ICOS Cities

Task 1.4 & sub-task 1.4.1:

Report on evaluation and benchmarking of existing services for monitoring of CO2 emissions in cities

Deliverable 1.12

Project number 101037319

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ICOS Cities

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Executive Summary

ICOS Cities (PAUL – Pilot Applications in Urban Landscapes) is a Horizon 2020 project that aims to develop a systematic greenhouse gas measurement system for urban areas. The Work Package (WP) 1 of the project investigates economic, societal, and political dimensions that influence how city decision makers use and will use emission data. The two main aims of WP1 are to collect, unlock and harmonize prior information on city climate infrastructures and emissions, and to investigate relevant services the city observatory should provide to answer the needs of cities in terms of estimation of their GHG emissions and implementation of their climate policies. Stakeholder engagement is facilitated in WP1 to map the information, service and policy needs of the city administrations, as well as by conducting social surveys and semi-structured interviews to the citizens.

WP1 task 1.4 focuses on the *co-design of service prototypes*. Ultimately, task 1.4 aims to develop a number of service prototypes, demonstrating the potential of the project in the pilot cities context, and also to refine a general methodology for service development for the use of other cities. The overall aim of the task is to assess the emission-related urban services from the perspective of user needs and to design improved service concepts for the use of major European cities.

Several service types related to carbon monitoring can be found, focusing on interactive carbon impact data, emission reduction monitoring, and services for estimating emissions of different types. These services have also been targeted at different actor groups and geographical resolutions and have different design realizations. Sub-task 1.4.1 aims to develop an in-depth understanding of existing services used by the cities to display and make sense of emission data and feed into policy processes from the perspective of their intended users (i.e. city officials). Specific focus is on three pilot cities of the PAUL project, Paris, Munich, and Zurich.

To achieve the aim, a number of stakeholders in different European cities have been surveyed to collect data on the existing services. The technological constraints as well as the situation in three selected pilot cities have been further explored in selected in-depth interviews with pilot city representatives or other topical experts. Benchmarking of selected services is carried out to analyse utilized data, context of utilization, and target users. Ultimately, this data will be analysed to develop a catalogue of services.

This Deliverable 1.12 provides the overview of the current status of services internationally, in Europe, and in the specific pilot cities, and presents a typology for services in the context of greenhouse gas monitoring to support climate governance and action. Overall, the results move focus to actions that are needed to promote the development of monitoring systems for atmospheric carbon, and their connection to climate strategy development. These actions connect to policy actions, but also technology development and strategic design processes to gradually scale-up the service domain.

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Glossary of key terms

CLRTAP	Convention on Long-Range Transboundary Air Pollution by UNECE, the United Nations Economic Commission for Europe
C40 Cities	C40 Cities Climate Leadership Group is a group of 96 major cities around the world
CF	CF metadata conventions are developed to share (for example) gridded data from climate and forecast (CF) models
CO2	Carbon dioxide
COP21	UN Conference of the Parties (COP) in 2015 where Paris Agreement was coined and signed
COVID-19	Corona virus disease 2019
EC	Eddy covariance measuring
EMEP/CEIP	European Monitoring and Evaluation Programme and its Centre on Emission Inventories and Projections, under the UN CLRTAP programme
EU	The European Union
GCoM	Global Covenant of Mayors for Climate & Energy is an alliance for city climate leadership of over 11,500 cities and local governments
GHG	Greenhouse gas
GWP	Global warming potential
ICLEI	Local Governments for Sustainability, a global network of more than 2500 local and regional governments
ICOS	Integrated Carbon Observation System – a European research infrastructure
IG3IS	Integrated Global Greenhouse Gas Information System initiated by the WMO
MS	Milestone (in project)
NDC	The Nationally Determined Contribution (NDC) setting a GHG reduction target for a nation
NECP	National Energy and Climate Plans (NECPs) are required to be prepared by the EU member states
PAUL	Pilot Application in Urban Landscapes *(this project)*
PCN	PAUL City Network of 15 cities in Europe (including the pilot cities in this study)
SDGs	Sustainable Development Goals by the United Nations
SECAP	Sustainable Energy and Climate Action Plan
TNO-GHGco	An emission inventory at a resolution of 1 x 1 km by The Netherlands Organisation for applied scientific research
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council for Sustainable Development is an organization of over 200 international companies
WMO	World Meteorological Organization is a specialized agency of the UN
WRI	World Resources Institute is a global research non-profit organization

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1 Introduction

PAUL – Pilot Applications in Urban Landscapes (ICOS Cities) is a Horizon 2020 project that aims to develop a systematic greenhouse gas measurement system for urban areas. The Work Package (WP) 1 of the project investigates economic, societal, and political dimensions that influence how city decision makers use and will use emission data. The two main aims of WP1 are to collect, unlock and harmonize prior information on city climate infrastructure and emissions, and to investigate relevant services the city observatory should provide to answer the needs of cities in terms of estimation of their greenhouse (GHG) emissions and implementation of their climate policies. Stakeholder engagement will be facilitated under WP1 through the use of co-creative and inclusive service design methods to capture the information, service and policy needs of city governments, as well as by conducting social surveys and semi-structured interviews to the citizens in the pilot cities.

WP1 task 1.4 focuses on the *co-design of service prototypes*. Ultimately, task 1.4 aims to develop a number of service prototypes demonstrating the potential of the project in the pilot cities context, and also to refine a general methodology for service development for the use of other cities. The overall aim of the task is to assess the emission-related urban services and to design improved service concepts for the use of major European cities. As part of this work, the current status of monitoring and measurement systems as well as connected existing services are reviewed, especially in the context of climate action governance. Sub-task 1.4.1 (see Box 1) aims to develop an in-depth understanding of existing services used by the cities to display and make sense of emission data and feed into policy processes from the perspective of their intended users (i.e. city officials). Specific focus is on three pilot cities of the PAUL project, Paris, Munich, and Zurich, that also represent different sizes as cities.

Several service types related to carbon monitoring can be found in Europe and internationally, focusing on interactive carbon impact data, emission reduction monitoring, and services for estimating emissions of different types. These services have also been targeted at different actor groups and have different design realizations. Benchmarking is thus needed regarding the usefulness, design solutions, data requirements and practical challenges related to emission-related services. In this assessment, we benchmark both services for atmospheric carbon assessment as well as for climate action monitoring.

To achieve the aim of sub-task 1.4.1, a number of stakeholders in different European cities have been surveyed to collect data on existing services. The technological constraints as well as the situation in three selected pilot cities have been further assessed in selected in-depth interviews with pilot city representatives or other topical experts.

Overall, we approach benchmarking in this assessment as a broad concept, as the contextual breadth of the potential service space calls for many types of technical settings and systems, targeted to different audiences and at different phases of the climate action monitoring. Benchmarking of selected services is carried out to analyse utilized data, context of utilization, and target users. Ultimately, this data will be analysed to develop a catalogue of service types.

The work is guided by the following research questions:

- What types of CO_2 monitoring services exist and how do they contribute to cities' climate program activities and follow-up?
- How are these monitoring services used in the three pilot cities of the PAUL project?
- What types of services could be connected to monitoring data? Who could be the users and providers of these services?

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This report (Deliverable 1.12) provides an overview of the current status of services internationally, in Europe, and in the specific pilot cities, and presents a typology for services in the context of greenhouse gas monitoring to support climate governance and action. The report also summarizes relevant findings from other PAUL project deliverables, such as Milestone (MS) 1 report 1.1 on city emission inventories and report 1.2 on policy context. After introduction, the report continues in Chapter 2 with a background overview into atmospheric CO2 and GHG monitoring and the connection to cities' climate action governance. In Chapters 3 and 4, we describe an overview of the gathered data, and assess the current situation in the three pilot cities. Lastly, Chapter 5 concludes the assessment with reflections on results and the next steps in developing services for carbon monitoring. The benchmarking of selected services is also carried out to analyse data acquisition, input, and processing models.

Besides the earlier project internal materials, this report is based on:

- Background research for project preparations (from 2021)
- Contextual interviews with stakeholders (Spring 2022; in Finland)
- Benchmarking of service examples online/in articles/via email inquiries (Spring–Summer 2022)
- Project-internal expert interviews; Pilot city contacts (Spring–Summer 2022)
- Secondary materials (research papers, reports, websites)

Box 1. Description of this sub-task and deliverable

Sub-task 1.4.1: Front-end research: benchmarking and evaluating existing services

This sub-task develops an in-depth understanding of existing services used by the three pilot cities to display and make sense of emission data and feed into policy processes from the perspective of their intended users (i.e. city officials). Several service types related to carbon monitoring are found in European cities, such as interactive carbon monitoring maps, emission reduction plan progress sites, calculator services for estimating emissions and reduction potentials and comparative calculators. These service types have also been targeted at different actor groups and geographical resolutions and have different design realizations. Benchmarking is thus needed regarding the usefulness, design solutions, data requirements and practical challenges related to emission-related services. To achieve the aim of sub-task 1.4.1, a series of European cities will initially be surveyed to collect data on existing services. This data will be analysed to develop a catalogue of service types. Next, in-depth interviews will be undertaken in each pilot city with the users of each service type to understand their experiences of using these services and their aspirations for improved and new services. Technical benchmarking of selected services will also be carried out to analyse data acquisition and processing models. Finally, as relevant, the services will be benchmarked to identify the business models the services are delivered through.

Deliverable (D1.12): Report on evaluation and benchmarking of existing services for monitoring of CO2 emissions in cities

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2 Atmospheric carbon dioxide monitoring services

Air pollution, its monitoring, and climate policymaking at the urban level in Europe are connected on various levels. Atmospheric carbon impact monitoring services are currently developed in various contexts, and cities are obvious users for these to transition towards more sustainable processes and infrastructure (e.g. energy and transport; climate actions; etc.). Assessing the development of the services also requires an understanding of how science and policy contribute to the potential service development.

2.1 Technical and theoretical background

The three most important greenhouse gases in the atmosphere are carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). While carbon dioxide is the greenhouse gas we hear the most about, methane and nitrous oxide have greater global warming potential (GWP). Whereas GWP for CO2 is 1 for a 100-year period, methane has a GWP of ~30 and nitrous oxide has a GWP of over 200.[1]

Measuring carbon dioxide (CO2) in the air is in principle simple and it can in general be measured with simple infrared sensors.[2] However, expanding from single measurements to a broader picture of atmospheric carbon impacts is more challenging.

Atmospheric gasses move in rotating circular currents that are called eddies. As air moves, friction makes the air tumble in smaller and bigger eddies, with both horizontal and vertical components. Eddy covariance (EC) measuring describes a technique that simultaneously measures the differences between the gas concentrations and the direction of wind components.[3] A wind sensor (sonic anemometer) measures the direction of the turbulent wind, and spectrometers measure gas concentrations in the air by monitoring how many gas molecules pass through a defined volume over a given time.[4] EC measurements are typically carried out in 10–20 Hz frequencies (10–20 measurements per second). When the data is post-processed according to published standards final data is represented in 30–60 minute intervals.[5] Typically, EC measurements are continuous and these cases research site will produce annual estimates regarding the carbon and energy fluxes of the site, but seasonally monitored sites exist as well.

In the PAUL project, monitoring of atmospheric CO2 is based on a city-specific networks CO2 monitoring stations with low-precision (~50 ppm), mid-precision (~1 ppm) and high precision (~0.1 ppm) sensors, as well as a smaller number (<10) of EC towers.

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[1] https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FullReport_small.pdf page 1034

[2] One of the most common types is the NDIR non-dispersive infrared sensor; an NDIR CO2 sensor sends an infrared signal through an air sample and measures the light absorption at a specific wavelength. The absorption is proportional to the gas concentration.

[3] More specifically, IRGA (infra red gas analyser) laser measures the concentration of the target gas at a specific time.

[4] Besides CO2 also N2O can be measured (a quantum cascade laser (QCL) measures nitrous oxide; N2O makes up about 0.00003% of the atmosphere by volume but it is a potent greenhouse gas.

[5] See Baldocchi (2014), https://doi.org/10.1111/gcb.12649

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2.1.1 *Measuring carbon dioxide impacts*

Point-specific measurements and data of atmospheric CO2 concentration can be acquired relatively easily with existing technologies, ranging from distributed small monitoring stations to global satellite data. The information can also be interpolated[6] to even finer resolutions (down to less than 100 meters). However, extrapolating this data to describe activities on a sectoral basis or to the assessment of specific interaction is far more difficult. Instead, the data is used to refine various 'impact indicators' (kind of 'conversion factors') that are used in calculating carbon dioxide impacts in relation to different sectors. On the city level, the overall impacts are then collected with sectoral indicators that comprise the emission inventories and the related impacts.

Spatial assessment can, however, be connected to various temporal dimensions, and to the development of more refined models on atmospheric interactions. Spatial data also allows the development of gridded networks of emissions connecting with specific temporal aspects and allow further development on specific impact assessments and the related indicators. In this process, there are already consultants and companies that work as intermediaries in offering services to public actors and businesses.

In developing monitoring networks, it is important to ensure transparency and accessibility to data. Integrated Global Greenhouse Gas Information System (IG3IS) was initiated by the World Meteorological Organization (WMO) and its partners to assist the countries in meeting their commitments to the Paris Agreement. IG3IS is an observation-based information system for determining trends and distributions of greenhouse gases (GHGs) in the atmosphere and the ways in which they are consistent or not with efforts to reduce GHG emissions. This is already being done on a global scale through existing networks, but currently provides only a modicum of useful information at the spatial scale of nations and regions managing emissions and offsets.[7]

The IG3IS team defined four implementation objectives:

- Improve knowledge of national emissions (including reduction of uncertainties of inventory reporting to the United Nations Framework Convention on Climate Change (UNFCCC)).
- Locate and quantify previously unknown emission reduction opportunities such as fugitive methane emissions from industrial sources.
- Provide sub-national entities such as large urban source regions (for example, megacities) with timely and quantified information on the amounts, trends and attribution by sector of their greenhouse GHG emissions to evaluate and guide progress towards emission reduction goals.
- Support for the Paris Agreement's global stocktake[8] through the integration of these objectives.

According to IG3IS best practice guidelines,[9] urban greenhouse gas and ancillary data should follow 'FAIR' data principles, meaning they should be Findable, Accessible, Interoperable, and Reusable/Reproducible.

- Findable data sets: A globally unique and persistent identifier such as a Handle PID or Digital Object Identifier (see https://www.doi.org/).

[6] Extrapolation refers to estimating an unknown value based on extending a known sequence of values or facts; interpolation is the act of estimating a value within two known values that exist within a sequence of values.

[7] https://ig3is.wmo.int/en/about

[8] The global stocktake of the Paris Agreement (GST) is a process for taking stock of the implementation of the Paris Agreement with the aim to assess the world's collective progress towards achieving the purpose of the agreement and its long-term goals.

[9] https://library.wmo.int/doc_num.php?explnum_id=11292

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- Accessible data: Data and metadata should be accessible in open data formats such as NetCDF (https://www.unidata.ucar.edu/software/netcdf/), HDF5 (https://www.hdfgroup.org/), or plain text.
- Interoperable data: Data and metadata should follow Climate and Forecast (CF) naming conventions for the description of the measured variables.[10]
- Reusable/reproducible data: Methods to produce data should be well documented so that results or products can be reproduced by others.
- Machine readability + clear data license + usage conditions (e.g. open data Vs. embargo).

A key component in promoting collaboration is in creating data sets that follow FAIR principles, mainly by utilizing the CF conventions for data and metadata.[10]

The Greenhouse Gas (GHG) Protocol, is a joint initiative of World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD). It aims to supply greenhouse gas accounting standards for world-wide use. The GHG Protocol provides accounting and reporting standards, sector guidance, calculation tools and trainings for businesses and local and national governments, and also provides GHG Protocol material and impact inventory information for the use of cities.[11]

2.1.2 Assessing CO2 impacts with indicators

The atmospheric carbon monitoring data contributes to scientific research on atmospheric models in relation to various sectors of action. This research then contributes also to the development of specific impact indicators to estimate the carbon impacts of various activities. Consequently, one key question in developing services for atmospheric carbon impact assessment is to select specific areas of analysis, in which impact indicators are selected and further developed to follow the CO2 impacts.

Despite existing guidelines, there is no strict regulation or standardization on either indicators or inventories. Rather, cities and various research and policy networks interact to develop inventories and indicators bottom-up. However, certain areas of impact are often considered of key focus in assessing carbon impacts, such as the impacts of public power generation, industry, transport, and waste management (see Table 1 for an example of UK emission categories (UK gov., 2022; see Appendix 2 for the Paris inventory as assessed in the ICOS PAUL project's MS1 report 1.1).

While the developing monitoring networks are difficult to be connected to real-time monitoring of sectoral impacts or climate actions, the data that they provide create a basis for various developments around impact indicators and regional specifics in inventory, as the findings from assessments are inter- and extrapolated to sectoral and interaction-specific indicators.

There is also work to study how well various sectoral and regional assessments fit together with the national and global scale measurements. In this area, focus should also be drawn on how and what aspects of scope 1–3 emissions are incorporated to city climate strategies. The scopes 1–3 (also titled as 'tiers 1–3') describe impacts ranging from direct impacts of city activities (scope 1) to also incorporate used energy (scope 2), and finally also externalized impacts of energy and manufacturing (scope 3).

[10] http://cfconventions.org/

[11] https://ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

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Table 1. Example categories for converting emission factors (UK gov., 2022)

Scope	Sector	Units for conversion
Scope 1 factors	• Fuels • Bioenergy • Refrigerant & other • Passenger vehicles • Delivery vehicles • SECR kWh pass & delivery vehs	Total kg CO2e per ton; total kg CO2e per km
Scope 2 factors	• UK electricity • Overseas electricity • UK electricity for EVs • SECR kWh UK electricity for EVs • Heat and steam	Total kg CO2e per kWh
Scope 3 factors	• Well-to-tank (WTT)- fuels • WTT- bioenergy • Transmission and distribution • UK electricity T&D for EVs • WTT- UK electricity • WTT- heat and steam • Water supply; Water treatment • Material use • Waste disposal • Business travel - air • WTT- business travel - air • Business travel - sea • WTT- business travel - sea • Business travel- land • WTT- pass vehs & travel - land • Freighting goods • WTT- delivery vehs & freight • Hotel stay • Managed assets- electricity; vehicles • Homeworking	Total kg CO2e per unit

Apart from the emission inventories for cities, there is also the option to down-scale national scale reported data to the city scale using a variety of spatial proxies like population density and road network maps.[12] The national downscaled emission inventory is based on national reported emissions (as reported under UNFCCC and CLRTAP[13]), which are spatially distributed based on maps with proxy data.

The TNO-GHGco inventory[14] has been prepared within the VERIFY research project for CO2, CH4, CO and x emissions in Europe at a resolution of 1/10° x 1/20° (lon x lat) (approximately 6x6 km) for the years 2005–2017

[12] This approach is used by the TNO- GHGco inventory developed under the H2020 projects VERIFY and CHE at a 1 x 1 km resolution over North-West Europe.

[13] UNFCCC refers to *United Nations Framework Convention on Climate Change* that entered force in 1994 and CLRTAP refers to UN's *Convention on Long-range Transboundary Air Pollution* that entered force in 1983.

[14] The Netherlands Organisation for applied scientific research (TNO) GHGco Inventory is an European database 105 that includes spatially resolved emission data for CO2, CH4, CO, NOx and NMVOCs; VERIFY project was funded by the EU's H2020 programme, no. 776810.

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(see Super et al., 2020). Also, a specific zoom version was made, where spatial 're-gridding' was performed at a much higher resolution of 1/60° x 1/120° (lon x lat) (approximately 1x1 km). The methodology for the inventory is based on calculating the regional anthropogenic emissions starting with the reported emissions by countries to UNFCCC and EMEP/CEIP (European Monitoring and Evaluation Programme; Centre on Emission Inventories and Projections). After checking and correcting gaps, errors and inconsistencies, the emissions were spatially distributed based on specific proxies per emission source.[15]

Besides the impact assessment of current city operations and interactions, inventories and their related data developed with various impact indicators are important in assessing future changes in city development. Consequently, the information developed for the management of climate actions also comes of use in assessing future scenarios. In these studies, the current impacts and their related indicators are studied, and the related actions to mitigate them are studied further.

Lastly, quantitative impact assessment with impact indicators, and also the assessment of actual real-world carbon impacts, will become increasingly important for several emission assessment and trading systems that are being developed for different sectors in the EU.

2.1.3 Assessing impacts of climate actions

Based on the international and EU-level developments in policies promoting climate actions (see section 2.3), cities and nations are acknowledging targets to reduce their greenhouse emission impact. Many city- and project-level assessments of climate actions include the use of quantitative impact indicators for carbon emissions, and cities develop emission inventories with impact indicators for their annual reporting. Similar data can also be used in assessing future developments and competing scenarios.

Services for common public and business use can utilize similar emission information depositories. For the citizens, services are offered in which their personal carbon footprint is assessed based on their lifestyle and consumption choices. For business, various assessments are needed to manage the progress to zero-carbon operations, also including emission trading and compensation services.

However, often the progress in climate actions especially on the municipal level is communicated mainly with qualitative aspects. Qualitative assessment will typically describe the nature and direction of the change, with considerations on temporal and spatial nature and scale of the change; for each of the above. In this process, uncertainties and gaps in knowledge should be identified (UK gov., 2013).

Qualitative assessment is also common for communicating progress in relation to several other targets that relate to sustainable development, for example the UN's Sustainable Development Goals (SDG). However, even for more complex criteria also various quantitative indicators can be utilized.[16]

[15] See more information in https://verify.lsce.ipsl.fr/images/PublicDeliverables/VERIFY_D2_3_TNO_v1.pdf

[16] https://www.mayorsindicators.com/ is an online service that lists SDG development as a quantitative rating for different municipalities in Finland, Sweden, and the UK.

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2.2 Service design to support climate action policies and planning

In developing services to support climate action monitoring and for connecting to the carbon impact data, there are several areas for professional design action.[17] In the context of sustainability and climate change, the scope of professional design action can cover a spectrum of potential needs; for example, improving technological systems to develop better practices, or developing solutions to empower citizens in transforming their life-styles and ways of consumption. Professional design action can also support collaboration and communication among stakeholders, and facilitate joint strategy-making for achieving sustainability transitions.

2.2.1 Sustainable design supporting climate actions and their monitoring

Approaches in sustainable design cover a large range of activities including material, product and technology-specific practices (e.g. ecodesign; sustainable product design), innovation to optimise or radically change the logics of production and consumption systems (e.g. sustainable product-service-system design; design for social innovation), and support for socio-technical systems innovation and transition management (e.g. design for sustainability transitions) (Ceschin & Gaziulusoy, 2019). In this regard, the scope and framing of design actions cover a spectrum from insular, once-off, efficiency- and optimisation-oriented, techno-centric interventions to those that aim for structural and long-term changes across interacting socio-technical systems.

To promote more radical changes for sustainable consumption there is a need for widening the innovation beyond the product to the stakeholder systems that connect to it. Product-Service System (PSS) design refers to the development of new business models, where the sales of conventional product is appended or even replaced by an improved service model that either expands the product offering (e.g. by introducing guidance, or expanded guarantee), or then even seeks new ownership models (e.g. leasing and sharing of products; sales of services instead of products; see UNEP, 2002). PSS innovation often requires not only prototyping with new technologies, but also testing them in real-life contexts with various stakeholders, and the connection of several projects together to scale-up transitions on a broader scale (Ceschin, 2014). In participatory design, infrastructuring acts as one key concept to discuss engagement and participation over time (see Botero & Hyysalo, 2013; Botero et al., 2020), referring to the ongoing work involved in building the necessary, social, material and technical infrastructures.

To support the development of these new technical and procedural infrastructures for achieving more accurate follow-up on various climate actions, a variety of stakeholders need to be involved in co-designing service solutions. Professional design activities also exist to support collaborative strategy-making within or across several contexts including businesses, provisional systems and cities. Design connecting to transition management (see e.g. Hyysalo et al., 2019; Angheloiu et al., 2017) seeks to identify the dynamics in relation to future scenarios and transition pathways, connecting niche developments with broader ideas of policy development and technological change.

Overall, contemporary design approaches to sustainability challenges range from product- and technology-related improvements to system design and finally to support various processes of collaboration.

[17] According to World Design Organization (https://wdo.org/) "(industrial) design is a strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services, and experiences."

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Consequently, the multilevel perspective on socio-technical systems can also be adapted for design activities. In the Multilevel Design Model, designers connect their focus on a specific level of interest to more systemic considerations on socio-technical transformation and change (Joore & Brezet, 2015).

2.2.2 Designing services for carbon impact assessment and monitoring

Service design is a human-centered and iterative approach to creating new service solutions (Meroni & Sangiorgi, 2011). In service design, rational problem-solving approach that is closer to engineering design is connected with a more exploratory inquiry (Kimbell, 2011).

In approaching the service development for monitoring the carbon impacts, or for monitoring progress in relation to various climate actions, there is a need to anticipate technology developments that enable future service innovations. Currently connecting to the real-time monitoring data on atmospheric carbon fluxes remains most relevant for scientific assessments and further scientific work on refining various models, indicators and inventories. These studies, however, also open up possibilities for future service design.

Several focus areas for service design can be envisioned each with quite different emphasis (see Table 2). For the research community, the main focus in regard to real-time spatial CO2 monitoring data is to promote developments and services to improve the accessibility and usability of data. This research helps to develop more refined indicators to assess the impacts of various activities – even with improved temporal dynamics.

In the policy domain, however, work is needed to support the harmonization of the indicators, and to scale-up the use of impact indicators in connection to climate action assessment. The improved use of indicators needs to be supported also with tools for communication for external public. Besides information on their cities' climate actions, ordinary citizens would benefit also from improved services to assess impacts of their life-style choices, and the impacts of various products and/or services options.

Finally, also businesses benefit of developing impact indicators. They can utilize indicators in their internal impact assessment processes or be involved in the markets as developers for the services for various touch-points in the 'service eco-system'.

Table 2. Potential users and areas of focus in service design action

Potential users	*Potential emphases in service design*
Researchers	• Access to data for research and, model and indicator development • Support for scientific communication on results • Support to connect to policy development
Municipal planners	• Access to indicators on CO2 impacts of various sectoral activities for assessment and planning of climate actions • Support from research and intermediaries for monitoring impacts • Tools to monitor and communicate on progress
Citizen, laypeople	• Easy-to-use services to assess and compare personal life-style impacts • Services to assess impacts of various other activities and/or products or services
Businesses	• Access to indicators on CO2 impacts of various sectoral activities for assessment and planning of climate actions • Support from intermediaries for monitoring impacts • Tools to monitor and communicate on progress

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2.3 Climate governance in the project's focus context

The 2015 Paris Agreement urges states to hold the "increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels." The Paris Agreement also recognizes the role and importance of non-Party stakeholders, including cities, other sub-national authorities, civil society, and the private sector, in addressing climate change and building resilience.

The EU's initial Nationally Determined Contribution (NDC) set a GHG reduction target of 40% below 1990 emission levels by 2030. Moved by the increasingly dire warnings of the IPCC and the demands of citizens, in December 2020, the EU Commission proposed to enhance its emissions targets to achieve at least 55% reduction of 1990 GHG emission levels by 2030. This target became law with the passage of the European Climate Law in June 2021, setting a binding target to reduce GHG emissions by at least 55% of 1990 levels by 2030 and climate neutrality by 2050. A climate advisory body was then tasked with developing a GHG budget and a target for 2040 (Regulation (EU) 2021/1119).

The European Union is in the process of developing a package of climate and energy legislation intended to make Europe "Fit for 55", to achieve its target of reducing GHG emissions by 55% of 1990 levels by 2030. Measures being negotiated include a revision of the energy taxation directive, a carbon border adjustment mechanism, reducing methane emissions, the revision of several related directives, and many additional measures. The "Fit for 55" package also involves revisions to the emissions trading system to expand its coverage to the maritime and other sectors previously not included in the Emissions Trading Scheme and will phase out free emission allowances for aviation. An additional emissions trading system is to be created to address fuel distribution for road transport and buildings. All funds derived from the pricing of CO_2 emissions are to be used to make progress on climate and energy projects and to cushion socially weaker segments of the population and small- and medium-sized enterprises from rising energy costs.

In 2019, with the launch of the "European Green Deal," which aims to make Europe climate neutral by 2050, it became clear that this target would need to be strengthened. Considering Russia's invasion of Ukraine, "REPowerEU," the EU Commission's plan to make Europe independent from Russian fossil fuels before 2030, sets a 45% target for renewables as a share of power generation for 2030.[18] It further emphasizes the importance of saving energy, producing clean energy, and diversifying supplies and recommends that member states speed up permit-granting procedures for renewables deployment.

In addition to these binding measures (see Table 3), the EU provides a number of other supportive mechanisms to its member states and their cities, which aim to advance progress on climate neutrality. The Covenant of Mayors founded in 2008 (a part of GCoM alliance) engages with cities and supports them in sharing information on actions which can be taken to lower emissions. It also empowers cities to speak with a stronger voice in European policymaking processes. One of the latest EU Missions is "100 climate-neutral and smart cities", which will provide funding, advice, and other types of support to 100 selected cities in the EU. Of the focus cities in this study, Munich and Paris are among those chosen. Under this program, they are invited to prepare Climate City Contracts, which set out their plans to achieve climate neutrality by 2030 and ensure high engagement of citizens and partners (European Commission, 2022c). There are several similar EU

[18] REPowerEU Plan (see also https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131)

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initiatives which aim at promoting climate protection measures in European cities, including the European Green Capital Award,[19] the Green City Accord,[20] the Circular Cities Declaration[21], and the Aalborg Charter.[22]

There is a consistent direction towards low- and zero-carbon societies, affecting all the cities in Europe. International and EU-level agreements promote also emission trading mechanisms and compensation services. Many of these include the assessment of carbon impacts, and their mitigation on various sectors of action. Finally, there are also broader sustainability considerations, evident in the UN's Agenda 2030 and SDG's. In these areas, more qualitative assessment is often necessary.

Table 3. International/supranational frameworks affecting climate governance in pilot cities

Policy framework	Paris	Munich	Zurich
Paris Agreement	✓	✓	✓
Agenda 2030 for Sustainable Development with 17 Sustainable Development Goals (SDGs)	✓	✓	✓
European Green Deal	✓	✓	X
European Climate Law	✓	✓	X
EU Mission: 100 climate-neutral and smart cities	✓	✓	X

19 European Green Capital Award (europa.eu)

20 CC Declaration | Green City Accord (circularcitiesdeclaration.eu)

21 CC Declaration | Home (circularcitiesdeclaration.eu)

22 European Sustainable Cities Platform | The Aalborg Charter

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3 Interviews

The background research encountered several contextual aspects that are important in developing monitoring services for atmospheric carbon, and the connected solutions to build service platforms to support climate action monitoring. In addition to compiling relevant prior research, the findings in this report are based on interviews conducted in three phases and with several types of stakeholders.

Background research to support PAUL project preparation (in 2021):

- 5 cities were assessed in Finland (Helsinki, Lahti, Turku, Joensuu, Vantaa)
- General benchmarking of CO2-footprint/measures related services/platforms

Contextual background interviews in Finland (Spring–Summer 2022):

- 3 interviews conducted (2 service developers, 1 municipal planner)
- Benchmarking examples of municipal level services

PAUL project-internal interviews (Spring–Summer 2022):

- 5 interviews conducted with PAUL project-internal WP1–WP3 members and pilot city contacts
- Identification of (pilot city related) situation with CO2 measurement and services

3.1 Background data gathering

3.1.1 Background interviews

The early background interviews that were performed in project preparation phase (see Table 4) created an overview into what kind of data tools do the city administrators use in their climate work, to whom they are targeted, what kind of data do the city decision makers or advisories use, do they have all the information they need, what kind of data would have an impact on decision making, and what kind of data services are used in Finland and abroad.

Table 4. Background interviews during project preparations in 2021

Interview #	Interviewee(s) profile	Organization (role)
#1	City administration	Helsinki City, Finland (environmental planner)
#2	City administration	Lahti City, Finland (environmental coordinator)
#3	City administration	Turku City, Finland (specialist advisor)
#4	City administration	Joensuu City, Finland (climate coordinator)
#5	City administration, 2 interviewees	Vantaa City, Finland (environmental planning)

The five Finnish cities in the background study all either utilized or then developed a platform for following and communicating the progress of their climate program actions. However, the platforms were perceived more important to facilitate further collaboration and communication. The most important user groups, defined by the cities, were identified as experts (i.e., city officials), decision-makers, but also citizens more broadly.

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By the time of the study, Helsinki and Lahti utilized a service platform called 'Ilmastovahti', developed by a start-up initially formed from Helsinki city project workers (Kausal Watch, see section 3.1.2.2). According to the interviews in Helsinki and Lahti, the web-based tool was integrated in environmental work: They felt it's useful and it drew also international interest for further collaborations. Lahti representative said it effectively helps in keeping issues on the table. However, since the interviews Helsinki has stopped utilizing the service, and is communicating of its climate actions on a more general level (i.e., in relation to heating, electricity, and transport).

The data tools that were brought up were related to either emission calculations or assessing emission scenarios. However, both require plenty of background information and expert know-how from users. The interviewees also discussed of the need of more streamlined online tools for impact analysis and scenario assessment. The data presentations that decision-makers need, or that has an impact, was described as: Visual (graph or picture); Concise textually; Understandable, clear, simple; Up-to-date and comparable.

The real-time atmospheric monitoring was mainly associated with air quality information that needs to be assessed and communicated according to EU regulation.[23] Currently, however, in following the progress on climate actions, all of the studied cities utilize services that are built on general indicators rather than (directly measured, localized) data on emissions.

One important network that was mentioned as a provider of tools was the Global Covenant of Mayors (GCoM; https://www.globalcovenantofmayors.org/). GCoM, as mentioned also in section 2.3, has been founded as a response to climate change from cities around the world, being the largest global alliance for city climate leadership, built upon the commitment of over 11,500 cities and local governments. These cities hail from 6 continents and 142 countries. Their *Data4Cities* initiative aims to support to measure and manage cities and local governments' climate ambition and progress. It aims for standardized data by streamlining – with consistency and transparency – how and what climate information from cities is collected, what data can be made available to support cities to act, alongside the mechanisms used to analyze this information.

3.1.2 Service examples

3.1.2.1 Examples of emission monitoring services

As a part of the background studies and project preparations, also international examples of services were reviewed. These examples include service platforms to communicate atmospheric GHG emission impact data and various other impact data combined with various sectoral and/or demographic aspects.

- **ClimateWatch** (https://www.climatewatchdata.org/)
  ClimateWatch is an international service including national data on:
    - Overview on NDCs – national level agreements
    - Long-term strategies overview, including links to national strategy documents
    - Climate Vulnerability and Readiness, including climate risks and extending to poverty considerations

[23] The Cleaner Air For Europe (CAFE) Directive, 2008/50/EC sets out the need to ascertain the ambient air qualities, assessing for comparison and informing the public; see https://www.eea.europa.eu/policy-documents/directive-2008-50-ec-of

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- Sustainable Development Goals (SDGs) in relation to an aligned climate target, action, policy measure or need in the NDC (identified based only on the information communicated in the NDC).

- **World Bank DataBank** (https://databank.worldbank.org/)
The World Bank DataBank database is an online analysis and visualisation tool that contains collections of time series data on a variety of topics. Information for example on:
  - World Development Indicators
  - Education, equality, poverty, etc.
  - Sustainable Development Goals (UN SDGs) (also UN Millennium Development Goals)
  - Sustainable energy; Sustainable mobility for all
  - Environment Social and Governance (ESG) data (e.g. CO2 emissions (metric tons per capita)

- **Environmental Insights Explorer** (https://insights.sustainability.google/)
EIE by Google and the GCoM provides basic information on city emission impacts, distributed into building (residential & non-residential) and transport (inbound & outbound) emissions. The Environmental Insights Explorer (EIE), launched by GCoM and Google, is designed to make Google's significant data resources available to cities with the aim of accelerating measurement and planning stages for cities in favor of action. EIE can support cities in the development of their emissions inventories by providing granular GHG emissions data estimates in four key areas: building emissions, transportation emissions, solar energy potential, and 20-year climate projections, as well as air quality, facilitating access to insights that can be used to act.
  - Data based on consistent assessment model
  - Several US, Canadian cities involved. However, no data from Europe has been published on the platform!
  - However, only some cities are currently presented, and for many there is only a developer access
  - Private provider for modeling and data – an issue to accessibility?

Other, more specific case examples exist focusing on specific cities. Examples of these are brought up by the IG3IS network (with last one added for European comparison):

- **Origins.earth project** (Paris, France) assists cities to achieve their goals to reach zero carbon emissions. Their science-based approach uses sensors to measure a cities' CO2 emissions. Paris, France is the Origins.earth flagship and is leading the way for cities, who want to measure and efficiently manage their greenhouse gas emissions. The measurements lead to an improved mapping of emissions, which is used to target the most efficient low carbon projects.
https://www.origins.earth/

- **The Global Carbon Project (GCP)** is a global research project of Future Earth network initiated already in 2001, and a research partner of the World Climate Research Programme, that aims to integrate knowledge of greenhouse gases for human activities and the Earth system, including global and continental budgets for three dominant greenhouse gases — carbon dioxide, methane, and nitrous oxide — and complementary efforts in urban, regional, cumulative, and negative emissions. https://www.globalcarbonproject.org/

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- **INFLUX project** (Indianapolis, USA) was the first of three urban GHG measurement testbeds established by the US National Institute of Standards and Technology (NIST) created to evaluate how accurately CO2 emitted from a small city can be measured with top-down and bottom-up approaches. https://www.nist.gov/topics/greenhouse-gas-measurements/indianapolis-flux-experiment

- **Los Angeles Megacity Carbon Project** was the second of three urban GHG measurement testbeds established by NIST created to measure multi-year GHG emission trends by sectors such as electricity, transportation, and agriculture. https://www.nist.gov/topics/greenhouse-gas-measurements/los-angeles-megacity-carbon-project

- **The MERCI-CO2 project** (Mexico City, Mexico) is set to measure atmospheric CO2 concentrations in order to verify the effectiveness of emission reductions taken by authorities in the Mexico City megacity. http://www.agence-nationale-recherche.fr/Project-ANR-17-CE04-0013

- **Toronto GHG monitoring program** (Toronto, Canada) measured atmospheric CH4, N2O and CO2 concentrations in The Greater Toronto Area (GTA) as part of Chasing Greenhouse Gases network. http://www.chasing-greenhouse-gases.org/toronto-ghg/

- **CarboCountCity project** (Recife, Brazil) measured atmospheric CO2, CH4, and CO concentrations in the Recife megacity area as part of Chasing Greenhouse Gases network. http://www.chasing-greenhouse-gases.org/carbocountcity-recife/

3.1.2.2 Examples of services for climate action monitoring and management

In the previous section, the focus was on services connecting with emission data and impact estimates in specific areas or contexts. The following municipal and national level examples connect more to the monitoring and communication of the progress of climate actions in cities. These services are not directly based on impact information, but rather on quantitative impacts and manual updates on progress in relation to various climate actions.

- **Kausal Watch** ('Ilmastovahti', Finland; https://kausal.tech/en/) is an open-source platform created by a Finnish company Kausal. Kausal is a Finnish start-up, that originated in developing the service for Helsinki city. It is aiming to develop an international service platform for climate program action monitoring. Similar communication platforms are developed in Finland also Vantaa and Joensuu by utilizing common Microsoft cloud-service elements. Kausal also develops scenario tools ('Kausal Paths').

- **Miljöbarometern** (Sverige; https://miljobarometern.se/) is a monitoring and communication platform and service developed for Swedish municipalities and organizations. The service-platform is broader than just climatewatch, also looking at environmental quality. It aims to produce a transparent and clear web account of environmental development and sustainability work.

- **Mayors Indicators** (https://www.mayorsindicators.com/) is a service to follow SDG development on a municipal level, developed by a Finnish company MSDI for the use of cities in Finland, Sweden,

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and in UK. However, the service does not specifically communicate development in carbon impacts or specific climate actions.

- **Futureproofed** (Belgium; https://www.futureproofed.com/) develops software and service platform for measuring and reporting carbon footprint and climate actions. The service can also be utilized for scenario work.

- **ClimateView** (Sweden; https://www.climateview.global/) is developing a service called 'ClimateOS' that allows improved management, monitoring, and communication of climate actions.

Besides services and tools for monitoring and communication, the interviewees also discussed of several other review tools to assist in decision- and strategy-making. Other discussed tools included:

- **UN Voluntary Local Review,** a municipal reporting scheme for sustainable development by UN following Agenda 2030 principles and SDG goals.

- **UN Voluntary National Review,** a national reporting scheme for sustainable development by UN following Agenda 2030 principles and SDG goals.

- **Green City Tool** developed by European Green Leaf -network as a self-assessment and benchmarking tool for cities.
- **Covenant of Mayors' Sustainable Energy and Climate Action Plan (SECAP)** template for climate and energy reporting constitutes the standard reporting framework for Covenant Signatories.

As a summary, the services range from online platforms to digital infrastructures, and are aimed to various types of users (see Table 5 for collected examples). While many of them include data also in connection to selected sectors of action, regional or spatial assessment is less common, and more refined assessment on climate actions remains insufficient.

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Table 5. Examples of services used for carbon impact monitoring

Service name	GHG footprint information (of CO2 equivalent)				Target users
	National level	Local/ municipal level	Location-based/spatial assessment	Other (e.g. industry sector-based)	
ClimateWatch	Yes	No	No	Yes, selected sectors (e.g. agriculture, energy)	Targeted to broad, global audience
WorldBank DataBank	Yes	No	No	Few sectors in relation to GHG emission data	Targeted to broad, global audience, esp. researchers
Kausal Watch	No, but possible	Yes, munici-palities in Finland	No, but possible to integrate	Possible	Targeted to municipalities, also on citizen level; Not for private use for companies, but could be adapted by outside party as open-source based platform
Miljöbarometern	Yes	Yes	Possible (in piloting?)	Yes, selected sectors (e.g. energy, transport)	Targeted to municipalities, associations, citizens
UN SDG reviews	Yes	Yes	No	No	Targeted to municipalities and for national level

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3.2 *Interviews within the project context*

To discuss technological possibilities and to validate findings from the background study and the benchmarking process, further interviews were conducted with service design and technology experts. During Spring 2022, five project-internal and external experts were interviewed (see Table 6; see Appendix 1 for the interview frame).

Table 6. Interviews in Spring–Summer 2022

Interview # (date)	Interviewee(s) profile	Organization (role)
#6 (22.2.2022)	Service design developer, 2 interviewees	Design consultancy (researcher/designer)
#7 (24.2.2022)	Service design developer	Service consultancy (service developer)
#8 (30.3.2022)	City administration (focus on services)	Vantaa City, Finland (environmental planning and use of services)
#9 (29.4.2022)	PAUL project: WP1 lead (and T1.1 Emission inventories)	TNO, the Netherlands Organisation for applied scientific research (researcher)
#10 (29.4.2022)	WP2 T2.1 Modelling (also PAUL project: Paris)	CEFE-CNRS, French research center in Ecology and Evolutionary Ecology (researcher)

The interviews provided insights on how existing services are utilizing the monitoring data, and on what basis existing service design projects have built their systems. Furthermore, the interviews mapped out technological limitations and possibilities.

The studied services that were utilized to assess GHG impacts of projects, activities, or intended climate actions utilized often generally available GHG impact indicators (e.g. greenhouse gas conversion factors by UK government; UK gov., 2022) or then specifically developed impact indicators for the region (e.g. electricity production from local companies). The EU does not provide any shared depository of GHG indicators, but national and municipal depositories are being developed. The GHG Protocol by WRI and WBCSD (see section 2.1.1) is one example.

The progress in climate actions is often monitored only annually (or more sparsely) and only with qualitative metrics and manual processes for update. While monitoring platforms exist, the interaction is often limited to automatic messages regarding an annual update of progress. These platforms may also be used to communicate this progress to the general public.

The actual data on atmospheric carbon fluctuation mainly contributes to scientific research, and there exists several (global, European) networks producing research and services based on atmospheric GHG measurements, emission inventories and indicators (see examples in section 3.1.2.). Improved measurements on atmospheric carbon and better understanding on its temporal fluctuations help to develop improved atmospheric models, in which specific sectoral interactions can be better connected to expected impact and the resulting impact indicators.

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3.3 *Interviews of pilot city contacts*

Finally, the findings from the background study and benchmarking as well as the discussions around the potential of the technology were assessed in the context of the three pilot cities in the PAUL project, Paris, Munich, and Zurich, with four interviews (see Table 7; see Appendix 1 for the interview frame).

The interviews were held with project-internal contacts that were knowledgeable of the local situation in relation to project's focus. All of the interviewees were researchers, who are also active in their local networks on GHG monitoring.

Table 7. Interviews with pilot city representatives in Spring–Summer 2022

Interview # (date)	Interviewee(s) profile	Organization (role)
#10 (29.4.2022)	PAUL project: Paris (also WP2 T2.1 Modelling)	CEFE-CNRS, French research center in Ecology and Evolutionary Ecology (researcher)
#11 (6.5.2022)	PAUL project: Zurich	University of Freiburg, Germany (researcher)
#12 (6.5.2022)	PAUL project: Zurich	EMPA, Swiss Federal Laboratories for Materials Science and Technology (researcher)
#13 (6.5.2022)	PAUL project: Munich	Technical University of München (researcher)

The discussions with the pilot city project contacts pointed out how each city is active in both developing climate action monitoring, as well as in improving atmospheric carbon monitoring systems (supported by research actors). However, connecting these two areas of study remains often indirect and not formally supported.

The technology development (in both monitoring and satellite data) is enabling access to data on GHG emissions on up to 100 x 100 meter resolution, and this enables the development of improved atmospheric models that connect to various activities and temporalities. Since 2015 and the Paris agreement there has also been a surge in interest, and several new opportunities in the business domain.

The impact indicator data, emission inventories, and their use in guiding various climate actions need to be developed in parallel with the improved measurements and models. From the researchers perspective, there remains a gap between science and policy-making, and although there is already a lot of data, its connection to policy action is more demanding. Cities are also mainly interested only of their scope 1 and 2 emissions (direct uses and purchases of heat and electricity), and most of the climate actions are not assessed in detail.

While the study assessed only three pilot city contexts, when supported with background materials it points out to general lack of tools and processes, and also regulation, on how climate actions are to be pursued and assessed.

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4 Results

This section summarizes the findings from the interviews, and revisits also the main information on policy context as gathered for the MS1 reporting. The focus in the assessment has been broad, with specific focus on the PAUL project's three pilot cities representing different sizes on profiles. Later on, discussions can be expanded also to the PAUL City network of 15 cities in Europe (including 3 pilot cities), to expand service design activities to a broader audience.

4.1 Monitoring atmospheric carbon dioxide

Overall, while in each of the three pilot cities there existed climate action programs with semi-regular follow-ups, the data on atmospheric GHG impacts was connected to the assessments only indirectly via indicator information, or then the assessments focused on some other type of criteria.

To develop more refined GHG impact assessment processes, several components in the system need to be considered. First, there needs to be accessible data on atmospheric CO2. Secondly, based on the data researchers are able to develop atmospheric models to develop improved GHG impact indicators and inventories. The improvement of atmospheric modelling and indicator information, the promotion of harmonization of indicators and inventories, and consequently the improvement of climate governance that utilize the indicators is thus inter-connected in development.

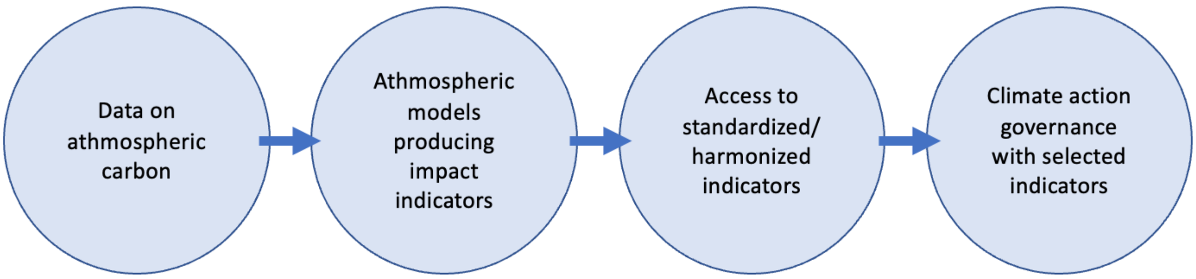

Figure 1. The existing 'system' of services in relation to climate indicators

Potential services can be envisioned between each component (see Figure 1), ranging from data services to modelling, and from access to indicators to platforms for climate action governance and communication. This report examined various services and platforms to better understand the current state of atmospheric carbon monitoring, particularly in the context of community climate action.

4.1.1 Carbon impact monitoring in the context of municipal climate actions

While there are carbon impact assessments connected to policy-making, urban planning, and climate action assessment in several ways, and also projects and networks developing impact indicators and inventories (also excluding the PAUL project), there are no evident direct connections between monitoring data and policy actions. The reporting of municipal carbon impacts is often, if not always, limited to general indicators for the use of heat, electricity, and fuels.

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While there exists organizations, projects and networks that aim to improve data availability and its communication (see e.g. GHG Protocol in section 2.1.1), most of the related services and communications promote climate actions in other ways than with impact assessment data or even general indicators. The systems to monitor and communicate climate actions are often manually managed with irregular follow-ups. Furthermore, outside the annual reporting on general impacts the follow-up on climate actions is not yet properly harmonized, and the assessment methods vary. Overall, the main points of the background studies can be coined up as follows.

Existing services for (near) real-time CO2 monitoring:

- No examples of real-time CO2 monitoring systems directly in use in city administration; however real-time air quality monitoring and communication is an existing practice
- Pilot projects for real-time CO2 monitoring exist, but they are not yet connected directly to policy or planning (as an example in development, see *Climate Plan Mapper* developed in PAUL project, Box 2)

Assessment processes for municipal level climate actions:

- Several municipalities are communicating not only plan but also status of climate actions, however, the role of citizens ranges from active participants to passive audience
- Data in services is often manually inputted or exists only as qualitative criteria
- The gap between currently utilized criteria and methods and climate target assessment with real-time CO2 measurements is substantial both in processes and technology

In summary, the monitoring services for climate data with (close to) real-time or high spatial resolution have not yet been connected to monitoring of climate targets in cities; Rather such services are only provided by specialist consultancies for specific studies (e.g. impacts of traffic, district developments, specific and selected climate actions, etc.). However, various climate and sustainability-related indicators are already followed; Some measurements are also mandatory through policy frames (national, EU-level; e.g. energy consumption and transport). Furthermore, specific indicators are used for specific actions, as described in actions and strategies (e.g. number of electric vehicles).

New tools are also already in development. Several European intermediaries operating to support policy-making and business are already connecting existing indicator information to climate action assessment and work on future scenarios. Despite the shortcomings in climate action monitoring, cities do utilize impact assessments in various ways, also pointing out to already existing or potentially possible business opportunities for intermediaries and other actors.

Besides the domain of municipal climate actions and intermediary roles as service providers, there are further opportunities in business domain, as there is an increasing corporate interest towards carbon measuring services, including emerging impact compensation services. Simple and accessible impact assessment services needed for organizations and companies, but also for individuals. In this process one issue is also to standardize data and processes to support accessible and transparent assessment processes.

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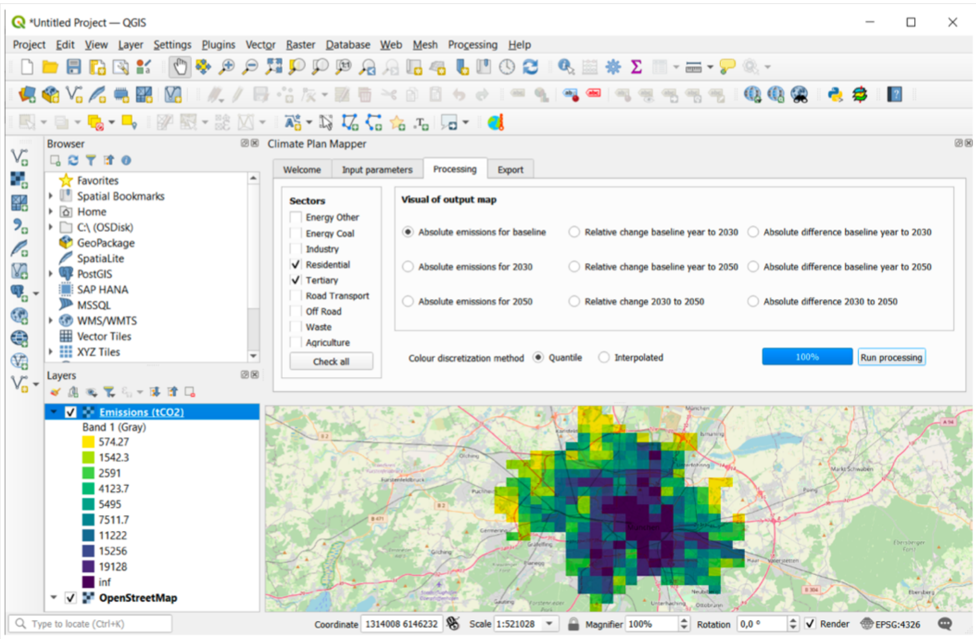
Box 2. Climate Plan Mapper tool for climate action impact assessment (source: PAUL project Deliverable 1.6)

Climate Plan Mapper tool

- Developed by Origins.earth in the ICOS PAUL project, based on TNO-GHGco inventory[14] data the tool allows to assess the expected changes in impacts in relation to various climate actions.
- Currently, Munich and Paris are example cities (requires assessment of climate plans).
- The tool builds the basis for a more rigorous design of urban monitoring networks capable of tracking long-term emissions trends beyond the simple assessment.
- MeteoCarbone and VisionCarbone platforms by Origins.earth are similar but more complex, complete and user-oriented service platforms for the Paris region.



4.1.2 *Services for communicating climate actions and their related progress*

While monitoring of progress in climate actions is somewhat lacking, cities are however increasingly interested to communicate their climate actions to the common public. Citizens can also be a powerful actor in promoting change agendas. Consequently, one area of services focuses on communicating progress on various climate actions. While none of the three pilot cities offer any public forum to follow developments, broader benchmarking pointed out to services developed for communicating climate actions on a city-level.

Service platforms aimed for cities' climate action reporting (see Section 3.1.2. for details):

- City-specific service platforms based on corporate IT solutions (e.g. Microsoft infrastructure; Google insights platform)
- Open-source platforms (e.g. Kausal ClimateWatch)
- National level solutions (e.g. Miljöbarometern in Sweden)
- Others by specialist consultancies (examples e.g. in Belgium: Futureproofed, Sweden: ClimateView)
- Additional services targeted also to citizens, business

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4.2 *Status of services in three pilot cities*

European Union Member States are required to prepare National Energy and Climate Plans (NECPs) for the period 2021-2030 (European Commission, 2022). France and Germany as members of the European Union and Switzerland as a country that aligns its targets closely with those of the European Union have all established national climate legislation for the process.

Overall, while all three cities have a climate strategy with several actions that have been identified and that are carried through and monitored, there are no direct connections to real-time monitoring network and gathered data. However, in each city, there is development going on with impact indicators and inventories that connects with the assessment of real-world carbon impacts (see Box 3).

General overview of pilot city situation (Paris, Zurich, Munich):

- Despite similarities in climate programs and their monitoring, there exists also differences, and even a larger variety can be found in how public is connected to the processes; the activity around climate program also connects to the current phases of action, and programs and actions have been assessed renewed with varying intervals.
- There exists a positive general public view towards climate actions; however, in each area connected also to political developments (and to which political party happens to be in power).
- In public/city view, the development of CO2 monitoring is associated to developments with the already existing network of air quality stations (which is needs to be communicated as regulated by EU); however, GHG monitoring requires also technology developments, and most of the climate actions only call for periodic and inventory-based assessment information.
- PAUL project is also testing different technologies, models; the idea in PAUL project also to further build on this expertise (also on inventories, indicators, utilized models) and potentially add additional techs/data.
- In regard to impact inventories, for Munich city-level data is available, but no spatially explicit city inventory; for Paris, local data is used for spatially explicit city inventory; in Zurich, spatial emission data is projected on 3D model of the city.
- Currently there exists already possibilities to utilize measurements in periodic follow-up of climate actions and also in connecting this to city planning (e.g. new districts, mobility systems), but the work is performed by a limited number of specialist consultants/organizations.
- It remains difficult to see major business cases outside specialist intermediaries, as the processes of climate action assessment are not clearly structured, and access to data and indicator information remains difficult.
- However, examples such as event-based assessment have been developed (e.g. Oktoberfest)[24], and research progresses in developing models with a focus on different temporalities.

[24] See Chen et al. (2020), https://doi.org/10.5194/acp-20-3683-2020

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Box 3. Summary of situation in three pilot cities

Situation in Paris, France:

- Paris has quite ambitious climate program initiated already in 2007 which has been regularly updated (although in previous elections the agenda was not popular).
- Program actions are communicated in public reports and stakeholder interaction is active.
- However, there is no public portal for follow-up, and various initiatives are progressing in silos hidden from public.
- Paris has a high accuracy network for CO2 monitoring provided by AIRPARIF, an organisation responsible for monitoring air quality in the Paris agglomeration.
- AIRPARIF is also developing the impact inventories.
- Also: Pilot website to show real time CO2 data, opened in 2022 (by Origins.earth).

Situation in Munich, Germany:

- In Munich, a climate program was developed with citizens: The basic decision on the Integrated Action Program on Climate Protection (IHKM) initiated already in 2008.
- Until 2019, every 3 years a package of measures was adopted as a climate protection programme under the IHKM. In 2022, a new climate protection package was adopted as part of the so-called "Multi-year investment program", replacing the former IHKM.
- However, no active or consistent public follow-up or monitoring of progress of climate program actions.
- Munich has a permanent high accuracy network for CO2 monitoring operated by the Technical University of Munich (MUCCNet).[25]
- The emission inventory based on GHG protocol is developed in collaboration with an external expert.

Situation in Zurich, Switzerland:

- In Zurich, there is an ongoing climate program since 2014, and also a lot of citizen activism and involvement, pressure to political system.
- Strategies and actions communicated on website.
- However, no public follow-up of progress in climate program actions.
- Zurich has mid-cost sensors for CO2 monitoring.
- The emission inventory is developed by EMPA, Swiss Federal Laboratories for Materials Science and Technology, in collaboration with the municipality of Zurich.

[25] https://atmosphere.ei.tum.de/

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4.2.1 Paris, France

France aims to be a leader in European climate policymaking. France has played a powerful role within Europe and is one of the key states promoting ambitious European climate action. As host to the negotiations that led to the Paris Agreement, France has also played a role of global significance. In 2015 in the months prior to COP21 where the Paris Agreement was signed, France issued the Energy Transition for Green Growth Act, setting a national target to reduce GHG emissions by 40% below 1990 levels and to increase the share of renewables to over 30% of final energy consumption by 2030. The leadership for climate actions has continued, as France was one of the initial European states to back a climate neutrality target for the continent by 2050 (Mon projet pour la planète, 2021). Several actors are involved in the climate policymaking process, from ministries to several agencies, associations, and also the common public.

For Paris, the emission inventory is developed by AIRPARIF. Paris has a high accuracy network for CO2 monitoring. The carbon monitoring network is provided by AIRPARIF. However, currently contracts with service provider prevent direct access to measurement data.

4.2.1.1 Climate Governance in Paris[26]

Climate governance takes many forms in the city of Paris. The city administration is led by the mayor, and below the mayor are 32 deputy mayors, one of whom is in charge of the ecological transition, the climate plan, water and energy (Ville de Paris, 2022a). These focus areas are further addressed in the Council of Paris (*Le Conseil de Paris*) and its 8th Committee dedicated to the environment, climate and biodiversity, and cleanliness (Ville de Paris, 2022b), and in the city of Paris' 22 departments or directorates (*directions*) dedicated to affairs such as housing and public health.

The Paris Climate Action Plan (*Plan Climat de Paris*) is the overarching framework in Paris' climate governance. It was first adopted in 2007 and was revised in 2018. Developed in consultation with citizens, the plan outlines 500 concrete measures which can lead the city towards achieving its goal: carbon neutrality and 100% renewable energy by 2050 (Ville de Paris, 2021). Revision of this plan began in September 2022, with the goal being to develop an operational action plan for 2024-2030 in consultation with citizens.[27]

Citizen participation is a core component in Paris' climate policymaking. Since 2019, Parisians are invited to participate in a debate before any meeting of the municipal councils (Ville de Paris, 2019a). The city took further measures to involve citizens in policymaking in 2019, establishing a permanent citizens' assembly (*l'Assemblée citoyenne*) which consists of a demographically representative group of 100 Parisians over the age of 16 (Ville de Paris, 2022c). Besides these two platforms, citizens can get directly involved in the city's climate action by joining the community of Climate Volunteers (*Volontaires du Climat*) to participate in workshops, challenges, and the Climate Agora (*l'Agora du Climat*), one of the shared governance tools established with the Paris Climate Plan (Ville de Paris, 2019b).

The city of Paris encourages the active participation of not only citizens but also companies. Paris-based companies and institutions can become partners in the climate plan by signing the Paris Climate Action Charter (*Charte Paris Action Climat*). On signing, they commit to helping the city to achieve carbon neutrality and 100% renewable energy by 2050.

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[26] For more detailed information, see PAUL project MS1 report 1.2.

[27] Révisons ensemble le Plan Climat de Paris - Ville de Paris

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The Paris Climate Charter project is jointly managed by the City of Paris and the Paris Climate Agency (*Agence Parisienne du Climat,* APC), another important actor in Paris' climate governance. The APC is an operational agency dedicated to the ecological transition of the city. It was founded in 2011 by a mix of public and private stakeholders to support the implementation of the Paris climate plan. The agency's main function is to inform and advise citizens in their own efforts against climate change, particularly in the area of building renovation (Agence Parisienne du Climat, 2017).

Paris is a member of several transnational city networks, including Energy Cities[28], the Covenant of Mayors, C40 Cities, and ICLEI – Local Governments for Sustainability[29]. Here, the focus is mainly on collaboration, knowledge-sharing and example-setting.

4.2.1.2 Monitoring technologies and services in use in Paris

The city emission inventory of Paris is prepared by AIRPARIF for the Île-de-France region (see Figure 2 for a map of the domain). CO2, CH4, NOx, CO and BC emissions are available in the city emission inventories for Paris (2015 and 2018, but only 2015 can be provided). The emissions are calculated based on regional statistics combined with emission factors, based on reported emissions from individual companies. The AIRPARIF website provides access to the emissions[30] and the latest methodology[31]. A summary of the Paris' emission inventory and the methodology is included as an example in Appendix 2 in this report.

The technologically possible gridded resolutions for mapping on-point impacts in Paris is down to 300 x 300 meters or higher. However, currently contracts with service providers prevent direct access to measurement data and the resolution is limited to 1km x 1km.

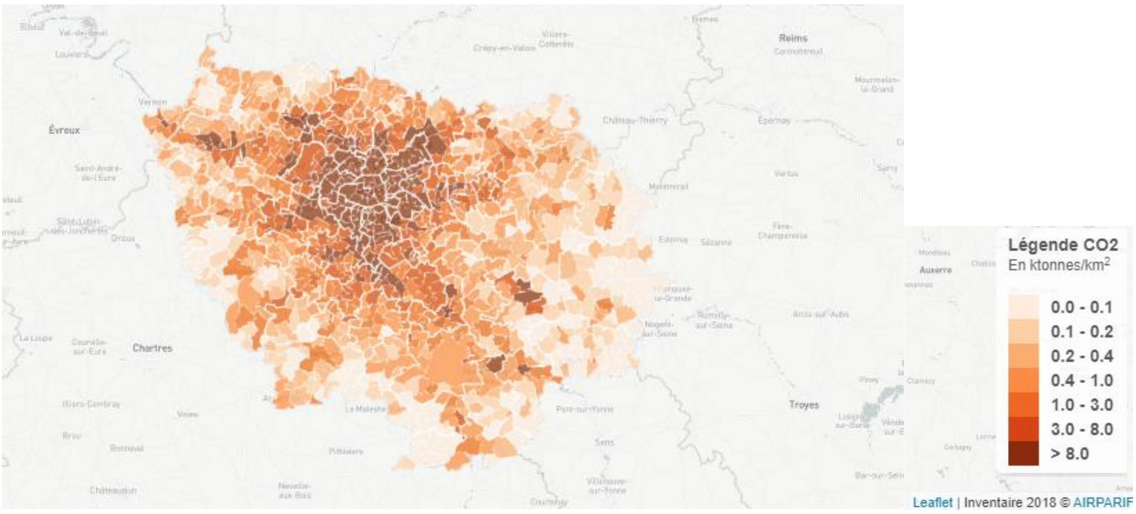

Figure 2. CO2 emissions map in Ile-de-France in 2018 (kton CO_2/km^2) by AIRPARIF (source: PAUL project MS1 report 1.1)

[28] https://energy-cities.eu/

[29] https://iclei.org/

[30] https://www.airparif.asso.fr/en/monitor-pollution/emissions

[31] https://www.airparif.asso.fr/index.php/bilan/2021/bilan-2018-des-emissions-atmospheriques-en-ile-de-france

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4.2.2 Munich, Germany

Munich is Germany's third largest city (Landeshauptstadt München, 2022a). Due to its ambitious climate policies and mitigation efforts, it is seen as a climate forerunner within Germany (Otto et al., 2021). At the time of writing, it is not mandatory for local governments in Germany to prepare climate action plans, with the national government rather adopting an enabling governance approach to promote climate action in cities (Climate Chance, 2021b). The city of Munich (like many other German cities) has voluntarily prepared a climate action plan. Munich aims to reach climate neutrality by 2035, with the city administration aiming to reach this goal for itself already in 2030 (Landeshauptstadt München, 2022b). This is reminiscent of other cases where cities have set more ambitious climate targets than the EU and national governments, and is not unique to Germany (Kern, 2018).

At the core of Munich's climate strategy is the Integrated Action Program for climate protection in Munich (*Integriertes Handlungsprogramm Klimaschutz in München,* IHKM). This was first rolled out in 2008 with the intention of establishing cross-functional management of urban climate protection measures. The latest version was published in 2019. In 2022, a new climate protection package was adopted as part of the so-called "Multi-year investment programme", replacing the former IHKM. The development of climate action plans was the responsibility of the former Department of Health and Environment (*Referat für Gesundheit und Umwelt,* RGU), which is now split into two separate departments for the different areas (Landeshauptstadt München, 2021a).

The IHKM includes a reporting system, comprising the CO2 monitoring report published every two years, a climate protection report for the entire city, the evaluation of the individual climate protection programmes by an external specialist institute, and reporting to the GCoM. In 2022, the city of Munich complied the first complete greenhouse gas inventory of the city for the years 2019 through 2021. The inventory is based on the GHG Protocol. In future, the city plans to compile greenhouse gas inventories annually (Stadtwerke München, 2022).

4.2.2.1 Climate Governance in Munich[26]

Since 2019, the Department of Climate and Environmental Protection (*Referat für Klima- und Umweltschutz,* RKU) has led the city of Munich in the areas of climate and environmental protection, climate adaptation and sustainability (Landeshauptstadt München, 2021b). Under the leadership of the current Climate and Environmental Protection Officer (*Referentin für Klima- und Umweltschutz*), the department prepares climate action plans for the city of Munich and works closely with other departments and organizations. In order to extend the reach of climate action, ten climate protection managers (*Klimaschutz-Manager*innen*) work full-time in other city departments such as the Department for Urban Planning and Building Regulations (*Referat für Stadtplanung und Bauordnung*) and the Department of Labor and Economy (*Referat für Arbeit und Wirtschaft*).

External knowledge actors are also important players in Munich's climate governance structure. Prominent scientific institutions such as the Institute for Applied Ecology (*Öko-Institut*) and the Research Institute for Energy (*Forschungsstelle für Energiewirtschaft*, FfE) are instrumental in contributing to reports on climate neutrality and city action plans. For example, the two institutes (recently) collaborated on a report about possible solutions for climate-neutral heat supply in Munich (FfE GmbH & Öko-Institut e. V., 2021).

Like most major cities, Munich is part of several transnational municipal climate networks, including Energy Cities, the Covenant of Mayors, and the Climate Alliance. The focus of these networks is mainly on a shared

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commitment to climate protection as well as the sharing of knowledge and best practices. In a study by Busch et al. (2018), transnational city networks were found to have a significant influence on local climate governance in Germany by raising public awareness of the issue, institutionalizing climate policies, and facilitating direct exchange between cities. Munich is also a member of the Association of German cities (*Deutscher Städtetag*) that represents Germany's cities at the national and EU level.

The city of Munich incentivizes private citizens to get involved in climate action through its funding programs, the most well-known of these being the Energy Saving Funding Program (*Förderprogramm Energieeinsparung*, FES). First established in 1989, FES incentivizes climate-friendly building by providing funding to private homeowners and the housing industry for the building of new energy-efficient homes, renovation of old buildings, and installation of renewable energy (Landeshauptstadt München, 2014).

In order to encourage local businesses to participate in climate action, Munich launched the Climate Pact for Munich Economy (*Klimapakt Münchner Wirtschaft*) as part of the IHKM. Now entering its third implementation phase, the pact is signed by 15 of Munich's largest companies. On signing, the companies voluntarily commit to active climate protection. They also share knowledge and work together on sustainable projects (Landeshauptstadt München, 2022c).

The city of Munich also collaborates with the surrounding district of Munich (*Landkreis München*) on the area of climate protection, especially in the area of mobility (Landratsamt München, 2020).

4.2.2.2 Monitoring technologies and services in use in Munich

The emission inventory for Munich is currently being developed by TUM in collaboration with TNO. Apart from these bottom-up emission inventories for cities, there is the option to down-scale national scale reported data to the city scale using a variety of spatial proxies like population density and road network maps (see Figure 4 for industry emissions). An emission map with a higher resolution is still under development in the PAUL project. Technologically feasible gridded resolutions for mapping on-point impacts is down to 100x100 meters.

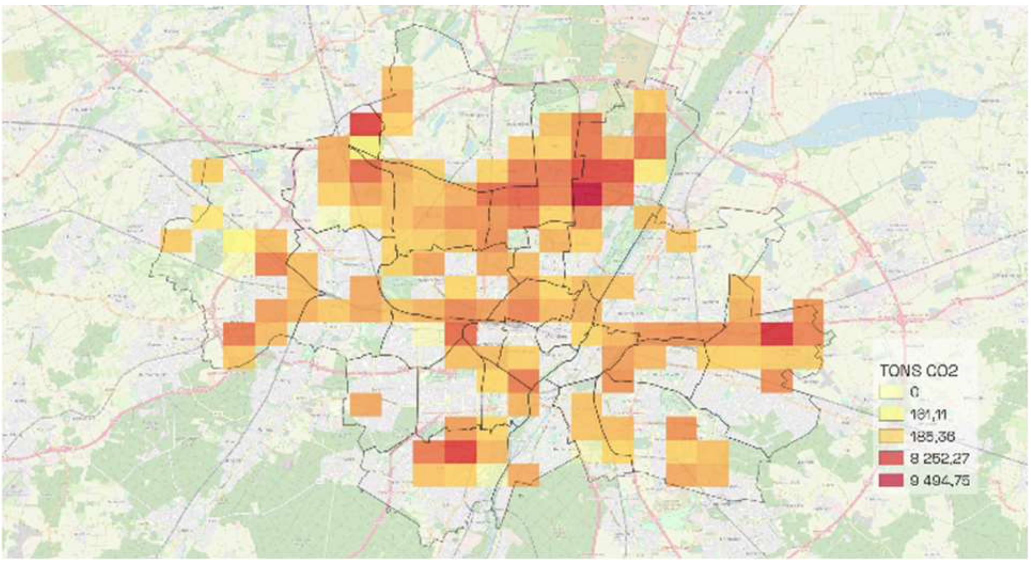

Figure 4. Industry emissions for Munich in 2019, as reproduced by the TNO data (source: PAUL project MS5 report)

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4.2.3 Zurich, Switzerland

In response to the growing urgency of climate action and international frameworks such as the Paris Agreement, the Swiss national government has developed numerous strategic plans, laws, and policies to both mitigate and adapt to climate change. Although not a member of the European Union, Swiss environmental policies are heavily influenced by EU developments. The Swiss political system is characterized by a very high level of citizen participation in climate governance. Municipal voters have a say on proposed laws and candidates (Stadt Zürich, 2019).

In 2012, the Federal Council passed the Swiss National Adaptation Strategy to Climate Change. Its Action Plan 2020-2025 outlines a basic structure for meeting climate governance challenges and contains/includes 63 measures with which the federal government contributes to achieving the adaptation goals, as well as 12 cross-sectoral measures.[32]

Zurich develops its emission inventory in collaboration with EMPA (Swiss Federal Laboratories for Materials Science and Technology). Zurich has a focus on mid-cost sensors for CO2 monitoring. The carbon monitoring network is provided by EMPA.

4.2.3.1 Climate Governance in Zurich[26]

The city of Zurich's administration is separated into nine departments. The administration is governed by a nine-member executive, the City Council (*Stadtrat*), with each member being responsible for a department. The president of the executive department is analogous to a mayor in other cities. The municipal council (*Gemeinderat*) is the legislative body. Its 125 members are responsible for making and enacting laws in the city. The Office for Environmental and Health Protection (*Gesundheits- und Umweltdepartment*) and the Office for Urban Development (*Stadtentwicklung Zürich*) oversee the city's climate action plan. The city's climate plan includes four concrete goals: Climate Neutral City, Healthy Urban Environment, Networked Urban Nature, and Intelligent Use of Resources. Each goal is distinguished by a different area of focus and composed of specific targets for which various strategies and projects are developed within different city departments (Stadt Zürich, 2022a).

Zurich's climate plan requires the collaboration of multiple actors. Under the leadership of the present City Councilor, the Health and Environment Department is responsible for monitoring progress towards meeting targets and submitting annual reports. City networks also play an important role in city management in Switzerland. The city of Zurich collaborates with different organizations and private companies. As part of their Eco-Compass project (*Öko-Kompass*), the city of Zurich is working through the Clean Agency Switzerland AG to provide free-of-charge consulting services for small and medium businesses regarding environmental measurements (Stadt Zürich, 2021).

As a direct democracy, Swiss citizens have the opportunity to vote in referendums on climate proposals. The city of Zurich implements a Climate Forum (*Klimaforum*) to involve multiple stakeholders in the development and discussion of climate protection programs for the city. In 2020, for example, around 100 people from different organizations and businesses joined the forum to discuss climate-related topics and possibilities for the city (Stadt Zürich, 2022b).

[32] Strategie des Bundesrates zur Anpassung an den Klimawandel in der Schweiz (admin.ch)

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Zurich participates in various transnational city networks related to climate action. It is a member of ICLEI – Local Governments for Sustainability, Climate Alliance[33], and the Covenant of Mayors.

4.2.3.2 *Monitoring technologies and services in use in Zurich*

The emission inventory of Zurich is prepared for the domain of the city of Zurich (see Figure 3). The emissions are calculated based on regional statistics combined with emission factors, and based on reported emissions from individual companies. The website of the city of Zurich provides access to the emissions and a general description of the methodology.[34] The emission inventory is developed by EMPA in collaboration with the municipality of Zurich.

CO2, CH4, NOx, CO and BC emissions are available in the city emission inventories for Zurich (2015 for CO2, NOx and CO only and 2020 for all pollutants). The possible gridded resolution for mapping on-point impacts is down to less than 100x100 meters.

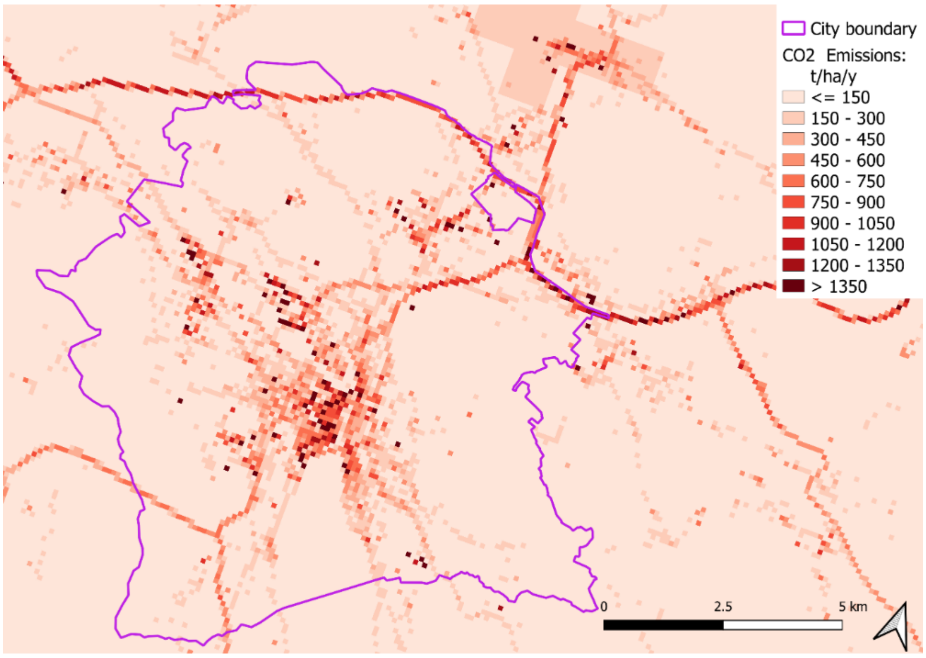

Figure 3. CO2 emissions in Zurich in 2015 (ton CO2/ha), based on the national Swiss inventory; map provided by EMPA (source: PAUL project MS1 report 1.1)

4.3 *Comparison of the current use of monitoring services*

Multi-level climate governance is to be seen in all three pilot cities. Paris, Zurich and Munich are subject to vertical influences on policy development from the supranational, national, and regional levels as well as horizontal influences from local businesses, citizens, research institutes, and transnational city networks. There also exists climate action programs that include similar focus areas with each other, and that are

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[33] https://www.climatealliance.org/en/home.html

[34]https://www.stadt-zuerich.ch/gud/de/index/umwelt_energie/luftqualitaet/schadstoffquellen/emissionskataster.html

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communicated to stakeholders. However, there are no examples of the utilization of near real-time and/or spatially gridded GHG measurements in assessing the cities climate actions, outside on-going research within the scientific domain (e.g. in this project).

4.3.1 Comparison of climate governance systems in pilot cities[26]

Vertical climate governance differs across the three pilot cities, depending on the strength of the national government and the relative strength of regional and city governments. An overview of the main points of comparison can be found in Table 8 below. As both Switzerland and Germany are federal republics, there is a vertical separation of powers, with regions (cantons and *Länder* respectively) and municipalities enjoying a substantial degree of political and legislative freedom. Therefore, the cities of Zurich and Munich are relatively independent from the national government, and free to develop their own climate protection measures. In France, by contrast, the national government requires local governments and regions to prepare climate plans. These differences are reflected in the climate governance structures of the cities.

Despite these differences, all three cities are obliged to meet certain targets set out in national climate change legislation as well as in national climate action plans. Regional climate legislation and plans also influence climate governance at the city level.

Table 8. Comparison of vertical climate governance in Paris, Zurich and Munich

Climate governance level	Paris	Munich	Zurich
International level	Paris agreement; SDGs; EU laws, plans	Paris agreement; SDGs; EU laws, plans	Paris agreement; SDG
National level (Climate action plans)	National Energy and Climate Plan of France; Regional Plan for Development, Sustainable Developer and Equality (SRADDET)	National Energy and Climate Plan of Germany; Climate Action Program 2030; Climate Action Plan 2050	Long-Term Climate Strategy to 2050; Swiss National Adaptation Strategy to Climate Change;
National level (Mandate for a plan)	Yes, for regions over 20,000 inhabitants	No	Yes, cantons
Regional level (Climate action plans)	Ile-de-France Region master plan (SDRIF); Regional Climate, Air and Energy Scheme of Ile-de-France (SRCAE)	Bavarian Climate Protection Program	Canton Zurich's Long-term Climate Strategy

Transnational municipal climate networks play an important role in the horizontal climate governance of the three cities. Paris has active membership in four such networks, while Munich and Zurich each participate in three (see Table 7). The only networks of which all three cities are members are the Covenant of Mayors and ICLEI – Local Governments for Sustainability. Zurich and Munich are both members of the Climate Alliance,

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which primarily consists of cities in German-speaking countries. Paris and Munich are members of the Energy Cities network, while only Paris is a member of the C40 Cities network.

The three cities also take similar approaches to encourage cross-departmental collaboration. All three cities have departments dedicated to climate action, and implementation systems that set the ground for cross-departmental coordination. In the three pilot cities, it is possible to see multiple initiatives being taken with the collaboration of various stakeholders, departments and regions. Within this transdisciplinary policy-making environment, the cities all prepare climate action plans on a semi-regular basis. Table 9 gives an overview of the departments and climate plans in the three cities. Some key insights to consider regarding each city's approach were how Munich's governance structure gives high importance to research institutions and program funding, while Paris and Zurich highly encourage citizen participation.

Table 9. Comparison of horizontal climate governance in Paris, Zurich and Munich

Action plans, stakeholders, networks	Paris	Munich	Zurich
Climate action plan	Paris Climate Action Plan	Integrated Action Programme for Climate Protection in Munich (IHKM); Multi-year investment program (MIP)	2000-Watt Society Strategy; Zurich's Environmental Strategy; Energy Master Plan; Green City of Zurich
Key department responsible for climate action	Directorate of the Ecological Transition and Climate (DTEC)	Department of Climate and Environmental Protection (RKU)	Department of Health and Environment
Initiatives for stakeholder participation	Climate Action Charter	Climate Pact Munich Economy	Climate Forum
Forums for citizen participation	Paris citizens' council; Climate Agora; Citizens' assembly	N/A	N/A
Membership of transnational municipal climate networks*			
Energy Cities	✓	✓	X
Covenant of Mayors	✓	✓	✓
C40 Cities	✓	X	X
ICLEI – Local Governments for Sustainability	✓	✓	✓
Climate Alliance	X	✓	✓

* "✓" means member, "X" means not a member.

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4.3.2 Carbon monitoring systems and their related services

Despite shortcomings in refined services to connect many potential stakeholder interests, the scientific research around atmospheric carbon impact assessment is already going rapidly further. In this process there are also challenges and gaps, for example in regard to data and model availability, data and the resulting indicator compatibility and credibility, and in relation to technology interfaces and the required expertise to use the tools. Challenges also exist in policy development and harmonization of the interfaces between potential service system components.

Furthermore, comparisons between cities' carbon emission impact monitoring have not yet been properly performed, and only initial studies have been made for comparing city impact inventories. In PAUL project's pilot cities, there exists a relatively high-resolution monitoring grid, as well as a network of actors (private, scientific, municipal) that are involved in working with the direct emission data. However, the connection from data analysis from the management of climate actions and targets is only indirect. This connection happens through the development of emission inventories, in which cities list their sectors of focus and methods to gather information.

In PAUL project's Milestone 1.1 report the emission inventories of Paris and Zurich were compared. For this first quantitative comparison between the different city inventories, an assessment of the relative share of sectors, pollutant ratios and implied emission factors per capita were prepared. Several differences in these inventories can be analysed, along with their potential causes. For example, for 'other stationary combustion' the pollutant ratio of CO/CO_2 is higher for Paris than for Zurich, which can be explained by differences in the appliances used for wood combustion. Wood combustion is the main source of CO emissions from other stationary combustion, especially from fireplaces and conventional wood stoves. For road transport, the pollutant ratio of NO_x/CO_2 of road transport is higher for Paris than for Zurich, which can be explained by difference in the fleet composition. Diesel vehicles emit relatively more NOx emissions than petrol vehicles, diesel trucks emit more NOx emissions than diesel passenger cars and Euro 6 vehicles emit less NOx emissions than pre-Euro vehicles. Besides these examples, more general differences can be seen below.

Differences in the emission inventories of Paris and Zurich are visible for:

- Public Power: Zurich has one waste incineration plant, which is included in the Public Power sector; This one plant is responsible for the relative high share of the Public Power sector for CO_2 emissions in Zurich
- Industry: The emission inventory of Zurich only includes the city of Zurich itself, while the Paris emission inventory consist of the Île-de-France region (Paris and the surrounding departments); because of these differences in domain, more industry is included in the Paris emission inventory
- Aviation: No aviation is included in the Zurich inventory, as the airport is not included in the defined domain for Zurich
- Fugitives: CH_4 emissions of gas distribution are not yet calculated for the city of Zurich
- Shipping: Shipping in Zurich mainly consist of small recreational boats with small engines which have less efficient combustion and relatively large emissions, resulting in larger CO/CO_2 ratios than in Paris

Furthermore, the TNO-GHGco emission inventory of gridded emissions has been prepared for Paris, Zurich and Munich, for the same domain as the city inventories of these cities. This cut-out of the TNO-GHGco inventory has been compared to the city inventory, in order to assess gaps, inconsistencies and inaccuracies. The comparisons show differences for road transport emissions. The CO_2 and NOx emissions in the TNO-GHGco inventory are 28–61% lower than the emissions in the city inventories. Differences are also visible for

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industry for both Paris and Zurich. For Paris, this is probably caused by differences in coordinates of point sources in this region, which is planned to be improved in the TNO-GHGco inventory. For other stationary combustion, the NOx emissions are higher in the TNO-GHGco inventory than in the city inventories (13% higher for Paris and 40% higher for Zurich). For methane there is a large discrepancy between the waste sector estimates. This is most likely related to the distribution of landfill emissions. These differences will need further investigation.

In PAUL project, the TNO-GHGco inventory will mainly be used to assess the quality and completeness of the city emission inventories, and it can be used to connect to the emissions from the city emission inventories.[35] Moreover, it provides a link to the reported national data to UNFCCC. Vice versa, this comparison is also used to assess the quality of the TNO-GHGco emission inventory and to identify potential improvements.

However, the work on emission inventories mainly involves scientific actors and networks, and the data that their development is based on is not yet connected with any existing service platforms except the few pilot cases as discussed in Chapter 3.

4.4 Summary

Based on the gathered overview on the pilot city situation, currently, the status of services that utilise more real-time and/or spatially gridded GHG and CO2 measurements, and connect these with climate action targets, is almost non-existent and rather based on quantitative assessment with impact inventories. There are no examples of real-time measurements (or even periodic measurements) connected to activities in municipal planning. Rather, general city-level emission inventories are utilized. A lot of data already exists, but the standards on how it is processed and used are only emerging, and it is scattered amongst several actors. There also exists major challenges to move assessments further from scope 1 (the direct impacts of energy and fuel use), and the process depends on many types of supplementary data.

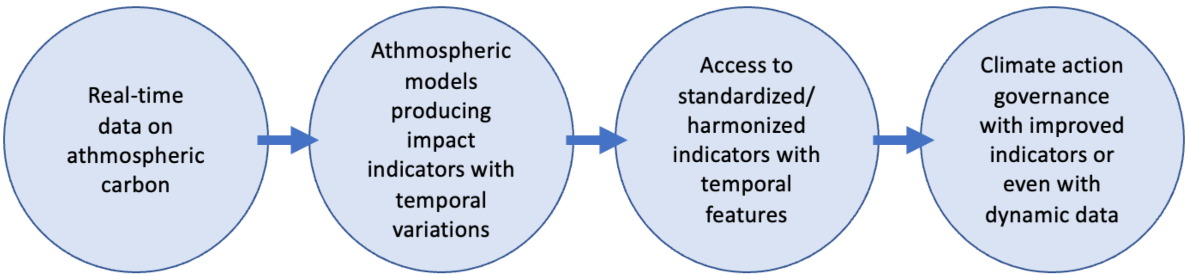

Figure 5. The envisioned 'system' of services in relation to climate indicators

When discussing the future development of services and the necessary technological and policy development to support it, there are several opportunities. Real-time CO2 monitoring systems are under development already, however harmonization, interfaces between actors, access to data still need further work. There is

[35] Nesting refers to regional differences on how projects and jurisdictions generate and issue emission reduction units.

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also a need to gradually harmonize processes, inventories, and indicators for impact assessment on the city level that connect to international policy developments.

Near real-time data availability on atmospheric carbon allows further improvement of atmospheric models for different sectors of action, with improved temporal variations. While direct measurements contribute mostly to scientific work, this supports the development of impact models and indicators utilized in assessing actions. Atmospheric models are then producing improved impact indicators in relation to sectors and activity, potentially with more refined temporal variation. The improved accuracy of the models allows access to improved indicators, potentially including also temporal variations.

The harmonization and further development of indicators and inventories also acts one potential contribution from PAUL project work, resulting into scaling-up of more standardised monitoring processes. However, the harmonization of inventories and/or indicators is still an ongoing process. The need has also been identified in financing sector (see e.g. von Kalckreuth, 2021).

There is yet no great feasibility or even interest to connect direct measurements to follow-up on actions on municipal level and in planning actions, however the data could be (and already is) connected through intermediary actors supporting city officials (and business) with various impact assessments. Services to support climate action governance are based on improved, harmonized indicators. Later, however, even more dynamic data could be connected to the models. However, policy actions to promote harmonization, (public) communication, also data gathering, and access (also to private sector) are still needed.

More detailed insight is also needed from specialist studies. For example, an analysis of CO2 emissions during COVID-19 lock-downs is showing changes in emissions in connection with changes in activities in various sectors (e.g. mobility, energy use at homes).[36]

When considering the potential services and their target users and their possibilities to promote sustainable transitions, the interviewees discuss of several opportunities. While there is a varying level of public interest monitoring and communication has potential to create further support for climate actions. This connects also to work in previous projects, gathered resources for communication, and existing networks.

Another area of potential is services outside city administration focus. There exists an expanding area of business opportunities in impact assessment and compensation services and for communicating the results, including services targeted to both ordinary citizens as well as to various business-to-business service schemes (see summary in Table 10).

[36] See Le Quéré et al. (2020), https://doi.org/10.1038/s41558-020-0797-x

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Table 10. Types and purposes for different services utilizing urban CO_2 monitoring data

Service focus	Target users, stakeholders	Purposes	Connection to monitoring data
Real-time spatial CO2 monitoring	Researchers; Private sector intermediaries	(Near) real-time monitoring data made available for different purposes	Connected to (near) real-time data on CO2 fluxes
CO2 data translation into impact indicators	City planners, policy development; Researchers; Private sector intermediaries	Improved and harmonized indicators are crucial in improving impact assessment	Based on data through research and modelling
Climate plan action progress monitoring	City planners, policy development; General public	Monitoring data helps to assess the success of specific climate plan actions	Data only indirectly connected to indicators which are gradually refined based on monitoring data
Scenario tools	City planners, policy development; Private sector, intermediaries	Monitoring data helps to improve impact assessments for scenario comparisons	Data only indirectly connected
Impact assessment services	City planners, policy development; Private sector, intermediaries; General public	Monitoring data helps to improve impact assessments of various kinds	Data only indirectly connected
Compensation services	Private sector, intermediaries	Monitoring data helps to improve compensation services and their impact data	Data only indirectly connected

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5 Discussion and conclusions

Based on initial data-gathering, project-internal as well as external expert interviews, and selected materials collected for the other Milestones in PAUL project so far, this report has provided an overview of monitoring systems for atmospheric carbon and their connection with climate governance actions internationally, in Europe, and in the three pilot cities of Paris, Zurich and Munich. Besides studying the situation in the pilot cities, this report has also revisited international examples.

As pointed out in the MS1 report 1.2 of the PAUL project, all three cities have departments dedicated to climate action and prepare climate action plans on a semiregular basis. All three cities also have measures towards the decentralization of government and the push for multi-level climate governance, with France's climate governance being the most centralized of the three. The national governments of Germany, France and Switzerland are themselves subject to vertical influences from the global and supranational level.

However, despite strong connections with several climate policy developments, this assessment has identified various gaps in connecting more refined monitoring to the services used for climate governance. On one hand, the cities are developing various collaborations with citizens and other stakeholders that seek to transform various practices to better consider the resulting climate impacts. On the other hand, cities are communicating of the progress in relation to these actions often irregularly, and based on insufficient metrics. The overall success in municipal climate strategy is often assessed only on a very general level in relation to development in use of energy and fuels.

The main findings for this Deliverable 1.12 continue and expand the above findings towards technical and sociotechnical developments, and consideration on the necessary infrastructures to support further development in the field. Overall, they move focus to actions that are needed to promote the development of monitoring systems for atmospheric carbon, and their connection to climate strategy development. These actions that connect also to policy and technology development can be coined up as follows:

- **Policy action:** Standardisation and regulation of CO2 monitoring systems; harmonization of indicators and assessment processes; harmonization of climate actions and reporting.
- **Technology development:** Harmonization of monitoring technologies and systems, and data depositories and indicators; development of interfaces between technologies.
- **Service design:** Human- and user-centred approach to design; stakeholder involvement and iterative design collaboration between actors.
- **Scaling-up of markets:** The elements above enable developing markets to which also private sector intermediaries can be involved.

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5.1 Revisiting research questions

The Chapter 3 introduced the gathered data, with further analysis in Chapter 4. In the following section, we will summarize the results, and revisit the guiding research questions and hypotheses for the work.

What type of CO2 monitoring services exist and how do they contribute to cities' climate program activities and follow-on?

- There exists only few examples of (near) real-time monitoring, and not in connection to climate action assessment; the research resulting from monitoring data contributes to climate program action follow-on only indirectly through utilized impact indicators or through specific case studies.
- Overall, no consistent approach to (public or other) climate program action follow-up and/or reporting; no regulation either on monitoring technology, data extrapolation through models into indicators, indicators utilized, typology of actions.

How are these monitoring services in use in the three pilot cities of the PAUL project?

- The way climate program actions are monitored varies from action to another and has in general limited connections to monitoring data; some assessment done when renewing actions, targets but only in specific cases, also various case studies exist (e.g. Oktoberfest, COVID-19).
- Focus has been rather in setting strategies, targets than in monitoring impacts (not to mention real-time carbon monitoring); city level data not connected with observational data; However, case studies and also scenario work is regularly done, also on-going improvement with indicators (e.g. in Zurich).

What types of services could be connected to monitoring data? Who could be the users and providers of these services?

- Besides city planners, potential users of services in research, business and intermediaries, also general public (see Table 10).
- Obvious focus areas of utilization in climate program action follow-up, but the process lacks a regulatory framework and typology for climate actions.
- A lot of potential for scaling-up (also in private sector), but mixed interests as still vague context and frameworks.

5.2 Next steps and further work

This section is to reflect on further work and revisit next steps in the PAUL project, focusing on the development of new services for carbon monitoring and climate action follow-on. The work on services for monitoring carbon impacts continues in PAUL WP1 task 1.4 and the following sub-tasks (see Box 4). Besides WP1 task 1.4, further related work is also done in other PAUL project work packages (WPs).

WP1 also continues to assess the practical and policy-related context of the focus topic. In task 1.1 'State-of-the-art emission inventories' is to provide complete, spatially explicit, state- of-the-art emission inventories for greenhouse gases CO2 and CH4 and co-emitted species (CO, NOx, BC). The research in task 1.1 has started with an analysis of the available emission data in city inventories, and a comparison of methods and emissions. The city emission inventories have also been compared to the TNO-GHGco emission inventory for the relevant cities. These comparisons provide insight of the completeness and quality of both the city emission inventories and the TNO-GHGco inventory. The data from the emission inventories will be used by Task 1.2 and Task 2.1. Task 1.2 studies the information and policy needs of the pilot cities. Task 2.1 aims to add value to the emission

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inventory created in WP1 using new modelling techniques and dynamic data. This task focusses on estimating recent year emissions and emission scenarios, temporal variability in emissions, and to test the emission model product with eddy- covariance flux estimates. In Task 1.3, the focus is on the human dimension of climate policies assessed in citizen surveys.

With a more technological focus, The PAUL WP2 studies models and simulation. WP3 focuses on technical testing in the pilot cities, and WP4 focuses on mapping various data streams, depositories, and model requirements, to harmonize assessment processes and accessible data.

Lastly, in WP5 the focus is on interaction with pilot cities and the wider PAUL City network and WP6 plans to integrate the new capacities into the existing European research infrastructures and related governance. Ultimately, the idea is to provide material for the European cities to support both technology development as well as the development of improved services for monitoring and assessing climate actions.

Box 4. WP1 Task 1.4 continuation: sub-tasks 1.4.2 and 1.4.3

Sub-task 1.4.2 (AALTO): Exploration and ideation (M14-M30)
In this sub-task we will implement workshops for stakeholders to create service design approaches and new services for the project context. The researchers will engage with city officials, experts within the other WPs of the project as well external experts, existing carbon monitoring service providers and various other stakeholders.

Deliverable (D1.13): Report on preliminary outcomes of co-design workshops (Due in May 2024)

Sub-Task 1.4.3 (AALTO): Service prototyping (M30-M46)
Based upon the insights gathered and analyzed in the previous step, this sub-task will introduce service prototypes - various representations of new services that will be tested by the participating stakeholders in the real-world setting. Eventually, the aim is to introduce concepts for smart pilot services (e.g. interactive emission maps, emission development tracking websites, and comparative carbon calculators) for evidence-based decisions of policy makers, initially for the piloting cities, but with the clear objective of scaling up.

Deliverable (D1.14): A portfolio of service concepts and prototypes (Due in September 2025)

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6 Bibliography

Agence Parisienne du Climat. (2017, June 2). *The Paris Climate Agency*. Retrieved August 1, 2022, from https://www.apc-paris.com/article-rubrique/the-paris-climate-agency

Angheloiu, C., G. Chaudhuri, and L. Sheldrick (2017). Future Tense: Alternative Futures as a Design Method for Sustainability Transitions. *The Design Journal* (Vol. 20, pp. S3213-S3225): Routledge.

Baldocchi, D. (2014). Measuring fluxes of trace gases and energy between ecosystems and the atmosphere – the state and future of the eddy covariance method. *Global Change Biology,* 20: 3600-3609. https://doi.org/10.1111/gcb.12649

Botero, Andrea & Sampsa, Hyysalo. (2013). Ageing together: Steps towards evolutionary co-design in everyday practices. *CoDesign,* 9, 37–54. http://dx.doi.org/10.1080/15710882.2012.760608

Busch, H., Bendlin, L., & Fenton, P. (2018). "Shaping local response – the influence of transnational municipal climate networks on Urban Climate Governance." *Urban Climate,* 24, 221–230. https://doi.org/10.1016/j.uclim.2018.03.004

Ceschin, F. (2014). How the design of socio-technical experiments can enable radical changes for sustainability. *International Journal of Design,* 8, 1-21.

Ceschin, F., and İ. Gaziulusoy (2019). Design for Sustainability – A Multi-level Framework from Products to Socio-technical Systems. Routledge.

Chen, J., Dietrich, F., Maazallahi, H., Forstmaier, A., Winkler, D., Hofmann, M. E. G., Denier van der Gon, H., and Röckmann, T. (2020). Methane emissions from the Munich Oktoberfest. *Atmospheric Chemistry and Physics,* 20, 3683–3696, https://doi.org/10.5194/acp-20-3683-2020, 2020.

Climate Chance (2021b). Germany: Case study on multi-level climate governance. (adelphi, Ed.). https://www.climate-chance.org/en/card/germany-climate-multi-level-governance/

Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'). PE/27/2021/REV/1, OJ L 243, 9.7.2021, p. 1–17. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R1119

European Commission. (2022). National Energy and Climate Plans (NECPs). Energy. Retrieved August 9, 2022, from https://energy.ec.europa.eu/topics/energy-strategy/national-energy-and-climate-plans-necps_en

FfE GmbH, & Öko-Institut e. V. (2021). Klimaneutrale Wärme München 2035: Mögliche Lösungspfade für eine klimaneutrale Wärmeversorgung in der Landeshauptstadt München. https://www.oeko.de/publikationen/p-details/klimaneutrale-waerme-muenchen-2035

Hyysalo, S., Lukkarinen, J., Kivimaa, P., Lovio, R., Temmes, A., Hildén, M., Marttila, T., Auvinen, K., Perikangas, S., Pyhälammi, A., Peljo, J., Savolainen, K., Hakkarainen, L., Rask, M., Matschoss, K., Huomo, T., Berg, A., & Pantsar, M. (2019). Developing Policy Pathways: Redesigning Transition Arenas for Mid-range Planning. *Sustainability,* 11(3), 1-22. https://doi.org/10.3390/su11030603

International Atomic Energy Agency. (2021, August 22). Law n. 2021-1104 of the 22 August 2021 bearing struggle against climate disruption and strengthening of resilience in front of its effects. inis.iaea.org. Retrieved August 15, 2022, from https://inis.iaea.org/search/search.aspx?orig_q=RN%3A52093360

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037319

Joore, P., & Brezet, H., (2015). A Multilevel Design Model: the mutual relationship between product-service system development and societal change processes. *Journal of Cleaner Production,* 97, 92-105. https://doi.org/10.1016/j.jclepro.2014.06.043

Von Kalckreuth, U., (2021). Carbon costs – Towards a system of indicators for the carbon impact of products, enterprises and industries. Presentation for the International Conference on "Statistics for Sustainable Finance", co-organised with the Banque de France and the Deutsche Bundesbank 14-15 September 2021, Paris, France. Kern, K. (2018). Cities as leaders in EU Multilevel Climate Governance: Embedded upscaling of local experiments in Europe. *Environmental Politics,* 28(1), 125–145. https://doi.org/10.1080/09644016.2019.1521979

Kimbell, L. 2011. Designing for Service as One Way of Designing Services. *International Journal of Design,* 5(2). Available: http://www.ijdesign.org/index.php/IJDesign/article/view/938/345

Kohtala, C., Hyysalo, S., Whalen, J. (2020). A taxonomy of users' active design engagement in the 21st century. *Design Studies*, 67, 27–54. https://doi.org/10.1016/j.destud.2019.11.008

Landeshauptstadt München. (2014). IHKM Integriertes Handlungsprogramm Klimaschutz in München: Klimaschutzprogramm 2015 Maßnahmenkatalog. https://www.muenchen-transparent.de/dokumente/3464290.pdf

Landeshauptstadt München. (2021a). Das Handlungsprogramm Klimaschutz - IHKM. Retrieved July 21, 2022, from https://stadt.muenchen.de/infos/handlungsprogramm-klimaschutz-ihkm.html

Landeshauptstadt München. (2021b). Das Referat für Klima- und Umweltschutz. Retrieved July 21, 2022, from https://stadt.muenchen.de/infos/portrait-referat-klima-umweltschutz.html

Landeshauptstadt München. (2022a). Statistik Bevölkerung. Retrieved July 20, 2022, from https://stadt.muenchen.de/infos/statistik-bevoelkerung.html

Landeshauptstadt München. (2022b). Klima- und Umweltschutz. Retrieved July 20, 2022, from https://stadt.muenchen.de/infos/klimaschutz-nachhaltigkeit.html

Landeshauptstadt München. (2022c). Klimapakt2. Retrieved August 5, 2022, from https://stadt.muenchen.de/infos/klimapakt-2.html

Landratsamt München. (2020). Klimaschutz im Landkreis München Treibhausgasbericht und Projekte. Retrieved July 22, 2022, from https://formulare.landkreis-muenchen.de/cdm/cfs/eject/gen?MANDANTID=72&FORMID=6696

Le Quéré, C., Jackson, R.B., Jones, M.W. et al. (2020). Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. *Natural Climate Change,* 10, 647–653 (2020). https://doi.org/10.1038/s41558-020-0797-x

Meroni, A., & Sangiorgi, D. (2011). *Design for services*. Gower.

Mon projet pour la planète. (2021). Le plan climat. Retrieved August 2, 2022, from https://www.monprojetpourlaplanete.gouv.fr/pages/le-plan-climat

Otto, A., Kern, K., Haupt, W., Eckersley, P., & Thieken, A. H. (2021). Ranking local climate policy: Assessing the mitigation and adaptation activities of 104 German cities. *Climatic Change,* 167(1-2), 5–23. https://doi.org/10.1007/s10584-021-03142-9

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037319

Stadt Zürich. (2019, December 16). Politics & Law. Retrieved July 21, 2022, from https://www.stadt-zuerich.ch/portal/en/index/politik_u_recht.html

Stadt Zürich . (2021). Uber den Oko-Kompass - Gesundheits- und Umweltdepartement. Retrieved August 17, 2022, from https://www.stadt-zuerich.ch/gud/de/index/beratung_bewilligung/klimabuero/kmu/oekokompass/geschaeftsstel le.html

Stadt Zürich. (2022a, May 4). Environmental Strategy. Retrieved August 1, 2022, from https://www.stadt-zuerich.ch/portal/en/index/portraet_der_stadt_zuerich/environmental-strategy.html#four_concrete_environmentalgoals

Stadt Zürich. (2022b, July 8). Klimaforum - Gesundheits- und umweltdepartement. Klimaforum. Stadt Zürich. Retrieved August 1, 2022, from https://www.stadt-zuerich.ch/gud/de/index/departement/strategie_politik/umweltstrategie/klimapolitik/klimafor um.html

Stadtwerke München. (2022). SWM Sustainability Report 2021. Retrieved December 15, 2022, from https://www.swm.de/dam/doc/english/swm-sustainability-report.pdf

Super, I., Dellaert, S. N. C., Visschedijk, A. J. H., and Denier van der Gon, H. A. C.: Uncertainty analysis of a European high-resolution emission inventory of CO2 and CO to support inverse modelling and network design, Atmos. Chem. Phys., 20, 1795–1816, https://doi.org/10.5194/acp-20-1795-2020, 2020.

UK Government: Department for Business, Energy & Industrial Strategy (2022). Greenhouse gas reporting: conversion factors 2022. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022

UK Government: Department for Environment, Food & Rural Affairs (2013). Wider Environmental Impacts: Step by Step Guide. Retrieved October 10, 2022, from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/218691/env-impact-step-by-step.pdf

United Nations Environment Programme, UNEP (2002). Product-service systems and sustainability: opportunities for sustainable solutions. https://wedocs.unep.org/20.500.11822/8123.

Ville de Paris. (2019a). Le Conseil de Paris citoyen. Retrieved August 2, 2022, from https://www.paris.fr/pages/le-conseil-de-paris-citoyen-6596

Ville de Paris. (2019b). Volontaires du Climat : agir face à l'urgence climatique. Retrieved August 2, 2022, from https://www.paris.fr/pages/volontaires-du-climat-agir-face-a-l-urgence-6675/

Ville de Paris. (2021). Plan Climat Air Energie : 500 mesures pour la Ville de Paris. Retrieved August 3, 2022, from https://www.paris.fr/pages/nouveau-plan-climat-500-mesures-pour-la-ville-de-paris- 5252

Ville de Paris. (2022a). Dan Lert. Retrieved August 2, 2022, from https://www.paris.fr/pages/dan-lert- 7973

Ville de Paris. (2022b). Fonctionnement du Conseil de Paris. Retrieved August 2, 2022, from https://www.paris.fr/pages/fonctionnement-du-conseil-de-paris-216#les-commissions

Ville de Paris. (2022c). Une Assemblée citoyenne pour faire entendre votre voix. Retrieved August 15, 2022, from https://www.paris.fr/pages/assemblee-citoyenne-20187

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Appendix 1

Expert interview frame for interviews 6–13 (held in Spring–Summer 2022):

1. **Introductions**
   - PAUL project
   - Interviewee organisation, background
2. **Current status of services that utilise climate data and targets?**
   - What type of services already exist and are in use? (target stakeholders, sectors, areas)
   - What type of indicators can be utilised and what are challenges in connecting them to services?
   - What type of interfaces exist? How is infrastructure and information shared? (data, technology, platforms)
3. **Future development of services, necessary technological and policy development?**
   - How do you perceive the development of services utilising climate data? What type of technology development is crucial? (future user expectations, contexts of use)
   - How is (climate data) measuring and tracking, resolution, and availability of relevant indicators developing?
   - How could policy development promote and/or support the development of services?
4. **Services and user roles to promote sustainable transitions?**
   - How to promote sustainability transition with climate data related services?
   - To whom should such services be targeted, and how should their application be promoted?

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Appendix 2

City emission inventory of Paris for the pollutants, including a summary of the methodology for acquiring each sector's impacts (source: PAUL project MS1 report 1.1):

Sector	Description	Methodology (indicative, as in PAUL MS5)
A - Public Power	Fossil and biogenic fuel combustion in public heat and electricity production	Punctual: Emissions and activities data are given by industries who have the obligation to declare their emissions in the national register
B - Industry	Fossil and biogenic fuel combustion in industry, process emissions from industry	Fossil and biogenic fuel combustion in industry, process emissions from industry
C - Other stationary combustion	Stationary combustion of fossil and biogenic fuels in services, residential and agricultural/forestry sector	Services: regional unitary energy consumption per type of services combined with employees Residential: regional unitary energy consumption per type of houses combined with number of houses Specific work for wood burning Agriculture: regional energy consumption combined with EF and spatialisation according to the number of employees
D - Fugitives	Fugitives from oil distribution, gas transport and gas distribution	Fugitive emissions from gas distribution and transport are taken into account based on the length of the gas network and the gas consumption per sector.
E - Solvents & product use	Fireworks, smoking	For each sector, use of national EF per inhabitants
F - Road transport	Combustion of fossil and biogenic fuels, tyre wear, brake wear, road wear.	Bottom-up approaches based on traffic loops data, traffic model, regional fleet of vehicles. COPERT V EF
G - Shipping	Combustion of fuels from ships in ports, ferries, cruise ships and recreational shipping. Not occurring: Fishing and domestic/international shipping	Only ships on the Seine river: methodology based on traffic ships on the Seine river. Recreational shipping and cargo ships are taken into account
H - Aviation	LTO domestic and international, stationary combustion at the airport	Tier 3 methodology takes into account : number of flights, engines types, ICAO EF per LTO phase, specific taxi time
I - Off Road (railways)	Combustion of fossil fuels. Not included: Combustion of biogenic fuels	Top-down approach based on regional energy consumption for the railway sector. This consumption is spatialized according to the number of trains.km
I - Off Road (mobile machinery)	Mobile machinery in the construction, industry, residential, agriculture/forestry and airports sector. Tyre, brake and road wear of mobile machinery.	Industry top-down based on regional energy consumption and national EF Agriculture: bottom up based on fleet of specific machines and unitary consumption factor Residential: bottom up based on fleet of specific machines and unitary consumption factor Airport: top-down approach Construction: top down based on regional energy consumption and national EF
J - Waste	Managed landfills, waste incineration, cremation, open burning of waste, domestic waste combustion, waste water treatment. Not included: unmanaged landfills, composting and anaerobic digestion, bonfires	Punctual: Emissions and activities data are given by industrials who have the obligation to declare their emissions in the national register
K - AgriLivestock	Enteric fermentation and manure management	Agricultural census of livestock combined with emission factor by type of animal
L - AgriOther	Fertilizer/manure application, urea application Not included: Liming Not occurring: Field burning of agricultural residues, rice cultivation	Tonnages of regional fertilizers delivered distributed over agricultural land combined with national EF
Other	Natural NO emissions from soils Not included: accidental fires, respiration	NO emissions from soils come from soil denitrification and nitrification phenomena. Methodology takes into account soil temperature and humidity

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