Why all cities should have “Clean Air as a City Service”

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1. Introduction.

Currently humans on the planet have very little information about the quality of the air that they breathe as they move through their daily lives. In 2019 the UN Secretary-General estimated that polluted air is responsible for an estimated 7 million deaths per year world-wide, building on earlier research showing vehicle emissions to be responsible for ~200,000 early deaths in the US alone (Caiazzo et al.[1]). We focus this document on making the case that cities should provide Clean Air as a service and that air quality data is an essential element of managing this essential resource.

“You can’t manage what you don’t measure.” (W. Edward Deming)

Cities currently provide many services to their residents, aimed at supporting public health, education, and safety. Typical services provided or regulated by a city or metropolitan region include firefighting and prevention, public safety including police, traffic lights, etc., healthcare including mental health and welfare services, transportation (road maintenance and public transit), parks and recreation, energy (electrical, gas), communication (voice and data), food (zoning), education (schools, continuing education), trash, sewage, water. All of these services are managed. Data guiding the application of resources to these efforts is organized for use by managers and for public review and assessment of the efficacy of the services.

As clean air is fundamental for public health and an essential human right, we believe that air quality data should be collected by cities and made available to residents, policymakers, and third parties (e.g., the Open Data network[2]). The data should be analyzed to inform residents and guide policy decisions. High levels of ozone, aerosol, CO, SO_2 and other emissions have long been recognized as damaging, and regulations govern their emissions. Globally, high aerosol is a leading cause of premature mortality (Ford et al.[3]). Air quality has been linked to asthma, cardiovascular disease and diminished cognitive ability among other health effects (Fuller et al.[4]; O’Connor et al.[5]), and in the recent COVID-19 pandemic asthma has been identified as a comorbidity trait. A set of studies[6] in the Boston area explored the health effects for residents living near freeways (Somerville CAFEH[6]). Since the vast majority of air pollution as well as greenhouse gases come from fossil fuel burning, monitoring pollution and air quality for public health reasons also naturally overlaps with collecting data needed to study and reduce Greenhouse Gas (GHG) emissions to lower the rate of climate change and the warming of the planet. Over 70% of GHG emissions are associated with urban areas (e.g., EIA[7] and Hutyra et al.[8]) and it is projected that by 2050 more than 75% of the Earth’s people will live in cities. Many cities have detailed plans for GHG reduction without a comparable plan for assessing the efficacy of the government policies necessary to meet their stated goals.

Currently, highly accurate but very expensive air quality monitoring stations are deployed around the U.S. by state and federal agencies. The density of these stations is not sufficient to study air quality at the local level corresponding to different neighborhoods in cities where different city sectors can have very different air quality levels. For example, the State of Washington has deployed[9] around 65 sensors for the whole state, and the federal Environmental Protection Agency (EPA) reports[10] only 4 stations in the cities of Seattle-Bellevue-Tacoma. Obtaining fine-grained information about air quality for residents necessitates the deployment of a low-cost network of air quality sensors. New solutions for low-cost sensors and communication networks are now possible with current technology. This document describes some of those potential solutions.

A city-level Air Quality Data Service should

1. consist of a gridded, temporal map of air quality,
2. provide clear descriptions of the changes in air quality at each hour of the day and over many years,
3. explain the emission sources that are responsible for poor air quality, and
4. allow prediction of the efficacy of different policies to manage and assess clean air within cities.

Distinct space and time scales are needed to support different strategies for coping with poor air quality. For example, knowing the aerosol levels at a moment may enable someone to avoid a region with poor air quality from a fire, while hourly measurements might support asthma management by susceptible individuals who might choose to avoid the outdoors. Longer term measurements are needed to support discussion of policy choices that require large capital investments to reduce the frequency of poor air quality. Similarly, different spatial resolutions such as the block-level, 1 kilometer, the entire city, and continental scales support different kinds of thinking about environmental equity, personal behavior and policy across jurisdictional boundaries.

Greenhouse Gas emissions (primarily CO_2 and methane, as well as nitrous oxide and halogenated gasses) are the result of many of the same activities that lead to poor air quality—use of fossil fuels for energy, transportation, cooking, etc. Strategies for reducing CO_2 and methane are being widely adopted by cities, often in the form of climate action plans that make direct connection to the guidance in global agreements. Such plans include short term actions such as support for electric charging stations and longer-term ones such as changing zoning to favor dense housing near public transit. Observations are an essential part of any system that would evaluate the efficacy of these policies. Because the same activities contribute to poor air quality and greenhouse gas emissions, there are win-win strategies on both metrics. Strategies can also be implemented to both keep track of and identify discrepancies in air pollution impacts on low income versus wealthy communities. There is racial inequity when it comes to access to clean air, which is starting to be quantified in studies (e.g., Tessum et al.[11] and Angelique et al.[12]).

This document will spell out a technical roadmap to move toward enabling the next generation of Air Quality Data services for cities. It is our view that this next generation will emerge from technologies that allow personal, block level, and neighborhood scale understanding of emissions and concentrations. Technology deployment and data collection needs to be coordinated with communication that brings policymakers and stakeholders into conversations grounded in observations, and in models guided by observations. We identify some of the logistical and research challenges needed to move this agenda forward. We will summarize the state-of-the-art assets and ongoing efforts in this space. We will give examples of urban policy interventions that could benefit from such data as a service. Finally, we point to several high-level societal issues for which we do not have clear answers, but which merit further discussion by stakeholders.

2. Value Proposition:

An Air Quality Data Service for cities will be a tool to help cities:

1. understand the extent to which air quality issues may be affecting their citizens, particularly in heterogenous ways, and
2. provide clean air as a shared resource for all residents independent of income levels.

It will help cities decide on policies that impact local issues like public health and global issues such as climate change.

Impact on policy: Leaders and managers of cities want to deliver on clean air and reduce the climate impact in response to constituent demands. With current tools, showing there is progress toward these goals is difficult and almost impossible to produce in time for the next election, the time scale that naturally matters most to representatives who must stand before voters. An air quality service would provide an independently validated and objectively quantified measure of improvement to the air, enabling direct reporting on the efficacy of specific measures adopted by the city, and predictions to help evaluate options among proposed policy alternatives.

Economic and commercial value: Some direct economic benefits of clean air will be realized from reduction in adverse health and climate outcomes. For example, state or federal Medicare or the VA hospital system could potentially save million dollars by funding air pollution management. In addition, the data will enable commercial services to be provided to consumers, analogous to weather services that produce commercial revenue along the models of weather on the evening news and weather apps. As an example of the economic value proposition of ecosystem services for cities, a study[13] prepared for the City of Portland estimated that a flood abatement project "could provide more than 30 million dollars in economic value to the public over a 100-year timeframe". There is an opportunity to offer profitable and sustainable enterprise solutions. Currently, EPA air quality data is hosted in Google Maps. Azure Maps is already including some local air quality from various new sensor networks.

Public Awareness: Collecting the data and making it publicly available in easily understandable ways will also help to keep air quality in the public conversation. Ideas for making the public aware of local air quality range from an overlay on a map application on your cell phone, to audible chimes in public places signaling poor air. People often struggle to accurately assess the danger and damage from chronic problems. Air quality is both an acute and a chronic issue and making the data available to people so they can see or hear it daily may keep it in public discourse. For example, soaring gas prices in the late 2000s helped renew interest in hybrid vehicles like the Toyota Prius and, in turn, increased the public discourse on our fossil fuel consumption.

Using air quality data to inform policy decisions:

Urban Greening. Suppose your city council is deciding on putting a new policy in place aimed at urban greening with the hope of both improving air quality for residents and combating global warming. You would probably want to know what the impact of those trees might be on air quality in neighborhoods across the city. This is an example where an Air Quality Service could provide useful data to make an informed policy decision. Several cities are looking to implement policies like this. For example, the City of Seattle has a goal of achieving 30% canopy cover by 2037, in order to help reduce urban heat island effects, thus reducing air pollution and heat-related health conditions disproportionally impacting vulnerable populations (2016 Seattle Tree Canopy Assessment[14]). The city of Vancouver implemented a policy to plant a certain number of new trees, and looked at questions of type, quantity, and placement to achieve optimal impact (Vancouver's Urban Forest Strategy[15]). The City of New York launched the *MillionTreesNYC* initiative with the goal of planting one million trees across New York City's five boroughs by 2017 (MillionTreesNYC[16]). Studies have shown that the trees in New York City remove about 2,200 tons per year of pollutants (MillionTreesNYC[16]).

More generally, every city may want to answer the question: what greenspace and tree-cover plans should we put in place, where do we put them and how would cities and people benefit from this? One way to identify areas that require restoration of green space and tree cover is to use the Air Quality Data Service to identify 'hot-spots' or areas with historically poor air quality, and data on urban heat island effects to identify locations for restoring green space and tree cover. The city would benefit from a cost/benefit analysis in terms of economic impact, health outcomes and healthcare costs, air quality, GHG and climate impact, for implementing the proposed policy. The datasets needed to provide such a cost-benefit analysis includes a dense network of air quality sensors at the city-scale. Cities would also be able to estimate the benefits of implementing such a policy, based on the improvement in air quality measured by the tool.

The problem also requires an analysis of the air quality and GHG benefits and sequestration potential of greenspace/tree cover at a city/county level, which is a topic of ongoing research. For example, studies (Nowak et al.[17]; Gopalakrishnan et al.[18]) have shown that vegetation such as trees, shrubs and grasslands can directly sequester air pollutants and provide significant health and monetary benefits to urban areas. The CO2 flux into and out of the urban biosphere is very poorly understood, but it differs substantially from the surrounding rural biospheric fluxes. Management of public space (irrigation, fertilization, pruning, mowing, etc) and the urban heat island effect will all impact urban CO_2 exchange (Hardiman et al.[19]). These are motivating questions for numerous interesting research avenues, which will be described further in the Research agenda section below.

Traffic, vehicle emissions policies, transit systems. Although traffic emissions can be determined on a coarse scale using fuel consumption information and emission factors relatively easily, it is more difficult to understand where and when those emissions occur. Traffic emissions for individual cities, and their spatial and temporal distribution within each city, are currently poorly understood.

Suppose your city is trying to evaluate the impact of imposing traffic circulation restrictions, for example Glasgow (from December 2022) banning all non-emission compliant vehicles from entering a Low Emission Zone. In Mexico City, residents are only allowed to drive their car on certain days to limit pollutants in the city (Mexico News Daily[20]). In other cities, such as London, there is a congestion charge for cars that enter a specific zone for many hours of the day (Transport for London[21]). More generally, a city might want to analyze the impact of shared streets (those that are closed to through traffic and give the right of way to pedestrians and cyclists (Sunnyside Post[22]), traffic restrictions such as bus lanes, carpool lanes, adding public transit options, capping vehicle emissions, etc. All these questions can be addressed using the Air Quality Data Service at the appropriate time scale and resolution. For example, a group of researchers used sensors to evaluate the effect of new traffic restriction zones on local concentrations of black carbon in Granada, Spain and Ljubljana, Slovenia (Titos et al.[23]). With a dense network of low-cost sensors and insight into the data collected from the sensors, cities could compare the before and after values to gauge the impact of their intervention, and also see how the effect spreads out beyond the point of intervention. For example, restricting traffic on one street may increase traffic on another. With high resolution data, the city could monitor these changes and act on them appropriately.

Spatial resolution is a challenge for air quality data, particularly for large cities. Traffic changes can have a rippling effect on other streets, so a high density of sensors is key to understanding the exact impact of traffic interventions. Mobile sensors are an option, instead or in addition to stationary sensors to increase spatial resolution. For example, city rental bikes could be equipped with mobile sensors to record data as people bike around. Another challenge is that cities and researchers may require data for a long time duration to feel confident in the impact of their traffic intervention, particularly for cities that experience large weather changes. For example, if an intervention is put in place in Boston in the month of September and the city compares data from August and October, it would not be as convincing as comparing the prior August to the next one because pollutant levels change with seasons and temperature and humidity. Thus, cities need a solution that can provide data over long periods of time and help to see the meaningful patterns easily.

3. Pilot examples

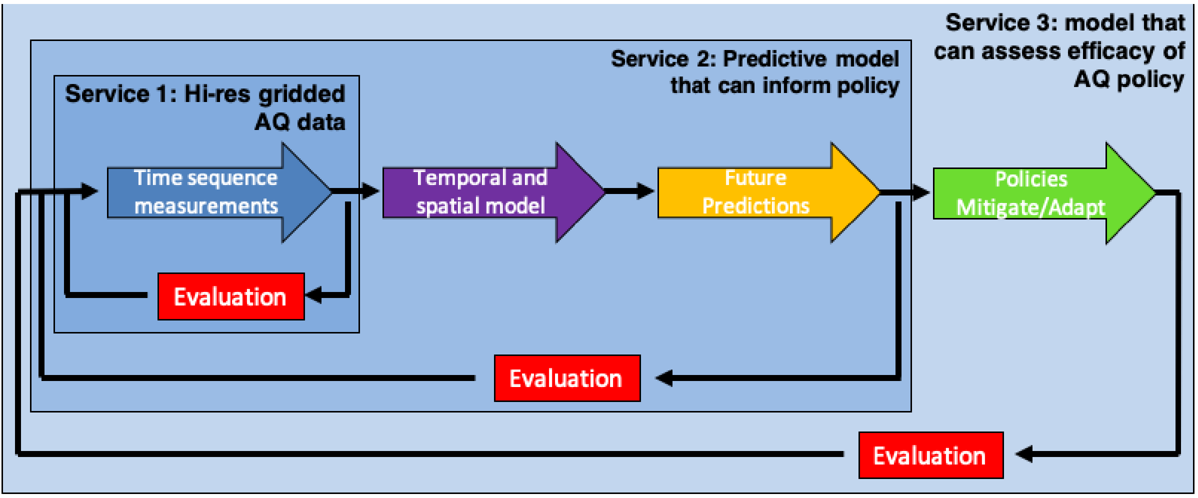
Bay area pollution levels. The BEACO$_2$N network[24] is an air quality measurement network with an extensive deployment in the San Francisco Bay Area, small pilot deployments in Houston, TX and NYC, and a soon-to-be-delivered city-spanning network in Glasgow, Scotland. BEACO$_2$N provides comprehensive air observations, including observations of CO_2, CO, NO, NO2, O3 and particles. Spacing between nodes is approximately 2 kilometers, a length scale that was chosen to match observed mixing length scales of plumes from highways. The observations are shared on a publicly accessible website. Analyses of the observations show the influence of vehicles is observed at every location in the network (Shusterman et al.[25]). Using the observations and a weather model, Turner et al.[26] find that there was a decrease in vehicle emissions of 45% in the early phase of the COVID-19 shelter-in-place. This is in excellent numerical agreement with the decrease in vehicles on the Bay Area's roads of 41%, confirming that the observations can provide the foundations of an extremely accurate emissions monitoring system. Extension to air quality variables is in progress, and to health through a project in Richmond, California, connecting childhood asthma episodes to exposure to poor air quality.

Indianapolis The Indianapolis Flux Project (INFLUX) aims to develop and assess methods for evaluating urban greenhouse gas (primarily CO_2 and methane) emissions. As one of the longest running urban greenhouse gas networks, multiple methodologies have been assessed, and the 10-year dataset is available for ongoing research. A recent study entailed a closed loop of GHG assessment in Indianapolis, comparing three different CO_2 emission estimation methods: an inventory-based method and two different top-down atmospheric measurement approaches. By accounting for differences in spatial and temporal coverage, and partitioning fossil fuel and biogenic CO_2 fluxes, they found agreement among the wintertime whole-city fossil fuel CO_2 emission rate estimates to within 7%. This finding represented a major improvement over previous comparisons of urban-scale emissions, making urban CO2 flux estimates from this study consistent with local and global emission mitigation strategy needs. (Turnbull et al.[27]). The INFLUX testbed affords opportunities for method development including the upcoming urban atmospheric inversion intercomparison (https://sites.psu.edu/influx/).

4. Technical roadmap

We envision Air Quality Services at multiple points along the Science-Policy pipeline. The technical roadmap to enable useful Air Quality Data Services for cities has 3 stages, as shown in the diagram below. The first stage (Service 1), provides high-resolution gridded air quality data to the cloud storage system, reliably, at scale, and for a reasonable cost. This is no small challenge. Pilot programs which have enabled networks of low-cost sensors include the BEACO$_2$N Network[24] in the Bay area and beyond, PurpleAir[28], Array of Things[29] in Chicago, Project Eclipse[30] from Microsoft Research in Boston, Seattle area, and Miami, and Cascade Corridor deployments by Portland State University in the Pacific northwest in collaboration with MetroLabs[31]. While each of these deployments represents a relatively successful approach to low-cost high-density sensing, ongoing research attempts to address questions of scale, power/battery life, bandwidth usage, enclosure design for airflow, calibration after deployment to address drift, and robustness in extreme temperatures.

The high-resolution air quality data should be made available to the public in near-real time. Real-time data can be incorporated into maps and services which help the public assess immediate risks and conditions and make decisions about their routes and behavior. See the Appendix covering Microsoft Azure's mapping services. A year-over-year record of air quality data can be used to provide information about extreme events – such as fires – and to assess discrepancies in air quality across socio-economic classes. This first service may utilize a combination of low-cost monitoring networks and data fusion techniques to interpolate between measurement sites.



A second, higher-level service (Service 2) would provide data-driven predictive models of air quality that can inform policy decisions. This will involve optimal syntheses of ideas from data science, weather modeling, and Bayesian inference to creating meaning for technically adept users of the information. It will include developing and improving emissions models to characterize pollution sources based on observed air quality measurements. It will involve developing predictive models to interpolate between discrete data measurements. This stage will involve integration with other data sources such as economic models, traffic data, map data, satellite data, etc.

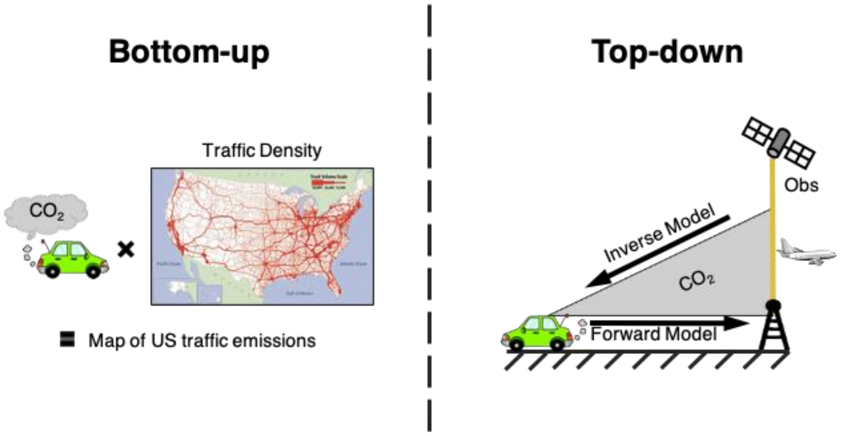
Finally, the synthesis of observations and models will be packaged for use by civic leaders and their constituents in assessing the path for government and private investment on cleaner air and climate protection (Service 3). As an example of this kind of work, IG^{3}IS[32] is a World Meteorological Organization ongoing program working on linking CO_2 measurements, observations, and modeling to policymakers and their goals. Current IG^{3}IS[32] efforts include regular science-stakeholder symposiums, and Good Practice Guidelines for assessment of urban greenhouse gas emissions.

5. Research questions and agenda

Measuring Air quality for public health and Greenhouse Gases for climate change are linked issues

Dense air quality measurements are useful for studying and understanding the presence and concentrations of pollutants throughout a city, for public health reasons as explained in the introduction. But they are also useful for studying emissions levels of pollution sources through an inverse modeling process, and this is key to addressing climate change issues. Although CO_2 concentrations are not high enough, even at 500ppm, to affect daily human health, CO_2 emissions are vitally important to quantify for the long-term health of the planet. Simply put, for climate change, we care about the emission rate of Greenhouse Gases (GHG) instead of concentration in place. For public health, we care about the concentrations of pollutants in locations where humans live and breathe. But both can benefit from the deployment of a dense air quality network throughout a city.

One approach to modelling GHG emissions was described above in Section 3 on the successful project in Indianapolis (Turnbull et al.[27]). Using a few towers per city with expensive, finely calibrated instruments to measure CO_2 levels in the atmosphere above a city, combined with ground-truth economic data and measurements from airplanes collecting measurements in downwind areas, (Turnbull et al.[27]) are able to accurately quantify CO_2 emissions in the city of Indianapolis. The following diagram illustrates this combined approach to modelling emissions.



Cities have historically relied on a *Bottom-up* approach to estimate their greenhouse gas emissions. This bottom-up approach can be thought of as an accounting method: “if we know how many cars there are and how much each car emits, then we can estimate their total emissions”. In contrast, the *Top-Down* approach measures the amount of CO_2 in the atmosphere and uses a model to track where the CO_2 came from. The top-down approach requires a city to have a monitoring network in place to monitor the concentrations in real time. This top-down approach is often formulated as a Bayesian inference (or machine learning) problem where the bottom-up estimate is the starting point (or the prior) and we use atmospheric observations to estimate the most likely emissions. This is the approach used to calculate the change in emissions in the San Francisco Bay Area during the COVID shelter-in-place (Turner et al.[30]). Other top-down approaches include mass balance methods which essentially treat the urban emissions as a giant hosepipe (e.g., Heimberger et al.[33]); and ratio methods that measure two gases, whereby the emission rate of one gas is known (or better known) and the emission rate of the second gas is determined from the ratio of the two in the atmosphere (e.g., Plant et al.[34]).

There are several promising research directions that involve the use of machine learning to process the massive datasets collected by air quality sensors, weather simulations, and remote sensing satellites. Machine learning can be used to combine measurements taken by a variety of sensors and interpolate or forecast future air pollution concentrations (Hamelijnck et al[35]). Similarly, machine learning can be used as a computationally efficient approximation for the more expensive mathematical inversion techniques traditionally used (Lucas et al.[36]; Rolnick et al.[37]).

Here are some concrete examples of the research questions and agenda to enable an effective Air Quality Service:

Question 1 (observation level): What is the air quality at the neighborhood scale?

Most previous air quality work has been done at the city-scale due, in part, to the limited density of measurements. Increasing the density of measurements with low-cost sensors in combination with data fusion techniques would allow us to characterize neighborhood scale variations in air quality. Example question: impact on public health (which requires knowing the spatial distribution of air quality at high resolution).

Question 2 (predictive level): How will air quality respond to a specific policy?

Example questions: how will air quality change in response to urban greening? How will electrification of the fleet affect air quality? What are the air quality co-benefits of CO_2 mitigation efforts?

Question 3 (inference level): Can we observe the impact of a specific policy on air quality and climate?

Example questions: What was the *actual* impact of an urban greening policy on air quality and climate? Are we meeting our commitments to emission reductions for climate agreements?

6. Issues and Opportunities

Jurisdiction: (city vs. county vs. region/state vs. Federal)
Mayors have recently emerged as critical leaders in policy evolution related to climate change and environmental issues (MAYOR Groups[38]). The hyper-local character of some air quality factors (e.g., vehicles, airports, seaports, industrial processes, buildings) implies that leadership on the city scale is well positioned to understand the best ways to leverage Air Quality Data Services for locally impactful change. However, air pollution does not obey municipal borders, and therefore city-scale optimizations made in isolation may simply shift air pollution between neighboring communities, generating a significant risk of exacerbating existing well-documented environmental justice issues (e.g., EnvJustice[39]).

As higher resolution data become available, opening new opportunities to measure impacts of interventions and develop responsive policies, it may be logical to develop metro-region (or "airshed") scale management groups to optimize improvements and minimize spillover effects. Federal legislation related to surface water pollution from stormwater discharges (EPA-MS4[40]) has resulted in a successful demonstration of a similar structure built around watersheds. Currently, not all components of air quality that may be considered "pollution" are regulated by the EPA. This therefore highlights critical questions related to geographic and regional coordination that must be answered alongside the development of technology solutions for Air Quality Data Services.

Economics: How can cities fund sensor deployment, data storage, and cloud services required?

Cities and regions will need to have an ongoing revenue stream to support the installation and maintenance of monitoring instruments and to finance secure raw data storage in the cloud and the high-performance computation necessary to properly evaluate the fossil fuel emission data. Ideally cities around the globe would be networked together to provide an extensive international marketplace and would share a common software infrastructure to ensure level participation. The GEMM initiative[41] is working with international standards laboratories to install GHG and air pollution measurement systems in a variety of urban environments and develop and demonstrate the appropriate analysis tools for reliable and reproducible GHG quantification. Microsoft, as a global supplier of software and hardware solutions, is well-positioned to be a key initiator and major player in the evolution of this new financial market.

The current carbon emission reduction Cap and Trade agreements that have been set up in various regions around the world are quite often limited by the availability of emission reduction credits. This limit is significantly slowing the reduction of greenhouse gas (GHG) emissions by restricting the volume of trades on the Cap and Trade marketplace, which industries use to offset their emissions and efficiently finance more cost effective GHG emission reduction programs. Because urban regions produce the most emissions, ~70% of the world total, reductions by cities and regions via various energy efficiency and renewable energy options are an attractive but unexplored option for obtaining credits, the magnitude of which has the potential to supply a substantial part of the anticipated stream. For urban involvement in Cap and Trade markets accurate quantification technologies to support emissions credits with scientifically defensible emissions measurements and reliable emission source models are essential. Such quantification capabilities would provide the support needed for the fungibility of these financial assets.

Linking the climate finance community with urban centers based upon advances being made by the emissions measurement R&D community is a critical step toward providing evidence to support quantification of urban emissions. Its realization would provide the essential confidence needed to support orderly entry into these markets. Urban emission credit quantification will significantly expand credit availability and contribute significantly to the acceleration of GHG emissions reductions in the US and worldwide. Moreover, an urban involved cap and trade program would provide additional revenues to the participating cities to implement strategies for reducing both GHG and air pollution caused by fossil fuel burning, supply funds to both implement carbon capture programs, such as expanded park areas and urban tree planting, and fund installation and operation of the necessary monitoring instrumentation, data collection/storage and software analysis systems that provide quantification capabilities. These capabilities are beginning to reach maturity levels although the need for significant further research remains.

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Appendices:

This document summarizes and draws on the collective work of many leading scientists, agencies and efforts. It is intended to amplify and tune the message emerging from the work ongoing in the following collaborations:

Umbrella organizations working to connect research to policy and stakeholders.

- WMO IG^{3}IS (Integrated Global Greenhouse Gas Information System). Links atmospheric observations and modelling to emissions reporting and policy. Four working groups: National, urban, methane, global stock take. Currently developing Good Practice Guidelines for Urban GHG Monitoring and Assessment. Buy-in from both research and policy communities. Endorses/supports GHG research projects that progress the IG3IS goals. https://ig3is.wmo.int/
- NIST/BIPM. Aims to eventually develop documentary standards for GHG monitoring and assessment at urban scale. Complements IG3IS effort. https://www.nist.gov/topics/greenhouse-gas-measurements
- CO2USA. Science-driven project that links urban GHG research with policy at the urban scale. It has made substantial progress in standardizing methodologies across cities in the US, and in engaging stakeholders. http://sites.bu.edu/co2usa/
- ICOS. European project using atmospheric observations and modelling to infer Europe's GHG emissions, one focus group on urban areas. https://www.icos-cp.eu/
- Helsinki Air Quality Testbed (HAQT) project involved building a more extensive air quality measurement system, which complements the existing network covering the entire Helsinki Metropolitan Area to develop measures that improve air quality. The project was led by the Finnish Meteorological Institute. Its partners were the University of Helsinki, the Helsinki Region Environmental Services Authority HSY, Pegasor, Vaisala and the Helsinki-Uusimaa Regional Council. The air quality data produced by the new sensor network is openly accessible to anyone through REST API.
- https://www.bristol.ac.uk/chemistry/research/acrg/current/dare-uk/

Other greenhouse gas projects in the US: INFLUX (Indianapolis Flux Project), LA Megacity, Salt Lake City, Boston, NorthEast Corridor. Internationally: Paris, London, Recife Brazil, Melbourne, Auckland, Beijing-Tianjin- Hebei, Tokyo. There are many others, some much smaller or newer projects.

Microsoft is already building and deploying significant assets in this space. Here is a summary of some of the current and future deployments.

Microsoft Azure Maps is a platform of geospatial APIs and SDKs offered natively in Azure. To highlight some current capabilities, Azure Maps offers current and forecasted weather air quality data, real-time and historical traffic information, routing (private vehicles, EV vehicles, trucks), public transit routing and real-time arrivals, high resolution satellite and imagery data, and integration with Microsoft Power BI and Power Apps. Specifically, the Azure Maps Platform is offering:

- Weather services which allow access to REST APIs to integrate highly dynamic, real-time weather data and visualizations into their applications and other solutions with the following capabilities:
    - Enhance data visualizations with past, current and future radar and infrared map overlays.
    - Make weather-based decisions with current and forecast based weather and air quality information, as well as weather along route that supports the generation of weather notifications for waypoints that are affected by weather hazards, such as flooding or heavy rain.
    - Access to historical weather data

  There are a multitude of scenarios that require weather information starting from end-user facing applications to creating AI models. For example, cities can reroute vehicles based on real-time and predicted weather, air quality and traffic conditions to minimize congestion and improve air quality in urban areas.

- Route services support multiple routing related scenarios covering routing support for private, electric, and commercial (trucks) vehicles. The routing directions and route matrix services in Azure Maps can be used to calculate ETA's for trips. The route directions service returns instructions, including travel time, and the coordinates for a route path while the route matrix allows you to calculate the travel time and distances for a matrix of locations. Our APIs have rich set of capabilities and parameters that enable customers to not only optimize routes for time and expense based on real-time or predictive/historic traffic data, but also for driving their sustainability goals through optimizing for environmental impact. This is achieved through the various parameters that are part of our APIs that enable customers to make the most environmentally sustainable routing decisions based on type of engine, fuel consumption, type of terrain and more. Routing for Electric Vehicles can consider locations of charging stations, remaining charge, traffic congestion, best times for travel based on weather conditions and traffic and more.

- Traffic services can be used for web or mobile applications that require real-time traffic information and want to visualize the traffic on a map. The service provides two data types:
    - Traffic flow: Real-time observed speeds and travel times for all key roads in the network.
    - Traffic incidents: An up-to-date view of traffic jams and incidents around the road network.
- Mobility services improves the development time for applications with public transit features, such as transit routing and search for nearby public transit stops. Users can retrieve detailed information about transit stops, lines, and schedules. The Mobility service also allows users to retrieve stop and line geometries, alerts for stops, lines, and service areas, and real-time public transit arrivals and service alerts. Additionally, the Mobility service provides routing capabilities with multimodal trip planning options. Multimodal trip planning incorporates walking, bicycling, and public transit options, all into one trip. Users can also access detailed multimodal step-by-step itineraries.
- Azure Maps SDKs allow developers to use this interactive map for both web and mobile (Android) applications. The web map control makes use of WebGL, so customers can render

large data sets with high performance. The Azure Maps Web SDK also provides the Spatial IO module, which integrates spatial data with the Azure Maps web SDK allowing developers to

  - Read and write common spatial data files. Supported file formats include: KML, KMZ, GPX, GeoRSS, GML, GeoJSON and CSV files containing columns with spatial information. Also supports Well-Known Text (WKT).
  - Connect to Open Geospatial Consortium (OGC) services and integrate with Azure Maps web SDK. Overlay Web Map Services (WMS) and Web Map Tile Services (WMTS) as layers on the map.
  - Query data in a Web Feature Service (WFS)