Innovative sensor networks and citizen empowerment for urban sustainable mobility and clean air - URBANITY

1 Challenges and needs

Many European cities experience substantial air pollution, which is to a large extent caused by road traffic. In Norway, air pollution causes around 2.000 premature deaths every year[1]. The external costs related to these health effects caused by air pollution amounts to 8-13 billion Euros per year[2]. Moreover, according to UN Habitat, cities produce more than 60% of the total greenhouse gas emissions[3] (GHGs). Transport represents almost a quarter of Europe's GHG emissions[4], making it crucial for cities to accelerate the transition towards low- and zero-emission mobility.

Municipalities need real-time environmental data at high spatial and temporal resolution in order to design effective plans, prioritize and monitor actions for tackling air quality and climate change mitigation (e.g. planning of cycling lanes, low-emission zones). However, current systems based on expensive and scarce air quality monitoring and traffic counting stations are not capable to offer information at the level of detail municipalities need. URBANITY will **exploit data collected by sensor networks in three Norwegian municipalities, combining static and mobile novel low-cost sensor (LCS) technologies** capable of offering real-time data on weather, air pollution, and multimodal traffic count. The LCS network will consist on municipality owned sensors (from precedent iFLINK public innovation project[5]) but will also actively involve citizens in the collection of environmental data.

State-of-the-art automated algorithms, based on machine learning and data assimilation, will process the collected environmental sensor data and perform real-time quality control and validation to provide high quality and locally specific open environmental information for the municipalities, for citizens and for other interested actors. The collected air pollution and traffic-counts sensor data will be combined with mobility data from Telenor and Ruter, satellite data and urban air quality and emission models, to provide municipalities with real-time environmental data at scales relevant for human exposure and improved emission inventories at a spatial resolution of meters. URBANITY outputs will allow municipalities to design integrated and cost-effective measures for air pollution and GHGs as well as to provide better information to their citizens. Moreover, the **involvement of citizens in environmental monitoring (citizen science)** will contribute to increase knowledge and raise awareness about air pollution and climate change among city dwellers.

URBANITY will organize **participatory design workshops with the municipalities, stakeholders and citizens to co-design human-centered services with focus on sustainable mobility,** engaging and empowering citizens to make a positive impact in their neighbourhoods and cities.

URBANITY novel products and services will be experimented in **urban living labs (ULL) that tackle specific challenges identified by the participating municipalities** as critical to achieve their sustainability goals: 1. Integrate different data sources to generate high-resolution and accurate emission estimations and air quality data as input for environmental, urban and mobility planners; 2. Design innovative and tailored information systems and services to facilitate the implementation of science-based measures to effectively tackle air pollution and climate change mitigation and protect vulnerable population; 3. Enable citizens to participate in co-design of their city while promoting civic action towards sustainable mobility.

The municipalities have different population sizes and face specific challenges in relation to air pollution, GHGs emission targets and sustainable mobility that will be reflected in the design of the ULL.

2 Excellence

2.1 The innovation

2.1.1 The innovation concept

Low-cost sensor (LCS) technologies bring the opportunity for ubiquitous monitoring, enhancing current monitoring systems. However, LCS suffer from measurement limitations that need to be assessed and

[1] Im, U. et al. 2019. Contributions of Nordic anthropogenic emissions on air pollution and premature mortality over the Nordic region and the Arctic. Atmos.Chem.Phys., 19, 12975-12992

[2] Nordic Council of Ministers. 2015. Future air quality and related health effects in a Nordic perspective. 978-92-893-4414-2

[3] https://www.un.org/en/climatechange/cities-pollution.shtml

[4] https://ec.europa.eu/clima/policies/transport_en

[5] http://iflink.nilu.no

characterized. The application of machine learning corrections has shown to significantly improve the sensor data quality[6], however, **additional research and development is needed on automated calibration approaches, especially as sensor networks become larger[7]**. Current methods of calibration based on co-location at reference stations are not applicable to large sensor networks (hundreds of sensors). Additionally, the integration of different data sources of observations is non-trivial. Observations about air quality and traffic are available from a wide variety of data sources, however they all have different sampling coverage and frequencies as well as different spatial representativity. So far, **only very few studies aim at merging heterogeneous data sources of urban air quality and mobility[8]**, and to our knowledge no previous work has provided products which can be implemented in cities. **This project will investigate and develop novel methods to enhance and exploit LCS networks for atmospheric and traffic monitoring, based on AI, data assimilation and Big Data integration**.

Reducing car usage in cities is crucial to reduce GHGs emissions, ensure clean air and the Norwegian zero growth goal (as defined in the National transport plan in 2014)[9]. This is even more critical in responding to the COVID-19 pandemic situation, as inhabitants increasingly use individual car transport over public transport. Moreover, recent scientific studies link air pollution with both the occurrence and severity of COVID-19[10]. We aim to engage neighbourhoods in designing people-centred sustainable mobility services to decrease air pollution and promote climate-neutral cities. **URBANITY will use innovative processes based on participatory design[11] and citizen design science[12] aiming at co-creating products and services for increasing use of sustainable transport modes**. The co-design of services and products aims at examining and altering transportation practices considering the way citizens use transportation modes in their daily life. The project will employ observations, interviews and workshops to map values, attitudes, needs, practices, and habits of diverse citizen groups in relation to mobility. Based on the results, a range of solutions and interventions in services and systems will be proposed. In this way, the municipalities can make informed decisions when implementing policies, and do it in a way that is beneficial and meaningful for the citizens.

URBANITY will **establish urban living labs in three Norwegian cities to collect environmental data using novel technologies and to experiment innovative processes to involve citizens in co-designing sustainable mobility in their neighbourhood.** The urban living labs will provide a space for public open innovation[13]. Through co-creation processes, communication and dissemination activities, the project will ensure **knowledge-sharing between Norwegian cities, private companies and citizens**. URBANITY innovation includes, but is not limited to new/improved goods, services and processes. Those contain:

1. **New/Improved goods, services and processes.**
   a. High-resolution data collection in real time through innovative monitoring solutions combining static and mobile sensor measurements.
   b. Improved air quality data for decision-making and personalized information through data assimilation of air quality models, satellite-based observations and mobility data with LCS data.
   c. Improved emission inventories for air pollutants and GHGs at high-resolution and real-time, allowing municipalities to implement effective measures and monitor progress towards their green agenda.
   d. Improved products for mobility planning considering high-resolution real-time traffic and air quality data.
   e. New products and services to increase the use of sustainable modes of transport (active and public transport) with higher public acceptance.
   f. Capacity to include environmental data gathered by citizens for municipalities' data-driven decisions.
2. **New/updated structures for organisational and governance forms**
   a. Co-creation processes, engaging public sector, private industry and citizens, to build commitment at local and national level and promote long-term sustainability.
   b. Empowerment of citizens as actors of change for the transition towards sustainable cities.
   c. Facilitating networking for the public sector to promote interoperability, dissemination and exchange of experiences and practices, in particular in the use of environmental sensor technologies.
   d. Exploitation of synergies and interoperability with current air quality and greenhouse gas monitoring networks and coordination with national and international environmental forums.

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[6] De Vito, S. et al. 2020. On the robustness of field calibration for smart air quality monitors. Sensors and actuators. B, 310, 127869.
[7] Alastair, C.L et al. 2018. Low-cost sensors for the measurement of atmospheric composition. World Meteorological Organization.
[8] Mijling, B. 2020. High-resolution mapping of urban air quality with heterogeneous observations. Atmos. Meas. Tech., 13, 4601–4617, 2020
[9] The Norwegian transport agencies (2014) The national transport plan.
[10] Hendryx, M and Luo, H. 2020. COVID-19 prevalence and fatality rates in association with air pollution emission concentrations and emission sources. Environmental Pollution, 265, 115126
[11] Asaro, P. M. 2000. Transforming society by transforming technology: the science and politics of participatory design A, M. and IT, 10, 33.
[12] Mueller, J., Lu, et al. 2018. Citizen Design Science: A strategy for crowd-creative urban design. Cities, 72, 181-188.
[13] Gascó, M. (2017). Living labs: Implementing open innovation in the public sector. Government Information Quarterly 34 (2017) 90–98

e. Improved use of scientific knowledge and citizens values for decision-making.
f. Environmental governance. Share good practices, discuss needs and challenges about citizen participation in decision-making processes.

2.1.2 Knowledge needs

Despite significant progress in our understanding of the complex issues linked to air pollution, climate change mitigation and sustainability over the past few decades, there are still important research gaps that limit the effectivity of municipal actions to combat air pollution and GHGs. Based on recent literature, the partners' experience and the dialogue with the participant municipalities, we have identified the following need to further improve relevant knowledge on the following topics:

1. Exploitation of dense sensor networks combining static and mobile platforms to better connect emission sources, air pollution, mobility and human exposure, and to provide evidence for informed decisions. *(new knowledge: data-as-a-service, high resolution monitoring, novel machine learning methods for sensor calibration and quality control, identify practices of data governance)*
2. Improvement of bottom-up emission inventories at high spatial resolution for air pollutants and GHGs in urban areas. *(new knowledge: real-time emissions from road traffic, reduced uncertainties in current city emission inventories, better planning of air pollution and climate change mitigation strategies)*
3. Aggregation of new and existing data sources of pollution, GHGs and traffic to provide value-added information for municipalities and other interested public and private actors. *(new knowledge: novel data assimilation algorithms; personalized information; high resolution mapping, data-driven decision-making)*
4. Enabling co-creation ecosystems to promote interoperability and co-design of end-user products and services towards sustainable mobility and human-centred cities. *(new knowledge: experimentation in public participation methods, equitable interaction and participation; explore emerging roles for citizens and local governments; participatory governance).*

2.2 R&D activities

2.2.1 R&D objectives

URBANITY's primary objective is to **facilitate participatory processes for environmental management based on the use of novel technologies and collaborative innovation.**

In order to achieve the objective, URBANITY will conduct the following R&D activities:

1. Incorporation of citizen-generated data into environmental policies through improved monitoring and understanding of air pollution and mobility patterns. *Anticipated result: new forms of public participation through digital technologies; richer and trusted data addressing current challenges.*
2. Integration of data from automated sensors mounted on mobile and fixed platforms, mobile network data on mobility, Sentinel-5P/TROPOMI satellite data, urban dispersion models, as well as alternative sources such as smart city data, crowdsourced data or historic data. *Anticipated result: improved air pollution monitoring and mapping at scales relevant for human exposure; provision of personalized information; Data-driven mobility planning.*
3. Reducing uncertainties on current urban emission inventories. *Anticipated result: emission inventories from road traffic at meters resolution, identification of the local sources of pollution and their relative importance; improved predictions from air quality models, prioritization of measures to combat air pollution and GHGs; monitoring progress towards Paris Agreement and EU legislation*.
4. Implementation of data outputs compliant with FAIR principles for scientific data management, allowing machine-actionability (i.e. capacity of computational systems to find, access, interoperate and reuse data). *Anticipated result: enable greater transparency, allow building new data-driven products; reduction of redundancy.*
5. Implementation of citizen design science methods for enabling co-creation ecosystems for innovative mobility services solutions. *Anticipated results: feeling of ownership of solutions; enhanced involvement of citizens in social innovation; long-term public commitment on supporting sustainable policies; inclusion of citizens' local knowledge on policy design; representative democracy.*
6. Using the city neighbourhoods as urban living labs to validate the products and services developed under "real conditions of use", using qualitative and quantitative key performance indicators. *Anticipated result: encourage citizen participation in the improvement of public services, creation of spaces to facilitate experimentation of sustainability solutions; ability to assess policy impact at city scale; enhance digital and data leadership to make public services more open to innovation.*

2.2.2 R&D challenges, design and scientific methods

URBANITY will provide **breakthrough research to fill in the existing gap on providing automated accurate data on mobility, emission and air quality in real-time and with high spatial and temporal resolution**. The monitoring, data processing, services and products developed in our project will allow to identify and address environmental problems more efficiently and **co-design effective mobility plans that have higher acceptance in the civil society**.

URBANITY research questions: *Can low cost sensor networks be used to improve current knowledge about urban air pollution, local emissions and mobility?* and *Can participatory processes be integrated into decision-making processes to meaningfully address air quality, climate change mitigation and sustainable mobility?*

Planned approach and choice of methodology

URBANITY aims to empower citizens to take a leading role in the production of data, evidence and knowledge around air quality, GHG emissions and mobility in their own neighbourhoods and at street level. In order to take full advantage of the potential of novel sensor technologies, the individual sensors will be connected to an IoT data structure based on big data principles[14] [15]. Automated artificial intelligence algorithms (e.g. machine learning) will allow to reduce the influence of interferences and improve data quality maximizing the data coverage[16] and minimizing co-location time[17]. Sophisticated algorithms including geostatistics, machine learning[18] and data assimilation[19] will be used to combine sensor data with a variety or other relevant information (models, satellite data, perceptions). This will provide products as hyperlocal air quality monitoring and mapping[20] and improved emission inventories[21], as well as a wide possibility of data-driven services for the municipalities. The data will be open and accessible through RestAPIs for third parties to develop their own products and services.

The project will follow citizen science design[22], participatory design methods[23] and multi-stakeholder engagement to co-design sustainable mobility services[24]. URBANITY will be piloted as 3 urban living labs in Oslo, Bergen and Kristiansand in collaboration with municipalities and stakeholders, including citizens.

Level of ambition and risks

There are risks associated with all steps of the value chain of URBANITY. We feel confident to be able to address most of the **technical and scientific** questions related to performance of sensors, structure of the IoT data infrastructure, machine learning, emissions, data assimilation and mapping. However, the process of ensuring good quality can be extensive and may require more **resources** than those available. This includes both **manpower** and **hardware costs.** Further risks are related to the **interplay of technology and users**: experience shows that when involving different types of users, we may encounter significant barriers (time, availability, interest, technological and scientific literacy, competing interests and others). This may require significant additional investments in **planning and coordination of the ULL and co-creation activities**.

3 Impact

3.1 Potential for value creation

Table 1 Potential for value creation from URBANITY for project participants.

Increased efficiency	Real-time information on air quality and traffic at high spatial and temporal resolution
	Enable data-driven decision-making, prioritization of measures to implement and evaluation of implemented measures for air quality and climate change mitigation
Improved quality	Better monitoring of the atmosphere through merging data from a wide range of sources (citizen data, official data, models, satellite data)
	Improved emission inventories based on high resolution and real-time data provided by sensors

[14] Ram, S. et al. 2015. Predicting asthma-related emergency department visits using big data. IEEE biom. and health inf., 19(4).
[15] Huang, T., et al. 2015. Promises and challenges of big data computing in health sciences. Big Data Research, 2, 1, 2-11.
[16] Borrego, C., et al., 2016. Assessment of air quality microsensors versus reference methods. Atmos. Environ. 147 (2).
[17] Castell, N. et al, 2017. Can commercial low-cost sensor platforms contribute to air quality monitoring and exposure estimates? Environ. Int. 9.
[18] Roman, D et al, 2017. ALaDIn: Shining a Light on Air Quality through Data Integration and Machine Learning. EnviroInfo 2017
[19] Lahoz, W.A., Schneider, P., 2014. Data assimilation: making sense of earth observation. Front. Environ. Sci. 2, 16.
[20] Schneider, P., 2017. Mapping urban air quality in near real-time using observations from low-cost sensors and model information. Envi. Int. 106.
[21] Ghaffarpasand, O. 2020. A high-resolution spatial and temporal on-road vehicle emission inventory based on hourly traffic data, At. Poll. 11
[22] Mueller, J. et al. 2018. Citizen Design Science: A strategy for crowd-creative urban design. Cities, 72, 181-188.
[23] Goldsmith and Crawford. 2014. The responsive city: Engaging communities through data-smart governance. John Wiley & Sons.
[24] Schaffers, H. et al. 2011. Smart cities and the future internet: towards cooperation frameworks for open innovation. The Future Internet. Springer.

Reduced costs	Reduced cost for environmental monitoring through a new generation of smart infrastructure based on the use low-cost environmental sensors and novel calibration methods
Improved services	Provide citizens with detailed/personalised data about air quality, specifically where they are
	Basis for automated traffic control according to different air quality situations.
Other aspects	Strong, competitive research on advanced environmental observations, machine learning and data assimilation.
	Boost interdisciplinary collaboration to address urban air pollution and climate change mitigation
	Enhance digital and data leadership to make public services more open to innovation
	Involvement of citizens in public innovation towards healthier and liveable cities
	Citizens' long-term commitment on supporting sustainable policies, and willingness to engage in co-creation and co-implementation of transition pathways.

Table 2 Potential for value creation from URBANITY for non-participating entities and society as a large

Increased efficiency	Creating a "hub" to assist municipalities, technology/service providers and citizens in knowledge exchange and dialogue in the area of air pollution and climate change mitigation.
	Bring a step change in the use of knowledge and information and allow citizens and businesses to become active players in reducing impact of air pollution and GHG emissions.
	Strengthening initiatives to enable citizens to monitor air pollution and climate gases using new sensor technologies.
Improved services	High resolution air quality maps worldwide and specially on developing regions by merging citizen science and satellite data.
Reduced costs	Standard and open solutions for managing environmental sensor data, facilitating to move services between cities.
	Economic savings, thanks to less duplication of infrastructure and services, common development and optimization of operations for sensor networks.
	Reduction of sickness related costs and premature deaths. In Norway, premature deaths attributable to air pollution in 2014 posed a socio-economic cost of 75.590 million NOK.
Other aspects	Local opportunities for technological firms related to maintenance of the sensor networks and provision of information services
	Step further in creating a digital twin of the city atmosphere by integrating data and models with digital technologies (e.g., AI and data analytics) into a digital component that represents a consistent high-resolution, multi-dimensional description of the urban atmosphere.

3.2 Utilisation of results

3.2.1 Plan for the realisation of the innovation

The new and updated products and services provided by URBANITY (high-resolution data and maps, improved emission inventories and mobility services) will be implemented through pilot activities as part of the ULLs. Telenor will provide IoT solutions for the data transfer from environmental sensors to the iFLINK data infrastructure operated by NILU, and mobility analytics for Oslo, Bergen and Kristiansand. Vicotee will contribute with knowledge on sensor manufacturing to assist on the sensor network deployment. OsloMet will use their design office infrastructure to prototype services to enhance the use of sustainable transport modes. The services will be demonstrated from year 2 to year 3 of the project, incorporating feedback from municipalities and citizens at various development stages. TØI will use their experience in mobility related urban living labs to provide the arena for municipalities and citizens to experiment with URBANITY innovative products and services. During the last project year, the municipalities will evaluate opportunities to incorporate the novel outputs of the project into ongoing or future urban processes. Lillestrøm joins as a follower city for knowledge-sharing around URBANITY innovation with the other participating municipalities.

One key strategy for the realisation of the innovation will be involving the participating municipalities in the transfer knowledge to other parts of the public sector via ad-hoc workshops that can continue after the end of the project. In this way, the main target group of the project (i.e. municipalities) will be highly engaged and open towards the use of novel monitoring techniques and co-creation processes to other Norwegian municipalities. All knowledge accumulated within the project will be documented, ensuring transferability to other municipalities after the finalisation of the project.

Table 3 documents the risk factors for the realisation of the innovation.

Table 3. Risk factors for realisation of the innovation.

Description *(Category)*	**Consequence**	**Action**
Problems in the sensor performance or connectivity *(Implementation)*	No data	Follow up incoming data, implement alert system based on machine learning for swift action; consult with Telenor for alternative connectivity solutions. Contact sensor providers
Citizen participation is low *(Implementation)*	Delay in network implementation and workshops	Contacting new communities with a stake on sustainability, increase promotion through social media, participation in local festivals, etc.
Slow adoption from the municipality side *(Implementation)*	Delay in realisation of the innovation	Establish contacts with municipalities that had success stories. Clarify the benefits and opportunities the project brings.
Sensor maintenance is more expensive *(Financing)*	Delay in network implementation	Reduction in number of sensors, finding other financial sources.
Change in political priorities *(Political)*	Project will lose support	Communicate within the consortium with weight on national and international political priorities (SDGs or Paris Agreement).
Unwillingness to share data, privacy concerns *(Political)*	Delays in access to data	Identify causes and concerns, develop measures, procedures for anonymization

Ethical issues and gender perspectives

We do not anticipate any ethical issues in relation to the implementation of our project. A data management plan will be compiled at the beginning of the project to ensure ethical and safe collection, handling, storage, use and archive of all data collected throughout the project. All participants will sign informed consent forms prior to their involvement in the project that will comply with GDPR requirements and will describe how the results of the research might be used. We will follow RRI and FAIR principles. Special attention will be given to gender balance in the project, as well as, engaging minorities and women in the project activities.

3.2.2 Dissemination, sharing and exploitation

NILU will be responsible for the dissemination and exploitation. The participating municipalities will be strongly encouraged to work with different departments across their public administrations (e.g. participation of different departments in the ULL). In order to share and exploit project outcomes to other segments of the public sectors, we will utilise **existing platforms** where partners are represented, including “Kommunenes sentralforbund”, “Bedre byluft” forum, the “Nettverk Sunne Kommuner” and “Smart by” network. There we will inform about the project activities, align with ongoing relevant activities and establish contact to other interested municipalities for mutual learning. Additionally, the project will organize specific events bringing together authorities, research, industry and civil society organisations from Norwegian municipalities (including non-participating municipalities) to promote knowledge sharing.

Communication and dissemination of project activities and results will be twofold: for academic and non-academic audience. We aim at publishing a minimum of four open access papers in high impact journals, as well as presenting the results at five scientific conferences. For popular science communication, all project partners will make use of their own communication channels, including newsletter, websites, annual reports and social media. Connections to the local and national press, as well as e.g., Forskning.no will also be used for dissemination, to reach a larger audience. To ensure a wide participation, we will present the project at local events (e.g., festivals, science fairs) and encourage participants to disseminate the project using their own social media channels.

We will also strengthen **international cooperation** through the **Smart City initiatives** in the participating municipalities and **R&D partners’ international activities** such as participation in scientific networks.

URBANITY will improve information services for air pollution, GHG emissions and urban mobility, **contributing to SDG** sub goal **3.9**, which aims at reducing “the number of deaths and illnesses” from amongst others air pollution. Through active citizen participation in the ULLs, URBANITY contributes to sub goal **13.3** to “improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning” and sub goal **10.2** to “empower and promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status”. The outcomes of the co-produced results in the ULLs will contribute to sub goal **11.2**, providing solutions for “access to safe, affordable, accessible and sustainable transport systems for all, (…) notably by expanding public transport access, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons”.

4 Implementation

4.1 Project plan for the R&D project

4.1.1 Main activities of the R&D project

WP1. Environmental co-monitoring using innovative sensors technologies. *(responsible: NILU; participants: municipalities, Telenor, Ruter, Vicotee)*

This WP will provide improved monitoring of air pollutants and road traffic in urban areas providing real-time accurate data at a granularity not achievable with traditional instrumentation. Environmental co-monitoring with citizens will employ low-cost air sensors (e.g., SmartCitizen, Airly) and traffic counts (e.g., Telraam) installed on citizens' houses and bicycles. This WP will develop advanced techniques for sensor calibration.

T1.1. Recruitment of participants. We will recruit citizens for participating in the project through large datasets, personal invitations and open calls, ensuring varied representativeness. Appropriate feedback will be given to participants to increase awareness and understanding about air pollution and climate change mitigation.

T1.2. Co-design of the environmental monitoring network. In a co-creation workshop we will identify together with the residents and the municipality the areas within the neighbourhood where both traffic counting observations and/or air quality information is needed due to low coverage of existing in-situ observations (e.g., secondary or district roads, residential areas, construction sides). The citizen sensor network will complement the current municipal sensor network deployed during the preceding iFLINK project. We will also develop metadata standards for citizen collected data ensuring their usability in WPs2&3.

T1.3. Smart calibration techniques of air sensors. Current methods for calibration, based on laboratory or field co-location at reference stations, are not scalable to dense sensor networks. Automated off-site calibration and quality control approaches are essential to ensure data consistency and reduce the costs associated to the maintenance of large sensor networks[25]. We will investigate several approaches as node-to-node or background concentration calibration [26] [27]. For the mobile sensors, we will also explore on-the-fly calibration on the proximity of fixed sensors[28]. Machine learning algorithms for sensor calibration (Hierarchical clustering, Gradient Boosting Machine, Random Forest, Multi-Layer Perceptron) will also be explored.

T1.4 Evaluation and preparation of traffic sensor data. The traffic counting data will be evaluated to identify potential uncertainties or inconsistencies by comparison with existing datasets from traffic stations from the Norwegian Road Administration and traffic models.

T1.5 Connection to a scalable open data infrastructure. All data from individual monitoring will be uploaded to the iFLINK platform (operated by NILU). The data will be compliant with the terms of the FAIR data principles to enable innovation by third parties and will be available after the project is finished.

T1.6. Maintenance of the sensor network. Ensure operability of the sensor network and infrastructure.

Deliverables*: D1.1 Article on protocols for quality control, traceability of measurements and LCS networks standards (M16); D1.2 Article on novel techniques of sensor calibration and validation (M34)*

Milestones**:** *M1.1 Protocols for sensor networks (M14); M1.2 Sensor network operative (M16).*

WP2. Improved emission estimation of air pollutants and GHGs at city level *(responsible: NILU; participants: municipalities, Telenor, Ruter)*

The aim of this WP is to provide improved air pollutant and GHG emissions inventories at urban scale by using the sensor network data collected in WP1. With this approach, we will improve the characterization of the emitting sources and reduce the uncertainties in existing emission inventories. This will allow to evaluate the potential impact of specific mitigation measures and the progress towards emission targets set by municipalities. Our special interest will be on the spatio-temporal distribution of emissions from traffic and non-traffic sources, and the relative source contribution to total emissions. Outputs will be used in WP4.

T2.1 Improvement of road traffic emissions and validations. Validated traffic counting datasets from LCS will be geoprocessed and used as input data in the HEDGE traffic emission model developed by NILU. Specific urban areas will be selected for a benchmarking exercise, where modelled emissions at high

[25] Esposito, E. et al. Assessing the relocation robustness of on field calibrations for air quality monitoring devices. Lecture Notes in Electrical Engineering, vol. 457, 303–312, 2018

[26] Mueller, M.; Meyer, J.; Hueglin, C. Design of an ozone and nitrogen dioxide sensor unit and its long-term operation within a sensor network in the city of Zurich. Atmos. Meas. Tech. 2017, 10, 3783–3799.

[27] Kizel, F. et al. 2018. Node-to-node field calibration of wireless distributed air pollution sensor network. Environmental Pollution 233, 900-909.

[28] Xiaoliang Qin, Lujian Hou, Jian Gao, Shuchun Si, The evaluation and optimization of calibration methods for low-cost particulate matter sensors: Inter-comparison between fixed and mobile methods, Science of The Total Environment, 715, 2020.

resolutions based on LCS data as input data will be compared with modelled emissions based on traffic models. This will show the advantages of using traffic data from LCS as input data for emission modelling.
T2.2 Concept development for near-real time road traffic model. Real time information is essential for citizens to optimize their mobility and for decision makers for effective management. The traffic counting based on LCS provides real time traffic information at hour resolution. We will evaluate the suitability of the LCS data to be used as basis for developing a near-real time traffic emission model.
T2.3 Evaluate the use of air pollution data from sensors to improve emissions from road and non-road sources. The evaluation of the existing uncertainties in the spatial and temporal distribution of emission at urban scale is a challenge due to the lack of observations. The use of a dense air quality sensor network provides fine resolved information on the spatial and temporal distribution. We will evaluate to what extend the air quality sensor network deployed in WP1 can reveal the spatiotemporal distribution of the emission from both road and non-road sources (e.g., residential heating, construction) within the urban neighbourhoods.
Deliverables and Results*: D.2.1 Report or article on evaluation of the use of traffic counting data to improve high-resolution emissions from road traffic (M20); D.2.2 Road traffic emission maps (M26)*
Milestones*: M2.1 Concept for near-real time road traffic model (M24)*

WP3. Data Integration: Adding value to individual datasets for personalized information systems and data-driven mobility planning *(responsible: NILU; participants: municipalities, Telenor)*

This WP will provide improved high-resolution mapping of atmospheric composition and particularly air quality at spatio-temporal scales relevant for human exposure. It will do this by optimally combining the wide variety of currently existing datasets. Thus, this WP will further advance data-driven mobility planning.
The datasets to be used here include, but are not limited to, a) observations from air quality monitoring stations equipped with reference equipment, b) data collected by sensor networks from both fixed and mobile platforms (collected in WP2), c) satellite-based Earth Observation data from TROPOMI/Sentinel-5P, and d) model information from the EPISODE-OSPM[29] model and uEMEP[30] model. In addition, other data sources such as general geospatial data collected by private companies (e.g. mobility data from Telenor and Ruter) and citizens' perceptions (collected in WP4) will be evaluated for potential integration.
T3.1 Dataset error characterisation. Comprehensive evaluation of the estimated uncertainties of the datasets to be integrated. We will further develop and implement software tools for an automated objective assessment of the spatial autocovariance structure, i.e. the "area of influence" of each observation in the spatial domain.
T3.2 Design of a data assimilation framework. Based on spatial analysis techniques stemming from geostatistics as well as data assimilation methods developed within numerical weather prediction we will set up a system for integrating the various datasets in a mathematically objective fashion, taking into account the individual error characteristics of the measurements as provided by T3.1. The outcome (high spatiotemporal air quality datasets) will serve also as input to WP4 to design a variety of products and services, e.g., dashboards for municipalities, air-quality aware urban routing and personalized services.
T3.3 Evaluation of novel data sources for use in data integration. This task will evaluate existing and new potential data sources that have so far seen no or only limited consideration for use in data assimilation. Promising datasets will be added to the data integration system in close collaboration with Task T3.2.
T3.4 Mobility analytics. In collaboration with Telenor, we will integrate data on people mobility behaviour and LCS data to build actionable traffic management data for sustainable mobility planning.
Deliverables: *D3.1 Dataset describing the error characteristics of the various data products (M12); D3.2 Report or journal article describing the methodology for integrating the various datasets (M30)*
Milestones*: M3.1 Data assimilation algorithms are implemented (M22)*

WP4. Co-design of products and services to increase the use of sustainable modes of transport *(responsible: OsloMet; participants: NILU, municipalities)*

This WP will implement citizen design methods accounting for diverse social structures to amass a broad set of issues and variables through workshops with citizens and stakeholders conducted as part of the ULL. Workshops, street interviews and participatory online tools (e.g., Maptionnaire, Folketråkk) will be employed to collect insights on transport and mobility from a wide range of citizens.
T4.1 Organization of participants for co-design groups. We will establish user groups consisting of municipalities, citizens and stakeholders (citizen recruitment done in T1.1), applying human centred design methodology for an as broad perspective as possible and establish crucial practices in research processes.
T4.2 Accumulate insights and determine emerging topics. The task will include data collection through ULL workshops as well as observations, questionnaires and interviews conducted in the urban space. The data will

[29] Hamer, P. D., et al. (2019). The urban dispersion model EPISODE. Geoscientific Model Development Discussions, 1–57.
[30] Denby, B., et al.. (2020). Description of the uEMEP_v5 downscaling approach. Geoscientific Model Development Discussions, 1–38.

be analysed through context mapping, as well as content analysis of findings, to identify key emerging topics around the issue of sustainability and transportation. Data collected through citizen science and potentially crowdsourced data will be open to all stakeholders in the project to generate novel data driven insights about habits and practices around transportation.

T4.3 Translate topics to concepts and prototypes. The groups will be invited to present their aspirations in the context of the preferable services (human-human relations) and preferable interface/information touchpoints (human-technology relations). Out of this we will propose prototypes (i.e. digital and physical) that allow for meaningful integration of the new products and services into daily practices.

T4.4 Evaluation of the services. The municipalities and citizens will be invited to apply the prototypes (T4.3) to own daily practice to reduce private vehicle usage and enhance the experience of walking and cycling. Mixed methods will be deployed to assess the impact of the new interface and service features on citizen sustainable practices. These assessments will be fed back as reassessment in T4.2

Deliverables*: D4.1 Journal article on citizen attitudes towards transportation pollution in the cities (M30); D4.2 Series of prototypes including user interface design (M30);*

Milestones*: M4.1 Co-design groups are established (M10). M4.2 Report on evaluation of services (M38)*

WP5. Urban living labs (ULLs) and lessons learnt *(responsible: TØI; participants: municipalities, NILU, OsloMet, Ruter)*

The ULLs will provide the arena to experiment the use of novel technologies for improved environmental monitoring and mapping, but with a "human" perspective in mind, eliciting people's imagination, creativity and engagement. The project will address specific challenges related to increase the use of sustainable mobility in Norwegian cities of different sizes (Oslo, Bergen and Kristiansand), with air quality and climate change mitigation as a key issue for urban liveability and health that concerns "everyone" and therefore requires multi-stakeholder engagement, including citizens. The city will be the lab and the experimentation will take place at the neighbourhood level. The research will take place in the other WPs. This WP is providing a framework for the ULLs and co-creation workshops to address innovation in bottom-up and multi-level communication of environmental monitoring.

T5.1 Define the use of ULLs. At project start, researchers of all WPs and the municipalities gather to discuss how the cities can be used as ULLs. This will be a joint meeting with separate sessions for each municipality. Key performance indicators (KPIs) will be defined in collaboration with the municipalities.

T5.2 Choose a neighbourhood for the ULL. After the use of ULL is agreed on for each city, the municipalities will identify, in collaboration with the project partners, on-going municipal processes that the project can be linked with, as well as neighbourhoods and local communities that can be the seed for the creation of the ULL.

T5.3 Observation of the co- creation in ULL activity in the other WPs. TØI will take part in the co-creation workshops in the other WPs to document the processes to consciously learn for the participatory processes, evaluate the results with qualitative and quantitative KPIs and document lessons learnt.

T5.4 ULL pop-up. To show URBANITY results, the project will use a space to exhibition and experimentation in each city. The ULL pop-up will be filled with activities and presentations from the WPs and will culminate in two co-creation workshops, one with government actors and one workshop that will be open for everyone. All WPs will present their result and engage the community

T5.5 Workshop with municipalities and other government actors. The workshop will focus on how the project results can enhance planning process and how co-produced material can be included in planning practice.

T5.6 Neighbourhood workshop. The workshop will focus on what kind of data neighbourhoods find relevant, how knowledge can be continued to be gathered and communicated with new technology, and how processes can be altered to include results from the research.

Deliverables*: D5.1 summary report on establishment of ULLs, lessons learnt (M40); D5.2 Summary of workshops and advice to the municipalities (M40).*

Milestones*: M5.1 Definition of ULL and neighbourhoods (M4); M5.2 Co-creation workshop with municipalities and other government actors (M38); M5.3 Neighbourhood co-creation workshop (M38)*

WP6. Management and Dissemination *(responsible: NILU; participants: all)*. Organization of consortium meetings, dissemination and communication activities, as well as reporting to NFR. Management will be done in collaboration with the project owner. Details on organization in section 4.1.2 and on dissemination and exploitation in 3.2.2. ***Milestones****: M6.1 Consortium agreement (M1); M6.2. Data management plan (M2); M6.3 Project website (M4)*

WP7. Exploitation *(responsible: NILU; participants: Ruter, Telenor, Vicotee, municipalities)*. This WP will together with municipalities, public sector and private companies design the exploitation plan for the project. *M7.1. Exploitation plan (M40)*

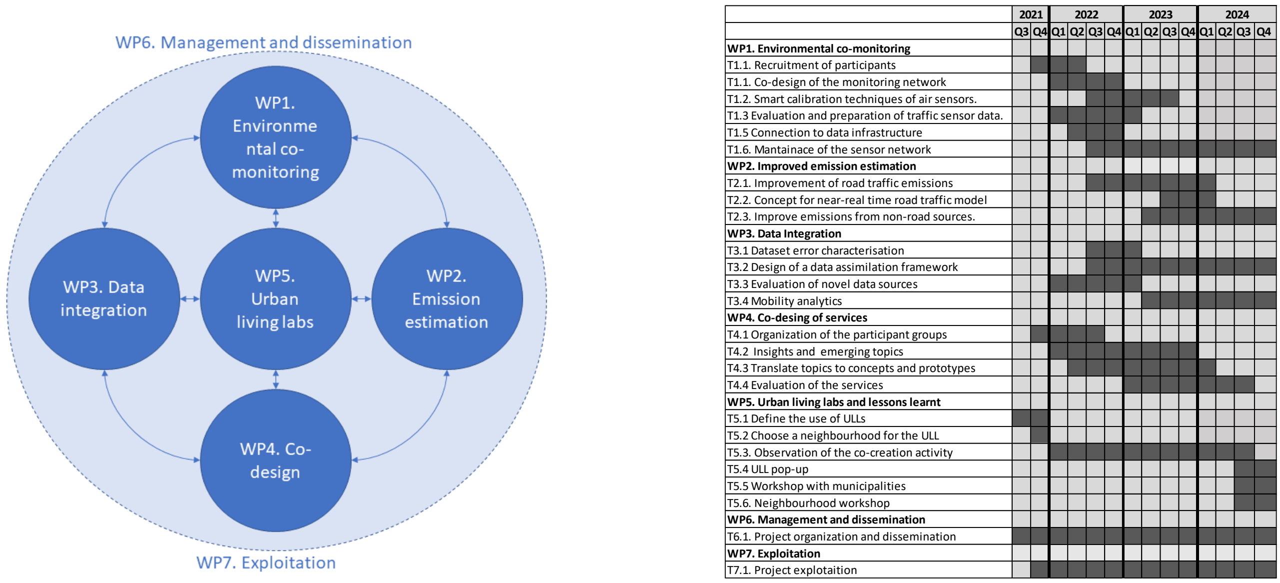

Figure 1 URBANITY work package flow and Gantt diagram.

4.1.2 Project organisation, cooperation and strategy clarification

The consortium consists of four municipalities, two research institutes, one university, one telecom company, one SME and one public transport organization. The management structure builds on the experiences from the preceding iFLINK project. The project steering group will be led by the project owner and formed by project leader and representatives from the municipalities. They will meet at least 2 times per year to ensure the correct project progress. The project implementation group will be formed by the project leader, project owner, WP leaders and representatives from the municipalities. They will meet at least 4 times per year. The proposed flat management structure will facilitate agile problem-solving. A consortium agreement will be signed by all partners in the beginning of the project, addressing issues such as IPR. For internal communication we will choose Microsoft Teams®/Sharepoint®, especially valuable with restrictions in physical meetings.

Table 4 Role of partners in performance of the R&D activities

Partner	**WP contribution/ WP lead (bold)**	**Expertise**
NILU	**WP1-3**, WP4 & 5, **WP6, WP7**	Atmospheric monitoring and modelling, sensor networks, emission inventories, atmospheric satellite retrievals, machine learning, big data infrastructure (Hbase/Spark), data assimilation, citizen science.
OsloMET	**WP4,** WP5-6	Product and service design, co-creation,
TØI	**WP5,** WP6	Exploitation and citizen participation, establishing and working within ULLs in and with municipalities; testbed for transport solutions on site
Municipalities	WP1-7	Establishing sensor networks together with NILU and Telenor in the preceding iFLINK project. Lillestrøm will be a follower city (WP6).
Telenor	WP1-3, WP5, WP7	Mobility analytics, smart cities, IoT data infrastructure, AI
Ruter	WP1, WP4-7	Public transport data analytics, urban infrastructure, mobility solutions
Vicotee	WP1, WP7	Sensor integration, sensor deployment, smart city

URBANITY contributes to solve state-of-the art scientific and societal challenges in urban air quality, climate change mitigation, sensor networks, participatory design, environmental governance and citizen science contribution to policy. The knowledge gained in the project will allow R&D partners to publish results in open high impact factor scientific journals, increasing possibilities for participation in national and international projects and facilitating follow-up research also by other institutes and universities. Telenor and Vicotee have plans for increasing their business opportunities in the operation and provision of services related to sensor networks. Ruter will apply the insights gained in the co-creation workshops to increase public transport attractiveness and reduce environmental impact. The municipalities will have a set of improved services to increase efficiency in environmental and mobility decision-making (e.g. hyperlocal data, detailed emission inventories), as well as, tested methods for including citizens' insights in municipal processes (e.g., co-creation, ULLs). NILU will warranty the continuation of services for the participant municipalities and other interested actors by operating, maintaining and updating the advanced infrastructure generated in URBANITY.