Control Panel, Information Panel, Information Overlays, and a Map Layer View. These UI components enable flexible user access, administrative control, and comprehensive data visualisation.

Beneath the interface, the architecture is divided into multiple modules with each module having a minimum of three layers, including:

- Information Generation: For processing and creating actionable insights from raw and transformed data.
- Data Transformation & Quality Checks: Central to ensuring data accuracy and reliability, this layer encompasses all transformations, corrections, and validations before integration.
- Data Selection & Aggregation: Responsible for sourcing, filtering, and combining data from multiple inputs.

Data may be sourced from various origins (APIs, databases, files, sensors), which are flexible and scalable to fit city-specific data landscapes. These data sources feed into the modular solution, which is capable of integrating with external transformation services via well-defined APIs. The Map Layer View is directly integrated with an ArcGIS-backed database, providing essential spatial analysis and visualization for climate-related urban data. This connection illustrates the architecture’s readiness to dovetail with commonly used city geospatial systems, reinforcing practical feasibility for municipal IT departments. To enhance adaptability and future-proofing, the framework adopts API-based integration for data transformation services, ensuring the modular dashboard can extend to new data sources and analytical functionalities as needed, supporting IT departments' goal of seamless integration with evolving urban data landscapes.

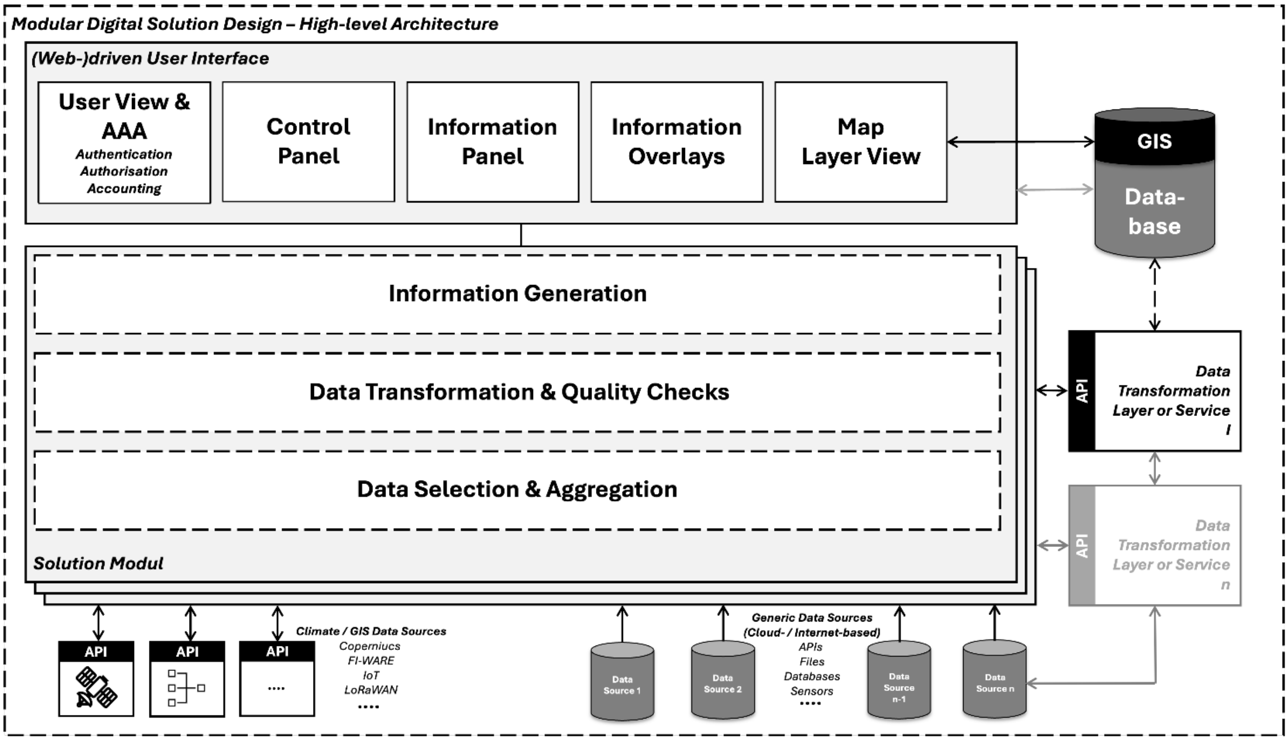
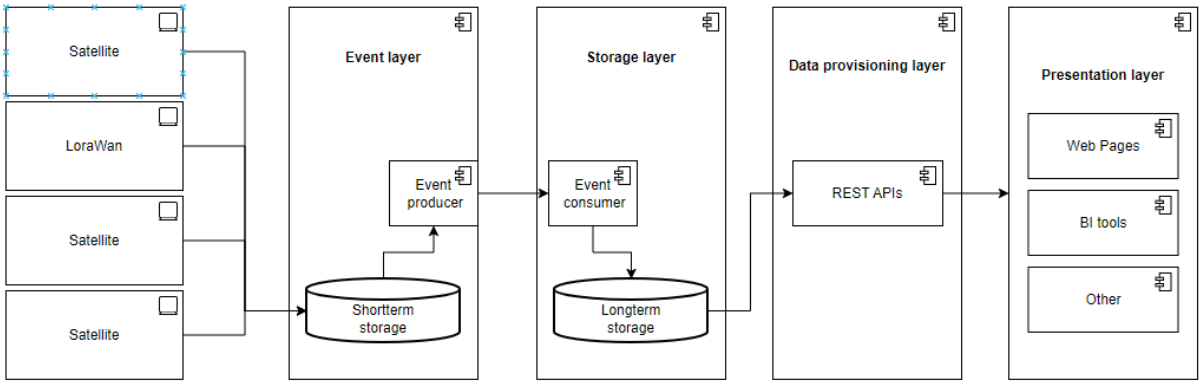


Figure 2: Modular Digital Solutions Design

2.4.1. Example for a Data Integration and Processing Architecture for Modular Climate Dashboards



3. User Needs

Collecting user needs for a modular climate resilience dashboard should begin with a thorough stakeholder assessment, identifying all relevant internal and external parties who will use or influence the platform. Involving stakeholders from the outset is helpful to ensure that requirements are comprehensive and aligned with real-world practices.

The Delphi method is widely recognised as robust approach for determining user needs or translating them into IT requirements, as it systematically gathers expert feedback through multiple iterative rounds of anonymous questionnaires, promoting consensus and reducing bias. The Delphi (see Figure 3) method is a structured, multi-stage survey process used to gather and refine expert opinions for estimating future events or circumstances, particularly in risk management. It begins by creating a catalogue of questions or statements that experts review during the first round, typically through questionnaires or working documents. After each round, expert feedback and comments are incorporated and the updated catalogue is redistributed for further refinement and discussion. This iterative feedback allows experts to reconsider their responses in light of anonymous group input, gradually building consensus. One of the main advantages of the Delphi method is its ability to avoid misjudgements caused by groupthink or the dominance of outspoken individuals in direct discussions, thanks to the anonymity and structured approach. However, a notable disadvantage is that the process can be cumbersome, often requiring many rounds to reach a consensus, and demands statistical expertise when the estimation of probabilities is involved. Overall, the Delphi method is highly effective for complex scenarios requiring unbiased, collective expert judgment, though the time and effort involved may make it less practical for rapid decision contexts.

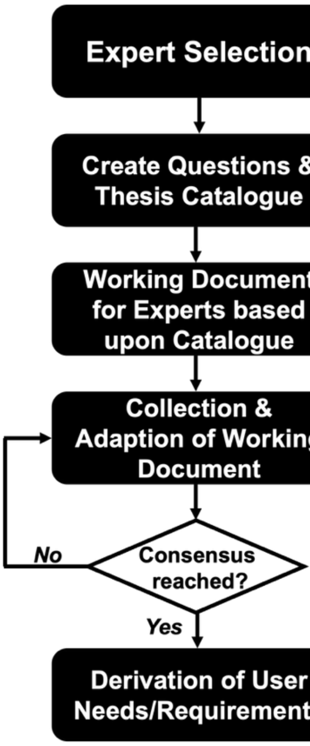


Figure 3: Delphi-Method Overview

Since it is important to note that the Delphi method can be time-consuming due to its iterative nature, making it less suitable when rapid development is required. In such cases, more straightforward methods should be considered, such as targeted questionnaires, collaborative workshops, bilateral discussions, or expert interviews.

Overall, the user needs collection process typically starts within a single institution or core project team, using initial assessment tools to gather preliminary needs and identify user expectations. Subsequently, it should be extended to incorporate input from all involved stakeholders, including external partners, community representatives, and technical experts, ensuring that a diverse range of perspectives is incorporated into the final requirements definition. Each step builds on the previous one, using stakeholder feedback to refine and validate the user needs.

A brief overview of the user needs collection process includes the following: begin by *mapping and consulting stakeholders*; *select appropriate methods for engaging* them (consider Delphi technique for depth and consensus), or simpler questionnaires and workshops for speed; *synthesise findings*; and *iteratively refine requirements in collaboration with all key user groups*. This extended and participatory approach ensures the dashboard’s technical features and functional capabilities are optimally matched to the evolving needs of its users and stakeholders.

3.1. Stakeholder & Target Groups

Stakeholder groups and target audiences for a modular dashboard supporting resilience and sustainability management encompass a broad spectrum, reflecting the multi-layered nature of climate adaptation and sustainable development initiatives.

The following list is intended as a guideline and starting point for stakeholder group and target group identification; concrete groups must always be defined based upon specific dashboard development. It might also be helpful to use the dashboard matrix from chapter 2 to assess especially citizen target / stakeholder groups.

Stakeholder Groups

- ***Local and Regional Authorities***: City governments, municipal climate teams, county administrations, and regional planning agencies responsible for policy-making, emergency response, adaptation planning, and reporting. These groups are of special focus for analysis of their climate related resilience, contingency, or even risk strategies.

- ***National Government Agencies:*** Ministries and departments focused on environment, sustainability, climate action, disaster management, and infrastructure at the state or federal level. These groups are of special focus for analysis of their climate related resilience, contingency, or even risk strategies.

- ***Community Groups and NGOs:*** Non-profits, environmental organizations, advocacy groups, and local resilience committees driving grassroots projects, public awareness, and community engagement.

- ***Businesses and Private Sector:*** Local entrepreneurs, corporations involved in green innovation, infrastructure, utilities, tourism, and sectors impacted by climate risk, contributing data and implementing adaptation measures.

- ***Academic and Research Institutions:*** Universities and scientific organisations that supply climate data, model projections, and conduct assessments, also facilitating citizen science initiatives.

- ***Funding Bodies and Investors:*** Regional, national, and international organisations, banks, and philanthropic entities supporting climate adaptation, innovation, and sustainability projects.

- ***Technical and Service Providers:*** IT companies, consultants, and platform vendors delivering dashboard software, IoT integration, and analytical tools.

- ***General Public:*** Residents, local community members, and vulnerable populations, especially those directly impacted by climate and environmental changes, as both data recipients and contributors through citizen science platforms.

Special Case - Stakeholder groups on a European Union level
On the European Union level, key stakeholder groups that support technological climate resilience strategies are broad and highly interconnected, reflecting the complexity and cross-sectoral nature of adaptation initiatives.

When designing a dashboard, one might consider analysis of the following movements or groups:

- ***European Commission Directorates-General (DGs)***: Especially DG CLIMA (Climate Action), DG ENV (Environment), DG RTD (Research & Innovation), DG REGIO (Regional & Urban Policy), and DG CNECT (Communications Networks, Content & Technology), which set policy, fund research, and drive digital infrastructure for resilience.

- ***European Environment Agency (EEA)***: Provides climate data, monitors progress, offers assessment platforms (e.g., Climate-ADAPT), and supports knowledge sharing at the union level.

- ***Joint Research Centre (JRC)***: Supplies scientific and technical support, develops risk and impact models, and creates harmonized datasets and standards for resilience strategies.

- ***Copernicus Programme***: The EU's Earth Observation programme provides real-time and historical climate and environmental data essential for resilience dashboards and digital decision support tools.
- ***European Investment Bank (EIB) & Horizon Europe***: Funding bodies supporting technological innovation, pilot projects, and large-scale deployment of digital solutions for climate adaptation.

- ***Eurostat***: Delivers harmonised statistical data and climate-relevant indicators across EU countries, which can be integrated into digital dashboards for monitoring resilience.

- ***EU Mission on Adaptation to Climate Change***: Engages regions and communities in experimentation, innovation packages, and 'twinning' programmes for scaling up climate resilience solutions with technology.

- ***Transnational and Regional Networks***: Bodies such as ICLEI Europe, Covenant of Mayors for Climate & Energy, Regions4Climate project, Pathways2Resilience, and REGILIENCE deliver best practices, capacity building, and coordination between cities and regions on digital innovation for adaptation.

- ***Pan-European Research Infrastructures***: Projects like ARSINOE, IMPETUS, and TransformAr supply models, data platforms, living labs, and digital toolkits for cross-border cooperation and replication of technological solutions.

- ***Stakeholder Advisory Platforms:*** Multi-actor forums, citizen engagement bodies, and professional networks (such as the European Urban Resilience Forum, EURESFO) validate, disseminate, and improve technological solutions for climate resilience.

Target Groups

Target groups for (modular) dashboards might include, but are not limited to:

- ***Decision Makers:*** Municipal managers, elected officials, program coordinators, and agency staff who oversee climate adaptation, sustainability projects, and allocate resources.

- ***Climate Action Professionals:*** Experts responsible for designing, implementing, and monitoring resilience and sustainability measures (includes planners, engineers, and emergency management personnel) – these professionals might be employees of a wide range of institutions, usually they are part of municipalities or civil engineering organisations.

- ***Community Leaders:*** Influencers, local organisers, and advocates who model adaptive behaviours and organise local initiatives.

- ***Technical Users and Data Scientists:*** Those utilising the dashboard for analytics, scenario modelling, and ongoing monitoring (includes academic researchers, municipal data teams, technical service providers, and others).

- ***Engaged Citizens:*** Individuals actively participating in climate action (e.g., citizen science, feedback, co-creation) and users leveraging dashboard tools for personal or community benefit.

- ***Underrepresented and Vulnerable Groups:*** Communities facing greater climate risks—elderly, low-income, minority groups—whose needs and voices must be prioritised in resilience planning. These groups might be especially important since underrepresented or vulnerable groups are usually impacted the most by a changing climate and its effects.

3.2. Climate Indicators

A broad range of indicators exist which might be displayed in dashboard or for which individuals modules could be developed and integrated into a dashboard. The categories in the following resemble *potential* categories for climate resilience indicators suitable for dashboard visualisation, including both simple sensor-based and complex composite examples for each.

A simple sensor-based indicator is usually based on one sensor or group of sensors which measure the same indicator, e.g., average of temperature sensors.

A composite-based indicator takes into account multiple data sources and combines the data into one derived indicator, e.g., perceived temperature by combining temperature and wind chill factors.

Also note, that the following indicators are relevant for Central Europe. In other regions, other indicator types might be more suitable (e.g., coastal and water level Indicators for non-landlocked countries).
A more extensive and full list of indicators might be obtained from Climate-Adapt[2] or ETC/CCA Technical Papers[3].

Exemplary Indicator Categories & Indicators

Category: **Climate Hazard Indicators**

Examples:
- Daily Maximum Temperature: Real-time readings from local temperature sensors.
- Heatwave Days (Composite): Count of periods exceeding high temperature thresholds for several consecutive days, combining multiple temperature sensors.

Category: **Hydrological Indicators**

Examples:
- Total Precipitation: Accumulated rain or snow data from precipitation gauges.
- Flood Recurrence (Composite): Ensemble index estimating 50-year flood recurrence by combining river discharge sensors, rainfall intensity records, and soil moisture data.

Category: **Drought and Water Stress Indicators**

Examples:
- Consecutive Dry Days: Measurement of longest periods with no significant rainfall, calculated from multiple precipitation sensors.

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[2] https://climate-adapt.eea.europa.eu/en/knowledge/mre

[3] *Example*: https://www.eionet.europa.eu/etcs/etc-cca/products/etc-cca-reports/tp_3-2018

- Magnitude of Meteorological Droughts (Composite): Severity index based on standardised precipitation and soil moisture datasets, integrating several sensor sources.

Category: **Fire Risk and Forest Health Indicators**

Examples:
- High Fire Danger Days: Number of days with elevated Fire Weather Index, using temperature, humidity, wind, and rainfall sensor data.
- Fire Weather Index (Composite): Combined output using meteorological sensor readings for temperature, precipitation, wind speed, and humidity.

Category: **Ecosystem and Land Cover Indicators**

Examples:
- Mean Soil Moisture: Measurements from distributed soil moisture probes to indicate water availability.
- Aridity Actual (Composite): Ratio of evapotranspiration to precipitation using soil moisture sensors, weather stations, and remote sensing data.

Category: **Human Impact and Health Indicators**

Examples:
- Frost Days: Number of days with temperatures below zero from weather stations.
- High UTCI Days (Composite): Days when the Universal Thermal Climate Index (UTCI) exceeds heat stress thresholds, calculated from air temperature, humidity, wind speed, and radiant temperature sensors.

Category: **Resource/Energy Use Indicators**

Examples:
- Heating Degree Days: Days requiring heating based on temperature sensor readings.
- Cooling Degree Days (Composite): Cumulative metric tracking demand for cooling, integrating air temperature records and building energy data.

Category: **Adaptation Response Indicators**

Examples:
- Green Infrastructure Coverage: Area or count data from GIS mapping and field sensors monitoring new green installations.
- Community Participation Rate (Composite): Percentage of residents actively engaged in climate adaptation activities, derived from citizen science app data, participation forms, and event sensors.

3.3. Further Climate Information for Dashboards

Besides indicator, dashboards might also be used to display relevant information, depending on the target group. Citizen and end-user focused dashboards might present a static tips & tricks section or derived recommendations based upon current indicator statistics.

Other climate information modules for such dashboards might cover a wide range of relevant topics critical for resilience and sustainability. They typically include climate projections that present expected changes in temperature, precipitation, and extreme events over future periods, often downscaled to regional or local levels for practical use. These dashboards can provide alerts and early-warning systems designed to inform users about imminent climate hazards, helping communities prepare and respond effectively. Additionally, many dashboards incorporate actionable recommendations tailored to everyday decisions, such as advising users to take shaded paths when moving from point A to B or reminding them to stay hydrated on hot days, thereby promoting climate-adaptive behaviours. Beyond data and alerts, these platforms often highlight climate action projects and local events underway in the region, raising awareness and fostering community engagement. Together, these elements might create an interactive, informative toolset that supports both informed decision-making and active participation in climate resilience efforts across diverse user groups.

3.4. User Needs: Use Cases Among Project Consortium

As an exemplary use case study, we performed a survey among the Mission CE Climate project partners and their stakeholders to generate an idea what partners might consider to be relevant for their dashboard development.

Questions of the survey included:

1. *Which environmental indicators are the most important for your field of expertise? Select by relevance (1 = not relevant; 5 = highly relevant)*
2. *Any other information or indicators that you suggest for the dashboard?*
3. *What climate-related information is most valuable for citizens from your perspective? Please select by relevance (1 = not relevant, 5 = highly relevant).*
4. *How should citizens interact with the dashboard? Please select one or more options*
5. *What else should the dashboard include to support your field of work?*
6. *Do you have any examples of good citizen engagement for dashboards?*
7. *What is your field of expertise?*

For Question 1 “*Which environmental indicators are the most important for your field of expertise? Select by relevance (1 = not relevant; 5 = highly relevant)*“ the raw indicators were rated as follows:

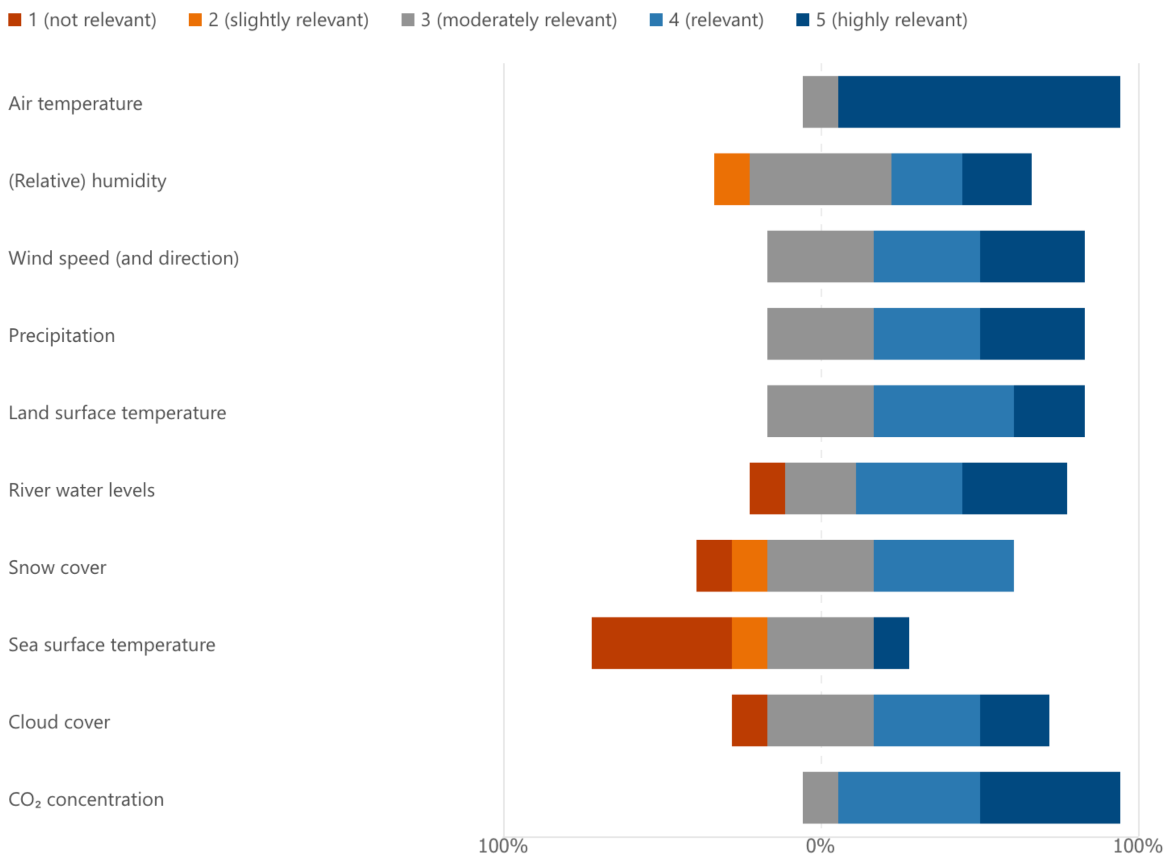

Figure 4: Exemplary consortium response to the question "Which environmental indicators are the most important for your field of expertise? Select by relevance (1 = not relevant; 5 = highly relevant)?"

For Question 3 "*What climate-related information is most valuable for citizens from your perspective? Please select by relevance (1 = not relevant, 5 = highly relevant)*" information categories for citizens was rated as follows:

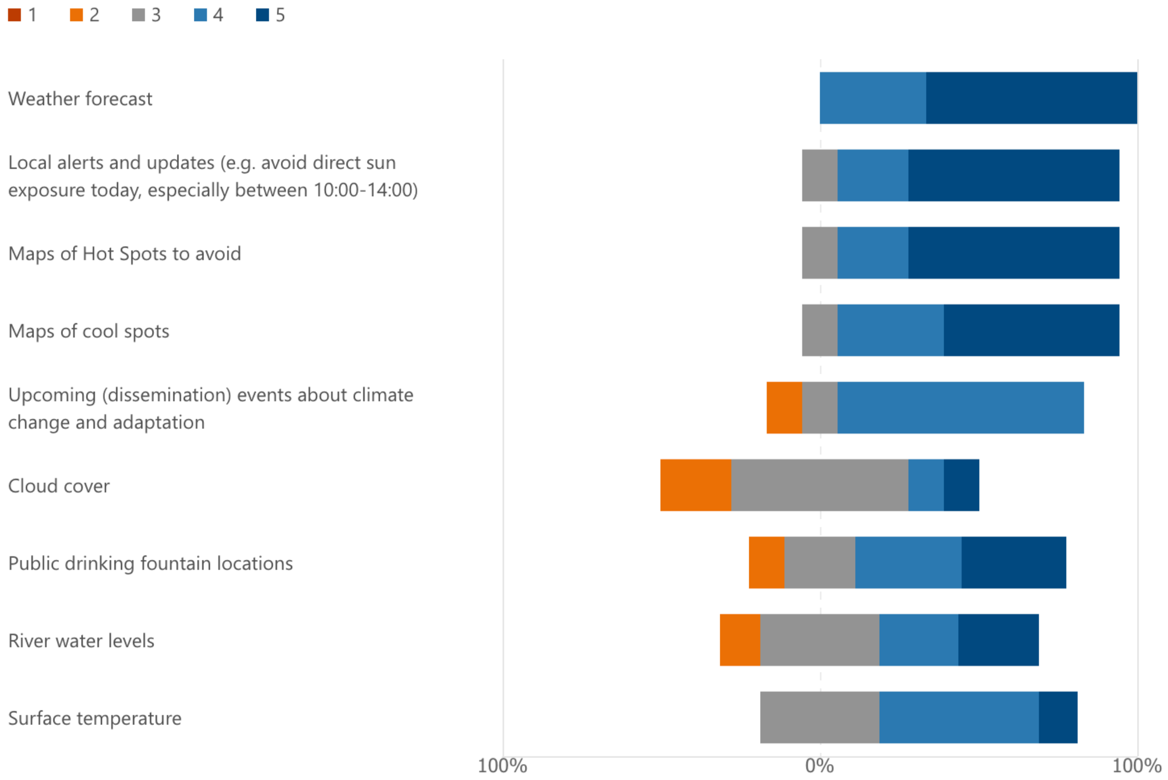

Figure 5: Exemplary response to the question "What climate-related information is most valuable for citizens from your perspective? Please select by relevance (1 = not relevant, 5 = highly relevant)."

For Question 5 citizen interaction with the dashboard was rated as follows:

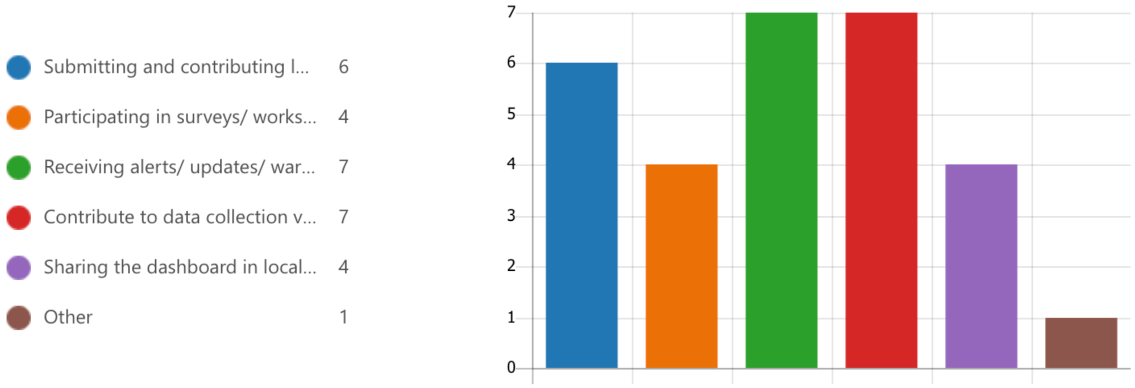

Figure 6: Exemplary response to the question "How should citizens interact with the dashboard? Please select one or more options"

3.4.1. Awareness Raising / Citizens Information

Designing effective awareness-raising programmes using modular climate resilience dashboards involves several key methods. Programmes typically start with stakeholder engagement and assessment of needs, ensuring that the dashboard content and features address target audiences' specific concerns and information gaps. Modular design allows dashboards to be tailored for different user groups—for example, providing high-level visualisations and actionable tips for citizens while offering in-depth data and monitoring tools for professionals and policymakers. Iterative co-design with stakeholders, including feedback loops and participatory workshops, enhances dashboard usability and relevance. Outreach strategies frequently combine dashboard launches with communication campaigns, interactive workshops, and digital storytelling to contextualise data and translate insights into practical community action. Additionally, embedding citizen science modules invites community contributions to climate monitoring, fostering ownership and boosting grassroots awareness. Programme success is further supported through ongoing evaluation and updates, informed by usage analytics and community input, to keep the dashboard content relevant and the engagement sustained over time. Adequate marketing and information campaigns may support the efforts.

Further information can be found in:

European Commission. (2021). *Resilience Dashboard for the social and economic, green, digital, and geopolitical dimensions*. https://commission.europa.eu/system/files/2021-11/dashboard_report_20211129_en.pdf

https://library.wmo.int/records/item/69061-2024-state-of-climate-services-five-year-progress-report-2019-2024

D. Existing Tools & Initiatives for Digital Solutions

4. Existing Tools & Supporting Initiatives

A plethora of tools, i.e., software solutions, exist to support the development of dashboards. Similarly, (technological) initiatives towards base technologies from the European Commission may aid the development of digital solutions. In the following, we give a brief overview over these tools and initiatives.

4.1. Existing tools

Several types of software tools and libraries are available to support the development of climate resilience dashboards, each catering to different development contexts and user needs. Open-source libraries, such as OpenClimateGIS and the tools provided by the Copernicus Climate Data Store, offer developers customizable frameworks and programmatic access to climate data for flexible and transparent solution building. Closed source, commercial solutions like those from Jupiter Intelligence provide integrated, enterprise-level platforms with ready-to-use climate analytics and user-friendly interfaces, typically tailored for business or governmental use (Jupiter, 2025). Some tools, such as the CLIMADA-App, bridge the gap by providing open-source modelling with a desktop user interface for ease of use by less technical users, while platforms like the CLIMAAX toolbox combine web-based environments for interactive visualization and offline downloadable components for advanced, standalone usage (American Planning Association, 2025; CLIMAAX, 2025; EIOPA, 2025; Jupiter, 2025).

The landscape thus includes both libraries for flexible, code-driven development and complete tools with graphical frontends requiring minimal programming experience. Web-based software facilitates collaboration and broad accessibility, allowing multiple users to access, visualize, and update climate data in real time, whereas standalone software is suitable for offline, high-performance processing or private data environments. This diversity ensures that climate resilience dashboard development can be tailored for varying technical expertise, security requirements, and use cases—from community-level awareness raising to large-scale professional climate risk assessment (American Planning Association, 2025; CLIMAAX, 2025; EIOPA, 2025; Jupiter, 2025).

When developing digital solutions, especially dashboards from scratch, one may use a dedicated developer (compare e.g., Dornbirn pilot dashboard provider weavs[4]). If a digital solution, which is established from scratch should be based upon common dashboard tools, one may use the following table in Figure 7. Please note, that these tools might not be climate resilience specific but rather generic data processing and dashboard tools.

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[4] Citymonitor - Die Urbane Datenplattform für Smart Cities: https://www.city-monitor.com/

Tool	Power BI (Microsoft)	Grafana	Tableau	Kibana	Domo	Metabase	Looker (Google)	Redash	Plotly	Qlik Sense
Dashboard availability for end consumer	Requires Pro or Premium license for sharing; free users can view shared content (no account needed to view shared reports; link)	Free and paid versions; no account needed for public dashboards	Requires license; free public version available	Free and paid versions; no account needed for public dashboards	Requires license; no free public version	Free and paid versions; no account needed for public dashboards	Requires license; no free public version	Free and paid versions; no account needed for public dashboards	Free and paid versions; no account needed for public dashboards	Requires license; no free public version
Server location	Multiple global locations; GDPR compliant	Multiple global locations; GDPR compliant	Multiple global locations; GDPR compliant	Multiple global locations; GDPR compliant	Multiple global locations; GDPR compliant	Multiple global locations; GDPR compliant	Multiple global locations; GDPR compliant	Multiple global locations; GDPR compliant	Multiple global locations; GDPR compliant	Multiple global locations; GDPR compliant
API connectability	Extensive API support; easy integration	Extensive API support; easy integration	Extensive API support; easy integration	Extensive API support; easy integration	Extensive API support; easy integration	Extensive API support; easy integration	Extensive API support; easy integration	Extensive API support; easy integration	Extensive API support; easy integration	Extensive API support; easy integration
User friendliness (project team)	Moderate learning curve; familiar to Office users, though	Moderate learning curve	Moderate learning curve	Moderate learning curve	Moderate learning curve	Moderate learning curve	Moderate learning curve	Moderate learning curve	Moderate learning curve	Moderate learning curve
Data visualization options	Area charts (Basic, Stacked) Bar and column charts Cards (Multi-row, Single number) Combo charts Decomposition tree Doughnut charts Funnel charts Gauge charts Key influencers KPIs Line charts Maps (Basic, Filled, ArcGIS) Matrix Pie charts R script visuals Ribbon charts Scatter and bubble charts Slicers Stacked area charts Table Treemap Waterfall charts Custom visuals from AppSource	Bar charts Line charts Pie charts Heatmaps Histograms Graphs Tables Single stat panels Gauge panels Text panels Custom plugins and panels	Bar charts Line charts Pie charts Maps Scatter plots Gantt charts Bubble charts Histograms Bullet graphs Heat maps Highlight tables Treemaps Box plots Waterfall charts Word clouds Custom visuals	Bar charts Line charts Pie charts Area charts Data tables Heatmaps Maps Tag clouds Timelion (time series) Vega visualizations Custom plugins	Bar charts Line charts Pie charts Maps Scatter plots Histograms Bullet graphs Heat maps Treemaps Box plots Waterfall charts Word clouds Custom visuals	Bar charts Line charts Pie charts Area charts Tables Maps Scatter plots Heatmaps Custom visual	Bar charts Line charts Pie charts Area charts Tables Maps Scatter plots Heatmaps Treemaps Box plots Waterfall charts Custom visuals	Bar charts Line charts Pie charts Area charts Tables Maps Scatter plots Heatmaps Custom visuals	Bar charts Line charts Pie charts Area charts Tables Maps Scatter plots Heatmaps Treemaps Box plots Waterfall charts 3D charts Custom visuals	Bar charts Line charts Pie charts Area charts Tables Maps Scatter plots Heatmaps Treemaps Box plots Waterfall charts Custom visuals
Time intervals of data refresh	Up to 48 times/day (every 30 mins); live data options (will be disabled in 2027, though)	Up to 48 times/day; live data options	Up to 48 times/day; live data options	Up to 48 times/day; live data options	Up to 48 times/day; live data options	Up to 48 times/day; live data options	Up to 48 times/day; live data options	Up to 48 times/day; live data options	Up to 48 times/day; live data options	Up to 48 times/day; live data options
Pricing	should already be part of our MS suite	Free and paid versions	Starting at $70 per month	Starting at $95 per month (some sources state there are free versions; I can't find it on Kibana's Website, though)	Custom pricing	Free and paid versions (free is self hosted!!!)	Custom pricing (complex)	Free but self hosted?	Custom pricing	Starting at $850 per month
Closed/open source	Closed source	Open source	Closed source	Open source	Closed source	Open source	Closed source	Open source	Open source	Closed source
Support	Extensive support	Community and paid support	Extensive support	Community and paid support	Extensive support	Community and paid support	Extensive support	Community and paid support	Community and paid support	Extensive support

Figure 7: Overview software for digital tools & dashboards

The table provides a comparative overview of several popular dashboard tools widely used for data visualisation and reporting, highlighting key features relevant for the development of climate resilience dashboards. It covers ten tools: Power BI (Microsoft), Grafana, Tableau, Kibana, Domo, Metabase, Looker (Google), Redash, Plotly, and Qlik Sense.

Each tool is evaluated across multiple criteria important for dashboard implementation. The table includes information about the availability of dashboards for end users, noting whether each tool offers free or paid versions and the requirements for user access. Most tools operate on multiple global server locations and comply with GDPR, which ensures data protection and privacy.

API connectivity is available and easily supported across all tools, facilitating integration with diverse data sources. However, all tools have at least a moderate learning curve for project teams, indicating that while they are powerful, some familiarity or training is necessary for effective use.

The data visualisation options vary among tools, with some like Power BI and Tableau offering a very wide range of chart types such as bar charts, pie charts, heatmaps, scatter plots, waterfall charts, and custom visuals. More specialised visualisations including decomposition trees, R script visuals, and 3D charts are also supported by some tools. This variety allows for tailored presentations of complex climate resilience data.

Regarding data refresh capabilities, most tools support live data updates up to 48 times per day, facilitating near-real-time monitoring. Pricing models differ significantly; some tools have free tiers or versions included in broader software suites (e.g., Power BI within Microsoft 365), while others require monthly subscriptions or custom pricing, with prices ranging roughly from $70 to $850 per month or more.

Another critical distinction is in open-source versus closed source-licenses. Tools like Grafana, Kibana, Metabase, Looker, and Redash are open source with community and paid support, allowing for more customisation and transparency. Closed source tools such as Power BI, Tableau, Domo, Plotly, and Qlik Sense offer extensive vendor support but may entail higher costs and less customization flexibility.

For dashboard development practitioners, this table may help identify appropriate dashboard tools by balancing factors such as user accessibility, visualisation capabilities, data integration, cost, licensing type, and technical support, all of which are necessary for creating effective, user-friendly climate resilience dashboards tailored to varied stakeholder needs.

4.2. Supporting Initiatives

Main supporting technological initiatives on a European level include Copernicus and FI-WARE. Key highlights of both programmes are shown below.

4.2.1. Copernicus and other Earth Observation (EO) Data

The European Commission has launched several important initiatives to provide extensive data sources for climate-related research and applications, with the Copernicus programme being a flagship effort in this regard. Copernicus is the European Union's Earth observation and monitoring programme, offering full, free, and open access to environmental data based primarily on satellite Earth observation and complementary in situ data (Climate ADAPT, 2025). Copernicus encompasses six core services, among which the Copernicus Climate Change Service (C3S) focuses on providing authoritative information about past, present, and future climate conditions to support climate change mitigation and adaptation strategies across Europe. The service is implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the Commission and offers access to a wide range of climate indicators and indices through its Climate Data Store.

A key component of Copernicus is the Sentinel satellite series (overview see in Table 2: Overview Sentinel Satellites), which provides critical Earth observation data covering atmosphere, land, oceans, and ice. Sentinel satellites serve as cornerstone satellites for delivering high-resolution, timely, and continuous data that underpins many climate monitoring applications. Sentinel data contribute to diverse sectors such as agriculture, forestry, water management, and disaster response, all of which help enhance climate resilience. Other Copernicus services, including the Copernicus Atmosphere Monitoring Service (CAMS), deliver quality-controlled information on air quality, greenhouse gases, and climate forcing, complementing climate data with atmospheric composition insights. Together, these initiatives ensure that public authorities, researchers, businesses, and citizens can access reliable, up-to-date climate data to inform policy, enhance early warning systems, and foster climate-resilient communities throughout Europe. The open data policy of Copernicus maximizes the potential for innovation and the development of downstream applications benefiting society and the environment.

Table 2: Overview Sentinel Satellites Capabilities

SATELLITE	PURPOSE	FEATURES	APPLICATIONS	MAIDEN

				LAUNCH
Sentinel-1[5]	Radar imaging for land and ocean services	Operates day and night, in all weather conditions	Monitoring sea ice, oil spills, and land surface movements	2014
Sentinel-2[6]	High-resolution optical imaging for land monitoring	Multispectral imaging with 13 bands[1]	Vegetation, soil, water cover, inland waterways, and coastal areas monitoring	2015
Sentinel-3[7]	Measuring sea-surface topography, sea and land surface temperature, and ocean and land colour	Multi-instrument mission[2]	Ocean forecasting, environmental and climate monitoring	2016
Sentinel-4[8]	Atmospheric monitoring	Embarked on a Meteosat Third Generation-Sounder (MTG-s) satellite in geostationary orbit[3]	Air quality and climate monitoring	2024
Sentinel-5[9]	Monitoring the atmosphere from polar orbit	Measures trace gasses and aerosols	Air quality and climate monitoring	2017
Sentinel-6[10]	Measuring global sea-surface height	Carries a radar altimeter[4]	Operational oceanography and climate studies	2021

4.2.2. FI-WARE technologies

The FIWARE programme by the European Commission and its community provides an open-source framework of components designed to accelerate the development of smart digital solutions, including those aimed at climate resilience. FIWARE's modular architecture and open standards enable the integration, management, and processing of diverse data streams from sensors, IoT devices, open data sources, and user inputs, which are crucial for building responsive, adaptive climate resilience dashboards and applications (FIWARE, 2025).

Several FIWARE components are particularly useful for climate resilience solutions:

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[5] Sentinel 1 - https://sentiwiki.copernicus.eu/web/sentinel-1

[6] Sentinel 2- https://sentiwiki.copernicus.eu/web/sentinel-2

[7] Sentinel 3 - https://sentiwiki.copernicus.eu/web/sentinel-3

[8] Sentinel 4 - https://sentinels.copernicus.eu/en/web/sentinel/missions/sentinel-4/data-products

[9] Sentinel 5 - https://sentiwiki.copernicus.eu/web/sentinel-5p

[10] Sentinel 6 - https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-6

- The Orion Context Broker is the core element that manages context information, allowing real-time updates and interoperability between different data sources and applications.
- The Data Models and NGSI API standards facilitate standardised data exchange, supporting seamless integration of heterogeneous environmental data such as air quality, temperature, and humidity measurements.
- Generic Enablers like IoT Agents enable connection to various sensor types and protocols, essential for capturing local environmental data and citizen science inputs.
- Components like Complex Event Processing (CEP) tools analyse data streams to detect critical conditions such as extreme weather events or pollution spikes, triggering alerts or automated responses.
- Visualization support through FIWARE’s dashboards and integration with third-party tools enhances data presentation for different stakeholders, from citizens to policymakers.

Use cases powered by FIWARE demonstrate practical applications, such as the ApriSensor platform for localised air quality monitoring, RainBrain for smart management of green roofs, and IDA for automated climate risk assessment in insurance (FIWARE Foundation, 2019).

These examples show how FIWARE’s components enable scalable, interoperable, and replicable climate resilience solutions that engage communities, and may help to optimise resource use, and improve decision-making under climate stress.

The open-source nature of FIWARE combined with its flexible architecture encourages innovation, cost-effectiveness, and the broad inclusion of stakeholders in climate resilience efforts.

E. Good Practices - Pforzheim

In order to collect dashboards and digital solutions within the Mission CE Climate consortium, which can be classified as good practices, we defined a template which can be found in Appendix I.

5. General Information

The Mission Climate Digital Monitoring Platform is not a monolithic product from a single vendor, but a strategically curated ecosystem of best-in-class technologies designed for flexibility, scalability, and long-term viability. This approach ensures that each component of the solution is optimized for its specific function, from the sensor at the edge to the analytical dashboard in the cloud. The key technology providers and partners in this ecosystem include:

- **Hardware:** LoRaWAN-based IoT sensors provide a highly efficient and scalable solution for environmental monitoring by enabling wireless data collection from a wide variety of physical and chemical parameters—such as temperature, humidity, air quality, soil moisture, and water levels—across large and even remote areas. These battery-operated sensors are designed for low power consumption, offering battery life of up to ten years, and can transmit data over several kilometres, making them extremely cost-effective and suitable for hard-to-reach sites. The gathered data is securely transmitted to gateways and then to cloud servers, where it can be visualized and analyzed in real time, supporting immediate action and long-term planning for applications in fields like smart agriculture, urban infrastructure, disaster prevention, and biodiversity protection.

- **Network Infrastructure:** The Things Network (TTN) provides the primary LoRaWAN Network Server (LNS), offering a globally distributed, scalable, and professionally managed network infrastructure that accelerates deployment and ensures high reliability. The Mission Climate team also possesses demonstrated internal competency in deploying and managing alternative open-source LNS solutions like Chirp Stack, as validated in internal projects. This dual capability represents a significant strategic advantage, offering long-term autonomy from any single provider and ensuring adaptability to future network requirements.

- **Software Platform**: enerchart is the central IoT platform that serves as the system's analytical and visual core. It provides the essential tools for data ingestion, device management, visualization, dashboarding, and advanced analytics, transforming raw data streams into actionable intelligence. A central role in making this sensor data truly actionable is played by software platforms such as enerchart. Enerchart acts as the integrative digital hub of LoRaWAN IoT systems. It provides a comprehensive suite of tools for real-time data ingestion from sensors, device management, visualization, dashboarding, and advanced analytics. With enerchart, data from many different sources—including various LoRaWAN networks and sensor payloads—can be unified and normalized, thanks to its modular architecture and dedicated payload parser. The platform's open approach means users have full access to their collected data and can interface with external systems through multiple supported standards (like Modbus TCP, OPC UA, SNMP, or common IoT clouds such as The Things Network and Chirpstack). Enerchart enables interactive dashboards, custom maps, and configurable analytics that transform raw IoT data streams into actionable intelligence. This empowers organizations to detect patterns and anomalies, conduct energy and environmental management in compliance with standards like ISO 50001, and generate meaningful reports for operational or regulatory needs. As a result, enerchart not only ensures seamless integration of IoT sensor data but also supports data-driven decision-making, driving both sustainability and efficiency in environmental monitoring initiatives.

6. Digital Solution

6.1. Digital Solution - Description

The Mission Climate Digital Monitoring Platform (MCDMP) is an integrated, end-to-end Internet of Things (IoT) solution designed to empower communities with the data and tools necessary for effective, evidence-based climate action. It leverages a low-power, wide-area network (LoRaWAN) to collect granular, real-time environmental and operational data from a diverse array of sensors deployed across the community. This data is then aggregated, visualized, and analyzed via the powerful enerchart platform, transforming raw sensor readings into actionable intelligence for a wide range of stakeholders, including urban planners, civil engineers, public works departments, and citizens themselves.

The project covers several innovative smart city use cases, each leveraging IoT sensor technology for sustainability and citizen engagement. Key use cases include monitoring water levels for flood prevention, tracking air quality and climate data in urban environments, optimizing road salt silo management for efficient winter maintenance, and analyzing soil conditions for sustainable land management. Additional cases focus on real-time traffic radar measurement and people counting systems to enhance urban mobility and energy efficiency. Each use case integrates sensor data into a central dashboard and features citizen participation through DIY sensor installations and collaborative data analysis.

Technology Stack: The technology stack for the Mission Climate Digital Monitoring Platform is a modular ecosystem integrating leading technologies for IoT-based environmental monitoring. LoRaWAN-based IoT sensors serve as the hardware layer, enabling energy-efficient, long-range, wireless collection of environmental data such as temperature, humidity, air quality, soil moisture, and water levels from even remote or hard-to-reach areas. The network infrastructure primarily relies on The Things Network (TTN) as the LoRaWAN server, with demonstrated in-house expertise for open-source alternatives like Chirp Stack, ensuring both reliability and long-term adaptability. The collected sensor data is centrally managed, visualized, and analyzed using the enerchart software platform, which provides real-time dashboards, analytics, and open interfaces, turning data into actionable insights to support environmental management and sustainable urban development.

Monitored Climate Indicators: The Project is designed to build climate resilience by developing and implementing innovative, smart city-based solutions for environmental monitoring and community engagement. At its core, the project empowers citizens, public institutions, and local authorities to collect, analyze, and act upon real-time climate data through a network of advanced IoT sensors, cloud analytics, and interactive dashboards. The pilot does not rely on a single product or provider but leverages a curated ecosystem of best-in-class hardware, network infrastructure, and software platforms, ensuring flexibility, scalability, and openness for future growth.

By monitoring a comprehensive set of climate indicators—ranging from air quality and soil moisture to flood risk, urban heat, and infrastructure health—the project delivers actionable insights for both immediate response and long-term planning. These indicators are directly linked to key climate adaptation and sustainability goals at the municipal level, enabling data-driven decision-making for public safety, environmental protection, energy efficiency, and citizen well-being. Through ongoing collaboration, testing, and feedback, the project advances public awareness, supports educational initiatives, and creates a robust foundation for replicable and scalable climate action across the region.

- **School Air Monitoring:** Air quality sensors installed in and around schools continuously measure concentrations of harmful pollutants like PM2.5 and NO_2. The collected data is visualized in real-time through dashboards, allowing for the early detection of pollution peaks associated with traffic patterns; directly linked to the climate indicator “urban air quality,” as pollution levels and exposure risk are critical for assessing the impact of emissions reduction and mobility interventions in cities.

- **Soil Moisture:** Citizen-deployed LoRaWAN soil moisture sensors in urban parks and community gardens gather hyper-local data on soil hydration. The results are mapped city-wide to guide efficient irrigation and drought response, supporting both public maintenance efforts and local initiatives; directly addresses the climate indicator “soil health and drought resilience,” since soil moisture trends reveal ecological impacts of climate change on urban greenery and water cycles.

- **Precipitation and Flood Risk**: Rain gauges and water level sensors managed by local residents deliver real-time, high-granularity measurements of rainfall intensity and flood risk across neighborhoods. This network feeds into flood preparation efforts and emergency planning dashboards; relates to “precipitation patterns and flood events” as climate indicators, providing vital evidence for changes in rainfall regimes and vulnerability to extreme weather.

- **Urban Heat**: Temperature and humidity are monitored with ground-based sensors and complemented by Copernicus satellite land surface data. This combination delivers detailed heat maps that help city planners understand and address the urban heat island effect; directly supports the indicator “urban temperature extremes,” crucial for monitoring heatwaves, public health risks, and the effectiveness of urban greening.

- **Road Salt Silo Levels:** Ultrasonic sensors in municipal road salt silos track fill levels, enabling responsive, data-driven logistics for winter road maintenance. The resulting operational gains lower emissions and ensure road safety during extreme cold events; aligns with the indicator “infrastructure resilience to extreme weather”, as resource readiness and adaptive logistics are core to climate adaptation.

- **Water Levels in Infrastructure:** LoRaWAN sensors in rivers, canals, and storm drains monitor water levels over time, feeding into predictive dashboards for flood prevention. Alert systems help avoid infrastructure failure and manage stormwater; tied to “hydrological extremes and urban flood management” as climate indicators, since real-time hydrology data underpin adaptation to increased precipitation variability.

- **Soil Nutrients and pH**: Advanced sensors with AI-based analytics track soil moisture, nutrient content, and pH in urban gardens and parks. This enables tailored fertilization and plant care, optimizing green infrastructure resilience; corresponds to “urban soil quality and ecosystem services”, a climate indicator reflecting city-level food sufficiency, biodiversity, and carbon sequestration capacity.

- **Outdoor Temperature and Humidity:** Distributed sensors continuously record temperature and humidity, establishing a long-term baseline for environmental conditions. This foundational data validates the impact of climate mitigation and adaptation strategies; core to tracking climate indicators like “ambient temperature and relative humidity”, enabling evidence-based progress assessment.

- **Microclimate Accuracy**: High-precision sensors, some shielded to avoid solar bias, are installed at strategic points to capture accurate microclimate data. These data sets improve urban climate models and help set standards for scientific monitoring; directly serves “local microclimate variability” as a climate indicator, which is essential for fine-tuned city adaptation plans.

- **Traffic Flow**: Digital radar sensors count vehicles, measure speeds, and classify types across major intersections, feeding data into visualized analytics for congestion, emissions, and safety planning; strongly related to “urban mobility emissions and congestion”, as observed traffic trends influence air quality, energy use, and the city’s climate footprint.

- **Public Space Occupancy:** Infrared people counters at park and square entrances track the use of public spaces, providing data for efficient facility management and event planning; relates to “urban resilience and adaptive public space usage”, climate indicator reflecting community adaptation, well-being, and effective use of green infrastructure.

- **Indoor Environment Quality**: Indoor sensors in municipal buildings measure temperature, humidity, and CO_2 levels, informing energy-saving ventilation strategies and improving occupant health; these data support tracking "energy efficiency and indoor air quality"—climate indicators linked to building sector emissions, adaptation, and public health.

- **Sewer Gas and Humidity:** Ruggedized sensors track key gases (H_2S, CH_4) and humidity in the sewer network, helping identify maintenance needs and flagging risks; this feeds into the indicator "urban sanitation and climate-induced risk management", ensuring critical infrastructure remains resilient as weather patterns change.

- **LoRaWAN Network Health**: Infrastructure sensors report on the operational status and signal strength of the wireless network, providing early warning for communication issues in the sensor grid; directly supports the climate indicator "infrastructure robustness and monitoring capacity", as a functioning network is foundational for data-driven resilience.

- **Privacy-respecting People Detection:** Edge-computing AI cameras count people in public buildings without storing video, offering accurate occupancy data while maintaining privacy; addresses the indicator "adaptive building occupancy and privacy protection", which supports energy efficiency, crisis response, and social acceptance in climate-resilient cities.

Geographical Coverage: Pilot Project in Pforzheim and the Northern Black Forest

6.2. Target Group

6.2.1. Who uses the digital solution?

Local governments and municipalities
Use: Actively use dashboards and alerts for city management, emergency planning, and infrastructure maintenance. Passively benefit from automated monitoring and reports for policy evaluation.

Urban planners
Use: Actively consult data to guide urban development, design interventions for climate adaptation, and monitor the effects of green infrastructure. Passively access historical trends for strategic planning.

Experts (nature conservation, civil engineering, meteorologists, etc.)
Use: Actively analyze specialized sensor data to support technical decisions, risk assessment, and environmental protection. Passively utilize ongoing data streams for research and reporting.

NGOs

Use: Actively engage in citizen science campaigns, deploy sensors in targeted projects, and use data for advocacy. Passively benefit from transparent, real-time access to environmental conditions.

Research institutions
Use: Actively conduct studies based on raw sensor data, develop new analytical methods, and publish findings. Passively gain long-term, open datasets for academic analysis.

Other stakeholders (e.g., schools, businesses, citizens)
Use: Schools use live environmental data for STEM education (active); businesses adjust operations based on climate and air quality info (active/passive); citizens receive alerts and view dashboards for personal awareness (passive).

Active use: Direct interaction with the digital platform—installing sensors, managing dashboards, analyzing real-time data, or making operational decisions.

Passive use: Receiving automated alerts, accessing published reports or visualizations, and integrating trends into background planning and awareness without direct system management.

6.2.2. Stakeholder collaboration?

The Mission CE Climate Pilot Project is fundamentally rooted in robust stakeholder collaboration that spans local communities, academia, municipal authorities, advisory boards, NGOs, and research organizations. Community members are actively engaged through citizen science activities, where residents participate directly in sensor deployment and data gathering, ensuring that local knowledge and grassroots perspectives are integrated into environmental monitoring. Academia, particularly institutions like Hochschule Pforzheim, play a pivotal role in guiding the project's scientific rigor—leading technical prototyping, advanced data analytics, and validation of climate indicators, while also facilitating interdisciplinary teamwork and applied research. Close partnership with municipal authorities and their technical agencies ensures that the digital solutions respond directly to the real needs of city management, policy implementation, and resilience planning. Advisory boards, made up of experts from fields such as urban planning, environmental protection, and civil engineering, provide critical strategic direction and oversight, aligning project activities with policy priorities and national or European sustainability frameworks. NGOs and additional civil society actors contribute their specialized expertise, support outreach for environmental and social initiatives, and help drive public participation in project campaigns. These interconnected relationships foster transparency, shared responsibility, and cross-sector learning—laying a strong foundation for the success and future scalability of data-driven climate resilience in the region.

6.3. (Expected) Impact

The Pilot Project is designed to drive environmental monitoring and engagement through the deployment of smart city-based digital solutions. By harnessing the power of IoT sensors, participatory citizen science, and collaborative partnerships among municipalities, academia, NGOs, and local communities, the project aims to strengthen climate resilience and promote sustainable urban development. The initiative brings together diverse stakeholders to collect, analyze, and act upon environmental data, supporting evidence-based decision-making and fostering public awareness about pressing climate and environmental issues. This integrated approach not only improves operational efficiency and policy effectiveness but also deepens the involvement of citizens and community groups in shaping solutions for a more sustainable and adaptive future.

Impact Dimension	Qualitative Outcomes	Quantitative Outcomes
Environmental Awareness	Citizens gain deeper understanding of local climate risks and sustainability topics through direct, hands-on participation. Enhanced public dialogue around environmental issues and climate adaptation.	Over 250 citizens attended the main public event; increased participation rate in citizen science activities (to be measured annually).
Evidenced-based Policy Making	Municipal officials and planners use real-time, granular sensor data to inform decisions, prioritize interventions, and monitor the results of climate adaptation strategies.	Number of policy interventions or planning adjustments informed by project data (target: 5+ per year).
Operational Efficiency	Automated data flows support faster response to weather, infrastructure, or environmental incidents (e.g., floods, road salt management), improving public safety and resource allocation.	Reduction in field staff deployment and response times for maintenance (target: -20%). Road salt logistics optimized (>10% fewer trips).
Community Engagement	Community members and NGOs collaborate more closely with local government, fostering mutual trust, knowledge-sharing, and co-creation of local solutions (“citizen science approach”).	Number of sensors co-installed by citizens (>50 by project end). Number of NGO partnerships (target: 3+ NGOs actively involved).
Educational Impact	Increased digital and environmental literacy for participants, especially students, through hands-on IoT activities and real-world data analysis.	Number of student projects utilizing project data (goal: >10 per year); feedback from workshops (target: 90% positive).

Impact Dimension	Qualitative Outcomes	Quantitative Outcomes
Data-driven Sustainability	Continuous monitoring and visualization (e.g., air quality, soil, flood risk) enables detection of trends, targeted intervention, and improved tracking of climate indicators for adaptation and resilience.	Volume of data points collected and visualized (target: millions per year). Number of new climate trends successfully identified.
Stakeholder Collaboration	Strengthened collaboration between academia, city, NGOs, and residents; new regional networks and transfer of best practices.	Joint reports, workshops, and presentations held (target: 6+ per year); cross-institutional projects initiated (target: at least 2).
Scalability & Replicability	Digital solutions and methodologies are documented and made available for replication in other municipalities or regions, contributing to national/EU climate resilience goals.	Number of replication pilots started by 2025 (target: at least 2 external cities/regions piloting similar approaches).
Public Safety and Risk Reduction	Faster, data-driven alerts for floods, traffic, air pollution, or facility management, reducing immediate risk to citizens and infrastructure.	Reduction in response time to environmental alerts; comparative before/after incident metrics (target: -25% average time to response).

6.4. Technical Implementation Details

The project employs a hybrid data sourcing strategy, combining the strengths of high-resolution ground-based sensors with the broad coverage of satellite-based remote sensing to create a comprehensive and multi-layered view of the community's environment.

Primary Source: Sensor Data - IoT (via LoRaWAN): This is the core data stream of the platform. It consists of real-time, time-series data generated by a distributed network of LoRaWAN sensors. This source provides the high-frequency, hyper-local "ground truth" that is essential for operational decision-making and detailed environmental analysis.

The platform is designed to handle and integrate the following types of data:

Time-series data: This is the continuous stream of measurements from the IoT sensors, where each data point is associated with a specific timestamp (e.g., temperature, humidity, air quality readings).

The architectural approach rooted in the use of open and widely-adopted standards to ensure maximum interoperability and future-proofing. The reliance on the LoRaWAN open standard for wireless communication, MQTT for data transport between network components, and the provision of open APIs by the enerchart platform ensures that the solution can seamlessly integrate with other municipal data systems (e.g., GIS platforms, asset management systems) and adapt to emerging technologies. This commitment to open standards prevents vendor lock-in and fosters a collaborative ecosystem where data can be easily shared and leveraged across different departments and applications.

6.5. Overview of Implementation

The process for deploying a new monitoring point on the MCDMP is a standardized and well-documented workflow, demonstrating the operational maturity of the solution. The implementation follows a logical progression from the physical device to the final data visualization.

Sensor Activation and Configuration: The first step takes place in the field. The specific sensor is activated and configured using its corresponding manufacturer's mobile application. For the recommended SenseCAP sensors, this is done via a Bluetooth connection using the SenseCraft app. For Milesight devices, configuration is performed via Near Field Communication (NFC) using the Milesight Toolbox app. This step involves setting key parameters such as the measurement and transmission interval.

Network Registration (TTN): Once configured, the sensor must be registered on the LoRaWAN network. This is done through The Things Network (TTN) console. The administrator adds a new end device to the appropriate application, manually entering the sensor's unique identifiers: the DevEUI (a global device identifier), the AppEUI (an application identifier), and the AppKey (a secret key used to secure the connection). The correct frequency plan (e.g., EU868) and LoRaWAN version must also be specified to ensure compatibility.
Platform Integration (enerchart): With the device now transmitting data to TTN, the final step is to integrate it into the enerchart platform. This involves a three-part process within the enerchart interface.

Device Registration: The new device is added as a data source within enerchart, linking it to the corresponding device in the TTN application.

Data Point Creation and Mapping: For each metric the sensor measures (e.g., temperature, humidity, battery), a corresponding data point is created in enerchart's evaluation structure. The incoming data fields from the TTN payload are then mapped to these newly created data points.

Structural Integration: The new data points are added to a logical evaluation structure (e.g., a structure for "Outdoor Environmental Monitoring"), which allows for aggregation and hierarchical analysis.

Visualization: The final step is to make the data visible and useful. Within enerchart, new charts (e.g., time-series line graphs) are created using the newly integrated data points as their source. These charts are then added to a new or existing dashboard, positioned, and sized as needed. Once the dashboard is saved, the sensor's data will begin to populate the charts in real time, completing the implementation process.

6.6. Screenshot

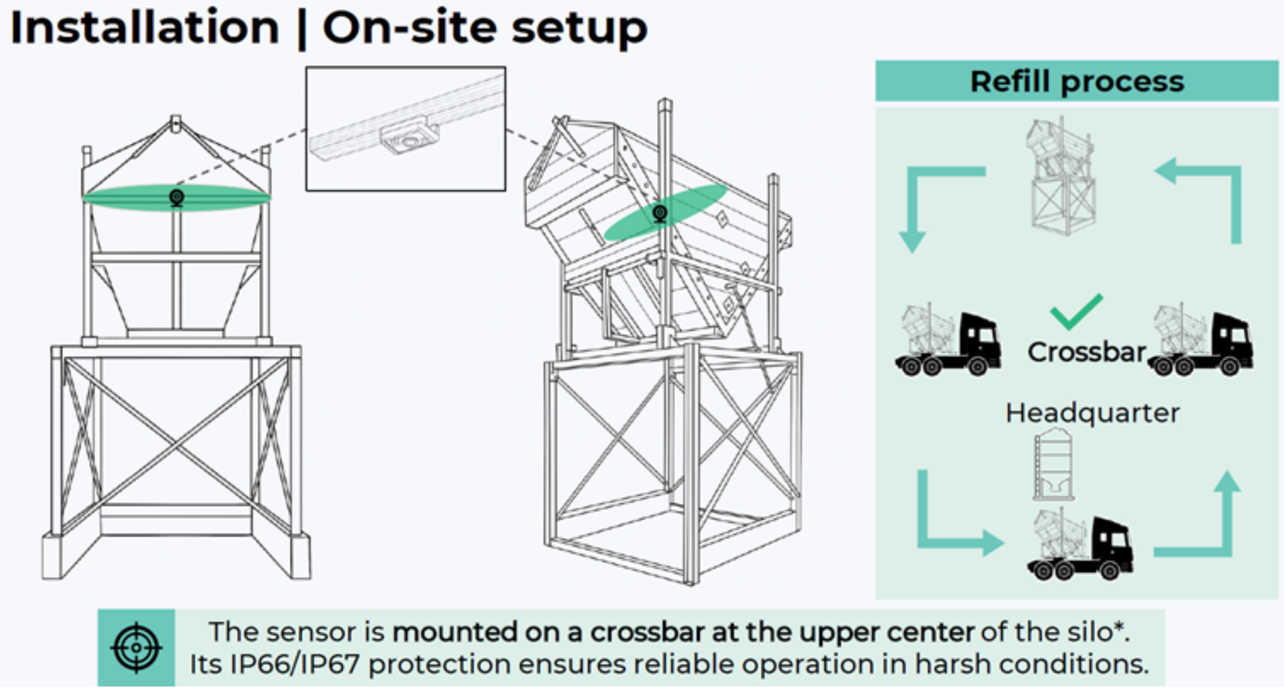
https://www.linkedin.com/pulse/streusalz-f%C3%BCllst%C3%A4nde-im-blick-mit-lorawan-und-schlauen-krutwig-riv9e/

Illustration 1:Streusalz-Silo in Pforzheim

This semester, the course “Managing of Emerging Technologies” at Pforzheim University under the direction of Prof. Dr. Bernhard Koelmel was offered. After a theoretical section on LoRa technology, the course was divided into individual teams, each of which was assigned its own smart city use case. Equipped with different LoRa sensors, each group was able to implement a typical use case from the Smart City sector.

This year, we were also able to count on the support of the City of Pforzheim and Stadtwerke Pforzheim (SWP), who provided us with interesting sensor technology and real-life scenarios as well as specific requirements. We would like to take this opportunity to express our sincere gratitude to our colleagues at the City of Pforzheim and SWP. This equipment not only enabled us to use high-quality hardware, but the expectation of useful research results also created a certain pressure to succeed, which led to excellent results.

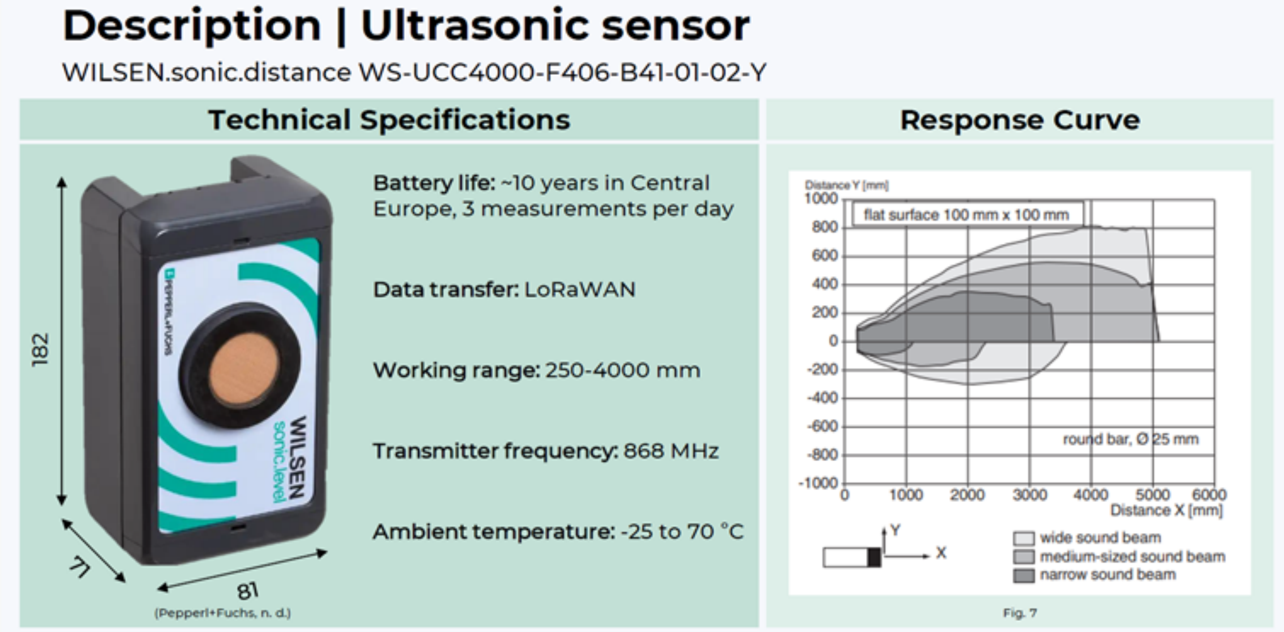
Road salt is stored in high silos in many municipalities, and the city of Pforzheim has a total of 17 such containers. And these may well be filled with sufficient salt when winter sets in. Two to four fill level readings per day are sufficient for continuous monitoring, and even less frequently in summer, so the amount of data generated is perfectly suited to LoRa transmission. In addition to the suitability of the sensor, the study also assessed the complexity of the sensor configuration and network integration, so that the rollout to all silos remains enjoyable.



The sensor is **mounted on a crossbar at the upper center** of the silo*.
Its IP66/IP67 protection ensures reliable operation in harsh conditions.

Illustration 2: Sketch of the sensor assembly

To keep track of the fill level in the silos, a WILSEN.sonic.level UCC400 ultrasonic sensor from Pepperl+Fuchs will be used. Mounted centrally on the inner top surface, it will measure the distance to the grit in the range from 0.25 m to 4 m. Thanks to IP67 protection, the device should be able to cope with dust, dirt, and moisture without any problems. The extent to which the salt will cause damage remains to be seen.



Description | Ultrasonic sensor

WILSEN.sonic.distance WS-UCC4000-F406-B41-01-02-Y

Technical Specifications

Battery life: ~10 years in Central Europe, 3 measurements per day

Data transfer: LoRaWAN

Working range: 250-4000 mm

Transmitter frequency: 868 MHz

Ambient temperature: -25 to 70 °C

(Pepperl+Fuchs, n. d.)

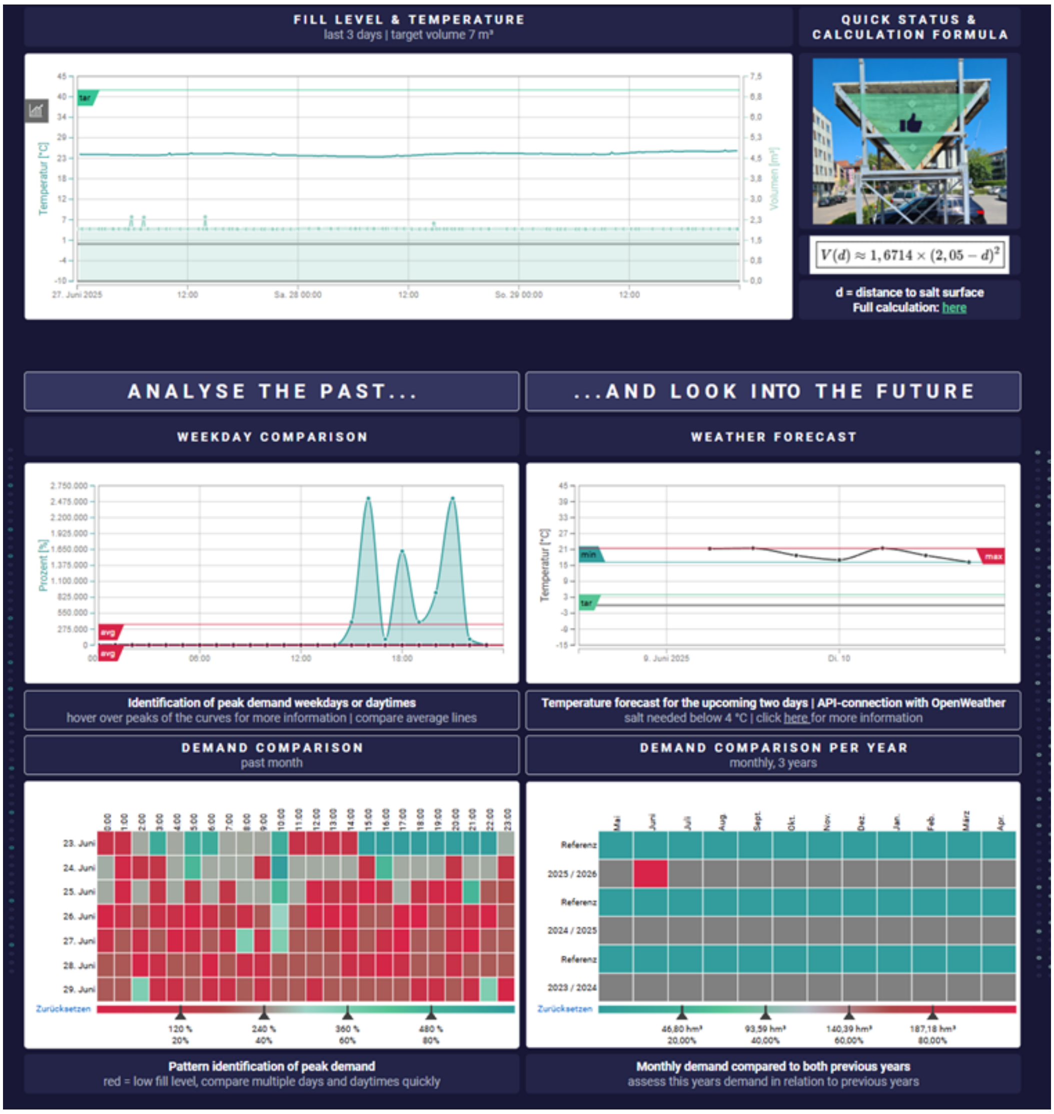
Response Curve

Fig. 7

Illustration 3: Sensor Description

The TTN community network was used as the wireless counterpart (to be replaced later by the city's own infrastructure). During the TTN registration process, the students were able to successfully demonstrate their proficiency in nerdy topics.

Now it was time to create the dashboard in enerchart, which was essentially the final challenge, and one that was carried out with great detail and care in view of the promised grading. The dashboards go far beyond data visualization: they include the use case description, the sensor description (including manual download), illustrations, charts, statuses, interactive maps, and more. Unfortunately, the dashboard scrolls across four screens, so an overall view would be disadvantageous for this text. I will therefore limit myself to partial views; anyone who would like to see everything is encouraged to contact me. Incidentally, enerchart is actually a specialist in energy data—most of its functions were irrelevant to the project. However, it shows potential for use as a platform for a smart city (or smart building or smart production or ...).



FILL LEVEL & TEMPERATURE
last 3 days | target volume 7 m³

QUICK STATUS & CALCULATION FORMULA

$V(d) \approx 1,6714 \times (2,05 - d)^2$

d = distance to salt surface
Full calculation: here

ANALYSE THE PAST...

...AND LOOK INTO THE FUTURE

WEEKDAY COMPARISON

Identification of peak demand weekdays or daytimes
hover over peaks of the curves for more information | compare average lines

WEATHER FORECAST

Temperature forecast for the upcoming two days | API-connection with OpenWeather
salt needed below 4 °C | click here for more information

DEMAND COMPARISON
past month

Pattern identification of peak demand
red = low fill level, compare multiple days and daytimes quickly

DEMAND COMPARISON PER YEAR
monthly, 3 years

Monthly demand compared to both previous years
assess this years demand in relation to previous years

Illustration 4: enerchart Dashboard (excerpt)

I am every year amazed at how well students who have not received any training can use the software and exploit its full range of functions. It just goes to show how well you can get to grips with software – if you really want to. I would like to highlight two details that particularly impressed me: firstly, the formula for converting the fill level into the fill volume, taking into account the silo geometry, was easily implemented as a virtual data point using the integrated formula editor. Second, the function for illustrated statuses was used perfectly: an empty silo is colored red, half-full yellow, and full green (see image below). This is exactly how you build beautiful dashboards and control stations.

Enerchart | Road salt cockpit

Over 75 % green
Under 75 % yellow
Under 25 % red

Over 3,3 Volt green
Under 3,3 Volt yellow
Under 3 Volt red

Illustration 5: Condition-dependent representation of the silo

Now the utility value explodes: in addition to the historical progression of sensor data (fill level, outside temperature) and various comparative analyses, a weather forecast has also been added. The students developed their own API for OpenWeather in Python and integrated this data into enerchart as well. The alarm is triggered as soon as the temperature is expected to drop below four degrees and the silo is not prepared for this. The students put a lot of thought into their ideas and implemented them perfectly.

The images are taken from the enerchart dashboards of the projects and/or from the presentation slides of the respective group. The project groups' presentations were given in English.

Smart City - Air Quality Monitoring with Milesight EM500

Outdoor Environment Monitoring Sensor zur Messung von Temperatur, Luftdruck, Luftfeuchtigkeit & CO2 Gehalt

28.09.2024

Smart City Use Case

Luftqualitätsüberwachung in einer Smart City

Hintergrund

Luftqualität in Städten:
- kritisch für Gesundheit und Wohlbefinden

Verschmutzungsquellen:
- Verkehr, Industrie

Gesundheitliche Risiken:
- Atemwegserkrankungen
- Herz-Kreislauf-Probleme, etc.

Luftqualitätsüberwachung:
- wichtiger Teil von Smart City Initiativen

Ziele:
- Verbesserung der Lebensqualität
- Schaffung nachhaltiger Zonen

Anwendungsfall

Überwachung der Luftqualität

Fokus:
- Stadtzentren, Schulen und Krankenhäuser

Vorteile:
- Kontinuierliche Überwachung
- Schnelle Reaktion auf erhöhte Schadstoffwerte

Mögliche Maßnahmen:
- Temporäre Verkehrsbeschränkungen
- Erhöhung der Grünflächen

Aktueller Standort:
- Balkon in dicht besiedeltem Gebiet in Höfingen
- Nähe zu Schulen und Kitas

Anwendungsfall - Balkon

Über Milesight EM500-CO2 Sensor

Allgemeines und Anwendugsgebiet

Datenqualität

SNR-Wert	RSSI-Wert
dB	dBm
5,50	-113
28.09.2024 10:59	28.09.2024 10:59

Standort

Sensorbild

Beschreibung

Sensor-Funktionen:
- **CO2-Messung**: Bereich von 400 bis 5000 ppm

Zusätzliche Messungen (jede 10 Minute):
- Luftdruck
- Temperatur
- Luftfeuchtigkeit

Luftqualitätsanalyse:
- Kombination der vier Messwerte (CO2, Luftdruck, Temperatur, Luftfeuchtigkeit) ermöglicht zuverlässige Aussagen zur Luftqualität

Energieversorgung
- **Akku**: 19000 mAh
- **Stromverbrauch**: Gering
- **Nutzungsdauer**: Mehrere Jahre

Einsatzgebiete:
- **Umweltüberwachung**: Verschiedene Szenarien
- **Gehäuse**: Sehr stabil, widersteht schwierigen Umweltbedingungen
- **Professioneller Einsatz**: Geeignet für anspruchsvolle Anwendungen

Installation

Installationsbeschreibung für den Milesight EM500 CO2 Sensor

Vorbereitung

1. **Auspacken**: Sensor und Zubehör auspacken.
2. **Überprüfung**: Überprüfen, ob alle Teile vorhanden sind (Sensor, Batterie, Anleitung).

Hardware-Installation

1. **Batterie einlegen**: 19000 mAh Batterie in den Sensor einsetzen.
2. **Montageort wählen**: Einen geeigneten Standort für den Sensor auswählen
3. **Befestigung**: Sensor mit dem mitgelieferten Befestigungsmaterial montieren (z.B. an einer Wand oder einem Mast).

Konfiguration

1. **LoRaWAN**: Sensor in das LoRaWAN-Netzwerk integrieren (Details in der Anleitung).
2. **Kalibrierung**: Sensor gemäß Anleitung kalibrieren.

Datenblatt

Milesight EM500-CO2 Sensor

Datenauswertung

7. Use Cases

The true power and versatility of the Mission CE Climate Digital Monitoring Platform are best understood through its diverse portfolio of practical use cases. Each use case represents a specific application of the platform's core capabilities to solve a real-world problem for a particular stakeholder group. The following table provides a comprehensive summary of the platform's demonstrated and potential applications, followed by detailed descriptions of each use case.

Use Case	Topic	Data Collection	Visualisation	Problem Addressed	Decision Support
School Air Monitoring	Air Pollution	LoRaWAN air quality sensors (PM2.5, NO_2) on school grounds	Real-time graphs of pollutant concentrations on enerchart dashboards	Health risks from traffic-related air pollution; lack of tangible environmental education materials.	Adjusting school travel plans to reduce car arrivals/departures; integrating real-world data into STEM curricula.
Citizen-Led Soil Quality	Soil Health	Citizen-deployed LoRaWAN soil moisture sensors in urban green spaces	City-wide map of soil moisture levels on public enerchart dashboard	Water wastage from inefficient irrigation; declining health of urban trees and plants due to drought stress.	Data-driven irrigation scheduling for public works; targeted watering efforts by community volunteer groups.
Citizen-Led Flood Risk	Precipitation	Citizen-managed LoRaWAN rain gauges and water level sensors	Real-time precipitation intensity and flood risk map on enerchart dashboard	Lack of granular, real-time data on localized heavy rainfall events, leading to delayed flood response.	Proactive deployment of flood barriers by emergency services; operational planning for fire departments and civil engineering.
Urban Heat Monitoring	Urban Heat Islands	Copernicus satellite data (LST) fused with	Multi-layered enerchart dashboard	Increased public health risks during	Prioritizing urban greening interventions

Use Case	Topic	Data Collection	Visualisation	Problem Addressed	Decision Support
		ground-truth LoRaWAN temperature/humidity sensors	showing heat maps and sensor readings	heatwaves; degradation of urban green spaces due to heat stress.	(e.g., tree planting, green roofs); strategic placement of public cooling centers.
Road Salt Silo Logistics	Winter Maintenance	LoRaWAN ultrasonic level sensors in road salt silos	enerchart dashboard showing real-time fill levels of all silos	Inefficient, schedule-based logistics; risk of resource depletion during critical winter weather events.	Just-in-time, route-optimized replenishment of salt supplies, ensuring road safety and reducing operational costs.
Predictive Flood Prevention	Infrastructure Resilience	LoRaWAN water level sensors in rivers, canals, and storm drains	Well-designed enerchart dashboard with alert thresholds and historical trends	Reactive response to flooding; potential for catastrophic failure of critical drainage infrastructure.	Early warning alerts for civil engineering; proactive management of sluice gates and pumps to mitigate flood impact.
AI-Enhanced Soil Analysis	Precision Agriculture	Advanced LoRaWAN soil sensors (moisture, pH, nutrients) with AI-configured sampling	enerchart dashboards with predictive analytics on soil health	One-size-fits-all approach to urban agriculture and park management; inefficient use of fertilizers and soil amendments.	Precision application of water and nutrients; tailored soil management plans for different urban green spaces.
Outdoor Environmental Monitoring	Baseline Monitoring	Standard LoRaWAN temperature and humidity sensors (e.g.,	Baseline time-series graphs and statistical summaries in enerchart	Lack of foundational environmental data for climate action	Establishing long-term climate trends; validating the impact of

Use Case	Topic	Data Collection	Visualisation	Problem Addressed	Decision Support
		SenseCAP S2101)		planning and tracking progress over time.	environmental interventions.
Hyper-Local Urban Climate	Scientific Research	High-accuracy LoRaWAN sensors with custom 3D-printed radiation shields	enerchart dashboards for comparative analysis of shielded vs. unshielded sensor data	Inaccurate microclimate data due to measurement biases (e.g., solar radiation), leading to flawed models.	Improving the accuracy of urban climate models; developing best practices for scientific sensor deployment.
Advanced Traffic Analysis	Urban Mobility	LoRaWAN-connected traffic radar sensors	enerchart dashboard visualizing vehicle count, speed, and classification data	Traffic congestion leading to increased emissions and economic loss; lack of data for road safety analysis.	Optimizing traffic signal timing; identifying accident hotspots for infrastructure redesign; planning for future mobility needs.
Public Space People Counting	Urban Planning	LoRaWAN infrared people counters at entrances to parks and public squares	Visually strong enerchart dashboard showing footfall patterns over time	Inefficient management of public spaces; lack of data to justify investments in public amenities.	Optimizing maintenance schedules; planning for events; providing evidence for funding requests for park improvements.
Local AI People Detection	Privacy & Efficiency	LoRaWAN camera sensor with on-board (edge) AI for people detection and counting	enerchart dashboard showing anonymous people counts	Privacy concerns with traditional video surveillance; high bandwidth	Monitoring occupancy in sensitive areas (e.g., public buildings) while preserving privacy; efficient use of

Use Case	Topic	Data Collection	Visualisation	Problem Addressed	Decision Support
				requirements for streaming video.	network bandwidth.
LoRaWAN Network Management	Infrastructure Health	Monitoring of LoRaWAN gateway status and performance metrics (e.g., signal strength)	Internal enerchart dashboard showing network health and coverage map	Unreliable data delivery due to network issues; lack of visibility into the performance of the core infrastructure.	Proactive maintenance of network gateways; optimizing gateway placement to improve coverage and reliability.
Smart Building Management	Energy Efficiency	Indoor LoRaWAN sensors (Temp, Humidity, CO_2) in municipal buildings	enerchart dashboard for facility managers showing real-time indoor environmental quality	High energy consumption from inefficient HVAC operation; poor indoor air quality affecting employee health and productivity.	Demand-controlled ventilation based on CO_2 levels; optimizing heating/cooling schedules to reduce energy waste.
Proactive Sewer Management	Public Health	Ruggedized LoRaWAN sensors in sewer systems (Temp, Humidity, H_2S, CH_4)	enerchart dashboard with alerts for anomalous conditions	Health risks from pest infestations and hazardous gas build-ups; costly, reactive maintenance of sewer infrastructure.	Predictive maintenance alerts for cleaning and repairs; targeted pest control measures to protect public health.

Table 3: Summary of all use cases of the digital solution

7.1. Detailed Use Case Descriptions

7.1.1. School Air Monitoring (Awareness & Education)

Objective: To raise awareness about local air pollution and provide tangible educational tools for students by monitoring air quality directly on school grounds.

Technical implementation: LoRaWAN-enabled air quality sensors, measuring key pollutants like Particulate Matter (PM2.5) and Nitrogen Dioxide (NO2), are installed in strategic locations such as playgrounds and near parent drop-off zones. Data is streamed in real time to a dedicated enerchart dashboard accessible to school administrators, teachers, and students.

Problem Addressed (Strategic Context): This use case directly confronts the public health risk of traffic-related air pollution, which disproportionately affects children. It also addresses a gap in modern education by transforming an abstract environmental issue into concrete, localized, and data-driven learning experiences, fostering a new generation of environmentally literate citizens.

Decision Support: The real-time graphs on the enerchart dashboard provide clear, visual evidence of pollution peaks, particularly during morning drop-off and afternoon pick-up times. This data empowers school administrators to advocate for and implement changes to school travel plans, such as promoting walking or cycling, or redesigning pick-up procedures to reduce vehicle idling. For educators, the dashboard becomes a dynamic textbook, allowing students to download real data for analysis in science, technology, engineering, and math (STEM) classes.

7.1.2. Citizen-Led Soil Quality Monitoring

Objective: To create a high-resolution, city-wide map of soil moisture to enable efficient water management for urban green spaces and empower citizens to take an active role in caring for their local environment.

Technical Implementation: Citizen volunteers or "community scientists" are equipped with simple, robust LoRaWAN soil moisture sensors. They deploy these sensors in local parks, community gardens, and tree pits. The collective data is visualized on a public-facing enerchart map, showing the real-time moisture status of green spaces across the city.

Problem Addressed (Strategic Context): This addresses the dual challenges of increasing water scarcity due to climate change and the financial pressure on municipal budgets. Inefficient, timer-based irrigation systems lead to significant water wastage, while under-watering during drought periods threatens the health and survival of the city's vital green infrastructure.

Decision Support: For the municipal public works department, the soil moisture map provides the basis for a data-driven, city-wide irrigation strategy, ensuring water is delivered only when and where it is needed. For community groups and individual citizens, the dashboard provides the information they need to organize targeted watering efforts for specific trees or garden beds in their neighborhood, fostering a sense of stewardship and collective action.

7.1.3. Citizen-Led Precipitation & Flood Risk Monitoring

Objective: To build a dense, hyper-local precipitation monitoring network that provides early warnings of flash flooding and enhances the city's resilience to extreme weather events.

Technical Implementation: Building on the citizen science model, volunteers host LoRaWAN-connected rain gauges. For critical areas, these can be supplemented with ultrasonic water level sensors in culverts or small streams. The data feeds into an enerchart dashboard that displays a real-time map of rainfall intensity and flags areas where water levels are rising rapidly.

Problem Addressed (Strategic Context): Climate change is increasing the frequency of intense, localized downpours that can overwhelm urban drainage systems. Traditional, sparsely located weather stations often fail to capture this variability, leading to a delayed and inefficient response to flash floods. This use case addresses this critical "governance lag" by providing unprecedented situational awareness.

Decision Support: The enerchart dashboard becomes a critical operational tool for emergency services. Civil engineering departments can monitor the real-time load on their drainage infrastructure, while fire departments and emergency response teams can use the map to anticipate which neighborhoods are at highest risk and proactively deploy resources, such as temporary flood barriers or evacuation teams, before a crisis escalates.

7.1.4. Copernicus-Enhanced Urban Heat & Vegetation Monitoring

Objective: To create a comprehensive understanding of the urban heat island effect by fusing broad-area satellite data with precise, ground-level sensor measurements.

Technical Implementation: The platform ingests Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) data from Copernicus satellites. This is integrated within enerchart and displayed as map layers. This satellite data is then correlated with data from a ground network of LoRaWAN temperature and humidity sensors. The resulting multi-layered dashboard allows users to compare macro-level heat patterns with micro-climate conditions on the ground.

Problem Addressed (Strategic Context): Urban heat islands pose a significant and growing public health risk, exacerbating heatwaves and disproportionately affecting vulnerable populations. Effective mitigation requires a detailed understanding of which parts of the city are hottest and why—a question that cannot be answered by either satellite data or ground sensors alone.

Decision Support: This integrated dashboard is a powerful strategic planning tool for urban planners and public health officials. By analyzing the relationship between surface temperature, air temperature, and vegetation cover, planners can identify the most effective locations for greening interventions like planting trees, creating parks, or installing green roofs. During a heatwave, the dashboard can be used to strategically locate public cooling centers in the areas with the highest combination of heat and social vulnerability.

7.1.5. Road Salt Silo Logistics Management

Objective: To optimize the logistics of winter road maintenance by providing real-time inventory data for road salt supplies.

Technical Implementation: LoRaWAN-enabled ultrasonic level sensors are mounted inside each of the city's road salt storage silos. These sensors continuously measure the distance to the surface of the salt, providing a real-time calculation of the remaining volume. An enerchart dashboard provides the logistics manager with a single, clear overview of the fill level of every silo in the network. The project's excellent organization and requirements analysis ensured a technically optimal solution.

Problem Addressed (Strategic Context): This use case is a prime example of enhancing municipal resilience to extreme weather events while simultaneously improving operational efficiency under increasing "economic pressure". Traditional, schedule-based inspections are inefficient and create the risk of a critical resource shortage during a prolonged snow or ice storm.

Decision Support: The enerchart dashboard transforms the replenishment process from reactive to proactive and data-driven. The logistics manager can see at a glance which silos are running low and dispatch delivery trucks on optimized, just-in-time routes. This minimizes vehicle miles traveled, saves fuel, reduces emissions, and, most importantly, ensures that public works crews always have the resources they need to keep the city's roads safe during winter weather emergencies.

7.1.6. Predictive Flood Prevention System

Objective: To provide an early warning system for riverine and surface water flooding by monitoring critical water infrastructure in real time.

Technical Implementation: This use case expands on the citizen-led precipitation network by deploying industrial-grade LoRaWAN water level sensors in key locations such as rivers, canals, and major storm drains. The data is visualized on a "beautifully and attractively designed" enerchart dashboard that shows current water levels, historical trends, and pre-configured alert thresholds.

Problem Addressed (Strategic Context): As cities grow and climate change brings more intense rainfall, the risk of catastrophic failure of aging drainage and flood control infrastructure increases. This system addresses the need for a resilient infrastructure by providing the continuous monitoring required for predictive maintenance and proactive management.

Decision Support: The dashboard serves as a command-and-control interface for the civil engineering department. When water levels approach a critical threshold, the system automatically triggers alerts to key personnel. This enables them to take preemptive action, such as closing flood gates, activating pumps, or clearing blockages, well before flooding occurs. The historical data also provides invaluable insights for long-term capital planning and infrastructure upgrades.

7.1.7. AI-Enhanced Soil Condition Analysis

Objective: To move beyond simple irrigation scheduling to a more holistic, AI-driven approach to managing the health of urban soils.

Technical Implementation: This advanced use case deploys multi-parameter LoRaWAN soil sensors that measure not only moisture but also variables like pH and electrical conductivity (as a proxy for nutrient levels). A key innovation is the "use of AI for configuration," where a machine learning model might optimize the sampling interval based on weather forecasts and historical data. The project team developed their own "payload decoder" and 3D-printed a protective housing, demonstrating a high degree of technical innovation and going the "triple extra mile".

Problem Addressed (Strategic Context): A one-size-fits-all approach to managing urban green spaces is both inefficient and ineffective. This use case addresses the need for more precise, data-driven techniques in urban agriculture and park management, aligning with the broader trend towards a more circular and resource-efficient economy.

Decision Support: The enerchart dashboard, enhanced with predictive analytics, provides park managers and urban farmers with unprecedented insight into soil health. It can provide decision support for the precision application of fertilizers or soil amendments, recommend crop rotation schedules for community gardens, and identify areas where soil is becoming compacted or salinized, allowing for early intervention.

7.1.8. Outdoor Environmental Monitoring

Objective: To establish a foundational network for collecting baseline environmental data, serving as the backbone for more specialized climate initiatives.

Technical Implementation: This use case involves the systematic deployment of the recommended SenseCAP S2101 and benchmarked Milesight EM300-TH LoRaWAN temperature and humidity sensors across the community. The presentation was "solid, but unspectacular," focusing on the core, reliable implementation of the technology . Data is visualized in enerchart using standard time-series graphs and statistical summary widgets.

Problem Addressed (Strategic Context): Many communities lack the long-term, high-resolution environmental data needed to accurately assess their climate risks, develop effective adaptation plans, and track their progress over time. This use case addresses this fundamental data gap. It also highlights the importance of addressing "small inconsistencies" in data through proper validation and quality control procedures within enerchart.

Decision Support: This baseline network provides the essential climatic context for all other use cases. For municipal planners, it enables the tracking of long-term trends, such as the increasing number of high-heat days per year. It also provides the data needed to quantitatively evaluate the impact of interventions, for example, by measuring whether a newly created park has a measurable cooling effect on its immediate surroundings.

7.1.9. Hyper-Local Urban Climate Monitoring

Objective: To conduct scientifically rigorous microclimate research to improve the accuracy of urban climate models and develop best practices for sensor deployment.

Technical Implementation: This research-oriented use case focuses on the nuances of accurate environmental measurement. The team investigated the "importance of a [radiation] shield" to protect sensors from direct solar radiation, which can introduce significant measurement errors. They "designed and 3D-printed the shield themselves," demonstrating a capacity for rapid, in-house hardware prototyping. The technical and visual quality of the presentation was high.

Problem Addressed (Strategic Context): Inaccurate microclimate data can lead to flawed urban planning decisions and ineffective climate adaptation strategies. This use case addresses the scientific challenge of ensuring data quality and reliability, which is a prerequisite for evidence-based policy.

Decision Support: The findings from this research provide direct decision support for the managers of the MCDMP itself. The comparative data from shielded vs. unshielded sensors in enerchart allows for the development of a standardized, best-practice deployment guide for all future sensor installations. For academic partners, the high-quality, validated dataset produced by this project can be used to calibrate and improve the accuracy of sophisticated urban climate models.

7.1.10. Advanced Traffic Radar Analysis

Objective: To provide city transportation planners with rich, detailed data on traffic flow to improve mobility, enhance safety, and reduce emissions.

Technical Implementation: This sophisticated use case utilizes LoRaWAN-connected traffic radar sensors. Unlike simple magnetic loop detectors, these radars can provide data on not just vehicle count, but also speed and classification (e.g., car, truck, bus). The student team correctly identified the "complexity of the sensor" and demonstrated "very good methodology and project management," earning an "optimal rating in all points" . The data is visualized in an advanced enerchart dashboard.

Problem Addressed (Strategic Context): Traffic congestion is a major contributor to urban air pollution and greenhouse gas emissions, and it imposes significant economic costs through lost time and wasted fuel. Effective traffic management requires granular data that traditional methods often cannot provide.

Decision Support: The enerchart dashboard provides transport planners with a powerful analytical tool. They can identify congestion bottlenecks in real time, analyze speeding on residential streets to inform traffic calming measures, and understand the mix of vehicle types on different roadways to plan for freight management or public transit improvements. This data is critical for optimizing traffic signal timing, redesigning intersections to improve safety, and making informed decisions about long-term transportation infrastructure investments.

7.1.11. Public Space People Counting

Objective: To understand how public spaces are used to optimize their management and justify investments in their improvement.

Technical Implementation: Discreet LoRaWAN-based infrared people counters are installed at the entrances to public spaces like parks, libraries, or pedestrian zones. The project team demonstrated "good teamwork" and delivered a "good presentation" that relied exclusively on a "visually strong" enerchart dashboard, forgoing traditional slides

Problem Addressed (Strategic Context): The management of public spaces is often based on anecdotal evidence rather than hard data. This makes it difficult to allocate maintenance resources efficiently, plan for events, or make a compelling, evidence-based case for funding new amenities or improvements.

Decision Support: The enerchart dashboard provides clear, intuitive visualizations of footfall patterns, showing not just how many people use a space, but when they use it. Park managers can use this data to schedule cleaning and maintenance during off-peak hours to minimize disruption. City event planners can analyze historical data to better manage crowd flow. Most importantly, the quantitative data on park usage provides a powerful justification for budget requests for new playgrounds, benches, or landscaping.

7.1.12. Local AI-Powered People Detection

Objective: To monitor occupancy and usage patterns in a way that is both highly efficient and protective of individual privacy.

Technical Implementation: This cutting-edge use case employs a sensor with an integrated camera and a small, on-board (edge) AI processor. The "local AI programming" allows the device to perform people detection and counting directly on the sensor itself. It then transmits only the final, anonymous count (e.g., "5 people detected") over the low-bandwidth LoRaWAN network. The team conducted a "small live demo" and ran "two test cases" to prove the concept's viability.

Problem Addressed (Strategic Context): While video surveillance can provide rich data, it raises significant privacy concerns and requires high-bandwidth (and high-cost) networks like Wi-Fi or 5G. This use case addresses both of these challenges, demonstrating a privacy-preserving and highly efficient architecture for occupancy monitoring.

Decision Support: This technology enables occupancy monitoring in sensitive locations where traditional cameras would be inappropriate, such as inside public buildings, libraries, or transit shelters. Facility managers can use the data to optimize HVAC systems based on real-time occupancy. Transit authorities can understand waiting times at bus stops. The key decision support is enabling data collection in new contexts by designing privacy and efficiency into the solution from the ground up.

7.1.13. LoRaWAN Network Infrastructure Management

Objective: To ensure the reliability and performance of the entire Mission Climate platform by monitoring the health of its underlying LoRaWAN network infrastructure.

Technical Implementation: This is a "meta" use case where the platform monitors itself. Instead of focusing on a dashboard of environmental data, the "focus was on the setup" of the network itself . Data on LoRaWAN gateway status (online/offline), signal strength (RSSI), and signal-to-noise ratio (SNR) from incoming sensor messages are ingested and visualized in a dedicated enerchart dashboard. The project team also set up a TTN network "in addition for comparison" with a self-hosted Chirp Stack server, providing a valuable "comparison" and evaluation of different LNS options.

Problem Addressed (Strategic Context): The reliability of every single use case on the MCDMP depends on the health and performance of the LoRaWAN network. A single offline gateway could create a data blackout for an entire neighborhood. This use case addresses the critical operational need for network visibility and proactive maintenance.

Decision Support: The network health dashboard provides the platform's technical administrators with immediate alerts if a gateway goes offline. By analyzing signal strength data over time, they can identify areas of poor coverage and make informed decisions about relocating gateways or installing new ones to improve network-wide performance. The strategic comparison between TTN and Chirp Stack provides critical decision support for long-term network architecture planning, weighing the trade-offs between a managed service and a self-hosted solution.

7.1.14. Smart Building Energy Management

Objective: To reduce the energy consumption and carbon footprint of municipal buildings while improving the health and comfort of occupants.

Technical Implementation: This use case, derived from smart building examples, involves deploying indoor LoRaWAN sensors like the Milesight EM300-TH and AM107 to monitor a range of Indoor Environmental Quality (IEQ) parameters, including temperature, humidity, and CO2 levels.[1, 1] The data is fed to an enerchart dashboard designed for facility managers.

Problem Addressed (Strategic Context): Municipal buildings are often significant energy consumers. Inefficient operation of Heating, Ventilation, and Air-Conditioning (HVAC) systems not only wastes public money and contributes to greenhouse gas emissions but can also lead to poor indoor air quality, which has been shown to affect employee productivity and well-being.

Decision Support: The enerchart dashboard provides facility managers with the data they need to move from scheduled to demand-controlled building operations. For example, instead of running ventilation systems continuously, they can be programmed to activate only when CO2 levels (a proxy for occupancy) exceed a certain threshold. This single change can lead to significant energy savings. The data also allows for the fine-tuning of heating and cooling setpoints to optimize for both energy efficiency and occupant comfort.

7.1.15. Proactive Sewer System Management

Objective: To enhance public health and improve the efficiency of municipal services through the predictive maintenance of the sewer system.

Technical Implementation: Inspired by the successful deployment in Córdoba, this use case involves deploying ruggedized, IP67-rated LoRaWAN sensors within the sewer network.[1, 1] These sensors monitor key indicators such as temperature, humidity, and the levels of hazardous gases like hydrogen sulfide (H2S) or methane (CH4). An enerchart dashboard visualizes the data on a map and triggers alerts when any parameter exceeds a safe threshold.

Problem Addressed (Strategic Context): Sewer systems are critical but invisible infrastructure. Failures can lead to significant public health risks, from pest infestations (as high temperature and humidity create ideal breeding grounds) to dangerous gas leaks. Traditional maintenance is reactive and expensive. This use case addresses the need for proactive, data-driven management of this vital asset.

Decision Support: The dashboard provides the public works department with an early warning system for potential problems. An anomalous spike in temperature and humidity could trigger a targeted pest control intervention, preventing a larger infestation. A rise in methane levels could indicate a blockage and prompt a cleaning crew to be dispatched before a dangerous backup occurs. This predictive approach reduces health risks, minimizes costly emergency repairs, and improves the overall safety and efficiency of sewer system management.

F. Good Practice - Košice

8. General Information

Project Partners:

- Technical University of Košice (TUKE), City of Košice
- Contributors/Team Members/Experts involved:
- TUKE – Faculty of Economics (pilot team)
- City of Košice
- Department of Strategic Development
- Department of Environment
- Department of Education
- Elementary schools
- ZŠ Požiarnická
- ZŠ Staničná
- ZŠ Gemerská
- ZŠ Hroncova
- ZŠ Tomášikova
- ZŠ Nám. L. Novomeského
- ZŠ Park Angelinum

IoT weather station supplier – Multi-parameter climate stations for school environments (11 indicators) – (procured in 2025, no public URL)

Microsoft Azure – Cloud infrastructure (IoT Central, IoT Hub, Blob Storage, Data Lake, Log Analytics, Monitor, Security Center for IoT, DPS, Functions) – https://azure.microsoft.com

Microsoft Power BI – Data visualization and reporting – https://powerbi.microsoft.com

City of Košice Open Data Platform – Integration of sensor outputs for transparency and public access – https://data.kosice.sk Dataset

TUKE Faculty of Economics IT team – Local implementation, dashboard customization, interoperability support – (internal team, no public URL)

9. Digital Solution - Description

9.1. Digital Solution - Description

The solution ensures continuous monitoring of local climate conditions in Košice through a network of IoT weather stations installed at elementary schools. The stations record air quality indicators (particulate matter PM10, PM4,PM1; gases NO_2 and CO), meteorological parameters (temperature, humidity, atmospheric pressure), and wind dynamics (speed, gusts, direction). Data are transmitted in real time to the Microsoft Azure cloud infrastructure and subsequently visualized in dashboards made available through the City of Košice Open Data Platform.

The Košice pilot introduces an intelligent climate monitoring system that combines technical and educational objectives. Seven participating elementary schools serve as monitoring sites, providing both representative territorial coverage and active community engagement. The solution delivers transparent data for urban climate adaptation planning, while at the same time offering practical tools for environmental education of pupils and their families.

Technology Stack:

- IoT multi-parameter weather stations (11 indicators)
- Fixed power supply (230V), Ethernet/WiFi connectivity
- Microsoft Azure IoT Central / IoT Hub (data collection and management)
- Azure Blob Storage & Data Lake (data storage)
- Azure Log Analytics, Azure Monitor, Azure Security Center for IoT (security and monitoring)
- Microsoft Power BI (visualization and reporting)
- Integration with Košice Open Data Platform for public access
- Local customization and dashboard development by TUKE Faculty of Economics IT team

Monitored Climate Indicators:

- Meteorological conditions: temperature, humidity, atmospheric pressure
- Wind dynamics: wind speed, wind gusts, wind direction
- Air quality – particulate matter: PM10, PM4, PM2.5, PM1
- Air quality – gases: CO, NO_2
- Full List of Indicators with Units:
- Temperature – °C
- Humidity – %
- Atmospheric Pressure – hPa
- Wind Speed – m/s
- Wind Gusts – m/s
- Wind Direction – °
- PM10 – $\mu g/m^3$
- PM4 – $\mu g/m^3$
- PM2.5 – $\mu g/m^3$
- PM1 – $\mu g/m^3$
- CO – ppm
- NO_2 – ppm

Geographical Coverage:

The pilot covers seven elementary schools in the city of Košice, Slovakia. Monitoring stations are installed in schoolyards and rooftops across different districts, providing representative coverage of residential and traffic-exposed areas. The geographical focus ensures both educational impact (direct engagement with school communities) and spatial diversity in climate data collection.

7 elementary schools involved within the area of the City of Košice:

- ZŠ Požiarnická
- ZŠ Staničná
- ZŠ Gemerská
- ZŠ Hroncova
- ZŠ Tomášikova
- ZŠ Nám. L. Novomeského
- ZŠ Park Angelinum

9.2. Target Group

9.2.1. Who uses the digital solution?

- **Local governments and municipalities** – City of Košice (Department of Environment, Department of Education) for adaptation planning, transparency, and decision support.
- **Elementary schools** (7 involved) – teachers, pupils, and parents use the data for climate education, awareness raising, and participatory school projects.

- **Urban planners and experts** – using open data to integrate evidence into strategic plans (Adaptation Plan of Košice, Climate City Contract).
- **NGOs and community initiatives** – e.g., Klíma ťa potrebuje, Východné pobrežie, supporting public engagement and communication.
- **Research institutions** – TUKE (Faculty of Economics), Slovak Academy of Sciences, Climate and Development Institute, for technical expertise and long-term research on climate resilience.
- **General public** – citizens access open dashboards and receive transparent information on local climate trends.

9.2.2. Stakeholder collaboration

The pilot project in Košice is fundamentally built on close collaboration among multiple local stakeholders, ensuring both technical feasibility and community ownership.

- City of Košice – the Departments of Strategic Development, Environment, and Education play a central role in aligning the pilot with the city's Adaptation Plan and Climate City Contract.
- TUKE – Faculty of Economics – responsible for technical implementation, data governance, dashboard development, and methodological support.
- Elementary schools (7 sites) – act as monitoring locations and educational partners, actively engaging teachers, pupils, and parents in the interpretation of climate data.
- NGOs and community initiatives – support communication, awareness raising, and participatory engagement (e.g., local campaigns, school-level micro-projects).
- Research institutions – Slovak Academy of Sciences (Institute of Social Sciences) and Climate and Development Institute provide expertise on vulnerability assessment and integration of findings into resilience strategies.
- Technology providers – suppliers of IoT weather stations and Microsoft Azure services ensure reliable data collection, storage, and visualization.
- This collaborative framework not only guarantees technical robustness but also fosters participatory co-creation, with schools and local communities treated as active co-designers of the solution rather than passive recipients.

9.3. (Expected) Impact

9.3.1. Qualitative Outcomes

- Increased awareness of climate change impacts among pupils, teachers, and the wider community through direct interaction with real-time environmental data.
- Strengthened cooperation between the City of Košice, TUKE, and local schools, creating a replicable model for other municipalities.
- Enhanced evidence-based policy making, as reliable local data support the implementation of the Adaptation Plan of Košice.
- Improved integration of climate education into school curricula, supporting STEM education and active citizenship.
- Greater transparency and trust, as open data dashboards make climate indicators publicly available and easy to interpret.

9.3.2. Quantitative Outcomes

- Seven elementary schools actively participating in climate data collection and education.
- Eleven climate indicators continuously monitored across school sites.
- Three types of dashboards developed and in operation:
    - Seven individual school dashboards designed for teaching purposes and school community use.
    - Seven LED-screen dashboards installed in school entrance halls to raise awareness among pupils, parents, and visitors.
    - One integrated dashboard on the City of Košice Open Data Platform, supporting research, policy-making, and municipal management.
    - In total, fifteen dashboards are operational across the pilot ecosystem.
- More than 500 pupils directly engaged in educational activities and workshops.
- Four school subjects enriched with real data and climate content: Biology, Physics, Chemistry, and Civics.
- At least four regional stakeholders formally supporting the pilot through acceptance letters.
- Two local and regional strategies directly supported by the pilot solution (Adaptation Plan of Košice 2022–2030 and Košice Development Programme 2022–2027).
- Continuous collection of millions of data points per year, forming the basis for adaptation planning and future research.

9.4. Technical Implementation Details

9.4.1. Data sources:

The main source of data is IoT sensor stations installed at seven elementary schools in Košice. Each station measures eleven indicators, including particulate matter (PM10, PM4, PM1), gases (NO_2, CO), and meteorological variables (temperature, humidity, atmospheric pressure, wind speed, wind gusts, wind direction). Data are collected every minute and transmitted to the cloud in five-minute intervals.

9.4.2. Data type:

Sensor Data IOT -The solution generates continuous time-series data with precise timestamps. These data allow both real-time analysis and long-term evaluation of local climate conditions. They are suitable for anomaly detection, educational purposes, and integration into adaptation planning and research.

Interoperability - IoT devices are integrated into the Microsoft Azure IoT Central platform, supporting standard protocols (MQTT, AMQP, HTTPS). Data are stored in Azure Blob Storage and Azure Data Lake, while access and security are managed through Azure Active Directory (Entra ID). System monitoring and stability are supported by Azure Log Analytics, Azure Monitor, and Azure Security Center for IoT.

Data are further processed and visualized in Microsoft Power BI dashboards. Three types of dashboards have been developed and interconnected within the ecosystem: seven individual school dashboards for teaching and school community use, seven LED-screen dashboards in school entrance halls for awareness raising, and one integrated dashboard on the City of Košice Open Data Platform for research, municipal governance, and transparency.

9.5. Overview of Implementation

The implementation of the Košice pilot followed a phased approach, starting with analytical activities and proceeding to technical deployment and educational engagement. During the first stage, vulnerability and heatwave maps were analyzed to identify suitable school locations for sensor installation. Based on this analysis, seven elementary schools were selected in cooperation with the Department of Education of the City of Košice.

A public procurement process was conducted to acquire IoT climate stations, ensuring compliance with technical specifications and long-term warranty conditions. The sensors were installed in schoolyards and rooftops in early 2025, each measuring eleven indicators of air quality and meteorological conditions. The stations were connected to the Microsoft Azure IoT Central platform, enabling secure data transfer, cloud storage, and integration with visualization tools.

In parallel, cooperation with schools was established through preparatory meetings, classroom activities, and a co-creation workshop held on April 3, 2025. This workshop defined four data-use scenarios (pedagogical, strategic, community, spatial) and laid the foundation for integrating climate monitoring into curricula and school development plans.

Currently, three types of dashboards are operational: seven school dashboards, seven LED-screen dashboards in school entrances, and one integrated dashboard on the City of Košice Open Data Platform. This setup ensures a balance between educational use, community awareness, and public transparency.

Detailed documentation of the design and implementation process is provided in the following reports:
- MISSION CE CLIMATE – Pilot Design Report Košice
- Pilot Implementation Status Reports Nr.01 and Nr.02 and Nr.03
- Annexes to pilot activities (sensor specification, KPI coherence, curriculum design)

9.6. Screenshot

Meteostanice na vybraných ZŠ mesta Košice

Vydavateľ Košice
Košice

Summary

Dataset obsahuje namerané dáta z meteostaníc na niektorých ZŠ mesta Košice.

V rámci aktivít projektu Interreg Central Europe - Mission CE Climate, inštalovalo Mesto Košice meteostanice na ZŠ Gemerská 2, ZŠ Hroncova 23, ZŠ Nám. L. Novomeského 2, ZŠ Park Angelinum 8, ZŠ Požiarnická 3, ZŠ Staničná 13 a ZŠ Tomášikova 31. Meteostanice merajú veličiny CO (ppm), NO2 (ppm), teplota vzduchu (°C), vlhkosť vzduchu (%RH), atmosférický tlak (hPa), prašnosť PM1, PM4, PM10 (μg/m³), rýchlosť vetra (km/h), smer vetra (°) a nárazy vetra (km/h). Jedná sa o elektronické meranie, ktoré nie je certifikované SHMÚ, namerané dáta nie sú žiadnym spôsobom upravované ani normalizované. Je možný výskyt výpadkov v meraniach v súvislosti s extrémnymi prejavmi počasia (napr. pri silných búrkach), najčastejšie kvôli lokálnym technickým problémom - poruchy napájania elektrickou energiou, poruchy internetového pripojenia, poruchy jednotlivých senzorov, nekorektný reštart zariadenia a podobne.

Read Less

Životné prostredie a klíma Životné prostredie a klíma

Details

Dataset
Table

September 10, 2025 at 3:40:14 PM GMT+2
Info Updated

Daily
Data Updated: September 10, 2025 at 7:10:41 AM GMT+2

September 10, 2025 at 12:00:00 AM GMT+2
Published Date

Records: 287,736
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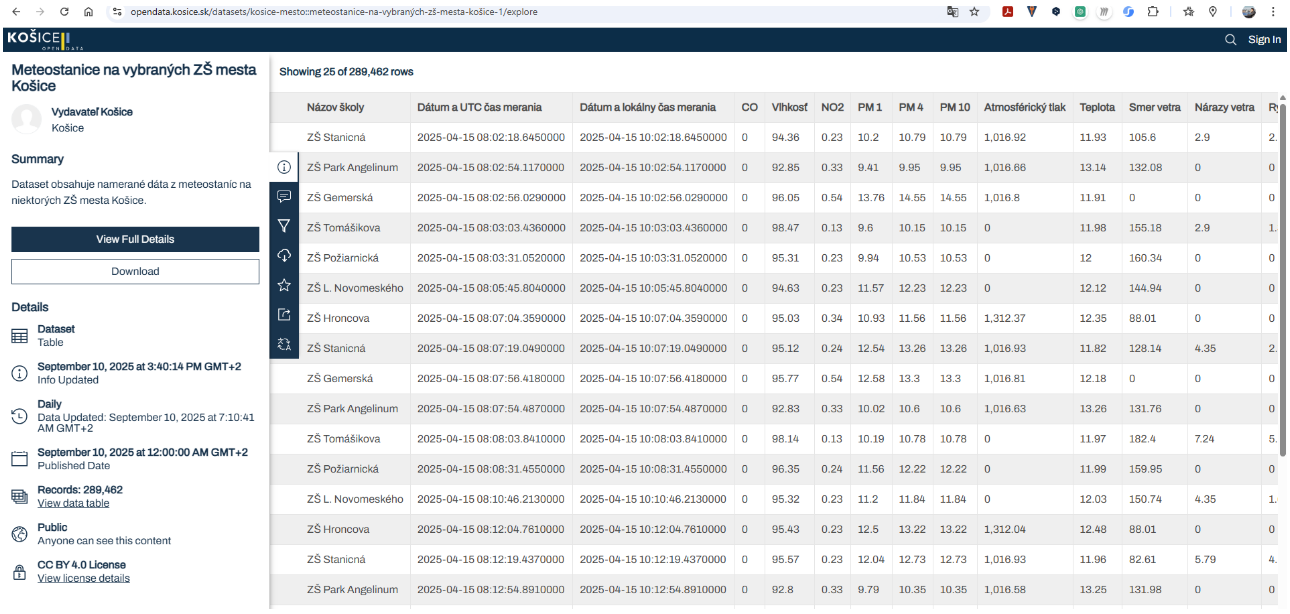

Meteostanice na vybraných ZŠ mesta Košice

Vydavateľ Košice
Košice

Summary

Dataset obsahuje namerané dáta z meteostaníc na niektorých ZŠ mesta Košice.

Details

Dataset
Table

September 10, 2025 at 3:40:14 PM GMT+2
Info Updated

Daily
Data Updated: September 10, 2025 at 7:10:41 AM GMT+2

September 10, 2025 at 12:00:00 AM GMT+2
Published Date

Records: 289,462
View data table

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Showing 25 of 289,462 rows

Názov školy	Dátum a UTC čas merania	Dátum a lokálny čas merania	CO	Vlhkosť	NO2	PM 1	PM 4	PM 10	Atmosférický tlak	Teplota	Smer vetra	Nárazy vetra
ZŠ Stanicná	2025-04-15 08:02:18.6450000	2025-04-15 10:02:18.6450000	0	94.36	0.23	10.2	10.79	10.79	1,016.92	11.93	105.6	2.9
ZŠ Park Angelinum	2025-04-15 08:02:54.1170000	2025-04-15 10:02:54.1170000	0	92.85	0.33	9.41	9.95	9.95	1,016.66	13.14	132.08	0
ZŠ Gemerská	2025-04-15 08:02:56.0290000	2025-04-15 10:02:56.0290000	0	96.05	0.54	13.76	14.55	14.55	1,016.8	11.91	0	0
ZŠ Tomášikova	2025-04-15 08:03:03.4360000	2025-04-15 10:03:03.4360000	0	98.47	0.13	9.6	10.15	10.15	0	11.98	155.18	2.9
ZŠ Požiarnická	2025-04-15 08:03:31.0520000	2025-04-15 10:03:31.0520000	0	95.31	0.23	9.94	10.53	10.53	0	12	160.34	0
ZŠ L. Novomeského	2025-04-15 08:05:45.8040000	2025-04-15 10:05:45.8040000	0	94.63	0.23	11.57	12.23	12.23	0	12.12	144.94	0
ZŠ Hroncova	2025-04-15 08:07:04.3590000	2025-04-15 10:07:04.3590000	0	95.03	0.34	10.93	11.56	11.56	1,312.37	12.35	88.01	0
ZŠ Stanicná	2025-04-15 08:07:19.0490000	2025-04-15 10:07:19.0490000	0	95.12	0.24	12.54	13.26	13.26	1,016.93	11.82	128.14	4.35
ZŠ Gemerská	2025-04-15 08:07:56.4180000	2025-04-15 10:07:56.4180000	0	95.77	0.54	12.58	13.3	13.3	1,016.81	12.18	0	0
ZŠ Park Angelinum	2025-04-15 08:07:54.4870000	2025-04-15 10:07:54.4870000	0	92.83	0.33	10.02	10.6	10.6	1,016.63	13.26	131.76	0
ZŠ Tomášikova	2025-04-15 08:08:03.8410000	2025-04-15 10:08:03.8410000	0	98.14	0.13	10.19	10.78	10.78	0	11.97	182.4	7.24
ZŠ Požiarnická	2025-04-15 08:08:31.4550000	2025-04-15 10:08:31.4550000	0	96.35	0.24	11.56	12.22	12.22	0	11.99	159.95	0
ZŠ L. Novomeského	2025-04-15 08:10:46.2130000	2025-04-15 10:10:46.2130000	0	95.32	0.23	11.2	11.84	11.84	0	12.03	150.74	4.35
ZŠ Hroncova	2025-04-15 08:12:04.7610000	2025-04-15 10:12:04.7610000	0	95.43	0.23	12.5	13.22	13.22	1,312.04	12.48	88.01	0
ZŠ Stanicná	2025-04-15 08:12:19.4370000	2025-04-15 10:12:19.4370000	0	95.57	0.23	12.04	12.73	12.73	1,016.93	11.96	82.61	5.79
ZŠ Park Angelinum	2025-04-15 08:12:54.8910000	2025-04-15 10:12:54.8910000	0	92.8	0.33	9.79	10.35	10.35	1,016.58	13.25	131.98	0

Monitoring klimatických údajov

ZŠ Gemerská 2
Adresa: Gemerská 2, 040 01 Juh

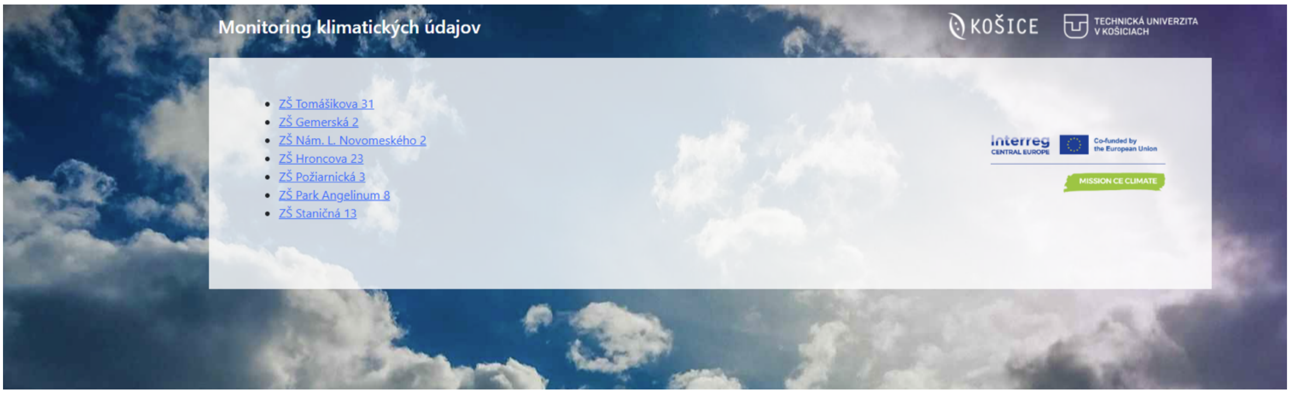
Teplota vzduchu: 14.71 °C
Vlhkosť vzduchu: 72.94 %
Tlak vzduchu: 0 hPA
Prašnosť - PM10: 14.42 µg/m³
Prašnosť - PM4: 14.37 µg/m³
Prašnosť - PM1: 13.37 µg/m³
Rýchlosť vetra: 1.33 m/s
Nárazy vetra: 5.79 m/s
Smer vetra: 12.41 stupňov
CO: 0 mg/m³
NO₂: 0.42 µg/m³

Teplota vzduchu

Význam indikátora – posledných 7 dní

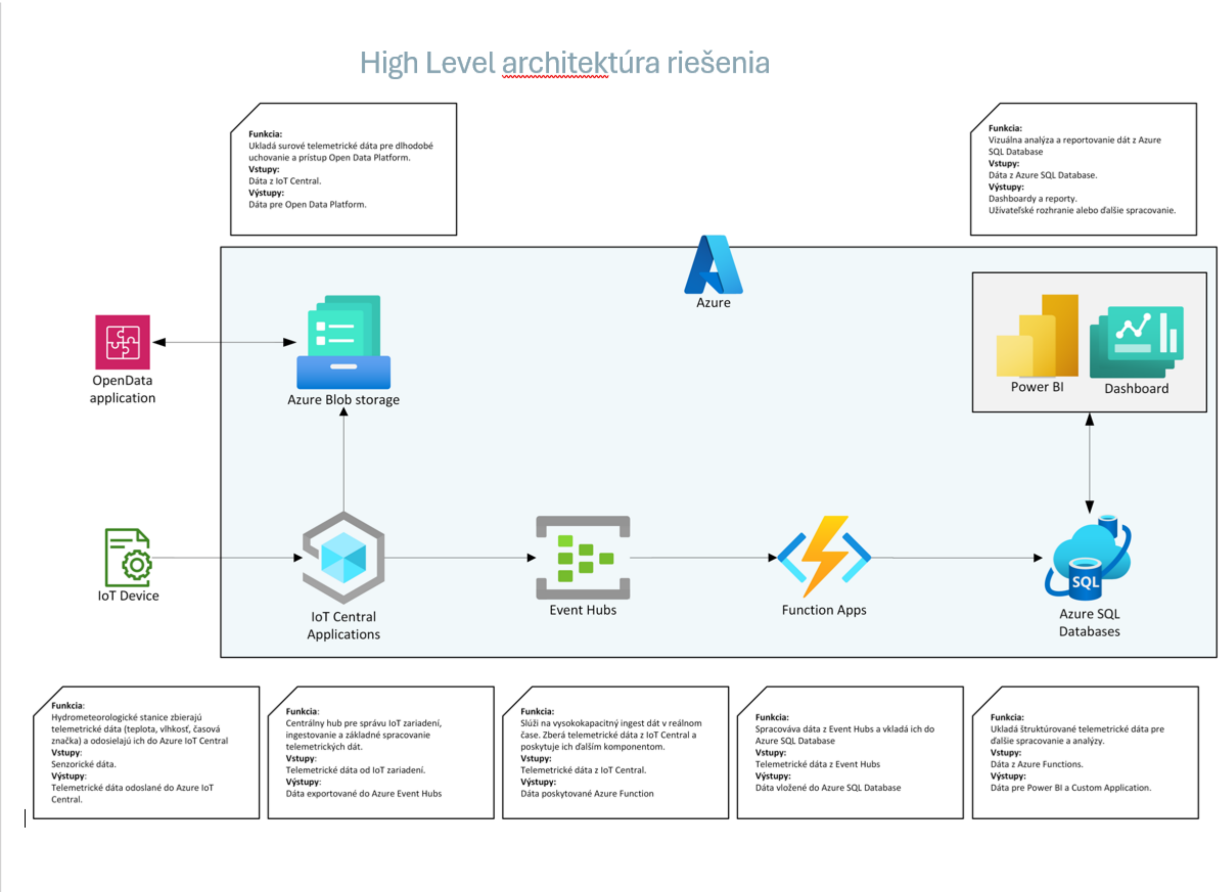
Informácie k indikátoru

Teplota predstavuje základný fyzikálny ukazovateľ prostredia alebo meraného zariadenia. Je dôležitá na posúdenie podmienok, ktoré ovplyvňujú bezpečnosť, komfort alebo správnu funkčnosť technológií. Sledovanie teploty umožňuje včas zachytiť odchýlky od bežného stavu a predísť poškodeniu zariadení či zhoršeniu kvality prostredia.



Monitoring klimatických údajov

- ZŠ Tomášikova 31
- ZŠ Gemerská 2
- ZŠ Nám. L. Novomeského 2
- ZŠ Hroncova 23
- ZŠ Požiarnická 3
- ZŠ Park Angelinum 8
- ZŠ Staničná 13



High Level architektúra riešenia

Funkcia:
Ukladá surové telemetrické dáta pre dlhodobé uchovanie a prístup Open Data Platform.
Vstupy:
Dáta z IoT Central.
Výstupy:
Dáta pre Open Data Platform.

Funkcia:
Vizuálna analýza a reportovanie dát z Azure SQL Database
Vstupy:
Dáta z Azure SQL Database.
Výstupy:
Dashboardy a reporty.
Užívateľské rozhranie alebo ďalšie spracovanie.

Funkcia:
Hydrometeorologické stanice zbierajú telemetrické dáta (teplota, vlhkosť, časová značka) a odosielajú ich do Azure IoT Central
Vstupy:
Senzorické dáta.
Výstupy:
Telemetrické dáta odoslané do Azure IoT Central.

Funkcia:
Centrálny hub pre správu IoT zariadení, ingestovanie a základné spracovanie telemetrických dát.
Vstupy:
Telemetrické dáta od IoT zariadení.
Výstupy:
Dáta exportované do Azure Event Hubs

Funkcia:
Slúži na vysokokapacitný ingest dát v reálnom čase. Zberá telemetrické dáta z IoT Central a poskytuje ich ďalším komponentom.
Vstupy:
Telemetrické dáta z IoT Central.
Výstupy:
Dáta poskytované Azure Function

Funkcia:
Spracováva dáta z Event Hubs a vkladá ich do Azure SQL Database
Vstupy:
Telemetrické dáta z Event Hubs
Výstupy:
Dáta vložené do Azure SQL Database

Funkcia:
Ukladá štruktúrované telemetrické dáta pre ďalšie spracovanie a analýzy.
Vstupy:
Dáta z Azure Functions.
Výstupy:
Dáta pre Power BI a Custom Application.

10. Use Cases

Use Case	Topic	Data Collection	Visualisation	Problem Addressed	Decision Support
Educational and Curricular Integration	STEM education and climate literacy	IoT climate stations measuring 11 indicators on school premises	Local school dashboard for teachers and pupils; QR codes linking to dashboards during lessons	Lack of real-world and local environmental data in school curricula	Enables integration into Biology, Physics, Chemistry, and Civics; supports project-based learning, hackathons, and environmental clubs
Awareness and Community Engagement	Raising awareness among pupils, parents, and local community	IoT data from school stations, linked to school communication channels	LED-screen dashboards in school entrances with QR codes; Edupage links to local dashboards	Limited visibility of environmental data and low parental/community engagement	Strengthens school-community cooperation; encourages behavioral change (transport, greening); motivates joint micro-interventions
Strategic Use by School Management	Evidence-based decision-making at the school level	Aggregated IoT data from school dashboards	School dashboards used internally by principals and staff	Lack of reliable evidence for investments and improvement projects	Provides arguments for grants, municipal communication, and physical planning of interventions)
Municipal Governance and Research	City-wide adaptation, transparency, and scientific use	Aggregated IoT data from all schools integrated into the Open Data	One integrated central dashboard on the City of Košice	Lack of open and reliable local climate data for adaptation planning, research, and	Supports city governance (Adaptation Plan 2022-2030, Development Programme

		Košice platform	Open Data Portal; detailed datasets for TUKE researchers; simplified	public transparency	2022-2027); provides datasets for research; offers low-threshold access for citizens

10.1. Educational and Curricular Integration (School Basic Dashboard)

The first use case is centred on the basic school dashboard, which functions as the primary entry point for accessing local climate data. Each participating school has its own dashboard displaying real-time measurements of air quality and meteorological indicators, along with historical records of environmental conditions. The dashboard provides access not only to current data but also to more detailed datasets for further exploration by teachers, pupils, and interested stakeholders.

All other communication and awareness tools – such as LED screens in entrance halls or Edupage channels for parents – are linked to this central school dashboard, making it the core reference point for information. In addition, specific worksheets and educational materials will be developed for teachers of different subjects (Biology, Physics, Chemistry, and Civics), enabling them to use the dashboard data in structured lessons and projects.

This approach ensures that each school has its own identity in climate monitoring, while at the same time establishing a standardized entry gateway for educational use and community engagement.

10.2. Awareness and Community Engagement (LED app linked to School Basic Dashboard)

The second use case focuses on raising awareness among pupils, parents, and the broader school community. Environmental data collected by the IoT stations are made visible through simplified visualizations on LED screens located in school entrance halls and through school communication channels such as Edupage. These entry points provide daily exposure to local climate data in an easy-to-understand form, helping to foster curiosity and awareness.

All these communication tools are directly linked to the School Basic Dashboard, where more detailed information and historical records can be explored. In this way, the LED screens and Edupage serve as gateways that encourage parents, pupils, and visitors to deepen their understanding by navigating to the school's main dashboard.

This setup ensures that climate data do not remain hidden in technical systems but are actively shared with the school community. It builds awareness, motivates behavioural change (e.g., transport choices, greening activities), and supports the school's role as a hub for environmental education and community dialogue.

10.3. Strategic Use by School Management (linked to School Basic Dashboard)

This use case highlights how school leadership can leverage climate data to strengthen its institutional position and improve the school environment. Principals and management teams use the School Basic Dashboard to review current and historical data as a foundation for evidence-based decision-making.

The dashboard enables schools to showcase their best results in climate monitoring and education, positioning themselves as leaders within the city, the region, or even nationally. This visibility provides strong arguments for securing financial resources, preparing project proposals, and building strategic partnerships.
The data also serve as practical input for planning improvements of the school grounds. Evidence from the dashboards can justify greenery and shading projects, redesign of outdoor spaces, or upgrading ventilation systems, ensuring that interventions are based on measurable needs.

Beyond the school premises, the data further inform discussions on traffic safety and mobility management in the school's vicinity. They provide a factual basis for introducing measures such as traffic calming, school zones, or reduced car arrivals. In cooperation with municipal authorities, these data can also support adjustments to local regulations (VZN), giving the school a stronger voice in shaping its broader environment.

In this way, the School Basic Dashboard is transformed into a strategic management tool. It allows schools not only to improve their own facilities but also to actively contribute to city-level discussions on transport, environmental quality, and regulatory change.

10.4. Municipal Governance and Public (Open Data Portal linked to School dashboards)

This use case brings the climate monitoring system to the city and academic level. All data from the seven elementary schools are integrated into one central dashboard on the City of Košice Open Data Platform. This ensures transparency for the wider public and makes climate data accessible to all interested stakeholders.

For municipal governance, the integrated dashboard provides a reliable evidence base for strategic documents such as the Adaptation Plan of Košice 2022-2030 and the Development Programme 2022–2027. City officials can use the data for climate adaptation planning, urban mobility regulation, and prioritization of investments. The open format also allows departments to cooperate more effectively across environmental, educational, and transport agendas.

For research purposes, detailed datasets are available to TUKE and other academic institutions. Researchers can use the time-series data for vulnerability assessments, climate modelling, and evaluation of microclimate interventions at the city level. This scientific use creates opportunities for joint projects, publications, and further innovation in digital monitoring.

G.Good Practice - Dornbirn

11. General Information

The city of Donbirn, the University of Applied Sciences in Vorarlberg and weavs collaborated on this pilot project. To investigate heat islands effect, the pilot project encompasses a digital solution supporting nature-based solutions in urban areas, to compare heat islands microclimate to ones of different nature-based solutions and sealed and unsealed surface areas. This will allow a better understanding of the temperature reducing potential of nature-based solutions. The collected data will be presented in order to raise awareness of climate change adaptation measures. Three different LoRaWAN® sensors were used to measure the surface temperature, air temperature and humidity.

12. Digital Solution - Description

12.1. Digital Solution - Description

Heat islands are a pressing issue for the city of Dornbirn and nature-based solutions such as tree planting can reduce the heat island effect. This preliminary pilot study focuses on exploring the potential impact of trees and different surfaces on temperature reduction. The aim is to quantify the extent of temperature reduction achievable through nature-based solutions. Through a sensor network, the cooling effect of trees will measured. By using sensors, we will gather data on surface and air temperature, as well as humidity levels. Specifically, different climate data indicators (surface and air temperature, humidity) will be collected to compare the perceived temperature on different surface types, as well as on places with and without shade from trees. Subsequently, the perceived temperature (heat index) will be calculated, enabling an assessment of the actual reduction in perceived temperature. To minimize external influences on the microclimate, all data collection for different surfaces and shading conditions will be conducted within the same park, ensuring consistent general weather conditions for accurate comparison.This pilot can be described as a digital solution, supporting the decision for nature-based solutions through climate data results.

The primary objective is to gain insights into the potential of nature-based solutions and unsealed surfaces to improve urban microclimate by mitigating the heat island effect. A secondary objective of the pilot project is to raise public awareness and educate citizents. Additionally, the pilot project aims to support the city of Dornbirn´s existing climate action plan by providing data-driven evidence on the importance of nature-based solutions and temperature-reducing surfaces. The third objective is to provide data-driven insights to strengthen Dornbirn´s climate action plan. The project results will be integrated into the Citymonitor dashboard (https://www.city-monitor.com/en/energie-und-umweltmonitoring) for transparency and informed decision-making.

12.2. Technology Stack:

The following senosors were installed:

Air temperature and humidity sensor for LoRaWAN®

TEMPERATURE
Range: -40 ... +125 °C
Resolution: 0.01 °C
Accuracy: ±0.1 °C from 20 ... 60 °C, ±0.2 °C from -40 ... 90 °C
RELATIVE HUMIDITY
Range: 0 ... 100% RH
Resolution: 0.01% RH
Accuracy: ±1.5% RH from 0 ... 80% RH, ±2% RH from 80 ... 100% RH

Winter road maintenance sensor for LoRaWAN®

SURFACE TEMPERATURE / INFRARED PYROMETER
Range:
-40 ... 1030 °C (target temperature)
-20 ... 80 °C (sensor head temperature)
Resolution: 0.1 °C
Accuracy: ±1.5 % or ±1.5 °C
Repeatability: ±0.75 % or ±0.75 °C
Spectral range: 8...14µm
Optical Resolution: 15:1
Environmental rating: IP 63
AIR TEMPERATURE
Range: -40 ... 125 °C
Resolution: 0.01 °C
Accuracy:
±0.1 °C (20 ... 60 °C)
±0.2 °C (-40 ... 90 °C)
AIR HUMIDITY
Range: 0...100%RH
Resolution: 0.01 % RH
Accuracy:
±1.5%RH(0...80%RH)
±2.0 % RH (80 ... 100 % RH)

Infrared thermometer/surface temperate sensor for LoRaWAN®
INFRARED PYROMETER
Range:
-20 ... 80 °C for ambient temperature
-40 ... 1030 °C for object temperature
Accuracy: ±1.5 % or ±1.5 °C
Optical Resolution: 15:1
Repeatability: ±0.75 % or ±0.75 °C
Spectral Range: 8 ... 14 µm
Environmental rating: IP 63

12.3. Monitored climate indicators

In this pilot study, the surface temperature, air temperature, and humidity are measured to investigate the effect of nature-based solutions on surface temperature, air temperature, and humidity and to allow the calculation of the heat index.

12.4. Geographical Coverage:

It is a local pilot project in Dornbirn.

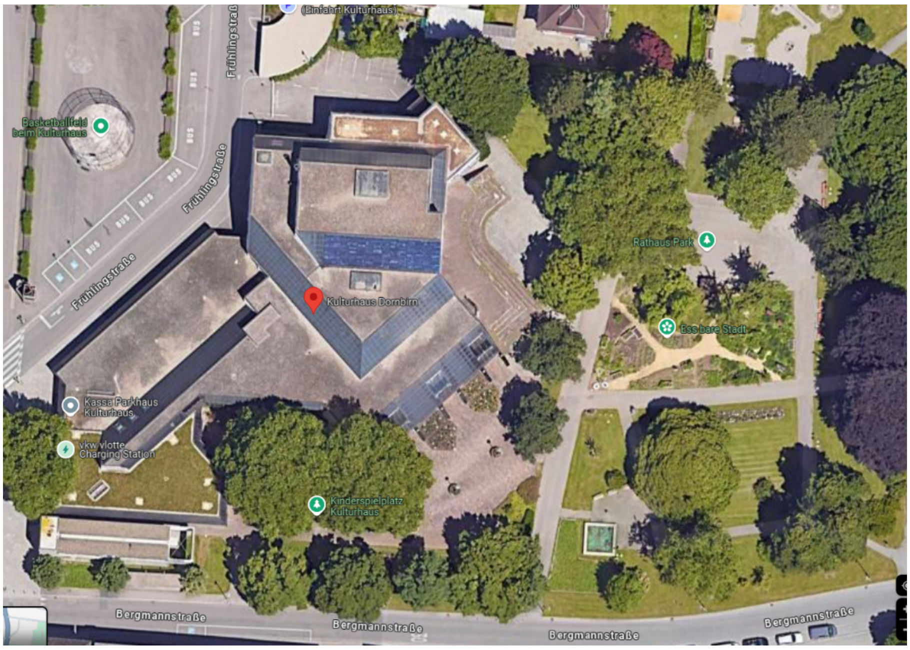


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Figure 8: Pilot study site, showing the "Kulturhaus"

Illustration 6: Location of sensors

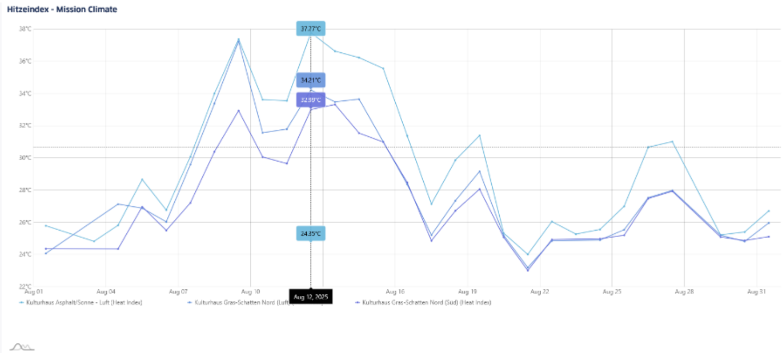
12.5. Target Group

The main target group of the pilot study is the city of Dornbirn to enable informed for adaptation planning and decisions. Further, the University of Applied Sciences will use it for research purposes to gain a better understanding of the cooling effect of trees on the urban heat island effect. Additionally, the results will be disseminated to the wider public through information and events.

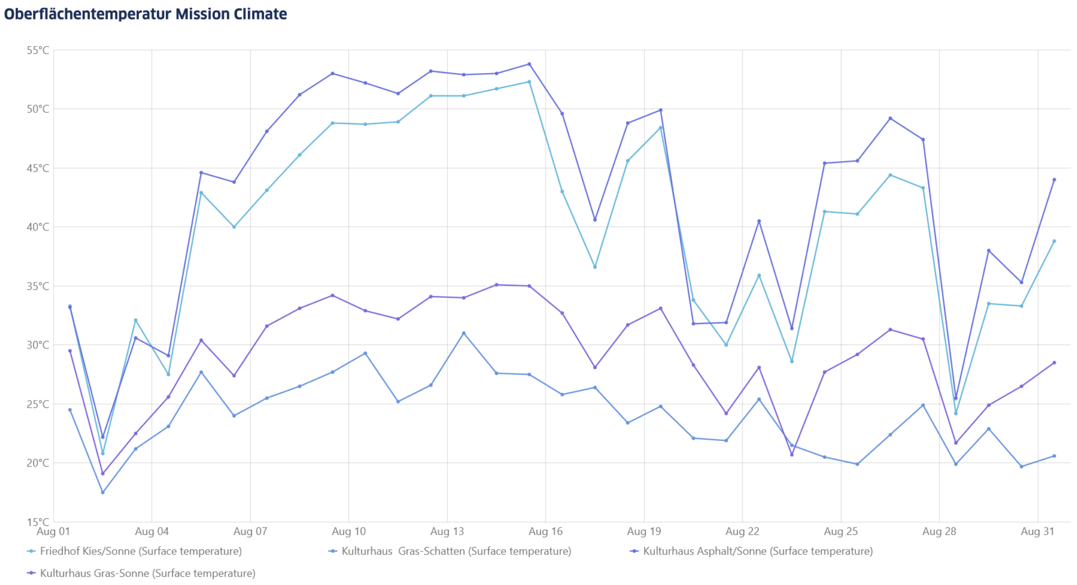
The pilot was only possible through a strong collaboration between the city of Dornbirn including different departments, the University of Applied Sciences, and weavs.

12.6. (Expected) Impact

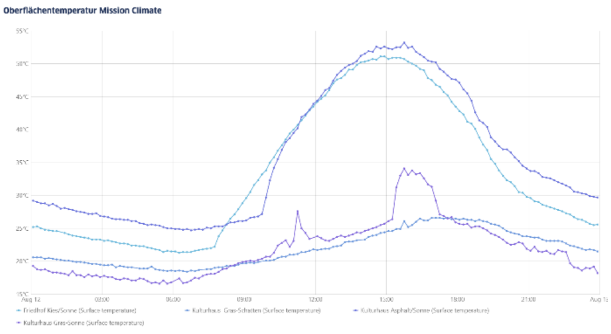
For the analysis of the collected data, the perceived temperature was assessed through measuring the heat index. The heat index combines air temperature and relative humidity in order to posit a human-perceived equivalent temperature. The heat index allows comparisons between the perceived temperature in shaded and non-shaded areas. However, it does not account for heating from direct sunlight or the effect of physical activity. In the Kulturhauspar are three locations. The light blue is a sealed surface exposed to



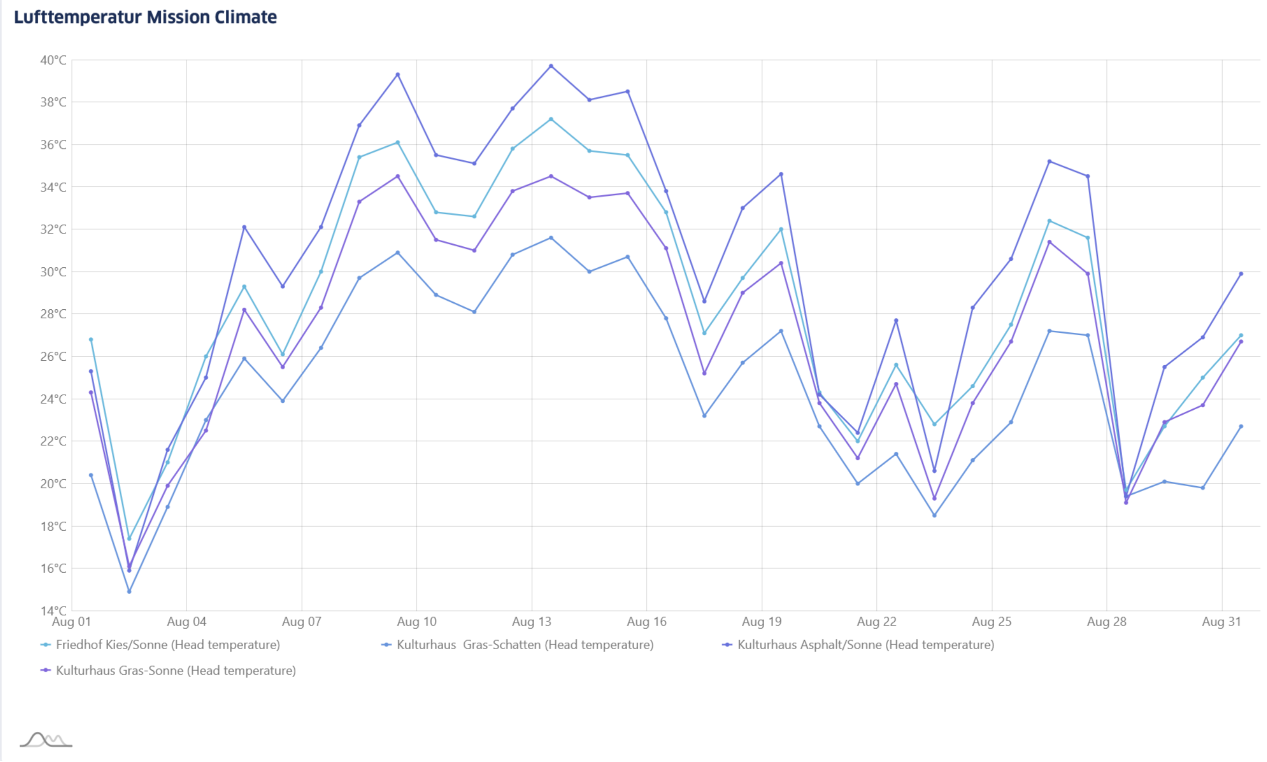
sun, the darker blue is grass exposed to sun and the violett is grass in the shade. The graphs shows the differences of the heat index of the different sensor locations. On the 12th of August, their was a differnece in perceived temperature of almost 4,78°C between sealed surface/sun and grass/shade with 32.99°C compared to 37.77°C.
The difference is even bigger if you look at surface temperature. On the 12th of August, the difference between sealed surface/sun and grass/shade reached 27.2°C. The sealed surface in the sun reached a temperature 53,2°C, gravel surface in the sun reached 51,1°C, grass in the sun 34.1°C and grass in the shade 26.0°C. This shows, on the one hand, the effect of shade as a cooling effect with reaching a difference with the same surface of 8,1°C and on the other hand, it highlights the importance of surfaces. Grass in the sun and shade have a temperature difference of 19,1°C.



Here, you can see the temperature development throughout the day of the 12th of August for all four locations. What is striking here, is that there is a temperature difference of more than 10°C during the night. Thus, the sealed surface has similar temperature at night as the gras area with shade during the day.



By looking into air temperature, the difference is smaller. The difference between sealed surface in the sun and grass in the shade, was on the 12th of August 6,9°C ranging from 37,7°C to 30,8°C. This highlights again, the heating effect of sealed surfaces in cities.



Findings:

- Nature-based solutions can play a very important role for enhancing climate resilience for cities. They can help cities reducing the urban heat island effect. Vegetation provides shade, enhances evapotranspiration, and lowers surface and air temperatures, making urban areas more resilient to heatwaves while improving comfort, health, and livability. Tree shade can also have a positive effect on the perceived temperature.
- The importance of surfaces should not be underestimated. Sealed surfaces like asphalt and concrete trap heat, block water infiltration, and intensify the urban heat island effect, while non-sealed surfaces—such as soil, permeable pavements, and vegetated areas—allow for cooling through water infiltration, evaporation, and plant growth. Shifting from sealed to non-sealed surfaces, where it is possible in terms of accessibility, it can reduce the urban heat island effect as well.

Methodological lessons:

- **Data compatibility**: Thorough planning of the conceptual design is essential to ensure that the collected climate data are compatible with exisiting networks.
- **Data reliablity**: In this pilot study, which assesses the potential of various surfaces and nature-based solutions to reduce perceived temperatures, it is crucial to minimize any disturbance factors (e.g., varying weather conditions). Therefore, the sensor networks used to measure different microclimatic conditions should be implemented in areas with similar external microclimatic characteristics (e.g., deploying sensor networks in different spots within the same park).
- Resolution trade-offs: Trade-offs between density and quality of sensors and costs.

Operational lessons:

- **Maintenance:** Regular site visits are necessary.
- **Wording matters:** The description of the study´s area of classification was changed from the phrasing “combined nature-based and digital solution” to “digital solution supporting nature-based solutions in urban areas” to avoid any confusions.

Impact

- **Better understanding of microclimates.** It will enable a better understanding of urban microclimates and the effects of surfaces and shades on microclimates. The study will provide quantitative evidence of how trees influence local temperature and humidity.
- It will allow **informed decision-making** on the city level through data collection that delivers reliable, localized measurements can inform urban planning.
- Further, it will show what role different surfaces have regarding the perceived temperature.
- The study can help to learn more about measurement protocols, sensor accuracy, and data collection logistics (e.g., placement height, time intervals, calibration).
- The results could quantify one of the ecosystem services provided by urban trees—temperature regulation—which is valuable for environmental valuation and cost-benefit analyses of green infrastructure.
- Communicating the findings can **raise awareness** among residents and policymakers about the tangible cooling benefits of trees.
- **Visualization of the data**: Turning technical readings into accessible outputs for policymakers, urban planners, or community members (e.g., dashboards) is as critical as the measurements themselves.
- **Scalability:** It will also offer methodological insights for scalability. A pilot study can inform municipalities on large-scale rollouts and maintenance efforts. Following the pilot study, the City of Dornbirn has shown interest in further developments and extensions of the pilot dashboard to other usage scenarions.

12.7. Overview of Implementation

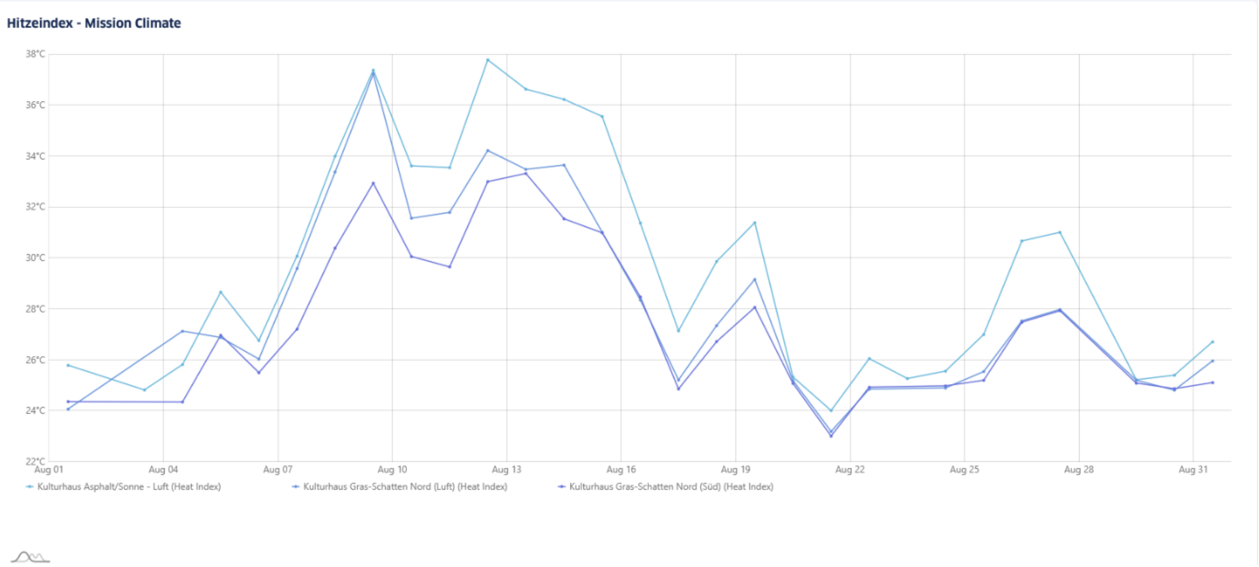
The pilot project was designed through a co-creation process between the city of Dornbirn and the University of Applied Sciences. To assess the potential of nature-based solutions within the project duration, it was decided to measure the shading effect and the associated temperature reduction of existing trees, allowing the focus on gathering data for supporting future implementations of nature-based solutions.The identified pilot study location (“Kulturhauspark” at the “Kulturhaus Dornbirn”) allows access to various different shaded areas as well as different surface types. Further, it allows data collection immediately after the implementation of the sensor networks without any time delays due to finding an appropriate spot, planning and growing of new planted trees.

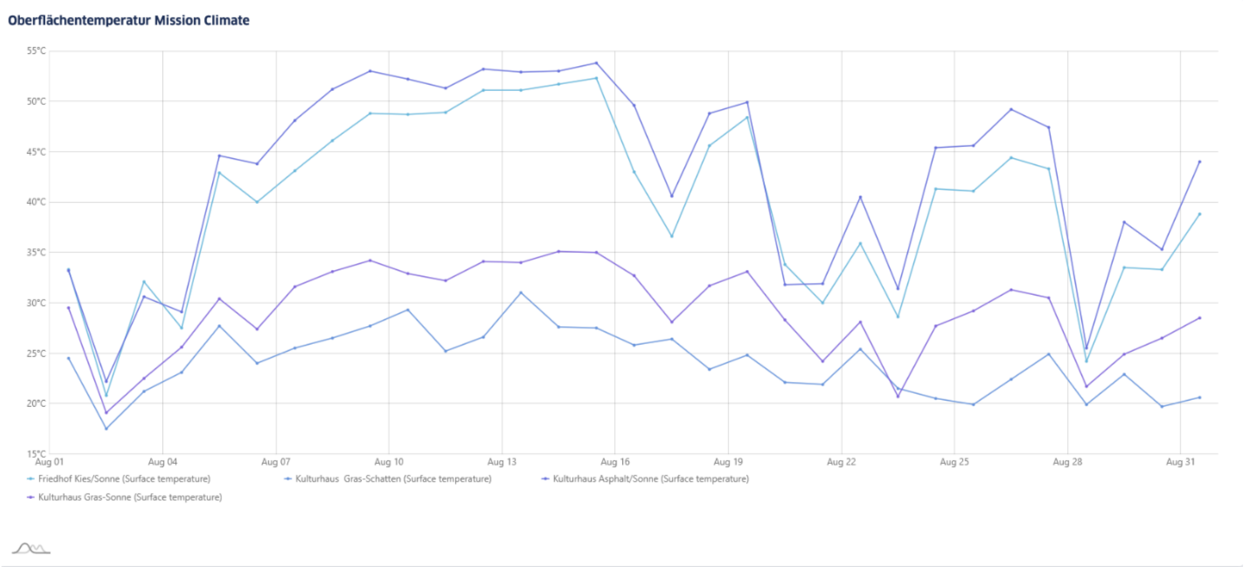
After careful considerations, the climate indicators and the respective sensor network were defined. The main criteria are compatibility with existing data and choosing equipment which allows adequate data accuracy. The requirements on the sensor networks were defined together with the city of Dornbirn. Quotations were requested by the city of Dornbirn after assessing the quotation requests for the equipment, the sensors were installed in spring 2025.

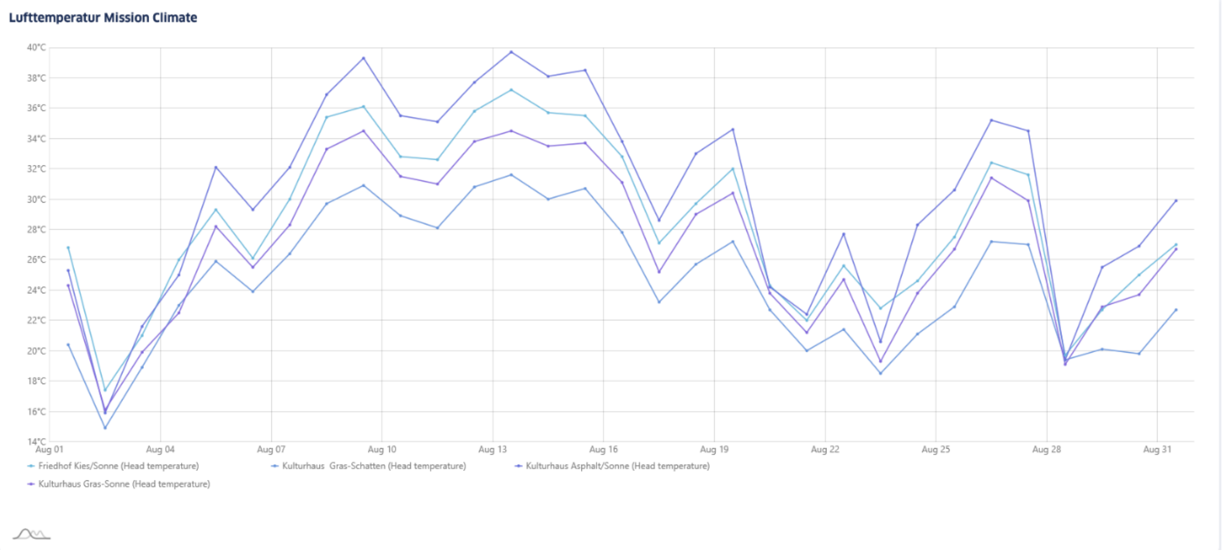
After evaluating various suitable locations during periods 1 and 2, the “Kulturhauspark” surrounding the “Kulturhaus Dornbirn” was selected as the final site for the pilot study. The park offers diverse surface types, including grass areas with and without tree shading, sealed surfaces with and without tree shading, as well as permeable surfaces with and without shading. Additionally, a basketball court with sealed ground and no tree shading was identified as a significant heat island within the park. This area was identified as the most appropriate spot to study and compare the microclimate of heat islands with other heat-reducing areas within the park.

The sensor network has been installed and the data collection is ongoing. The gathered data is visible on the citymonitor website for the city of Dornbir. This activity ensures that the gathered information is presented in a clear and easily understandable way, enabling effective communication of the findings. Further, the pilot study and its results have been disseminated through various media outlooks and dissemination events.

12.8. Screenshot







13. Use Cases

Use Case	Topic	Data Collection	Visualisation	Problem Addressed	Decision Support
Air Temperature	Heat index	Air temperature and humidity sensor for LoRaWAN®	Dashboard with daily maximum temperature	Urban heat island effect; Awareness Raising and Decision Support for the city	Importance of nature-based solutions
Surface Temperature	Heat Index & importance of surfaces	Winter road maintenance sensor for LoRaWAN® and Infrared thermometer/surface temperate sensor for LoRaWAN®	Real-Time graphs; daily maximum temperature	Urban heat island effect, Awareness Raising and Decision Support for the city	Illustrating the difference between sealed and non-sealed surfaces
Humidity	Heat index	Air temperature and humidity sensor for LoRaWAN®	-	Showing the effect of trees on humidity	Importance of nature-based solutions

Table 4: Summary of all use cases of the digital solution

CONCLUSION & OUTLOOK

The development of modular climate resilience dashboards faces important challenges, particularly in ensuring interoperability, adaptability across regions, and usability for diverse stakeholder groups. Designing a dashboard that can accommodate complex scientific data while remaining accessible and meaningful to citizens and decision-makers requires balancing technical sophistication with intuitive user experience. Furthermore, the integration of diverse data sources, from European climate programmes to local monitoring initiatives, demands robust data governance frameworks and scalable architectures. Addressing these challenges is essential for enabling communities to make informed decisions, strengthen resilience, and actively participate in climate adaptation processes.

In total, this document consists of seven parts; part A consists of an introduction, part B sets the context towards climate resilience, part C focuses on dashboard design, and part D looks at existing tools and initiatives of digital solutions. Parts E, F, and G describe good practices.

This deliverable has explored the multi-faceted requirements for building such solutions in detail. First, we have examined the purpose and context, highlighting the urgent climate challenges in Central Europe (part B, page 9), the relevance of quadruple and quintuple helix approaches (chapter 1, page 11), the inclusion of citizens, and the existing climate change information services. We then discussed requirements modelling based upon regional climate models (chapter 1.4, page 17), as well as technical considerations such as the importance of UI/UX in making dashboards both functional and engaging (part C, page 11). Building on this, various design approaches were introduced, with a focus on modular dashboard development, design goals, the participation matrix linking data depth with levels of citizen involvement, and a technical description referencing potential key technologies (chapter 2.2 and following, from page 24). The analysis of user needs included the definition of stakeholder and user groups, climate indicators relevant to resilience, and findings from the consortium survey (chapter 3, page 31). Additionally, the study presented selected publicly available EU data sources (part D, page 42) as well as a compilation of good practices from the Mission CE Climate consortium partners. These insights collectively demonstrate that developing effective modular dashboards requires not only technological innovation but also cross-sector collaboration and sustained community engagement to truly support climate-resilient futures. The findings of three best practices (Pforzheim, Košice, Dornbirn) are consolidated in the final parts (parts E, F, & G; starting from page 86).

Looking ahead, the next steps will focus on long-term testing of the developed solutions in real-world settings to evaluate their effectiveness and usability, while ensuring that the modular dashboard concept can be replicated and adapted to other regions and potentially use cases beyond the initial scope.

A particular emphasis will be placed on furthering the inclusion of citizen science approaches, allowing communities to actively contribute data and insights that enrich the dashboards and strengthen local ownership. At the same time, efforts will continue to deepen awareness-raising activities, both within target communities and the broader public, to build trust and understanding of climate resilience measures. An in-depth, long-term evaluation phase of the pilot results and the use of dashboards in practice remains an outstanding priority, ensuring that lessons learned can inform iterative improvements, broaden replicability, and ultimately establish a durable framework for climate resilience in diverse contexts.

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APPENDIX I: Best Practice Template

Appendix I lists the template used to collect good / best practices.

Template – part of *D3.4.1 Good Practices*
Design of a digital solution for monitoring of climate change in communities

CONTRIBUTION TEMPLATE – DIGITAL SOLUTION DESCRIPTION

Deliverable D.3.4.1. Design of a digital solution for monitoring of climate change in communities

Please fill in one form per best-practice tool, project, or platform. This information helps the Mission CE Climate FHV-Team to identify transferable ideas, visualize opportunities, and plan dashboard features that are grounded in proven methods.

A. General Information

Project Partner:

Contributors/Team Members/Experts involved:

Date:

If any, technology providers:

Title / Name of the digital tool + URL:

B. Digital Solution - Description

1. Digital Solution - Description

- What does the digital tool or solution monitor? 2-4 sentences
- Brief Summary (2-4 sentences):

- Technology Stack:

- Monitored Climate Indicators:
  - Air Quality (e.g., PM2.5, CO_2, NO_2)
  - Temperature, Humidity
  - Precipitation / Flood Risk
  - Heat Islands
  - Land Use Change / Vegetation Index (NDVI)
  - Citizen feedback & perception

- Geographical Coverage:

2. Target Group

- Who uses the digital solution?
    - Local governments and municipalities
    - Urban planners
    - Experts (natural protection, civil engineering, meteorologists etc.)
    - NGOs
    - Research
    - Other:

- Stakeholder collaboration?
    - Describe the collaboration (e.g. with local communities, teachers, academia, schools, advisory board), if any collaboration is happening

3. (Expected) Impact

- If feasible, provide the expected impact (for recent digital solutions), or reported impact (for well established digital solutions)
- Qualitative Outcomes?
- Quantitative Outcomes?

4. Technical Implementation Details

- Data sources:
- Data type:
    - Satellite Data
    - Sensor Data - IoT
    - LoRaWAN
    - Other:
- Interoperability:

5. Overview of Implementation

- Attach any relevant documents/ reports, that illustrate your work.
- Attach any relevant documents/reports, further describing the digital tools.

6. Screenshot

- Share screenshots or Links, if feasible

C. Use Cases

Please replace the following Table 1 with your own use cases. The Table summarizes some exemplary use case description.

Table 5: Summary of all use cases of the digital solution

Use Case	Topic	Data Collection	Visualisation	Problem Addressed	Decision Support
School Air Monitoring	Air Pollution	IoT air quality sensors on school areas	Real-Time graphs; Peak-Times/ “rush hours” (e.g. when parents come by cars)	Awareness Raising and Decision Support for schools	Reduce exposure on schools; reduce arrival/departure by car
School Air Monitoring	Air Pollution	IoT air quality sensors on school areas	Real-Time graphs; Peak-Times/ “rush hours” (e.g. when parents come by cars)	Curriculum for students (digital solutions; climate data)	Real-world cases as educational material; integration into curricula
Citizens Involvement into climate data collection	Soil quality	LoRaWAN citizen reporting via soil moisture sensors	Map of soil moisture on urban green places	Dry soil and plant/tree health	Irrigation planning based on data analysis

Citizens Involvement into climate data collection	Precipitation	LoRaWAN citizen reporting	Map of rainfall and flood risks via public dashboards	Awareness of locations of high flooding risk	Map and alert system to inform civil engineering planning and fire department for operational management
Copernicus Land Monitoring	Vegetation / Heat	Copernicus NDVI and Land Surface Temperature data	Satellite time series maps in web interface	Urban heat island effects; green space degradation	Urban greening decisions; heat management planning; early alerts for heatwaves

Please provide a short descriptive text on all use cases.

Use Cases:

1. Use Case Name

2. Use Case Name

3. Use Case Name

4. Use Case Name