Overview of the survey of the scientific community for COINS - WP6

This report is based on 15 interviews conducted by Ida Storm (Lund University/ICOS Carbon Portal) with inverse modelling experts between December 2020 and February 2021. The same questions were posed to all interviewees and all questions were sent out in advance to the respondents.

The first part of the report gives an overview of the interviewees and their specific field of expertise. In the next part each interview question has its own section where all the individual answers have been synthesized.

Table 1. Overview of interviewees

Name	**Location**	**City**	**Reg**	**Cont**	**Glob**	**$ffCO_2$ inv**	**Multi-species inv**
Dominik Brunner	Zurich, EMPA	x (IP*)	x	x			
Felix Vogel	Toronto	x					separate inversions
Frédéric Chevallier	Paris, LSCE				x	x (IP)	x
Ingrid Super	Rotterdam	x					x (pseudo obs. so far)
Jocelyn Turnbull	Auckland	x					
John Lin	Salt Lake City	x				x	
John Miller	NOAA				x	x	x
Ken Davis	Penn State	x	x	x		x	x
Kim Muellen	USA, NIST						
Matt Rigby	Bristol	x	x			x (IP)	x (IP)
Richar Engelen	ECMWF						
Thomas Lauvaux	Paris, LSCE	x				x	x
Wouter Peters	Wageningen	x (IP)	x (IP)		x	x	x
Anna Augusti-Panareda	ECMWF				x	x (IP)	
Hans Chen	Lund		x		x	x	x

*IP = in progress

City, regional (**Reg**), continental (**Cont**), global (**Glob**) refers to on what scales they are working.

$ffCO_2$ inversion (**$ffCO_2$ inv**) refers to if they are doing inversions for fossil fuel CO_2 rather than only total CO_2.

Multi-species inversion (**Multi-species inv**) refers to if they are doing inversions where measurements of other species are included to optimize fluxes.

Survey questions and summary of answers

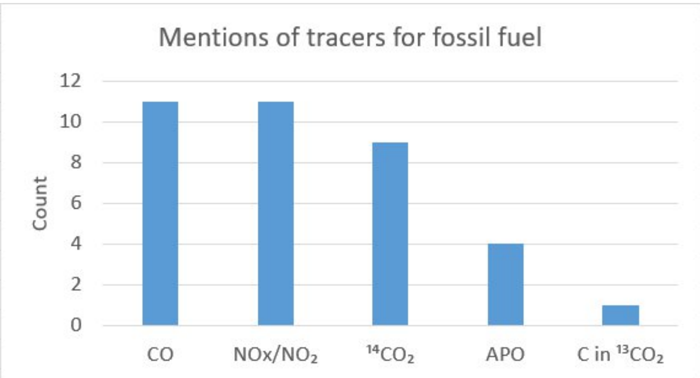
A general point made by many interviewees during the questionnaire is that their answers will depend on what the goal with the inverse modelling is, as well as the characteristics of the individual city that is planning to use inverse modelling to estimate their emissions. Goals of inverse modelling can range from getting annual total emissions for the whole city down to sectoral disaggregation on high spatial and temporal resolution. With the commonly used bottom-up approach, where reported emissions are combined with emissions available on national scale and attributed using different proxies, it is possible to get this information. However, it is easy to forget the associated uncertainties and fail to see the need to complement this information using top-down approaches where inverse modelling is one option. City characteristics include size and emission intensity because for smaller cities with lower emission intensity the signal from emissions will be low compared to the variation on the background CO_2 concentration and the signal caused by the natural CO_2 fluxes between biosphere and atmosphere. A dense network of high-precision measurement stations might be required for this purpose, whereas the fossil fuel signals from large cities with high emissions can be detected even from satellites. There are many other aspects of the city to consider when deciding what type of measurements to make and how to design the network of stations which makes it hard to answer some of the questions in general terms.

For estimating fossil fuel CO_2 fluxes it could be beneficial to include co-emitted species in the inversions. Which co-emitted species do you think would be most promising? Are sufficient measurements of co-emitted species available?

When assimilating measurements of co-emitted species in inversions, it is preferable to have them co-located with the CO_2 measurement stations. Which species to use depends on the specific situations and what sources of CO_2 to attribute.

Species mentioned by most interviewees were CO, NO_x and $^{14}CO_2$. $^{14}CO_2$ is generally accepted as the “golden standard”, but the high cost to make the measurements remains a problem. The ratio between $^{14}CO_2$ and CO_2 is essentially stable in a natural environment, and when fossil fuel combustion results in addition of CO_2 without $^{14}CO_2$, the depletion can be quantified into expected emissions within the influence region of the measurement station. However, emission of $^{14}CO_2$ from nuclear power plants with certain types of reactors complicates the process in Europe, and especially the UK. Due to costs and the influence of nuclear power plants, CO is rather more widely used. Depending on what sector the emissions come from, there are different ratios of CO to CO_2 and this information is used to attribute sources to the measured concentrations. However, the ratios have proven to vary greatly within the same sectors and in Toronto the ratios reported in the inventory was very different from what was observed. Another problem that was brought up with CO is that the measurements of CO in air-quality networks are not precise enough. CO can also be measured from satellites, but it is hard to get a good signal-to-noise ratio. NO_2 is better in terms of availability of observations from satellites. NO_2 observations are already used in ECMWF's global inversion system and despite the perceived difficulty to use CO measurement from satellites as a tracer for fossil fuel, ECMWF will still try to assimilate these measurements.

APO (atmospheric potential oxygen) was mentioned as upcoming in the past year or so and has yet to be proven. One advantage to $^{14}CO_2$ is that the cost is, as for CO, lower and that measurements can be made continuously. APO measurements will be used in the DARE-UK project and LSCE is also working on assimilating these types of measurements.



Are you performing multi-species inversions (CO_2, $ffCO_2$, CO, $^{14}CO_2$,...)?

An overview of which of the interviewees are performing multi-species inversions can be found in Table 1. LSCE is using CO and $^{14}CO_2$, and is working on including APO measurements. NOAA and Lund are also using measurements of $^{14}CO_2$. CO is used by the group at Pennsylvania state University, USA. The city of Rotterdam is using NO_x and SO_2, but only with pseudo-observations so far.

The inverse modelling group in Toronto has chosen to do separate inversions rather than multi-species inversions because they find it very hard to balance out how the uncertainty in one species translates to the uncertainty in another species and to in turn decide how that should be weighted. A more general concern is the number of measurements, where one interviewee called for making measurements of $^{14}CO_2$ a priority since it has the greatest potential. Also, the measurement of the co-emitted species should preferably be in the same locations as the CO_2 measurements, which many times is not the case. It was also mentioned how measurements of different species can be used in other ways than directly in the inversions, such as to calibrate CO to CO_2 emission ratios with measurements of $^{14}CO_2$.

What prior information are needed for your inversion system, and are they all available for city scale modelling in the quality and resolution that you think would be required? If not, what are the gaps?

Mentions on prior information needed included information on anthropogenic emissions, exchange of CO_2 between the biosphere and the atmosphere and boundary conditions (meaning background CO_2 and influence of CO_2 fluxes outside the modelled region). Also, for all information going into the inverse modelling system uncertainty estimates are needed/preferable. To the question whether this information is available in the quality and resolution that would be required, many interviewees answered that this depends on the goals.

In terms of anthropogenic emissions, it varies how good emission inventories are for different cities, but they are generally not good enough to use to attribute emissions by sector on high spatial and temporal level. Also, inventories are generally made available with a delay of a few years. Data on emissions might also be available, but in different places and with varying level of accessibility. In these cases, the modellers have to assemble their own inventory. Whether available in an emission inventory or assembled by the modeller, transparency is many times lacking which makes it is hard to know the quality of the data and in turn how to attribute uncertainties. Final uncertainty estimates are many times the result of "expert knowledge" and is expected to contain significant biases.

Prior information on fluxes between the biosphere and the atmosphere are very important since this signal can often be as large as the signal from the anthropogenic emissions. However, it remains a challenge for many, and in for instance the INFLUX experiment in Indianapolis the measured background concentrations in the upwind rural area of the city could differ by 2-3 ppm despite fairly homogenous vegetation. Also, the representation of the vegetation within the city is especially difficult since it is different than natural vegetation, for which the ecosystem models that generate the prior have been designed to estimate the fluxes for.

Other prior information mentioned was information about chemistry. Also, in order to evaluate transport models and attribute uncertainties to their output, vertical profiles such as wind lidars were called for.

Are appropriate transport models available for city scale modelling? Can the current transport models be applied with some adjustments to overcome the limitations? Or are different modelling approaches (e.g. Large-Eddy-Simulations) needed?

Just like in the discussion related to prior information, to answer the question if appropriate transport models are available will depend on what the goals of the inversions are. There is confidence among the interviewees that the transport models are appropriate at least for whole city estimates. For higher resolution fossil fuel CO_2 emission attribution, the "near field" – which is generally the area of an eddy-covariance measurements influence area - was pointed out as difficult for the transport models to represent. There is more confidence in measuring an integrated signal further from sources such as at higher altitudes or outside the city. Adding more measurement stations in the near-field might help, but can be difficult to interpret. Other known issues related to transport models include the urban heat island effect which is hard to represent, as well as the difficulty to represent the boundary layer height under stable (night-time) conditions. The difficulty with lack of night-time or cold stable periods for the representation of atmospheric transport means that measurements during these hours are many times disregarded which can lead to biases in the results.

In terms of overcoming the current limitations, interviewees see potential in improving the land-surface representation, to assimilate meteorological data, and more research related to how to adapt the parametrization of mesoscale transport models. Work has been done in Zürich to build in an urban canopy module to try to best represent the exchange of heat and momentum and radiation between their mesoscale transport model and the urban street canyon. ECMWF is creating this type of parameterization as well. When working on improvements of the models it is important to validate if it actually results in reduced uncertainties in the transport. This is difficult to do and is a topic that needs more research.

LES (Large-Eddy-Simulations), because of computational requirements, are currently not feasible to use to resolve the airflow in a larger city over longer periods of time. However, it comes down to what types of resources are available for the cause and it is not impossible. In the future, with continued improvements in computing capacity, it will be more economically feasible. LES could also be useful to validate and improve other types of transport models.

What are minimum requirements for in-situ networks to quantify urban emissions in enough detail?

Again, this will depend on the objectives and city characteristics, but even with this information many interviewees say that we simply don't know yet. Other mention that our knowledge is especially lacking for better spatially resolved and temporally disaggregated emissions. In the INFLUX project, with a dozen measurement towers over a modest size city (1 million inhabitants), they feel they are scratching the edge of this type of information. There are limits to what the atmosphere can produce and over the next few years we will be in a better position to know where those limits are.

More specific suggestions for minimum requirements include to have between two and four stations spread out around the city and not too close to the ground. A setup like this could suffice to arrive at annual emission totals. With wind from a narrow range of dominating wind directions, such as for Paris, two measurement stations could be enough and otherwise the city might need to be circled. For smaller cities with lower emissions totals more measurement stations would be needed because of the modest concentration gradients these emissions would cause. In order to get higher resolved information with reasonable uncertainty it was suggested to have a few measurement stations inside, and a few outside the city. Regardless of how the network is set up to capture the signal of the city emissions, good measured background concentrations are needed. Background concentrations can for instance be measured by tall-tower station(s) upwind of the city.

With more resources, how much better can the inversions get compared to the minimum requirements?

How well we will be able to get fine-scale details is a research question, but it is clear that it will be hard to attribute emissions on highly resolved geographical area without making measurements at many places. Also, adding more measurement stations, given that they are well-placed, will reduce the uncertainties in the results, but with a decreasing return on investments. Whether it can be made economically feasible to resolve emissions on fine-scale is yet another question.

Areas where the interviewees see potential improvements, other than to add more measurement stations, is to improve the prior information and associated uncertainty estimates, to measure a whole suite of tracers and in the representation of the near-field in transport model simulations. To have a tiered measurements system, meaning integration of different sources of measurements, was also mentioned.

Could you provide a rough estimate for the costs to be expected with setting up and running a system for ten years for 1 city with say 1 million inhabitants?

This will depend on the objectives and city characteristics. Only a few interviewees wanted to give estimates and they ranged between 2 and 15 million euros. It will be possible to optimize the costs by economy of scale when a multitude of cities would deploy similar systems.

How long is the time period that needs to be covered / can be covered by the inversions? What would be needed for estimation of emissions and emission changes?

Most answered that the time-period that needs to be covered range somewhere between 3-10 years whereas others said that it is still a research question. It will depend on the expected changes in emissions and the precision of the monitoring system. The relationship can roughly be boiled down to the following equation: multiple the relative precision of the monitoring system and divide it by the expected emission reduction trend per year. One more general suggestion was for the stakeholders to use the timescale in which policy interventions are expected to make changes, such as a target reduction by a specific year.

Are long term trend estimates possible or time slices needed? (computational limitations)

Most interviewees answered that there are no computational limitation and think the inversion system should run for all years for which there are measurements. However, depending on modelling approach and spatial and temporal resolution there might still be limitations but it always comes down to policy and whether there is a will to invest in the needed computing power.

What is the signal-to-noise ratio of emission reductions with respect to posterior uncertainties in the inversions (in particular on city scale)?

This was a difficult question for many interviewees to answer and again the answers depend on different factors such as the measurement station network. The variability caused by weather is for instance much larger, which makes it hard to distinguish changes caused by reductions in emissions in the short term. Hence, for the annual timescale the signal-to-noise ratio is expected to be less than one, whereas for a 20-year time-period it is somewhere between three and five. Other interviewees chose to answer in terms of what reductions the inversion system would detect and about a 10% reduction over a decade should be possible. Another interviewee replied that the goal of the inverse system should be to communicate to the city if they are reasonably in line with their emission reduction target or not.

Can the expected emission reductions be identified in the variability of the signal, e.g. Covid-19 lockdown signal?

The answer to this question depends on where you are looking and to which type of measurements: it is harder to detect from tall-tower mole fraction measurements that are away from cities since meteorology is the dominant driver in CO_2 concentration variability. In terms of satellite observations, the experience for one interviewee was that Covid-19 lockdown signal could be identified in some cases whereas another had concluded that the signal was generally too small to see. However, it was definitely possible to see the signal in measurements of NO_x and CO from Eddy Covariance flux towers placed in cities. How well the emission reductions can be quantified is still an open research question and the timing of the Covid-19 lockdown, in the spring when the biosphere is especially active, makes it harder. One interviewee wanted to make the point that this type of emission reduction, with over 80% reduction over a few weeks in some places, is a very different framework from the more permanent reductions that will hopefully happen over the next 30 years.

What was unexpected in terms of your recent research?

A couple of interviewees mentioned the strength of the biosphere signal in monitoring of cities. Another brought up the large impact of the temporal variability in emissions on the result from the inversions – despite similar priors other than changes in temporal profiles – as surprising. One unexpected result in the ACT-America study was that CO_2 and CH_4 signatures that are carried in weather systems was found to be potentially very large. In terms of satellite data in a comparison of error sources, one interviewee pointed out the discovery that the lateral boundary conditions, meaning the inflow and outflow of CO_2 in the domain, are associated with a lot of uncertainties. A couple of thigs that were mentioned in other questions were again brought up here, such as that measured CO to CO_2 ratios in Toronto were very different from what was reported in inventories for the city. Also, one of the interviewees concluded that they did not see the impact of Covid-19 from satellites and found this to be surprising.

What successes did you have in terms of your recent research?

One more general remark by one of the interviewees was that they are out of the "discovery phase" in terms of city scale modelling and that the scientific community is collectively moving on towards more operational systems. More specific successes included how the team in Salt Lake City feels that they arrive at good flux estimates from working with data they collect on light-rail trains. In terms of measurement instrumentation, the team in Toronto feels that they now have low-cost CO_2 sensors that withstand the cold and are fairly stable at about 1 ppm precision. Furthermore, they have had good success with total column instrumentation and can distinguish the upwind/downwind CO_2 gradient nicely for Toronto. The possibility to assimilate different types of data streams in CCffDAS run by the team in Lund was also brought up as a success. The interviewee from ECMWF thinks they have a good semi-lagrangian transport model for their global inversions at 9 km resolution and are currently working on limiting numerical errors related to the mass conservation issue. They are also improving their fully coupled photosynthesis model and the interviewee made the point that it is important to have good biogenic fluxes which will also enable to establish good quality boundary conditions for use in city inversions.

What challenges did you have in terms of your recent research?

Understanding the urban biosphere, the need to have better uncertainty estimates as well as to better understand how spatial and temporal errors are correlated, were brought up related to prior information. In terms of how errors are corrected, if for instance errors in emission inventories related to a specific source are correlated in space, the same correction can be applied to that emission source over the domain area. Another point related to priors is the delay that can be expected for the inventories to be published: it usually takes years before the bottom-up data becomes available. With regards to disaggregating emissions by sector, an attempt to use CO to subset emissions from traffic resulted in the conclusion from one of the interviewees that it was not successful. In terms of measurements, more stations are needed and related to this, funding was brought up as a challenge by an American interviewee. Where the stations should be placed and how their proximity to emission changes over time was brought up as another concern: in a growing city a measurement station that used to be outside the city might later find itself within the city. Also, what background concentrations should be used is a challenge and in for instance the INFLUX project the stations outside the city measured very different levels of CO_2, despite being located in proximity to similar vegetation. In terms of transport models, the near-field emissions are a challenge to simulate and using LES was suggested as a way forward. One final point brought up as a challenge was stakeholder engagement.

Which is and which is the combination of measurement techniques that provide the best information to reduce the uncertainty in the total annual budget of the city (choose the best technique and a combination of max 2 techniques)

Many of the interviewees said that this is still a research question, and a few of the ones that still chose to answer the question emphasised that it is their educated guesses based on current research. Also, the city characteristics and the objective with the inversions will affect what measurement technique(s) are advisable. Many find that a combination of methods is best, and that quite some measurement stations are needed to constrain different parts of the city. The placement of the measurement stations is highly important and thus requires good network design.

a. A ring of tall towers around the city using high precision mole fractions observations

This option was the most popular choice – only three of the interviewees that chose to answer the question did not have this as their first or second choice. Reasons given included that it is a well-proven option and can be used both for mass-balance approaches, which means to establish the difference in concentration gradient between air flowing in and out of the city, and inversions.

b. A ring of total column in situ instruments around the city

Motivations for choosing total column in-situ instruments around the city included that column measurements are better than point measurements when the goal is to compare concentrations in the in- and outflowing air of the city. One interviewee wanted to point out the problem interference with the column variability from the free troposphere and sometimes even stratosphere. This means that emissions from far away will potentially influence the column average, and this needs to be represented in the inversions.

c. A large number of low-cost sensors in the city combined with the air quality network

Under the condition that the low-cost sensors are well-calibrated and placed strategically, a couple of interviewees found this to be a good option whereas others stated that they are at present not precise enough.

d. Satellite observations with daily overpasses

The ones that found this to be a good option said it would be mainly for larger cities (>10 MT CO_2/year). Problems pointed out included monitoring cities located on high latitude or altitude, as well as clouds and aerosols. It might be difficult to scale the many times limited number of successful measurements to a full year and there might be fair-weather biases.

e. Mobile observations in the city on top of buses, trams, and in private cars

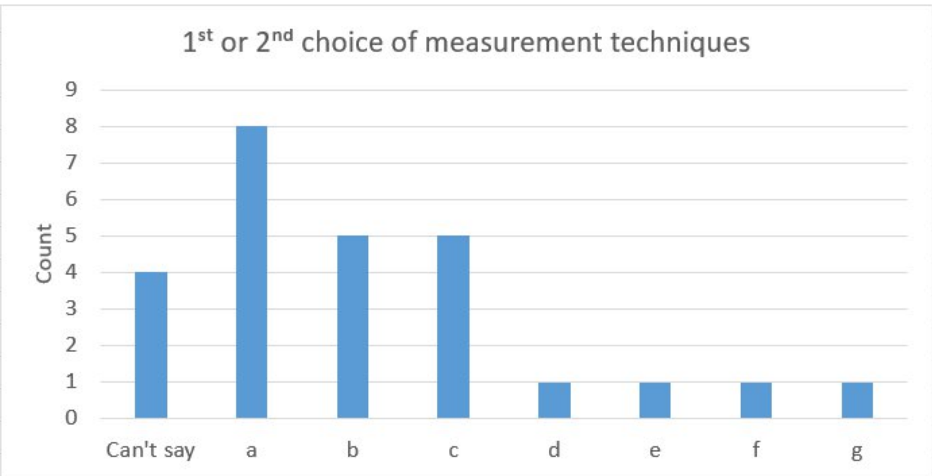
One interviewee especially liked this option and sees potential in deploying mobile observations upon seeing discrepancies between what emissions are reported and what is indicated in inversion results. Others see potential, but preferably if the measurement sensors can be slightly elevated. Otherwise there might be difficulties to estimate the emissions from the full city given that the measurements are potentially swamped by local sources such as the buses or cars they are placed on.

f. Newer horizontal of vertical gradient resolving remote sensing techniques as DIAL or LIDAR with a path length of 1 km or more

This is an option that is a bit early to recommend for most of the interviewees. Also, DIAL and LIDAR are currently not calibrated on international scale. However, a couple of them mentioned that they see potential. It could also be used to understand the errors in transport and mixing.

g. Airplane measurements in the PBL

As for the option with satellite observations, this is an option that will be hard to scale to a full year seeing that airplanes would not be flown several times per day or even daily. However, it could be good for testing the model and understand the errors in transport and mixing.



What are your expectations on future CO_2 satellites? Can total column satellite data constrain surface emissions in a quantitative way? What will the role of the in-situ network be in future?

The new satellites will have larger swath-width and with new constellations of multiple satellites being launched, the re-visiting time will be shorter which means more observations for the different locations. Also, more geostationary satellites that are focused on the same area at all times will be launched in the near future. The interviewees differed greatly in terms of their expectation on the new satellites, but especially to constrain emissions on an annual timescale seems like a good possibility to some. Especially geostationary stations – preferably with some altitude resolution in their measurements – would potentially give enough observations to scale to the year. Also, in global inversion systems satellites are essential as this is the only way to obtain observations from the large parts of the world that do not have in-situ measurements. These areas contain several key major cities with increasing emissions and here satellites are what we must rely on, at least for the foreseeable future.

Issues raised included the much lower signal-to-noise ratio of satellite observations compared to high-precision in-situ measurements. Aerosols and clouds within the column need to be understood and corrected if possible and will also give a fair-weather bias for the successful observations. Naturally, since it is passive sensing (reflected sunlight), night-time observations are not possible and high latitude locations will have very limited hours in the winter-months. Furthermore, where there are mismatches between modelled concentrations and observations the level of the mismatch needs to be established in order to bring it back to the emissions. For this one needs to apply the correct vertical profile.

Regarding the future of in-situ measurements interviewees generally agreed that this should be done as much as possible and that satellites will never replace these networks. In-situ measurements are needed for truth-check of the satellites and can fill in the gaps in space and time where satellite data is missing for any of the reasons previously listed.

Where do you see your research going?

Because of lack of time, a couple of interviewees chose not to answer this question.

Interviewee 1

Work on improving the the representation of atmospheric mixing and transport in their transport model and to reduce systematic errors in their system. In terms of transport model uncertainty, they wish to define it for each time-step rather than have the uncertainty fixed.

Interviewee 2

They will be staffing positions around modelling of the urban biosphere and make sure they have staff to continue the work on their total column network around the city. Another goal is to deploy more low-cost sensor in the city.

Interviewee 3

Where the research will go depend on funding agencies but there is currently momentum for what is covered in this interview. Hence, a likely focus will be to quantify fossil fuel CO_2 emissions in their city without giving up on research related to the rest of the carbon cycle.

Interviewee 4

Continued work on a dynamic emission model which tries to use spatially and temporally explicit activity data and emission factors. The goal is to capture the variability in the emissions - to have a better prior.

Interviewee 5

Work on best practices guidelines for monitoring urban emissions given what we currently know. Also investigate multi-species analysis which the interviewee feels are under-utilized and have lots of potential. The interviewee also plans to look at the problem in a different way than the traditional inversion framework.

Interviewee 6

Continue to zoom into their city more and more and use multiple tracers. The interviewee also plans to use satellite observations to look at more biologically active cities where the fossil fuel signal is harder to distinguish from the variability caused by the biosphere. The interviewee has previously successfully done this for 30 cities that have relatively low biological activity.

Interviewee 7

This interviewee works at NOAA where they are hoping to get reasonable inversion results on the regional/state scale in the U.S. They also plan to continue supporting the measurements at INFLUX as well as measurements at the North-East corridor of the country. They will also participate in measurement campaigns.

Interviewee 8

They will use a regional approach to estimate city-scale emissions that will likely involve some sort of nesting in urban areas. Also, further develop their methods and combine multiple data sources from different measurement platforms.

Interviewee 9

They will aim to obtain estimates of CH_4 and CO_2 on sectoral level. In terms of uncertainties, they wish to build emission-ratio uncertainties into their models and also to better quantify uncertainties in bottom-up emission estimates. In the longer term they hope to get measurements of APO at more of their current measurement sites. They would use the APO measurements to evaluate and potentially calibrate transport models over urban areas more rigorously. As a final point, they wish to integrate space-based and in-situ measurements in their inversion systems.

Interviewee 10

Work towards linking GHG and air quality measurements. From a policy point of view, it is more appealing for stakeholder to tackle climate change and air quality at the same time. This interviewee is also interested in what would be a smart combination of different measurement systems to monitor emissions in cities.

Interviewee 11

This interviewee feels that monitoring of emissions in cities is in general approached in the wrong way. The same principles that have been used to model areas of natural vegetation is expected to work also in cities. However, one major difference is that we know the emissions fairly well and this calls for a different tactic. The interviewee would like to monitor the top emitters because they will account for such a large part of the city's total emissions and is also interested in using inverse modelling to look for discrepancies. He wishes to conduct research that will lead to an understanding of what would be needed to best do this.

Interviewee 12

They are working towards making their system an operational service where they provide both fossil fuel fluxes and biogenic fluxes. They are hoping to improve their vegetation- and transport models.

Interviewee 13

This interviewee plans to continue with $^{14}CO_2$ measurements for ffDAS which is a fossil fuel modelling system. The interviewee wishes to add more realism such as the influence of $^{14}CO_2$ emissions from nuclear reactors as well as $^{14}CO_2$ fluxes in the biosphere. The interviewee also has many things planned for the regional system he has developed.

Is there something we have not covered that you think is important to communicate to local and regional stakeholders that are considering to use in-situ observations to monitor emissions of city-scale?

One point made by a couple of interviewees is that honesty is really important in the process of communicating with stakeholders. They should have realistic expectations of what the results of their investments might be. Related to this, another interviewee feels that it is surprisingly difficult to convince stakeholders to do investments and thinks that good demonstrations with clear examples of what types of results inverse modelling have generated in other cities would make it easier. This is in line with feedback from another interviewee who thinks that there needs to be better visualisations and explanations of the results rather than for instance only tabular data which is hard for stakeholders to relate to. Here, yet another interviewee thinks that we should not limit the visions of what information we can get on emissions from measurements to inverse modelling results but rather start with different methodologies that are easier for stakeholders to understand.

Another reason that makes it harder to convince stakeholders to make investments is their confidence in bottom-up emission inventories. A budget for a city to generate their inventories is normally somewhere between 20 000 and 100 000 euros per year and when stakeholders believe that this suffice to detect emission trends it is hard to convince them of another approach when the costs associated with in-situ observations to monitor emissions might be closer to 1 million euros/year.

However, in general the interviewees almost all agree that to do actual measurements is the only way to test and validate emission inventories. All believe it will be a good investment that allows stakeholders to make good decisions for the future.