CTT2.0 Carbon Track and Trace: Final Report

CTT Deliverable D1.4

Patrick Driscoll, Dirk Ahlers

Corresponding author: patrick.arthur.driscoll@ntnu.no

Trondheim, Norway | 31 December 2016

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EIT, a body of the European Union

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Preface

About LoCaL

This report was written through support from Low Carbon City Lab (LoCaL). LoCaL aims to reduce 1Gt of CO2 and mobilize €25 billion of climate finance for cities annually by 2050. It is an innovation platform aiming to provide cities with better tools for assessing greenhouse gas emissions, planning, investing and evaluating progress. Started in 2015, LoCaL is a growing community of more than 20 organisations dedicated to unlocking climate finance for cities. This report was realized as part of the project Closing the Gap through Transformative LoCaL Action (CGTLA) under LoCaL.. LoCaL is a Climate-KIC flagship programme.

http://local.climate-kic.org. Contact: victor.gancel@climate-kic.org

About Climate KIC

Climate-KIC is the EU's largest public private partnership addressing climate change through innovation to build a zero carbon economy. We address climate change across four priority themes: urban areas, land use, production systems, climate metrics and finance. Education is at the heart of these themes to inspire and empower the next generation of climate leaders. We run programmes for students, start-ups and innovators across Europe via centres in major cities, convening a community of the best people and organisations. Our approach starts with improving the way people live in cities. Our focus on industry creates the products required for a better living environment, and we look to optimise land use to produce the food people need. Climate-KIC is supported by the European Institute of Innovation and Technology (EIT), a body of the European Union.

About Carbon Track and Trace

The Carbon Track and Trace (CTT) project is intended to provide cities with real-time greenhouse gas (GHG) measurement capability. Traditional methods of building and maintaining municipal GHG emission inventories are expensive, time-consuming, and are of questionable utility for mitigation decision and planning support processes. CTT couples low-cost, open source sensors to a Big Data analytics platform that provides cities and regions with a unique capacity to directly measure the impacts of their policy and planning decisions and to develop a semi-autonomous system for building, maintaining, and reporting their annual GHG emissions.

Overview

Carbon Track and Trace 2.0 (CTT2.0) has been running as a Low Carbon City Lab (LoCaL) Climate KIC Flagship under the Decision Metrics & Finance theme. The project duration was 01/04/2016 - 31/12/2016. The present document is an extended version of the Performance Report and draws from other CTT deliverables.

The Carbon Track and Trace (CTT) project is intended to provide cities with real-time greenhouse gas (GHG) measurement capability especially to better understand transport emissions. Traditional methods of building and maintaining municipal GHG emission inventories are expensive, time-consuming, and are of questionable utility for mitigation decision and planning support processes. CTT couples low-cost, open source sensors to a Big Data analytics platform that provides cities and regions with a unique capacity to measure impacts of their policy and planning decisions and to develop a semi-autonomous system for building, maintaining, and reporting their annual GHG emissions. The project focused transport-related CO2 emissions as a major concern for Trondheim and Vejle, with better emissions data expected to feed into better strategic planning and improved transport policies. Low-cost sensors enable cities to deploy them in higher numbers, thereby enabling a more fine-grained overview within the urban area at lower cost than existing high-quality expensive official measurements, even at the trade-off of reduced quality. With almost no other large CO2 emissions at the street level, fluctuations in concentrations can be more easily be linked to direct emissions from vehicles. The project deployed sensor networks in Trondheim and Vejle and managed to overcome a high number of technical barriers and challenges. Some challenges are ongoing and are addressed after the project period. In addition, a start-up was created that refines the methods of CTT, but also addresses related aspects of the urban sensor network deployment such as air quality, noise, and traffic flows.

The main CTT project output in line with the proposal (cf. D1.1) consists of a prototype GHG measurement and reporting system showcasing the components from sensors and measurement devices through Internet of Things sensor networks, gateways, cloud storage, data collection, processing, and visualization for stakeholders and towards decision support. It additionally explores different sensor setups and processing systems, integration into emission inventories, and gap analyses of the current state to sensor-based systems as a roadmap from manual to automatic data gathering and emission monitoring and inventories. Prototypes for different aspects of the system have been built, including overall prototype deployments in the cities, sensor network overviews, data analysis tools, and visualizations of data analyses as well as a 3D GIS city model of Vejle with real-time data from deployed sensors.

CTT has reached its main goals and has been finished within 9 instead of 12 months due to LoCaL guidelines. In this time, it has overcome significant technical challenges and been working towards local sensor-based emission measurements as a complement to activity-based estimation methods for emissions inventories. It has worked on technical issues by building up knowledge about gaps in existing city GHG measurements, sensor technology, and monitoring networks, by rolling out prototype sensor networks in the two pilot cities of Trondheim and Vejle, and by demonstrating data analytics and visualization through a number of interfaces from statistical software to 3D city models. The 3D City Model integration has been done in collaboration with Virtual City Systems (VCS) and the LoCaL project 3D GPC. The sensor technology used was found to be lacking in certain quality aspects, requiring follow up work with

improved sensors for more accurate and precise measurements. It has worked on city issues by deeply engaging with pilot cities as well as with overall city emission inventory approaches and conducted outreach and gap analysis to European cities. It has worked on financial issues and bankability by analysing costs of inventories, creating a commercial spin-off, and pursuing financing options, including approaching cities worldwide, including China and India. It has worked on outreach to cities and the research community by participating in a large number of local, national, European, and global events to raise awareness for a complementary local measurement approach and did scientific outreach through conferences and scientific publications. These have consistently been met with high interest and positive feedback. With following efforts going towards a more ready-to-deploy solution, cities will be enabled to get better on-the-ground GHG data to do a reality check on assumptions and test reduction policies' impact.

Description of Work

This section lists high-level overview of organizational and technical work. More details are found in the deliverables.

- Project Coordination has been handled by NTNU. Additional outreach above the originally planned has been done, namely conference participation and a number of speaking opportunities about the CTT project in Europe and internationally.
- The GHG Sensor System Deployment has been completed, despite significant delays due to quality control, coding and other technical issues. The documented knowledge gained (D2.3) from this phase will ease future work, replication, and marketability.
- Software Development and Data Analysis has been completed, leading to prototype system components and visualizations, as well as the integration of external data sources such as, for example, integrating satellite, air quality, or traffic data. For the latter the feasibility of the data access could be shown, but the deep integration with measurements is an open issue due to insufficient data collected and more detailed models having to be built and evaluated once more data becomes available. Currently, satellite data is not yet sufficiently dense against local data collected, and traffic correlations were inconclusive.
- Open issues encountered within the project concern data quality and stability. More data will be needed to fine tune the respective models, as a data collection of less than a year can only lead to preliminary, but not fully stable models, especially given quality issues. Follow-up work on this aspect is being initiated.
- GHG Concentration Reporting/Visualization built the bridge to cities by having built knowledge, gap analyses, and cost-benefit assessments, as well as doing prototype visualizations and 3D models as a demonstrators of integrating city data.
- Sustainable Business Model Innovation and Dissemination has examined the market and financial side of the CTT2.0 approach, developed a business plan, and is implementing this through the start-up that was created, CTT A/S. Dissemination is being performed not only through deliverables, but also through partner engagement and local, national, European, and global outreach.
- One learning outcome is that planning a system as complex as that one developed by CTT takes much more time and overhead to implement within city structures. The project partners now have a better understanding of city structures involved and how to further extend the system. Also as can be seen within the deliverables, we managed to deal with many technical issues which will enable us to act faster in the future and

follow up projects. We are very thankful to our pilot cities for working with us and for being open to continue the partnership to continue the project.

- Improvements will still have to be made to all components of this first prototype developed. Integrating any changes should be more straightforward given the knowledge gained during the project. A major open issue is the data quality of the sensors themselves as well as the need to capture more data to develop better models based on a sufficient background of historical measurements. This will then enable better models to be built on top of the approaches demonstrated so far. That would then also be the way forward to apply more complex models on better quality data to move from measurements of concentrations to fluxes and emissions as well as develop valid correlations between, for example, traffic and emissions.
- For a broader take up of the solution, both the university side and the CTT A/S will work to make the solution more stable so that the strong interest from other cities can be turned into an actual deployment of a market-ready and low-maintenance solution. Regarding data quality, future work will have to build tailored sensor solutions and integrate them within the technical backbone to be able to use higher quality sensors that deliver more precise measurements. Others concern the deployed network, which means to implement better monitoring and maintenance systems in place.

Technical Concept

This section shows a high-level overview of technical achievements within the project, details are found in the respective deliverables, especially D2.4 and others. The idea of CTT is to enable city officials, decisions makers, citizens, and other stakeholders to access emission measurements throughout a city. To achieve this goal, we define a general concept and overall architecture of the system as outlined in the concept figure. It shows the system components and the simplified dataflow, starting from individual sensors through gateway antennas to a cloud data storage into an analytics backend that provides insight and visualizations to a range of stakeholders in various degrees of abstraction. The architecture is kept as flexible as possible to be able to exchange components easily with clear interfaces between them. This facilitates collaboration and development within the project for separation of concerns. For example, the wireless IoT backbone (LoRaWAN) used in the project can be scaled out to support other municipal IoT projects, but on the other hand, in a city with existing IoT backbone, the project should be able to integrate easily without the need for a dedicated network. The same holds for the data storage, which may instead use a city's existing open data portal. With this in mind, detailed hardware and software/protocol components can be exchanged with limited effort.

In the larger picture, CTT aims to better understand the gaps in current approaches and the tradeoffs inherent in the technical solutions that are being piloted. These are for example the conflicting priorities between high-quality measurements and the low-cost approach, the gap between concentration measurements and emission estimates, as well as the overall project aim of understanding relations between sensor-based measurements and yearly statistical inventories.

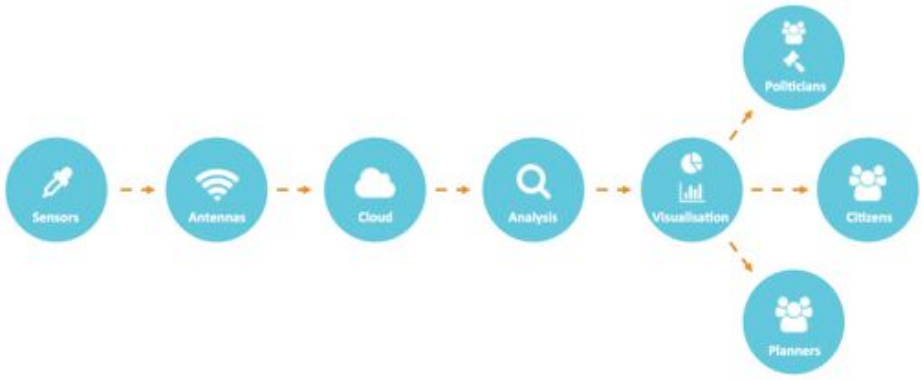

Figure 1 Concept Architecture

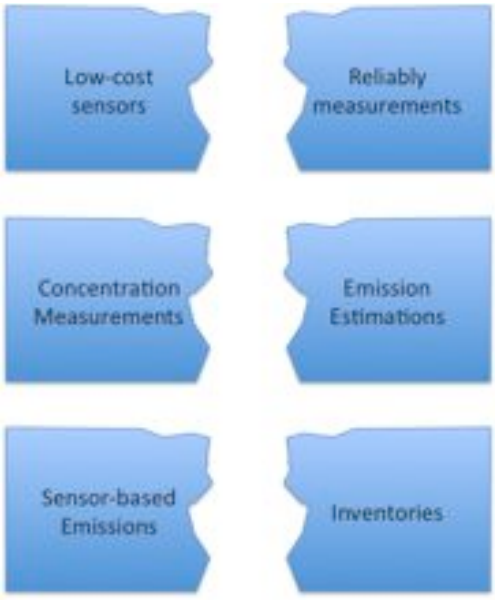

Figure 2 Gaps and Tradeoffs

Sensor communication and protocols

The implemented prototype of CTT for the cities of Trondheim and Vejle sets up the whole chain from sensor over gateway antennas and storage to analysis and visualization systems through a range of components. Details of deployed protocols and dataflow are shown in the following figure.

Figure 3 Network architecture and protocols

Deployment of Sensors and Gateways

The main requirements of the deployment in the city are a good coverage of the urban area with sensors (as mapped out by the municipalities), a stable deployment package of the sensor units, which have to be weatherproof (thus an enclosed unit, but with exposed sensors), and a connection of the units to the central data storage, realized through a coverage of the city area with a wireless transmission system (D2.3, D2.4).

Sensor deployment

Figure 4 PSSEP deployed in Trondheim (left) and Vejle (right) using deployment plate

Figure 5 Deployment locations in Vejle

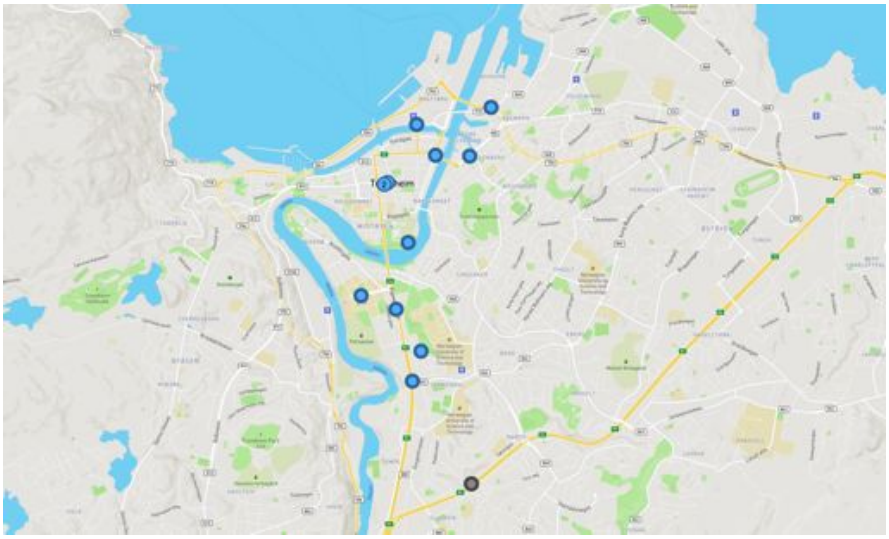

Figure 6 Deployment locations in Trondheim[1]

Gateway deployment

[1] Picture from: http://dataport.item.ntnu.no/

Figure 7 Deployment of LoRaWAN antenna gateway outdoors on the roof of the Student Society building in Trondheim (left) and elevated indoors in a clock tower in Vejle (right)

Analysis and Visualization

The platform, architecture, and the data provided by the sensors have been the basis for a number of analysis and visualization components and applications. These are presented in the following.

Figure 8 DataPort Full overview of a city area, and Detail view or sensor data for a node

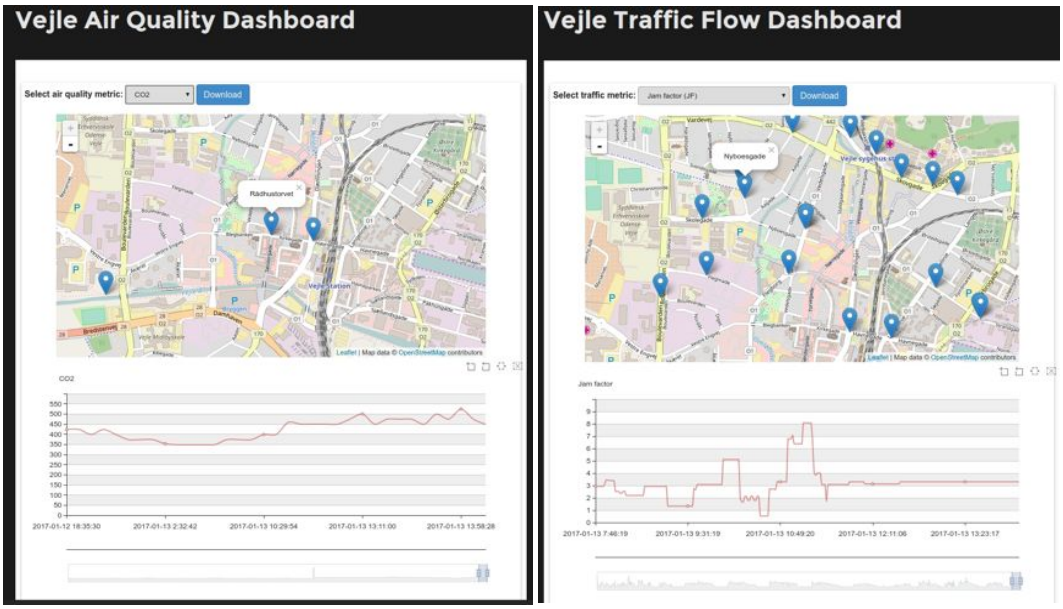

Figure 9 Traffic Flow and Air Quality Dashboard showing historical traffic data and live and historical CO_2 measurements in Vejle

Figure 10 Visualizing the measurements of a sensor in a graph linked to a situated symbol in the 3D city map of Vejle.

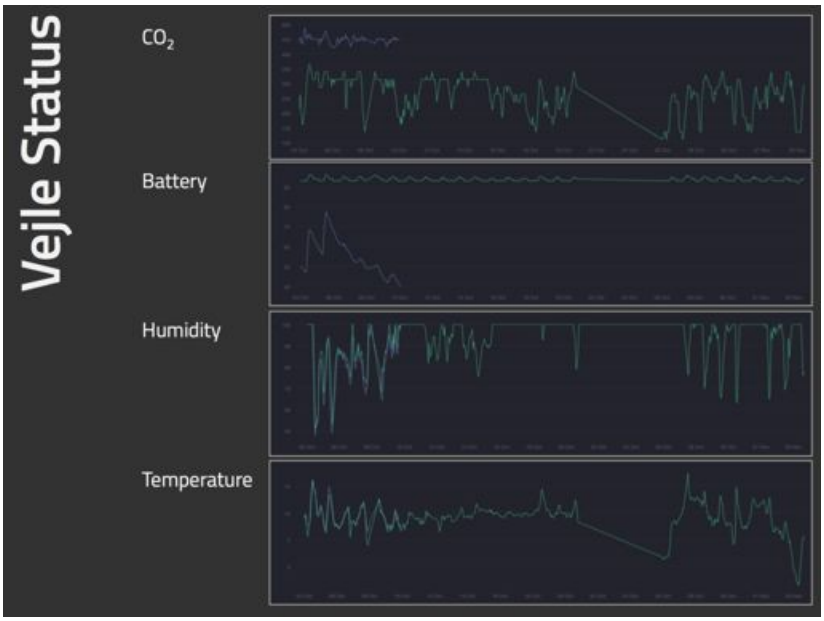

Figure 11 Vejle Dashboard mockup with a selection of real-time data.

Inventory Tool Integration

A study conducted by ICLEI World was also completed, investigating the existing data quality of transport-related emissions in European and East Asian cities that currently used the GPC reporting methodology (D4.1) and the potential for integration of real-time data into the ClearPath GHG emissions reporting tool (D4.2). Both studies concluded that there is significant promise for the use of sensor-based emissions data, given the rather low quality and availability of current activity data, especially within the transportation sector.

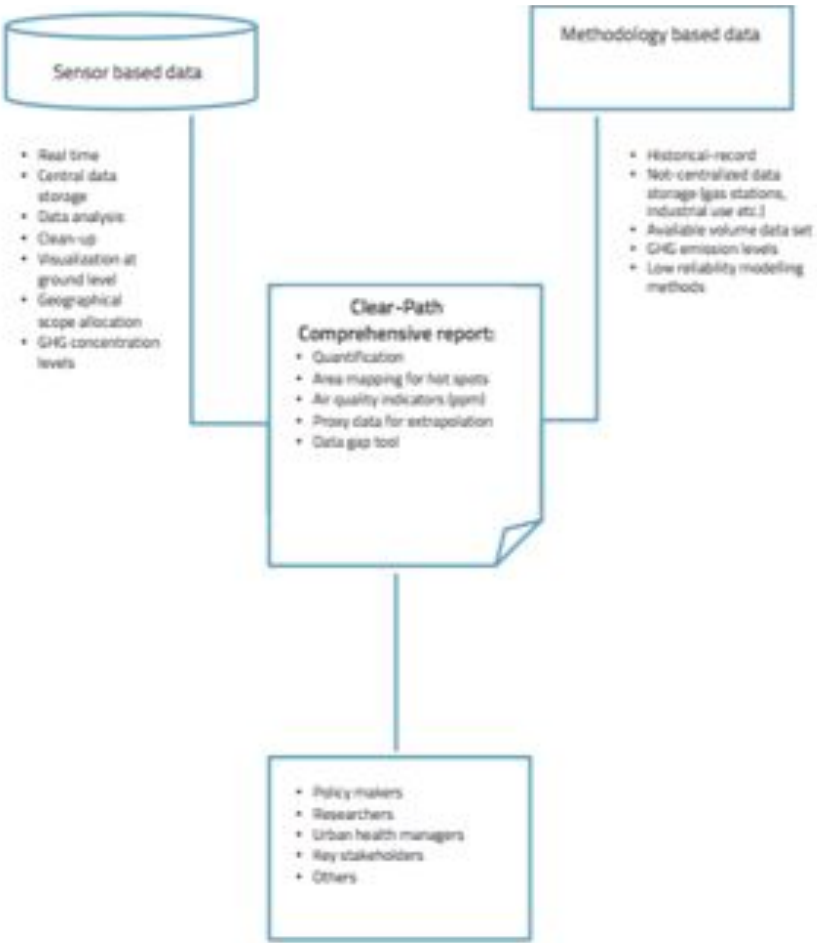

Figure 12 Possibilities of Real-time data integration into ClearPath reporting tool

Cost-benefit and quality analyses

Within D4.3, ICLEI Europe in collaboration with other project partners developed insight into the processes within municipalities to estimate effort and quality of existing emission inventories and systems. This is an extension on work started within CTT 1.0 and gives a better insight into pressure points for cities and ways that CTT 2.0 can deliver value to cities aiming and understanding and reducing their emissions.

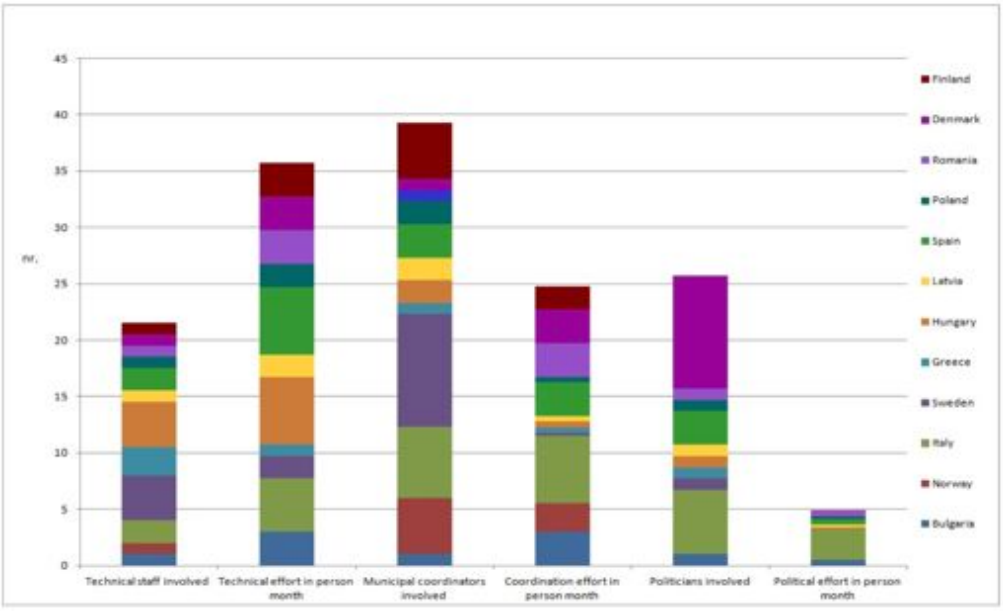

Figure 13 Effort accumulated per country for technical staff, municipal coordinators and politicians

	Which activity data can be regarded as objectively measured? (%)	Did you rely on estimates and educated guesses? (% of positive responses)	In which sector would the installation of sensors be most beneficial to efficiently and accurately measure direct emissions? (%)
Residential buildings – Electricity	69%	40%	38%
Residential buildings - Heating	62%	50%	38%
Commercial buildings - - Electricity	85%	40%	23%
Commercial buildings - - Heating	77%	50%	23%
Institutional buildings and facilities - Electricity	92%	25%	31%
Institutional buildings and facilities - Heating	85%	38%	31%
Transportation	38%	80%	77%
Waste	62%	50%	8%
Industrial processes and product use(IPPU)	15%	60%	8%
Agriculture, forestry and land use (AFOLU)	15%	83%	n.a.
Average	60%	52%	31%

Figure 14 Responses of interviewed energy experts on data reliability and the potential for direct measurements of emission categories (categories taken from the GPC protocol)

The results show that the use of aggregated data and consequently the application of estimates vary strongly between emission sources. While interviewed experts on average relied to about 80% on estimates in the transportation sector, electricity in institutional buildings and facilities were subject to estimated calculations of about one-fourth only. In regards to the overall development of a BEI about 52% of the activity data involved some estimations.

Regarding a CTT-like approach of direct measurements, 77% of the interviewees expressed their desire to install sensors in order to measure direct emissions and acquire more accurate data for the transport sector. The second highest score was allocated to the building sector. However, in general the perceived need for sensors was assessed with overall 31% as moderate, showing

that there is a clear ranking of priorities and of the needs for improved data quality and real-time capability [adapted from D4.3].

Milestones and Progress Report

Management

Following the kick-off meeting held 24-25 April 2016, work commenced on all of the work packages throughout the year until 31st December 2016. The original work plan for CTT 2.0 envisioned the project to be completed by March 2017, but in light of the budgeting structure for KIC the date for the main results was moved to 31 December 2016, with minor reporting and finalisation tasks running to March 2017. The material consequences of this shift means that the period of August to December was much more compressed than previously planned. Much of the evaluation and deployment work has therefore been shifted. Still, this shortening only allowed limited time for the analytics and visualisation stack to be validated on a much shorter data collection period, also following a number of technical issues that needed to be overcome as detailed in the quarterly reports, and in deliverables D2.3, D2.4, D3.2, and others. For details we refer to the quarterly reports 1-3.

Sensor system deployment

Pilot installations of sensor systems including Waspmote Smart Environment Pro sensors and LoRaWAN gateways have been completed in Trondheim and Vejle. The details are found in D2.3 and are repeated here.

Milestone	Date
Pre study of possible hardware platforms to be used.	December 2015
Testing of Nucleo L15RE platform at the Climathon event.	January 2016
First order of Libelium's Plug & Sense! Smart Environment Pro (PSSEP) nodes for Trondheim Municipality received.	February 2016
First PSSEP deployed at Elgeseter gate with CO_2 sensor attached.	March 2016
Shipment of Sodaq Autonomo for Trondheim Municipality received.	
Shipment of PSSEP nodes and Wirnet 868 Mhz IoT gateway received in Vejle Municipality.	May 2016
Initial deployment of PSSEP nodes and gateway in Vejle	June 2016
Relocation of sensor node in Vejle from Matrielgården to Vejle Library	July 2016

Second shipment of PSSEP nodes received in Trondheim.	July 2016
Deployment of 7 PSSEP nodes in Trondheim.	September 2016
Addition of direct power supply for two sensor nodes in Vejle.	October 2016
Pre-deployment roof test.	December 2016
Redeployment of 12 sensor nodes in Trondheim.	December 2016

Software development and data analytics

The project has reached its goals, but had to work around a number of issues regarding sensor data, transmission, collection, and analysis. This has been a learning experience and we gained substantial knowledge from this as evidenced in D2.1, D2.3, D2.4, D3.1, D3.2, D3.4. The basic CTT architecture of the sensor and network ecosystem is up and running with a number of systems connecting to it, thus proving its feasibility. Initial analysis of sensor data on its own and in combination with other publicly available datasets has delivered insights, even though some have been yet inconclusive due to less data collected than expected. We should note here that for a full system in place, apart from data quality issues, we would also have to collect at minimum one year of data to better calibrate models.

Decision support and GHG emission reporting/visualization

Much of the decision support work had been delayed to unavailability of data or issues outside our control where systems were not yet ready to deal with integration of ongoing measurement data. Respective deliverables by ICLEI World and ICLEI Europe were changed to provide general roadmaps or assess data quality in existing repositories to make a stronger case for where CTT can be of assistance in current setups and also to examine future extensions. VCS has decided to use Vejle as a test bed for their 3D GPC model (D4.4).

NTNU and Trondheim Kommune have begun to map the data requirements for the CTT project, in conjunction with a number of other related projects (Smart Cities and Communities Lighthouse, Knowledge Axis, Research Centre on Zero Emission Neighbourhoods in Smart Cities).

Sustainable business model innovation and dissemination

The business model canvas and the initial business plan for the start-up CTT A/S are completed. A select number of fundraising efforts are on-going, with parallel efforts focused on early stage private investment. Additional funding has been sought from NTNU Technology Transfer Office, but was rejected in the first instance since the business plan and commercial offering was deemed advanced enough to proceed without their involvement. The start-up was incorporated in August 2016. After careful consideration, only smaller investments were sought as indications from initial outreach and feedback from entities familiar with the business were pointing to the opportunity of smaller organic growth to keep the start-up more independent and focused on green goals. Cities involved in CTT have expressed interest in the CTT service and also related services and systems to be developed and deployed.

ICLEI World and ICLEI Europe have been very active in connecting CTT to various events and activities in Europe and East/South Asia. Additionally, Numascale A/S has drawn in CTT to a number of Smart City-related events through their contacts at Innovation Norway, including Smart Cities Expo in New Delhi, and the Smart Cities Expo in Barcelona. Additionally, CTT had space in Beijing in July 2016 for the Smart Cities Expo. CTT has also begun exploring other partnerships through contacts at NTNU and DTU to the Nordic Edge conference series and to link up to other Climate-KIC initiatives, as well as the European Space Agency, NASA, NILU and other organizations. Detailed outreach activities are listed below.

Deliverables

Deliverable Name[2]	Description of deliverable (as per BP2016)	Summary of deliverable	Completion Date (mm/yy)
D1.1 CTT Project Plan	Development of project plan	Adaptation of the original proposal due to a budget cut and the mandated reduction from 12 to 9 months. Plan finalized and uploaded to Asana and available as adapted Project Proposal D1.1.	05/2016
D1.2 Stage gate review	Preparation for stage gate	Stage gates completed with LoCaL.	06, 10/2016
D1.3 Quarterly performance reviews	Preparation of quarterly reports	3 quarterly reports	06/2016, 09/2016, 01/2017
D1.4 Final report	Development of final report	Change requests from the original workplan were agreed with LoCaL and are reflected in the final outputs. Changes concern technical feasibility, technology and conceptual readiness on linked projects, and administrative and legal issues around the consortium and the startup.	01/2017
D1.5x Trondheim Kick-off workshop	New milestone, Kickoff workshop	Workshop held in Trondheim with a wide range of stakeholders from partners, cities, industry, university	04/2016
D1.7x Midterm workshop Vejle	New milestone, Midterm workshop	Workshop held in Vejle with a wide range of stakeholders from the municipality in collaboration with an internal municipality workshop on the use of GHG data throughout city departments	11/2016
D1.8x Final workshop	New milestone, Final workshop	Workshop held after the project duration through co-funding, for project closure,	01/2017

[2] Taken from the CTT Performance Report.

		project continuation, handover, next steps	
D2.1 Systematic review of sensors	Conduct review of existing GHG sensor systems	Review completed as D2.1.	12/2016
D2.2 Deployment of Prototype	Milestone: Deployment of GHG sensor system in selected sites in Trondheim and Vejle	Due to technical issues and complexities, the deployment was carried out with a delay, a first minimal version was deployed in April in Trondheim, the Vejle system in summer with updates and tests throughout the year, the Trondheim system was deployed in September and after final adjustments redeployed in December. Documented within D2.3 and D2.4.	04/2016, 06/2016, 09/2016, 12/2016
D2.3 Sensor field reports	Field validation and report on deployed system	Two planned short reports were consolidated into one extended one, with an added focus on technical implementation. Additionally, the *CTT User Guide* was prepared, detailing the technical components. Completed as D2.3.	12/2016
D2.4 Technical white paper on network architecture	Development of documentation detailing the system architecture	Completed as D2.4	12/2016
D3.1 Initial Prototype Big Data Analytics platform	Development of a big data platform and initial analyses	Completed as D3.1	12/2016
D3.2 Big Data analytics	Development of data analytics, including external data sources and models	Completed as D3.2	12/2016
D3.3 Integration of GPC and SEAP databases	Development of transformation models	Agreed to remove technical implementation due to technical issues as the data platform and especially the GPC/SEAP are not ready. Potential discussed in D4.2.	--
D3.4 Technical and scientific	Integration and test of the system documented	Publication of: A Measurement-Driven Approach to Understand Urban Greenhouse Gas Emissions in Nordic Cities.	11/2016

papers on architecture and analytics approach		Dirk Ahlers, Patrick Driscoll, Frank Alexander Kraemer, Fredrik Anthonisen, John Krogstie. Norwegian Informatics Conference 2016 Publication: Understanding challenges in municipal greenhouse gas emissions inventories. Dirk Ahlers, Patrick Driscoll, IEEE ICE ITMC 2016. Additional scientific publications are under preparation but owing to the usual publication process duration will not be finished within the project time. All published deliverables and papers contain a reference to LoCaL and Climate-KIC. Additionally, selected deliverables will be made freely available online. An additional report was finished by NILU: NILU report 34/2016 CTT2.0 – NILU Know-how and experience (internal).	
D4.1 Technical white paper sensor-based data into GPC	Data review of GPC inventory reports	Adapted towards a data quality analysis as a prerequisite of the GPC data quality and sourcing. (as in D3.3).	12/2016
D4.2 Technical white paper on ClearPath integration	Brief on sensor measurement data as complementary evidence for emissions reporting	Adapted to a roadmap towards the potential of sensor-based data integration into inventories and emissions reporting.	12/2016
D4.3 Cost benefit assessment of activity-sensor based data	Closing the information gap through cost-benefit analyses and interviews	Added interviews with relevant stakeholders. Completed as D4.3.	12/2016
D4.4 3D GIS model of Vejle	Visualization prototype of a 3D city model of Vejle with access to live data from installed sensors	Completed as D4.4.	12/2016
D5.1 Market Survey - cancelled		Agreed to remove. D5.1 Market Survey was contingent on CTT being picked up by The Technology Transfer Office (TTO) of NTNU, but this did not happen as TTO	--

		considered CTT already mature enough. A short analysis is included in D5.2 and D4.3	
D5.2 Business model	Develop a CTT business plan	D5.2 is refined with additional input from ICLEI and a gap analysis. Business Canvas, Product brief, and a cooperation with the NTNU Accelarator are added as part of the startup activities.	10/2016
D5.3 Signed commitment of external financing	Pursuing VC and other funding opportunities	Changed from pure VC funding to a range of other measures of outreach, expos, pitching. The current plan as advised by TTO and T:Lab is to start growth organically, combined with a sustained research focus.	12/2016
D5.4 Dissemination	Dissemination through ICLEI channels and to relevant cities	Dissemination is being undertaken and extended into 2017 as well. No separate document was planned for this, results are integrated into the final report D1.4.	12/2016

Change Requests

Due to changed conditions within the project and its environment, a number of changes were necessary and were agreed with LoCaL. These are mostly minor, but are shown here for reference.

Personnel:

Additional student assistants have been hired at NTNU to help with sensor programming and deployment.

Additional researchers from NTNU have been involved: Frank Kraemer on Networking and IoT in collaboration with Wireless Trondheim, setting up monitoring.

A joint PhD student that was supposed to work on the programme started later than anticipated, and is now partially accompanying the project from a smart city and zero emission perspective.

Project structure/budget:

In accordance with the reduced period for reimbursable expenses, the project duration was adapted to end on 31.12.2016. This mandates shifts in deadlines for milestones and deliverables. Only special cases will be mentioned below.

LSCE has been changed by their own request to only co-funding, no EIT funding will be claimed (previously 10000 EUR). Their task will mainly be in a consulting and verification role.

Some subcontractors and partners started later than anticipated due to contract and partner agreements having needed to be negotiated. This did not overly influence the project results.

The budget for DTU has been adjusted downwards by 10000 EUR and the sum transferred by NTNU by common agreement.

Work tasks:

D2.2 Field reports are being combined into one larger one due to the project shortening and certain delays in deployment.

D3.3 on integration into GPC inventories is folded into D3.2 and changed to concern data transformations, as evolved knowledge in this project shows that full integration with GPC methods are beyond the scope of the project period.

D3.4 was planned to be a white paper, this is now a scientific publication (NIK2016).

D4.1 Analysis of automation of GPC through sensor data is adapted:

A necessary prerequisite for the automation is to better understand the data quality.

For this, we adapt towards data reporting requirements, especially by looking at data quality issues in existing reporting platforms (e.g., carbonn and GPC reporting) that appeared as a major point of concern even within existing reporting in e.g. carbonn.

D4.2 Explore inclusion of sensor data into ClearPath will be adapted to a more conceptual work, as the technical prerequisites from ClearPath and CTT are not yet ready for integration. It will examine sensor data integration with respect to a workflow from sensor data towards reported emissions.

D5.1 Market Survey was contingent on CTT being picked up by The Technology Transfer Office (TTO) of NTNU. This fell through, therefore a much shorter analysis is included in D5.2 and D4.3

D5.2 is being refined with additional input from ICLEI.

Some deadlines on deliverables and deployment were pushed back to account for initial issues with sensor deployment and with contractual negotiations.

Management:

As an additional outreach activity, we have included the Thora Storm high school that was interested in using sensor technology.

Overall, we have raised our activities compared to the proposal on outreach through an increased participation at events, expos, workshops, and conferences, including major events such as Nordic Edge, Smart City Barcelona, Low Carbon City Forum etc.

Additional workshops with the municipalities were held and the project was also linked as a possible prerequisite with other projects.

A final workshop was held after the project duration in January.

Outreach and Dissemination

Meetings, Conferences, Events

Outreach activities started before the project with, for example, a Climathon in January and Technoport conference participation in March, and will continue after the project. Some of these activities have been part of NTNU's co-funding.

Sept 2016 NIK Norwegian Informatics Conference 2016, Bergen, Norway.

Conference participation and talk for a paper presentation.

Sept 2016 Smart City Expo World Congress 2016, Barcelona, Spain.

CTT was presented at the Smart City Expo Barcelona 2016. NTNU and AIA Science present the CTT project at the pavilion of Innovation Norway at the Smart City Expo Barcelona 2016. The Innovation Norway pavilion was part of a larger pavilion area of the Nordic countries of Denmark, Finland, and Norway. DTU was also present at the EERA (European Energy Research Alliance) booth and presented work on dashboards.

Oct 2016 Local Renewables Conference 2016, Freiburg, Germany.

Invited talk and panel on Climate-Smart Cities

Oct 2016 Low Carbon City Forum Medellin, LoCaL Side Event on Innovative Financing, Medellin, Colombia.

Invited talk and panel on Impact Assessment for Climate-Smart Cities

Oct 2016 Nordic Edge Expo 2016, Stavanger, Norway.

CTT pavilion participation and invited talk at the Centre Court Public Solutions session on Climate-Smart and Sustainable Cities – CTT.

Oct 2016 Climathon Trondheim

The CTT project partner Trondheim Kommune held a Climate KIC Climathon. CTT project members gave inspiration talks and mentoring to the participants. "CO2-emissions from the transport sector account for approximately 50 % of the total CO2-emissions in Trondheim. The city needs measureable, integrated and engaging solutions to reduce the CO2-emissions from the transport sector. Through the Climathon Trondheim, CTT engaged students, scientists, entrepreneurs and citizens from different backgrounds to co-design innovative and future-oriented solutions and business cases for "Zero Emission Knowledge Axis" and the city beyond."

August 2016 CTT at Maker Faire in Trondheim

CTT was represented at the Maker Faire exhibition in Trondheim, Norway. The stand demonstrated the technical side of the project, and there was a lot of interest from the visitors. Maker Faire is a part of Trondheim Playground.

August 2016 CTT presentation at Sino-Norwegian Seminar

CTT was presented at the Sino-Norwegian Seminar on Zero Emission Buildings & Neighbourhoods / Green Buildings organized by NTNU for a Chinese delegation.

August 2016 Climate-KIC Summer School in Trondheim

The Climate-KIC Summer School Climate Journey16 stopped for a week in Trondheim. It is Europe's largest climate innovation summer school with over 220 students. The CTT project co-lead gave a lecture at the school at NTNU about city-level emissions and the CTT project.

July 2016 2nd China Smart City Expo

The theme of Expo was "Internet + Innovation Entrepreneurship". The expo contained exhibition, summit & forum, policy announcement, marching-making, and platform for dialog. Together with

an NTNU delegation, CTT is presented for the first time in China, show-casing modernized tracking and visualization of emissions, especially PM for China's case.

June 2016 ICLEI Smart CITIES 2.0 @ Metropolitan Solutions 2016.

CTT presented at ICLEI Smart CITIES 2.0 @ Metropolitan Solutions 2016. Vejle Municipality presented the city needs and requirements for emissions monitoring, after an introduction to the CTT project by NTNU.

June 2016 Workshop on City Climate Solutions, ICE conference 2016, Trondheim, Norway

CTT organised the Workshop on City Strategies for Smart Sustainable Climate Solutions, CS3CS, co-located with ICE. The purpose of this workshop is to discuss mitigation and measurement approaches that specifically address cities and city-scale strategies and solutions with a focus on fast and sustainable results.

May 2016 2016 Northeast Asia Forum on Air Quality Improvement EACAC in Seoul, Korea.

The CTT project and NTNU was invited to present at the 2016 Northeast Asia Forum on Air Quality Improvement EACAC in Seoul. The forum was organized by ICLEI East Asia and Seoul Metropolitan Government (SMG) as part of the East Asia Clean Air Cities program (EACAC). Following the forum, an expert workshop was held with partners and participating cities of the EACAC program. CTT was presented to an international audience at the forum and also to the technical expert workshop.

May 2016 LoRa Workshop, DIGS, Trondheim

CTT partner Wireless Trondheim hosted a LoRa Workshop, where CTT was a co-organizer. The purpose of the workshop was to introduce the participants to LoRa by giving them hands-on experience with hardware and development.

May 2016 Smart Cities Meeting at Innovation Norway in Delhi, India

In connection to the Smart Cities Expo India 2016, CTT and Numascale participated in a roundtable meeting at the Innovation Norway offices in Delhi, India, on Solutions for Smarter Cities in the Indian context, which was organized by NICCI, the Norway India Chamber of Commerce and Industry and the Norwegian Embassy.

May 2016 Smart Cities India 2016 Expo, Delhi, India

India has a very ambitious mission to develop 100 smart cities launched in 2015. CTT and NTNU was invited by Innovation Norway to present Smart Cities approaches at the Smart Cities India 2016 Expo in Delhi. NTNU together with Numascale presented the CTT project at a booth and also visited a number of local potential partners.

April 2016 7th National Annual Forum for Renewable Energy, Ulan Bator, Mongolia

The project co-lead of Carbon Track and Trace 2.0 attended the 7th National Annual Forum for Renewable Energy in Ulan Bator, Mongolia to expand on previous China talks, meet potential partners at the Forum, and also proceeded to meet a number of potential local partners and universities.

Publications and media outreach

Enhancing environmental control and reducing emissions in Nordic Smart Cities

CTT case study with Libelium. Together with the Libelium hardware provider, CTT has developed a case study within Libelium's series to showcase the use for environmental measuring of emissions.

A Measurement-Driven Approach to Understand Urban Greenhouse Gas Emissions in Nordic Cities

Norwegian Informatics Conference (NIK2016). Dirk Ahlers, Patrick Driscoll, Frank Alexander Kraemer, Fredrik Anthonisen, John Krogstie.

Overview paper of the CTT technical infrastructure: Cities are main drivers for climate change mitigation and emission reduction today. However, in many cases they lack reliable baselines of emissions to validate current developments over time, assess the impact of their projects, and prioritize investments and actions. They also need better data on a small geospatial and temporal scale to really understand local emissions. This paper describes the rationale and the design of the Carbon Track and Trace project (CTT) that aims to develop an automated system for greenhouse gas (GHG) emissions monitoring through a low-cost city-level sensor network. The system is based on a flexible architecture incorporating open source sensor platforms, an Internet-of-Things wireless backbone, and extensive data analytics. We describe concept, architecture, and deployment as well as initial results.

Media exposure in Vejle

The Danish website of Association of municipal IT managers (http://www.itchefer.dk/) published an article about CTT on their website, focusing on the sensor deployment.

Ducky: An Online Engagement Platform for Climate Communication

Bogdan Glogovac, Mads Simonsen, Silje Ström Solberg, Erica Löfström, Dirk Ahlers. NordiCHI '16 conference, Industry Experiences Track

Supporting Municipal Greenhouse Gas (GHG) Emission Inventories Using Business Process Modeling: A Case Study of Trondheim Municipality

Dirk Ahlers, John Krogstie, Patrick Driscoll, Hans-Einar Lundli, Simon-James Loveland, Carsten Rothballer, Annemie Wyckmans. Workshop on Sustainability-Aware Business Process Management @ BPM2016

Understanding challenges in municipal greenhouse gas emissions inventories

Dirk Ahlers, Patrick Driscoll, IEEE ICE ITMC 2016, Session Sustainable Technology Management.

A necessary prerequisite for impactful climate mitigation action is the availability of suitable and reliable baselines of emissions. This is especially true for urban and city-level actions and strategies that need reliable local data about emissions to prioritize actions and investments to achieve the highest possible impact.

Website

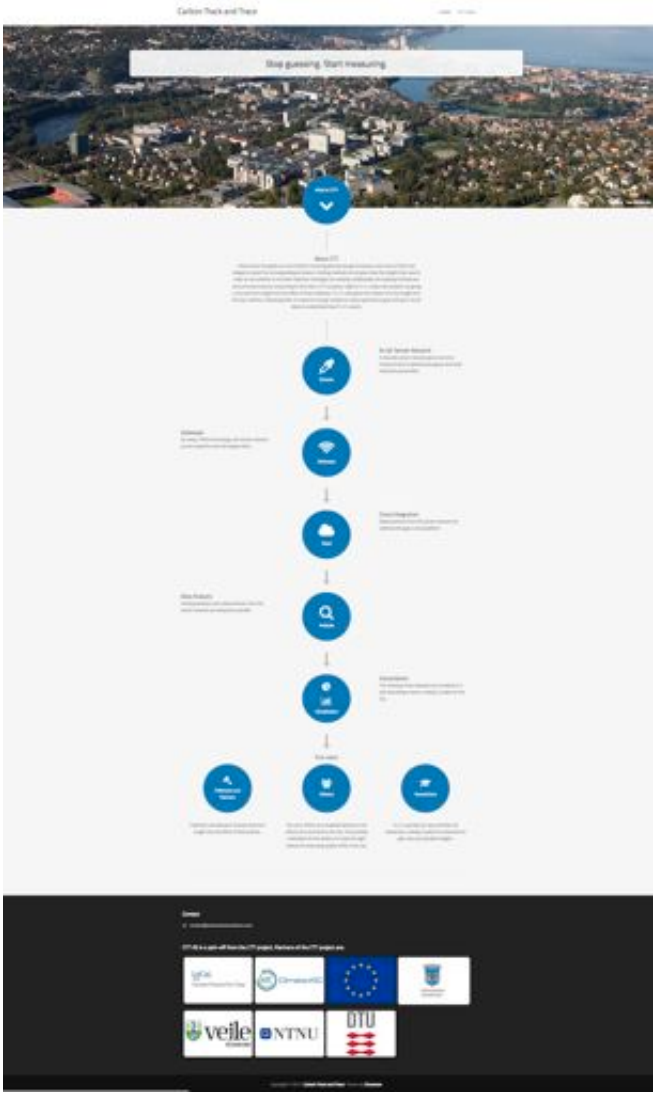

Figure 15 A website was set up for the project overview at http://carbontrackandtrace.com/

Summary of main CTT 2.0 dissemination activities of ICLEI Europe

In addition to general outreach performed by the coordinator NTNU, ICLEI used its network for more focused dissemination of the project and participation at relevant events.

1. Presentation and promotion of CTT 2.0 at Covenant of Mayors expert workshop
2. Organisation of CTT workshop on Smart Cities and Air Quality at Local Renewables 2016
3. CTT newsbit published on ICLEI Europe website
4. CTT news disseminated to ICLEI members and stakeholders
5. CTT news spread through ICLEI's energy policy and technical mailing lists

6. CTT tweets to ICLEI members and contacts

1. Presentation and promotion of CTT 2.0 at Covenant of Mayors expert workshop

Event Title: Workshop on Local Energy Data Collection for SEAP development

Date: 17 June 2016, 9:00-16:00

Type: Workshop

Location: Renewable Energy House, Brussels

Language: English

Participants: 28 registered participants, mainly CoM Signatory representatives, CoM Supporters and energy experts

CTT activity: Presentation of CTT, promotion and discussion on cost and benefits of activity versus automated based inventories

2. Organisation of CTT workshop on Smart Cities and Air Quality at Local Renewables 2016

Event Title: Smart Cities and Air Quality

Date: 27 October 2016, 14:30-16:00

Type: Workshop

Location: Historisches Kaufhaus, Freiburg, Germany

Language: English

Participants: 31 registered participants, mainly local governments, smart city stakeholders such as utilities and business companies

CTT activity: Presentation of CTT and air quality, promotion and discussion of Smart Cities

3. CTT newsbit displayed at ICLEI Europe website (26.000 hits per month)

4. CTT news disseminated to ICLEI members and stakeholders

Date	Topic	Name of	Print/ online	Target audience: (P) Policymakers;	No. of subscr	Type of recipients

		newsletter /mailing	?	(L/RA) Local or Regional Authorities; (I) Industry, (A) Associations; (NGO) NGOs; (SC) Scientific Community, higher education, research; (Pub) Public; (M) Media							ibers/ hits	Language	Country
19.12.2016	Cost benefit survey carried out on municipal emission inventories	ICLEI Europe News	Digital	x	x	x			x	x	x	1000	EN	EU & worldwide
20.10.2016	ICLEI Dec 2016 E-news	ICLEI in Europe e-News	Digital	x	x	x			x	x	x	1750	EN	EU & worldwide
19.01.2017	Carbon Track and Trace releases cost benefit survey on municipal emission inventories	ICLEI Europe News	Digital	x	x	x			x	x	x	1000	EN	EU & worldwide
19.01.2017	ICLEI Jan 2017 E-news	ICLEI in Europe e-News	Digital	x	x	x			x	x	x	1750	EN	EU & worldwide

5. CTT news spread through ICLEI's energy policy and technical mailing lists

Date	Topic	Name of newsletter /mailing	Print/ online ?	Target audience: (P) Policymakers; (L/RA) Local or Regional Authorities; (I) Industry, (A) Associations; (NGO) NGOs; (SC) Scientific Community, higher education, research; (Pub) Public; (M) Media							No. of subscribers/ hits	Type of recipients	
												Language	Country
19.12.2016	Cost benefit survey carried out on municipal emission inventories	LG Action mailing list	Digital	x	x		x	x				1500	EN	EU

19.12.2016	Cost benefit survey carried out on municipal emission inventories	Covenant capaCITY mailing list	Digital	x	x		x	x	x			450	EN	EU
19.01.2017	Carbon Track and Trace releases cost benefit survey on municipal emission inventories	LG Action mailing list	Digital	x	x		x	x				1500	EN	EU
19.01.2017	Carbon Track and Trace releases cost benefit survey on municipal emission inventories	Covenant capaCITY mailing list	Digital	x	x		x	x	x			450	EN	EU

6. CTT tweets to ICLEI members and contacts (1,100)

December 2016:

- Carbon Track and Trace (CTT) develops an automated system for greenhouse gas emissions monitoring and reporting. More at: http://carbontrackandtrace.com
- CTT tailored data analysis integrates sensor measurements with other open data sources to generate new insights and city-level emission overviews. Carbon #Track #Trace http://www.carbontrackandtrace.com
- The CTT system enables a municipality to automatically log and analyse calibrated measurements of their direct GHG emissions.
- CTT allows municipalities for the first time to develop evidence-based policy for mitigation strategies, linking specific actions and strategies to measured reductions.

January 2017 (scheduled):

- CTT analyses costs and benefits of GHG activity based and automated data gatherings.
- CTT gives politicians and planners more accurate real-time greenhouse gas emissions measurements, facilitating faster feedback loops between action and quantifiable impact.
- CTT seeks to unlocking the potential for significant increases in private capital investments in GHG emission reduction measures.
- The CTT ecosystem gives cities and their researchers an open source, low-cost platform for field measurements of GHG emissions in buildings, energy, transport, and waste, and will lower the threshold to engage with local emissions data.

Next steps

There is a range of next steps to take for the CTT 2.0 project. CTT 2.0 has produced a wealth of knowledge for the participating municipalities, research organisations, and other Climate KIC partners. CTT2.0 could make large steps into the right direction, but had more technical and organizational hurdles to master than expected. This means that a re-evaluation of the sensor systems needs to take place for improved data quality, as it was learned within the projects, while some questions were clarified and fleshed out in more detail, that requirements and available low-cost technology still show a gap. Due to the flexible structure of the CTT approach, such changes of parts of the overall system can be done rather easily.

The following details some of our future work:

- Ensuring a continuation of the CTT approach through various funding, research, and commercialization angles
- Using and disseminating the knowledge generated in CTT2.0
- Further collaboration with LoCaL and Climate-KIC
- Securing future funding for the continuation of the project work to bring it towards a stable and marketable solution
- Support of the startup to succeed with an MVP in this area as well as additional sensor network offerings to link climate measurements to other systems important for city operations.
- Continuous running of the sensor network after the project duration to collect more data for better models
- Reevaluation and testing of additional sensors, especially for CO_2 for higher quality measurements
- Further research by NTNU and DTU into systems and data
- Cooperation with the upcoming NTNU IoT lab which allows us to better evaluate and test sensor and hardware in more controlled conditions.
- Setup of the NTNU smart city lab for improved use of the sensor network
- Future student work (bachelor, master theses, etc.) to use and explore the system and the generated data.
- Publication of scientific papers and lessons learned
- Ongoing collaboration with CTT partners