Urban Pathways

# HIGH IMPACT, LOW-COST SENSORS AND CITIZEN SCIENCE FOR URBAN AIR QUALITY MANAGEMENT

UN-HABITAT FOR A BETTER URBAN FUTURE

Centre for Global Equality

open-seneca air quality sensing powered by citizen science

Author: Center for Global Equality; Open Seneca

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## Urban Pathways

***The Urban Pathways project helps delivering*** on the Paris Agreement and the NDCs in the context of the New Urban Agenda and the Sustainable Development Goals. It has established a facility in close cooperation with other organisations and networks active in this area to support national and local governments to develop action plans and concrete implementation measures to boost low-carbon urban development. This builds on UN-Habitat's role as "a focal point on sustainable urbanisation and human settlements including in the implementation and follow-up and review of the New Urban Agenda". The project develops national action plans and local implementation concepts in key emerging economies with a high mitigation potential. The local implementation concepts are being developed into bankable projects, focusing on the access to urban basic services to create a direct link between climate change mitigation and sustainable development goals.

## Project concept

***The project follows a structured approach to boost*** Low Carbon Plans for urban mobility, energy and waste management services that deliver on the Paris Agreement and the New Urban Agenda. The project works on concrete steps towards a maximum impact with regards to the contribution of urban basic services (mobility, energy and waste management) in cities to global climate change mitigation efforts and sustainable and inclusive urban development. This project makes an active contribution to achieve global climate change targets to a 1.5°C stabilisation pathway by unlocking the global emission reduction potential of urban energy, transport and resource sectors. The project will contribute to a direct emission reduction in the pilot and outreach countries, which will trigger a longer term emission reduction with the aim to replicate this regionally and globally to make a substantial contribution to the overall emission reduction potential.

## Project aims

***This project implements integrated urban services*** solutions as proposed in the New Urban Agenda providing access to jobs and public services in urban areas, contributing to equality and social coherence and deliver on the Paris Agreement and the Sustainable Development Goals.This is the first dedicated implementation action oriented project, led by UN-Habitat to deliver on inclusive, low-carbon urban services. Securing sustainability and multiplier effect, the project aims to leverage domestic and international funding for the implementation projects that will follow from this initiative

Urban Pathways

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# SETTING THE SCENE

Anthropogenic air pollutants from motor vehicles, heating, construction, and industry are a significant contributor to climate change and many health problems experienced today. In fact, atmospheric fine particulate matter (PM) is affiliated with the main driving forces of global warming and causes 7 million premature deaths every year, according to the WHO[1]. PM is usually monitored using large and expensive reference stations, which require costly calibration and maintenance. However, reference stations only provide air quality data from one fixed location, which generally is neither representative for an entire city nor for the experience of individuals moving around the city. In low- and middle-income countries (LMICs), where reference stations are often unaffordable, there is very limited data assessing air quality available, which results in a general lack of appropriate policies to control air quality and a lack of awareness about the negative health effects associated with the often-alarming levels of air pollution experienced by ordinary citizens. With the predicted rise in population and rapid motorisation rates in many LMIC cities, an urban health crisis is anticipated if no action to lower pollution levels is taken.

In order to support the development of sustainable urban mobility plans in LMICs, collecting finely grained air quality data of urban areas is essential to provide evidence for transitioning towards efficient and clean mobility systems. The use of low-cost air quality monitors has the potential to supplement existing monitoring stations (if any) by deploying affordable, rapid sensor networks across the city that can fill in spatial and temporal gaps in air quality data. Moreover, the flexibility of deployment of these low-cost sensors enables measuring the impact of intervention activities aimed at improving air quality at a far lower geographical scale than would normally be possible, fomenting their replication and scale-up at the local, national, and global level. Combining the hyper-local air quality data provided by these low-cost devices with air quality modelling tools, provides cities with a powerful city decision support tool to control air pollution and identify the best sustainable urban mobility plans.

Herein, in the framework of the Urban Pathways project, this project combines the deployment of low-cost, mobile open-seneca air quality monitors with the air quality modelling capacity of the University of Helsinki to empower Urban Pathways partner cities with an air quality city support decision system. The three selected cities for implementation of this project are Kigali (Rwanda), Quito (Ecuador), and Kathmandu (Nepal).

1 https://www.who.int/airpollution/data/cities/en/

# BACKGROUND

## Urban Pathways

The Urban Pathways project works closely with several cities in Asia, Africa and Latin America in the design, development and implementation of sustainable urban infrastructure projects that contribute to the achievement of the Sustainable Development Goals, the Paris Agreement, and the New Urban Agenda. Currently, the programme focuses on developing national action plans and concrete local implementation concepts to boost low-carbon urban development in key identified emerging economies, towards a maximum impact in cities to global climate change mitigation efforts and sustainable and inclusive urban development.

## The Centre for Global Equality (CGE), open-seneca initiative

The Centre for Global Equality (CGE) is a Cambridge-based charity, which facilitates collaboration between business, academia, and civil society to address the problems that undermine the wellbeing of the poorer half of the world's population. CGE cultivates innovative solutions to global challenges through their Global Goals Innovation Cultivator (GGIC). One of CGIC's members is the 'open-seneca' initiative, led by six PhD students at the University of Cambridge.

Open-seneca deploys low-cost, mobile air quality sensor networks driven by citizen science. The aim of the initiative is to build local capacity for deployment of large-scale air quality monitoring networks, with two main objectives: (1) provide actionable, high-resolution air quality city maps to policy makers to inform a data-driven transition towards cleaner transport systems, and (2) empower citizens with data about their personal exposure to pollution and drive behavioural change about the use of cleaner transport means.

Combining the use of low-cost sensors with a citizen science approach makes them even more powerful by enabling the monitoring of personal exposure and the identification of hotspots of air pollution. Engaging citizens allows raising their awareness about the importance of taking action to reduce air pollution and to empower them as active stakeholders in the search for solutions. A society that is aware can have a huge impact in reducing air pollution: by reducing their own individual emissions, by minimising their personal exposure, and by complying to measures to reduce emissions implemented in cities by local governments.

# OBJECTIVES

This project aims to build capacity and provide tools that improve the air quality monitoring and management system of LMIC cities to support evidence-based decision-making processes related to reducing air pollution. Three Urban Pathways partner cities have been selected for this implementation: Kigali, Quito, and Kathmandu. In particular, this project envisions to deploy a network of low-cost, mobile air quality monitoring devices with a citizen science approach as a tool to 1) obtain air quality data with a high spatial and temporal resolution to support decision-making, and 2) raise awareness among citizens about their personal exposure to pollution and health effects to trigger behavioural change.
Specific objectives include:

- Support the deployment of open-seneca low-cost air quality sensors in the partner cities.
- Build local capacity on the assembly, management and maintenance of the air quality sensor network.
- Inform and engage decision makers about the usefulness of integrating low-cost sensors in their air quality monitoring system, and about the applications of the collected air quality data in land use planning, mobility, and urban design.
- Promote a collaborative approach to urban planning by increasing citizen participation in AQ management and engaging them in the identification of issues, deployment of the sensors, and identification of potential solutions.

# GENERAL METHODOLOGY

Open-seneca deploys low-cost, mobile air quality sensor networks powered by citizen science. The sensors are open-source and transmit geo-tagged particulate matter (PM2.5), temperature and humidity data to a visualisation platform, where an automated data-processing pipeline generates aggregated city maps. These maps are shared with local communities and policymakers alike to drive the search for solutions that can be implemented at both individual and city level.

To ensure long-term uptake and impact of the initiative, open-seneca partners with local organisations and builds capacity on how to assemble, distribute, and maintain the sensor network. The open-source nature of the project allows for the sensor to be adapted to local requirements. The initiative has a strong focus on education and community engagement, involving citizens in all the phases of the project: sensor assembly, data collection and interpretation and identification of solutions to improve air quality.

To achieve the objectives of this project, the following interlinking methodology elements were implemented:

**Stakeholder identification**

The first activity was to partner with a local organisation that would lead the initiative on the ground ("local champion"), helping organise workshops, find volunteers for data collection, maintain the sensor network, and ensure local appropriateness of the project. Additionally, other stakeholders need to be involved:

1. Local government: to inform policy makers and ensure usability of the data
2. Air quality experts: to manage the air quality sensor network and ensure local appropriateness.
3. Delivery operators and citizen groups: to facilitate data collection.

The identification of stakeholders was led by the Urban Pathways team, which since 2017 has built long-standing relationships with the local governments and other stakeholders in its partner cities. Each city was represented by one Urban Pathways and one open-seneca team member. Once the relevant stakeholders in each city were identified, regular meetings with open-seneca, the Urban Pathways city representatives and local stakeholders were organised to coordinate the remaining activities.

**Deployment of low-cost, mobile air quality sensor network**

**The open-seneca sensor**

The open-seneca air quality monitor is a low-cost, small, portable sensor that measures

- PM2.5 / PM10 (Sensirion SPS30 Particulate Matter Sensor)
- Temperature and humidity (Sensirion SHT31)
- GPS location (u-blox GPS module)

at a sampling rate of 1 Hz. The sensor can be either carried on a wrist band or mounted on various vehicles through the integrated, standardised Garmin-style mount, ensuring secure operation.

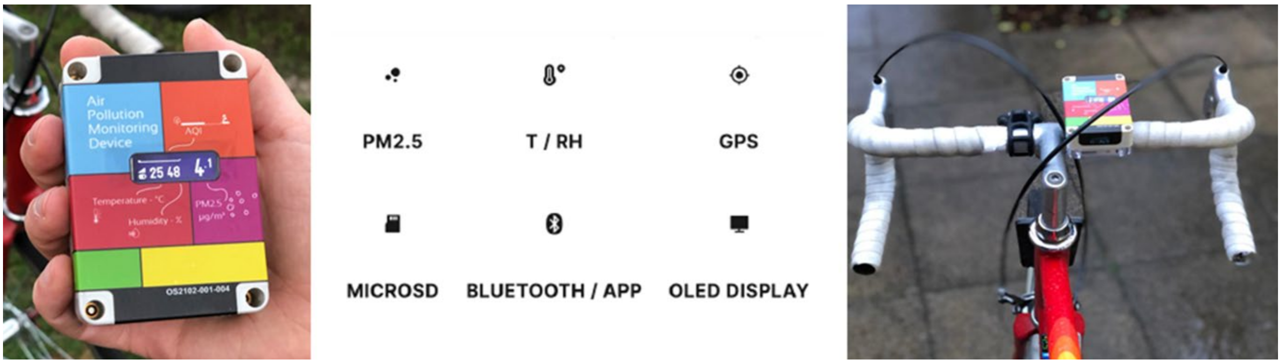



Figure 1. open-seneca air quality sensor, with main characteristics and mounting mechanism.

The live readings are displayed on an onboard display to allow the user to identify air pollution hotspots immediately, and there are two main modes for data transfer to choose from depending on the local context (i.e., mobile data availability on user's phone, internet connection, etc.):

- Connect to a smartphone app via Bluetooth protocol to autonomously send the gathered pollution data to the open-seneca platform for processing. By connecting the device to the open-seneca app, live data as well as historic user data can be visualised on a map and sources of pollution can be reported by the user.
- Save data locally in an SD card, that can be extracted from the device and

the data manually transferred to a computer and uploaded to the open-seneca platform.

**Data quality**

The open-seneca particulate matter sensor is pre-calibrated and shows excellent inter-sensor comparability. Previous field tests showed that when open-seneca sensors are co-located (placed in the same location for an extended period of time to compare the readings reported by each individual sensor), the measurements are within ±0.6 µg/m³. This allows to compare readings of sensors moving around the city and identify which areas are more polluted than others (understanding spatial distribution of PM2.5 and finding hotspots of pollution), as well as comparing PM2.5 levels before, during, and after intervention activities aimed at reducing air pollution.

In order to provide accurate PM2.5 absolute values (i.e., knowing the exact concentration of PM2.5 in a specific location instead of performing relative comparisons), an additional calibration step with a reference monitoring station in the city is necessary. This step is only possible if the city already has existing air quality monitoring reference stations and could be performed post-deployment. Due to the time restrictions of this project, it was agreed with the local stakeholders of each city that the calibration would be performed after the deployments and therefore it is not subject of this report.

**Procurement and deployment**

A total of 60 open-seneca air quality monitors were shipped to each city (20 sensors per city). Depending on the needs of each city, the sensors were shipped in two formats:

- Kit containing all the necessary parts to assemble an air quality sensor, with assembly instructions. These kits were used to build local capacity in workshops to teach local stakeholders how to assemble, repair and maintain the monitors.
- Pre-assembled sensors: to be used as reference in assembly workshops and accelerate the deployment of the network due to time constraints.

All three cities requested a mixture of the two formats. Shipment was arranged as a donation to the cities and the deployment was organised on different types of vehicles, selected by the cities.

**City air quality maps**

The collected geo-tagged pollution data is aggregated by open-seneca into meaningful air quality city maps. The resulting actionable datasets can not only provide a baseline for the whole city, but also a street-to-street level comparison that highlights hotspots of air pollution. All the collected raw data, as well as the generated city maps, was fed into the University of Helsinki's Mega Sense platform to provide real PM2.5 data as an input for their air quality model.

The collected air pollution data is aggregated temporally and spatially:

- *Temporal variations of PM2.5:* the data from the whole city is aggregated daily to obtain the baseline PM2.5 concentration of the city (calculated as the median in 24h periods) and analyse how this baseline varies over time. This baseline is not affected by localised spikes in air pollution that users might experience while they commute in the city, and rather gives an understanding of the city background pollution, which strongly depends on meteorological conditions and other external conditions, such as long-range transboundary particulate pollution.
- *Spatial variations of PM2.5:* the data is aggregated over the whole data collection period to provide city pollution maps that highlight which areas are more polluted than others. Two types of maps can be generated:
  a. *Absolute PM2.5 maps:* they display the spatial distribution of measured PM2.5 concentrations. It is important to note that sufficient data needs to be collected in the whole city every day to provide a realistic view of the air pollution distribution in the city. If the coverage is not sufficient, these maps could be highly skewed by the city baseline. As an example, if one part of the city was mapped on days with higher baseline, it would look more polluted than others mapped on days with low baseline. Therefore, the absolute PM2.5 map should not be used to understand spatial variations of PM2.5 in the city, and instead, the hotspot map (PM2.5 with baseline subtracted) should be used
  b. *Hotspot maps:* they display PM2.5 concentrations in the city once the cities' PM2.5 background is subtracted, effectively highlighting which areas of the city are more polluted than the average (hotspots) or which areas are less polluted ("cold spot"). This visualisation technique corrects for city-scale PM2.5 clouds (e.g., fog) that macroscopically moves across the city and can cause all active sensors to record "false" local hotspots. The PM2.5 background is calculated as the 15-minute moving-median value of all PM2.5 readings across the city. To facilitate the visualisation of these maps, the colour scale is set so that areas that have average pollution levels are shown in green, and areas that consistently exceed the city background will be highlighted in red. For example, in a hotspot map, a zone that displays a value of 15 μg/m³ means that its particulate pollution levels are 15 μg/m³ above the median value of all sensors that submitted PM2.5 data within the last 15 minutes. If that zone consistently records higher PM2.5 than the background, then it is classified as a hotspot. These hotspots can be filtered according to a chosen set of validation criteria: e.g., a minimum number of datapoints, minimum number of independent users or unique time

periods that measure high PM values in the same area.

- Temporal variation of city pollution maps: if sufficient data is collected regularly throughout the day and the city, pollution maps can be generated for shorter time frames than the total data collection period. For example, maps can be generated for different hours of the day or different days of the week to understand how changes in traffic behaviours impact different parts of the cities.

Additionally, other important information can be obtained by analysing the collected air quality data, such as at what times of the day the data was collected, or how PM2.5 varies at different times of the day according to traffic conditions and rush hours.


Figure 2. Community engagement in all the phases of the air quality monitoring process.

**Community engagement**

This project involves citizens in all the phases of the project (see Figure 2): sensor assembly, data collection and interpretation and identification of solutions to improve air quality. This holistic and inclusive approach not only helps build local capacity on how to assemble, deploy, manage, and maintain the sensor network; but it leverages the power that engaged communities can have in driving change and bringing value to the collected air quality datasets.

In order to involve local stakeholders and citizens, a series of online workshops were organised in all three cities:

- *Train-the-trainers workshop:* knowledge is transferred to the identified local organisation about the open-seneca sensor technology and operation, as well as on how to build, deploy, manage, and maintain networks of these mobile sensors. After this workshop, local stakeholders are able to test that sensors work appropriately, train citizens on how to assemble and use the sensors, and organise the network deployment on different modes of transport. During this workshop, specific local needs are addressed to make the sensor appropriate for the local context.

- *Sensor assembly and distribution workshops with citizens:* once trained, the local stakeholders can deliver workshops to engage citizens in both the assembly and use of the open-seneca sensor. These workshops were conducted in person and delivered by the local stakeholder with the online support of an open-seneca team member. Previously developed educational materials from open-seneca were used to facilitate the session, such as sensor assembly and operation video instructions. In some cases, local stakeholders contributed to the creation of educational materials translated to the local language to increase inclusivity and accessibility. At the end of the distribution workshop the sensors were directly mounted on the vehicles used for data collection and users instructed on how to visualise the air pollution they are exposed to while they carry the sensor.
- *Data interpretation workshop:* once the data is collected, an essential component is to bring meaning to the air quality maps. For this, local knowledge of the city dynamics and additional information is critical. The maps were shared with the local stakeholders to help identify hotspots and sources of pollution. In the cities where extra datasets were available, such as a map of paved/unpaved roads, the air quality data was linked to the provided datasets. Volunteers carrying a sensor contributed by answering questions about their experience during the data collection period. The questions were asked by the local stakeholders and answered in a conversational manner, therefore some quotes are available. Example survey questions were:
    - » How was the traffic when the sensor showed high values of PM2.5?
    - » How was the traffic when the sensor showed low values of PM2.5?
    - » What do you think are the main sources of particulate pollution in your city?
    - » What situations caused the sensor readings to spike?
    - » What did you learn during the experience?
    - » Did seeing your personal exposure to pollution cause any change in your perception or behaviour?
- *Presentation of results to policy makers:* the air quality city maps, together with the data analysis and University of Helsinki's modelling are presented to the local authorities with the aim to inform them on the power of using a combination of low-cost air quality sensors, citizen science, and air quality modelling to provide evidence for a transition to cleaner mobil-

ity and support decision-making. Another objective of this workshop is to identify initial recommendations or solutions that can be implemented in the city to reduce air pollution in the identified hotspots. Because the data collection is continuing beyond this project, this workshop will be conducted after the completion date of this project.

# IMPLEMENTATION CITIES

**Kigali**

**Local Stakeholders**

- Emilie Martin, Researcher at the Urban Electric Mobility Initiative (UEMI)
- Dr Egide Kalisa, Postdoctoral Researcher, Expert in Air Pollution and Environmental Science and Health, University of Toronto and College of Science and Technology, University of Rwanda
- Moise Bitangaza, Assistant Lecturer, University of Rwanda
- Ampersand Rwanda Ltd, c/o Clive Irambona, manufacturer of affordable electric motorbikes and charging systems
- Dr Alphonse Nkurunziza, Lecturer at University of Rwanda and international Transport Planning Consultant with the Institute for Transportation and Development Policy
- Francois Zirikana, E-mobility specialist, City of Kigali

**Deployment of Network**

open-seneca shipped 20 air quality monitors, including Garmin-compatible motorbike mounts and USB charging cables to the University of Rwanda in Kigali on 8th August 2021. Prior to the shipment, the respective documentation to release the shipment from customs was prepared in accordance with Rwandan law n°37/2012 of 09/11/2012, and particularly 6,3°, to assure rapid processing and release. The shipment arrived in Kigali on 18th August 2021. However, the customs office was awaiting the approval of the Rwandan Ministry of Education, which was gathered by the project's local champion Dr Egide Kalisa. The customs office released the sensors on 31st of August 2021 and the project's main local stakeholder, Moise Bitangaza, organised their transfer from the airport to the Ampersand office.

Following the delivery of the open-seneca sensors to Ampersand, a capacity building and deployment workshop was held on 1st September 2021 in Ampersand's Kigali office. During this workshop, 16 air quality sensors were fitted to the Ampersand electric motorbike fleet and four devices were fitted to private bicycles. The local stakeholders, including Moise Bitangaza, Clive Irambona and the Ampersand delivery drivers, independently resolved mounting issues by organising rubber spacers from a local shop, as the mounting arm was too wide to fit the motorbike's handlebar. The handlebar mounting position was chosen over various other suggested locations on the motorcycle to prevent compromises of the driver's safety while riding and to avoid splash water damaging the electronics of the sensor. During the workshop, the drivers were briefed on the basic operation of the open-seneca device, e.g., collecting data, charging as well as mounting, and received an introduction to the different parameters collected by it. As Ampersand's electric motorbikes are powered by battery, the open-seneca sensors were connected via USB to the motorbike, which made the continuous operation of the monitor possible and enabled the collection of air pollution data in unprecedented spatial and temporal resolution. While the Ampersand drivers were asked to operate their sensor constantly during the business hours, the cycling volunteers used their device during commutes and exercise. The sensors were deployed for four weeks (1st September 2021 - 1st October 2021) and are currently stored at the University of Rwanda, to be deployed by the end of the year on public bicycles.

Figure 3. Fitting of open-seneca sensors. Left and middle: open-seneca sensors are placed on the Ampersand electric motorbikes during the capacity building and deployment workshop at Ampersand's Kigali Office, 1 September 2021. Right: open-seneca sensor mounted on a private bicycle. Picture Credit: Moise Bitangaza.

## Data Collection with Citizen Science Approach

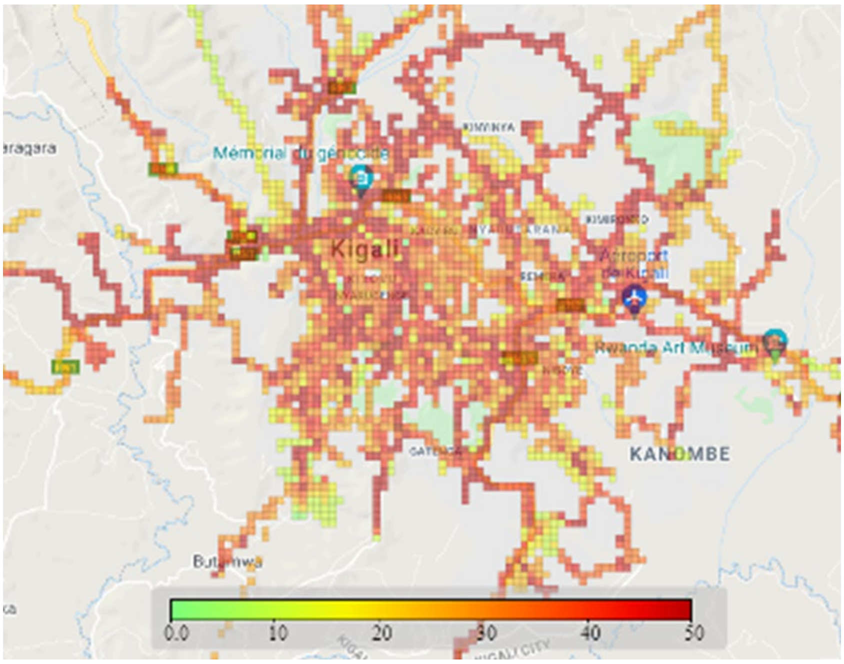



Figure 4. Air pollution map of Kigali. The map shows the aggregated, geotagged PM2.5 pollution data collected over four weeks with the open-seneca sensor mounted on Ampersand delivery motorbikes.

The data collection period was chosen to be four weeks initially with 16 sensors mounted on Ampersand's electric motorcycles and four sensors on private bicycles. Based on previous multilateral discussions between open-seneca, Ampersand and UEMI, it was decided that the data will be collected offline on the sensor's SD card, as the Ampersand drivers did not have access to a smartphone or sufficient data plan to upload data on the go. This required manual uploading to the open-seneca data platform, kindly facilitated by Moise Bitangaza once a week. After four weeks, the drivers had collected more than 6M data points in Kigali, each corresponding to an individual air quality measurement at a specific location. All data has been fed into the University of Helsinki's Mega Sense platform to validate their simulations. After processing the data and removing the pollution baseline of the city, open-seneca identified various air pollution hotspots across the city. The area around the segment of the RN1 in Kigali's Northwest, between Nyabugogo and Nyamabuye, was exposed as the most broadly polluted space in the city during this study. A particularly warning hotspot was found around the highly frequented Nyabugogo bus station area, on the intersection of RN1 and RN3. Around the bus station, the fine particulate matter concentration was determined to be on average 70.9 µg/m³, which was exceeding the newest WHO guidelines for annual exposure to PM2.5 by 14x and for daily exposure by more than 4x.

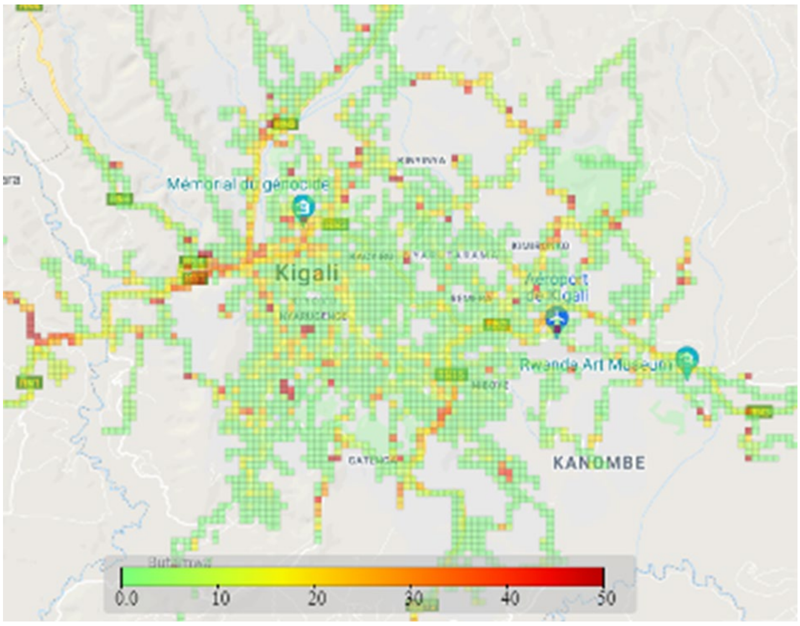



Figure 5. Hotspot (baseline removed) air pollution map of Kigali. The map highlights hotspots of air pollution in the city and shows the processed pollution data collected over four weeks with the open-seneca sensor mounted on Ampersand delivery motorbikes.

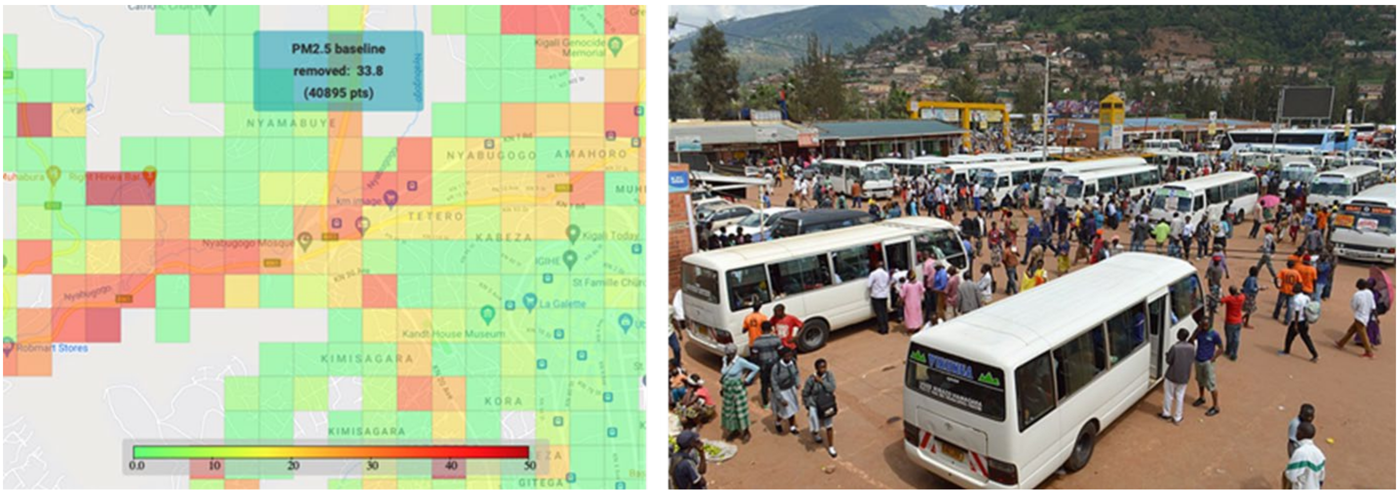



Figure 6. Left: Hotspot analysis in downtown Kigali conducted by open-seneca. The scale is referenced to the PM2.5 baseline of the city, which was found to be 31.0 μg/m³. After data processing and baseline removal, A PM pollution hotspot was exposed at the Nyabugogo bus station, with values exceeding the WHO guidelines on annual PM2.5 exposure by 14x. Right: Photograph of Nyabugogo bus station, highlighting the highly frequented nature of one of Kigali's main transport and trading hubs. Picture Credit: Franciscu Anzola, WikiCommons.

Over four weeks of data collection, the volunteers have gathered 6.6 million data points, each corresponding to an individual air quality measurement of the open-seneca device. Based on the mobility of the motorcyclists, a total area of 162 km² was geotagged with air pollution data, corresponding to over 40000 data points per km². As expected, the sensors were mostly operated during the drivers' business hours between 5 am and 11 pm CAT, with activity maxima at 10 am and 6 pm. The median baseline for the entire collection period in Kigali was found to be 31.0 µg/m³ overall, which is about 6x higher than recommended as annual average by the WHO and in good agreement with previous reports. As outlined above, however, the spatial and temporal concentration of PM in specific locations in Kigali varies greatly, with areas being significantly below the baseline and others strongly exceeding it, as shown in the baseline-removed pollution map.

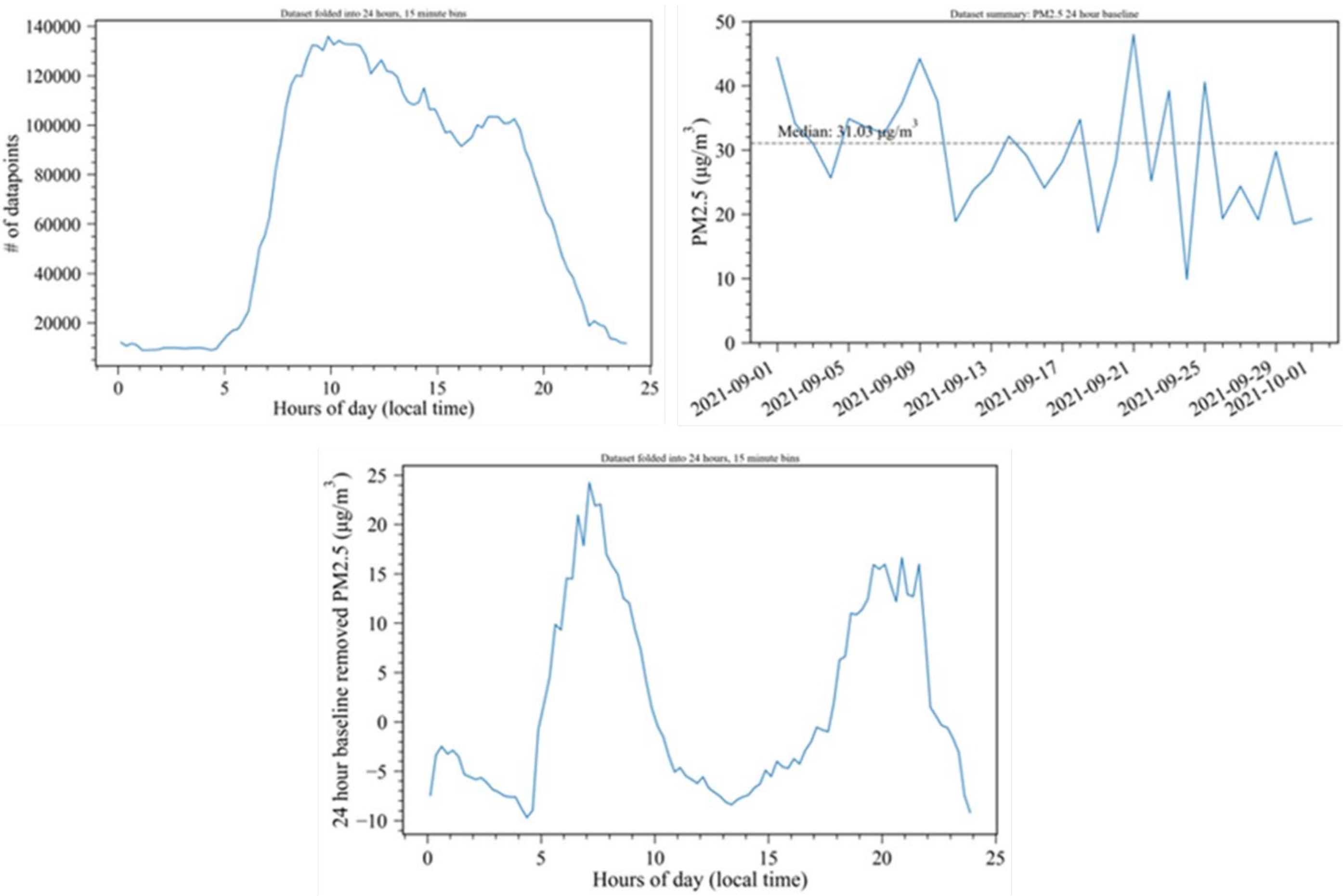



Figure 7. Top Left: Histogram of data point collection with regards to time of the day. The sensors were mostly used during the business hours of 5 am to 11 pm CAT, with maximum usage around 10 am CAT. Top Right: Histogram of average PM pollution during the four-week monitoring period. The baseline of the city is depicted as a dashed line at 31.0 µg/m³. Bottom Centre: Baseline-removed average PM2.5 pollution profile over the course of a day, showing peaks of air pollution during the morning and evening rush hours.

**Community Engagement and Education**

On 15th July 2021, a first collective meeting of open-seneca, Ampersand, Universities of Rwanda and Helsinki, UN-HABITAT and UEMI, was held, discussing the general outline of the project in Kigali. In this meeting, the Kigali partners were briefed by open-seneca on air pollution and the open-seneca sensor, to enable knowledge transfer between open-seneca and local stakeholders. In addition, on 9th September 2021, an internal workshop between open-seneca and Moise Bitangaza was conducted to discuss minor hardware related issues as well as to implement an update of the sensor software. In this context, capacity to maintain and occasionally update the open-seneca sensor locally was created and knowledge transferred to the Kigali team.

It shall be noted that the initial sensor deployment with the help of professional motorcyclists, despite the relatively low citizen engagement in this context, was chosen to assure maximum efficacy in terms of data collection in the remaining time frame of the project. As a result, the largest data set that open-seneca has ever collected could be shared with the University of Helsinki project partners. In line with this reasoning, Ampersand explicitly asked to keep the involvement of the drivers to a minimum to prevent potential interference with their working schedules. As a result, only a basic level of knowledge transfer to the actual end users of the sensor on air pollution and its negative health effects as well as an introduction to the data interaction pathways, e.g. open-seneca app and forum, was possible. Hence, the drivers did not interact with the open-seneca forum and did not comment on pollution hotspots they encountered through the open-seneca app directly. However, a user survey was designed and shared with the drivers, for them to provide feedback on using the device, whether they learned about air pollution and their opinion on sources of air pollution in Kigali. From 16 motorcycle drivers, 11 participated in the survey. All participants reported that they've enjoyed the experience of using the sensor but indicated that they still did not know about PM and air pollution after the end of project in detail, highlighting that informational material or an introductory lecture on air pollution is key to familiarise the users with the parameters they were collecting in order to assure a learning experience and initiate behavioural change. Similar experiences were shared by the cycling volunteers, who indicated that they had enjoyed using the sensor, but suggested that there should have been an informative document highlighting the basic operational features of the device.

The delivery drivers reported that they observed the sensor showing high PM values when they were in traffic jams, areas with high traffic volumes or next to old vehicles. In addition, four of the participants reported high PM values when they were driving on unpaved or dusty roads. In similar fashion, three of the four cycling volunteers indicated that in their experience old ICE-type vehicles are the main source of air pollution in the Rwandan capital, in addition to coal burning. Despite these reports being subject to each volunteer's own commuting route and individual experience in the city, they are clearly in line with reports on sources of air pollution in Kigali in the scientific literature.

In total, 16 motorcyclists, four cyclists as well as the main five local stakeholders were directly involved in the air quality monitoring process during the deployment in Kigali. In this context, a strong stakeholder team, consisting of local air quality experts with extensive knowledge of pollution phenomena in Kigali, academics in the field of Urban Planning, Transportation and Electrification and representatives of the City of Kigali was formed.

For the initial data collection period, only the professional motorcyclists were asked to directly participate and carry a sensor on their vehicle to ensure rapid deployment given the compressed timeline. However, an accessible workshop for the general public will be hosted on 3 November to engage the wider Kigali public and raise their awareness about the health problems associated with air pollution. The general public will have the opportunity to interact with the data and interpret the results with the help of local knowledge. This will be key in understanding the findings and pollution phenomena in the Rwandan capital and allow for citizens from all walks of life to learn about the air quality situation in their hometown. Furthermore, an additional deployment with rental bikes will be carried out at the end of the year to reach a wider audience in Kigali.

The city of Kigali is directly involved in the deployment. It was represented by Francois Zirikana, E-mobility specialist at the city of Kigali, as main stakeholder and will be provided full access to the air pollution maps, a list with the most heavily polluted areas as well as with anonymised survey results stemming from this study to act upon.

**Kathmandu**

**Local stakeholders**

- Bhushan Tuladhar: Head of Environment Department and Member of City Planning Commission at Kathmandu / Sajha Yatayat Cooperative Limited, Nepal
- Abhisek Karki, Department of Mechanical Engineering, Kathmandu University, Nepal
- Shritu Shrestha: Wuppertal Institute for Climate, Environment and Energy, Berlin, Germany
- Nivesh Dugar: Local Champion, GD Labs and Research, Kathmandu, Nepal
- Samip Sigdel: Environmental Engineer, Green Decisions Consulting, Kathmandu, Nepal
- Prof. Dr. Rajina Maskey Byanju: Head of Department of Environmental Science, Tribhuwan University, Nepal
- Kanak Mani Dixit, Chairman, Sajha Yatayat, Kathmandu, Nepal

**Deployment of Network**

With the support of Urban Pathways, open-seneca provided 20 air quality monitoring devices, which arrived in Kathmandu, Nepal, on 19 August 2021. Sajha Yatayat and TU-CDES facilitated arrangements for the devices to reach Kathmandu by signing an MoU with the Centre for Global Equality allowing for tax and duty exemption of the sensor shipment entering Nepal approved by the Ministry of Finance. After the devices were released by customs, a capacity building workshop in Kathmandu was remotely hosted by open-seneca and facilitated by Shrithu Shrestha, representing Urban Pathways, on 1 Oct 2021. The local sensor champion, Nivesh Dugar, gathered more than 10 volunteers for the event, mainly students and members of the cycling network in Kathmandu. The workshop introduced the participants to the sensing device and how to assemble it to build the capacity for a range of locally hosted small sensor building events over the weekend. The sensor distribution took place on 4 October 2021.

Figure 8. The local champions and other volunteers in Kathmandu manufacturing open-seneca sensors by following the online assembly guide.

In total, 17 sensors were deployed on five locally appropriate modes of transport, i.e. walking, bicycles, motorcycles, buses and minibuses. The various modes were chosen following unilateral discussions with the local stakeholders and transport providers, considering both individual and mass transport, as well as sustainable options and data collection aspects. Hence, seven open-seneca sensors were deployed on private bicycles, as it is a common and sustainable tool to travel short distances. Based on the terrain of Kathmandu valley, the city was divided into seven zones and volunteers were allocated a zone each to collect data.

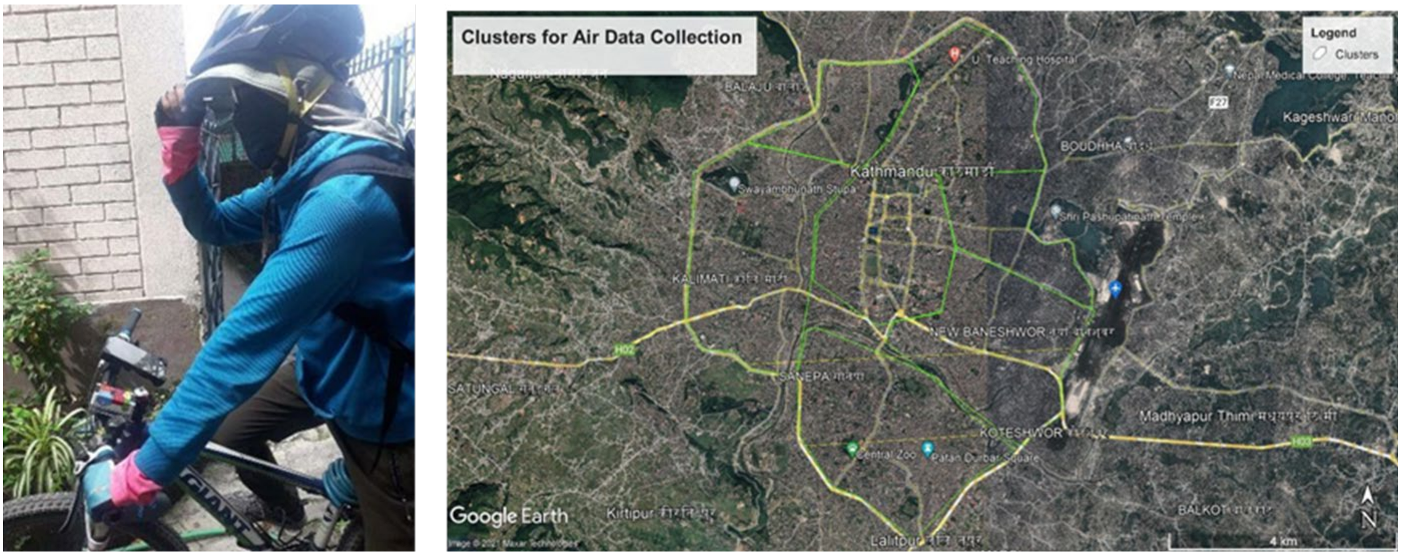



Figure 9. Left: Cycling volunteer and handlebar-mounted open-seneca sensor. Right: Kathmandu was segmented into zones to spread the sensors across the city for efficient data collection.

In order to cover a wide range of the city, six devices were deployed on Sajha Yatayat public buses. In this context, the drivers were asked to mount the sensors on the bus and charge it every night. Of the six sensors, four were mounted on buses operating on a specific route, covering the following areas:

- Lagankhel-Budhanilkantha
- Lagankhel-Narayenthan
- Lagankhel-Naya Buspark
- Ratnapark-Lamatar
- Godawari-Ratnapark
- Lamatar-Ratnapark
- Naya Buspark-Lagankhel
- Lagankhel-Godawari
- Ratnapark-Lamatar
- Lagankhel-Budhanilkantha
- Airport-Thankot

The remaining two devices were deployed on two buses operating on Kathmandu's H16 ring road, in order to monitor the 27 km long eight-lane wide highway encircling the cities of Kathmandu and Lalitpur, which is notorious as 'commuter hell' and a well-known pollution hotspot. Two further sensors were deployed on 'Tempos', a in Kathmandu commonly employed, electrified three-wheeler minibus. The Tempos covered the following routes during the deployment: Baneshor- Koteshor-Lagankhel and Imadol-Maitighar-Ratnapark.


Figure 10. Modes of transport in Kathmandu. Left: Electrified Tempo minibus with open-seneca sensor mounted on the roof. Centre: open-seneca device mounted on the side of a Sajha Yatayat bus. Right: walking volunteer presenting the open-seneca sensor in front of a temple in Kathmandu.

In addition, one sensor was deployed on a private motorcycle, representing a personalised form of transportation in Kathmandu. The last sensor was used by a walking volunteer. Both volunteers did not cover specific routes, but rather used the sensor on their daily commutes.

## Data Collection and Citizen Science Approach

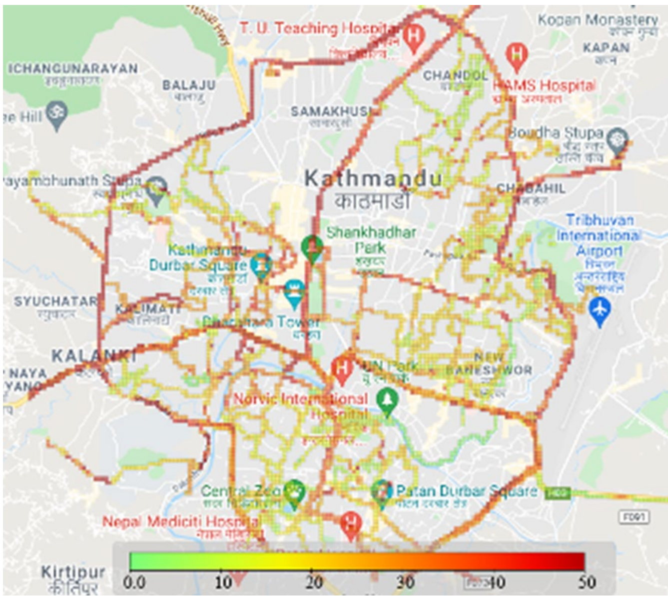



Figure 11. Air pollution map of Kathmandu. The map shows the aggregated, geotagged PM2.5 pollution data collected over one week with the open-seneca sensor mounted on various modes of transport.

As the shipment of open-seneca sensors to Nepal was held at the customs office for more than six weeks, the data collection was only carried out for one week. It should be noted that one week of data collection with 17 sensors is not sufficient to get detailed insights into pollution phenomena in Kathmandu. However, various areas were identified as pollution hotspots or areas of interest for potential interventions.

In Kathmandu, 17 sensors deployed on the various common modes of transport, as outlined above. While the cycling, motorcycling and motorcycling volunteers used the open-seneca mobile application to upload and visualize their data, the other modes of transport operated the open-seneca with the onboard SD card saving mechanism. This required manual uploading to the open-seneca data platform, facilitated by GD Labs after a week. Despite the short data collection timeframe, the volunteers had collected more than 400000 data points in Kathmandu, each corresponding to an individual air quality measurement at a specific location, and covered 42 km², corresponding to a data density of 9532 data points/km². All data has been forwarded to the University of Helsinki's Mega Sense platform to validate their simulations on the Nepalese capital. After processing the data and removing the pollution baseline of the city, open-seneca identified various air pollution hotspots across the city. Particularly, the western and southwestern segments of the H16 ring road were found to be the most polluted areas in Kathmandu during this study.

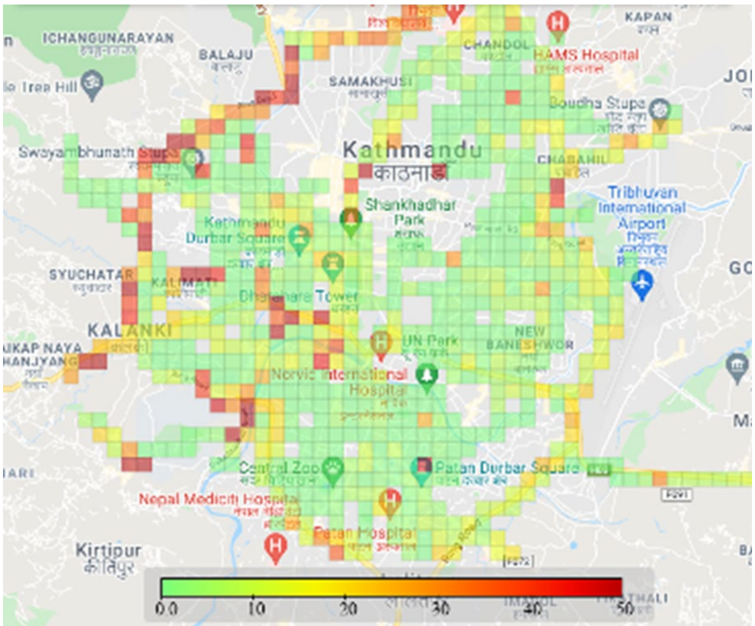



Figure 12. Hotspot air pollution map of Kathmandu. The map highlights hotspots of air pollution in the city and shows the processed pollution data collected over one week with the open-seneca sensor mounted on various modes of transport.

Similar to the findings in Kigali, the pollution varies greatly over the city. However, the city baseline and particularly local hotspots were exceeding the WHO guidelines tremendously. A particularly worrying hotspot was found around a secondary school. The area around the Visva Niketan secondary school and the Nepalese Ministry of Education's Educational Training Centre was found to show a PM2.5 concentration of 76.6 µg/m³ on average, however with a singular event causing a local spike of 191 µg/m³. Thus, the newest WHO guidelines for annual exposure to PM2.5 by 15x and for daily exposure by more than 5x, and for the spike event 38x and 12x respectively.


Figure 13. Hotspot analysis in Kathmandu. After data processing and baseline removal, A PM pollution hotspot was exposed at the Ce Viswa Niketan secondary school and the Nepalese Ministry of Education's Educational Training Centre, with values exceeding the WHO guidelines for annual exposure to PM2.5 by 15x and for daily exposure by more than 5x. A photo of the school on the right (source: Vijaya Malla).

The majority data points were recorded in the morning hours between 7 am and 11 am NPT, as indicated in Figure 14. The sensor activity decreased by up to 50 % towards the afternoon with peaks of higher activity at 1 pm and 4pm NPT respectively. Only sparse data was collected in the hours between 7pm and 6am. The average PM2.5 pollution in Kathmandu was recorded at 22.5 µg/m³, which is exceeding the annual and daily exposure recommended by WHO by 1.5x and 4.5x respectively. It shall be noted, however, that the depth of the dataset was severely limited by the short data collection period. Hence, the resulting pollution baseline and hotspot analysis can only be considered a preliminary result.

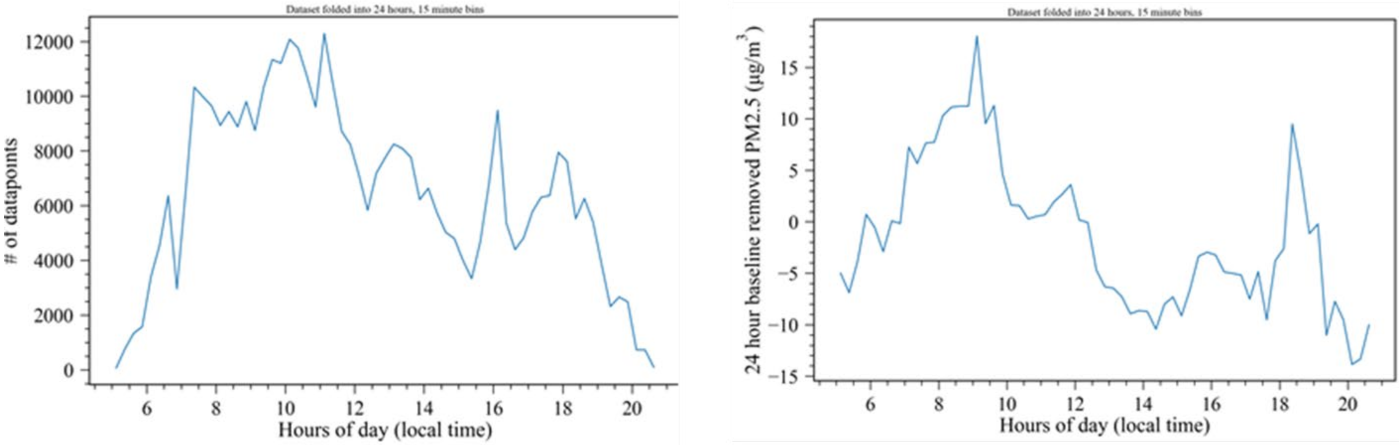



Figure 14. Left: Histogram of data point collection with regards to time of the day. The sensors were mostly used during morning hours, i.e. 7 am to 11 am NPT, during the one week of data collection in Kathmandu. Right: Baseline-removed average PM2.5 pollution profile over the course of a day, showing peaks of air pollution during the morning and evening rush hours.

**Community Engagement and Education**

Cycle City Network Nepal, Green Decision Labs and Research Pvt. Ltd. organised a local air quality sensor assembly event in which four MSc Environmental science students from TU University, eight members of the Cycle city network Kathmandu and volunteers from different agencies, such as Aeloi Technologies, participated. The community actively engaged in building and testing sensors that were supplied as a kit by themselves. During a remote presentation, open-seneca, with the support of Wuppertal Institute, introduced the attendees to the open-seneca project, gave an introduction on air pollution and its detrimental health effects, and assisted the volunteers with building the open-seneca air pollution monitor. The Green Decision Labs documented the community engagement workshop in a six minute-long video that was posted on social media and shared 26 times (as of 13 Oct 2021, LINK) This was followed by a series of tweets and reports by the volunteers on various social media platforms, including Instagram, Facebook and Twitter, where they shared their experiences and initial measurements with the sensor. In the future, the open-seneca initiative will be taken up by local researchers and used for their experimentation. Various quotes from volunteers highlight the success of the project and report initial success stories:

*“The MSc students said they want to use the device for research purposes.”*
*“The cyclist said it actually made them more environmentally conscious.”*
*“The participants were amazed to be part of it.”*

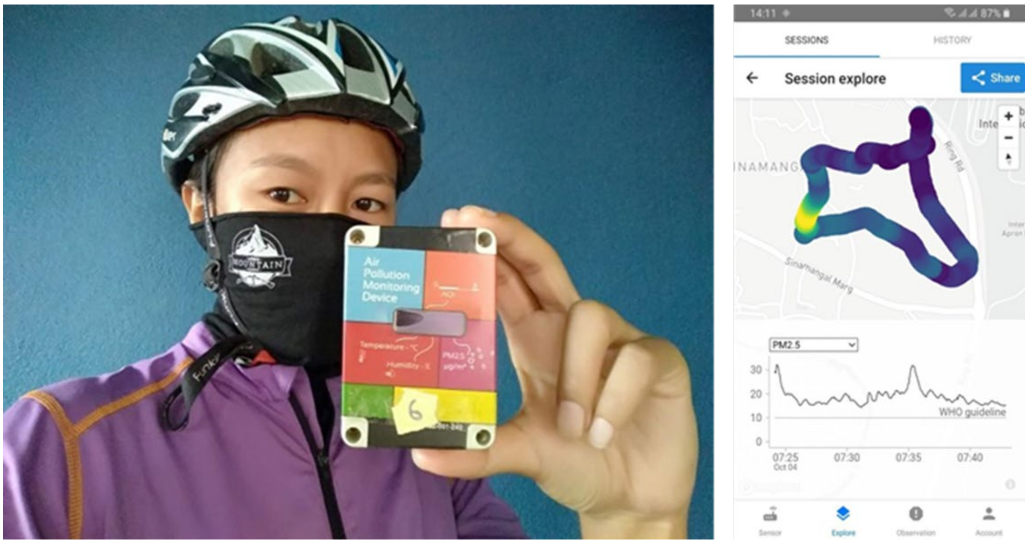



Figure 15. Left: One user showcasing their own open-seneca sensors, which they built during the workshop. Screenshot from a volunteer presenting their results from a walk around Kathmandu in the open-seneca smartphone app. Photo Credit: Mingmi Sherpa.

The Global Decisions Lab is committed to continue working with the sensor devices locally and redistribute them for research purposes with MSc students at TU University and for educational projects with local schools. Open-seneca and the Centre for Global Equality are supporting the creation of a local business model to maintain the sensor network for months ahead. This is anticipated to generate a continuous influx of air quality data into the Decision Support System and lasting impact on the improvement of air quality in the city of Kathmandu. However, as of 14 October, the results of this study have not been formally shared with the City of Kathmandu, and hence, no interventions or solution could have been implemented.

**Quito**

**Local stakeholders**

- M. Rosa Muñoz Barriga: Wuppertal Institute for Climate, Environment and Energy.
- Valeria Díaz: Fondo Ambiental (Environment Secretariat of the Municipality of Quito).
- María Elena Rodríguez, Frank Fuentes, David Alcívar, and Daniel Tixi: Plural Consultora, an Ecuadorian firm with more than 10 years of experience in social development projects and social intervention and public policy construction, currently developing electrical cargo bikes and tricycles for the SolutionsPlus project.
- Luis Miguel Torres, Juan Carlos de los Reyes: Escuela Politécnica Nacional (EPN) - ModeMat, meteorological modelling in Ecuador.

**Deployment of Network**

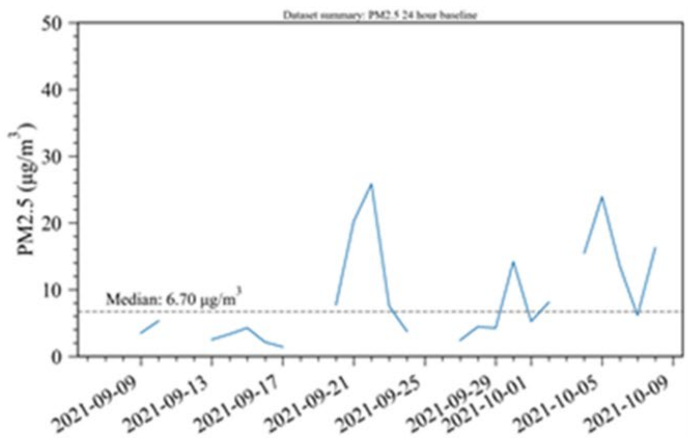
open-seneca shipped 10 pre-assembled sensors and 10 un-assembled sensors to Quito on 8 August 2021. The shipment was cleared from customs and delivered to Fondo Ambiental on 6 September 2021. Following the delivery, open-seneca and the local stakeholders organised a workshop with volunteers to build the remaining 10 sensor kits. This was organised to enable the local stakeholders to gain an understanding of how the sensors functioned, and build the necessary capacity to run, maintain and potentially repair the sensor network in the future. During the workshop, the volunteers were asked to follow the open-seneca building guide, which is publicly available on YouTube. For 9 September 2021, Fondo Ambiental organised a distribution event with 17 attendees (see Figure 16 and 17), to celebrate the launch of the project in Quito. At the beginning of the event, speeches from the local stakeholders and open-seneca were given - each expressing the importance of the initiative, their contributions, and their excitement. To conclude the event, the cycling volunteers who were to carry the sensors and present at the event, were invited one by one to have their sensors mounted on their bikes.

Figure 16. Deployment workshop in Quito. Picture credit: Fondo Ambiental.

**Data Collection with Citizen Science Approach**
For the deployment in Quito, a project approach with a strong focus on citizen and community engagement was chosen. Half the volunteers were identified by one of the main local stakeholders, Plural Consultora, who gathered local cyclists as well as professional bike messengers to carry a sensor on their bicycles while riding in Quito, and the other half by Fondo Ambiental, who identified local policemen cycling in Quito.


Figure 17. Two volunteers during the deployment workshop showcasing their open-seneca sensors mounted on the handlebars of their bike. Picture credit: Fondo Ambiental.

In total, 10 sensors were deployed on messenger bicycles, with the remaining reserved for deployment with the local cycling police (planned for the 18th of October 2021). The data derived from the cycling volunteers came solely from the open-seneca app when connected to a sensor. This was to allow the volunteers to visualise the pollution they experienced during their commutes and to transmit the geotagged air quality data to the open-seneca platform without having to wait for the MicroSD card data. During the experimentation period, the volunteers collected and transmitted more than 183,000 data points in Quito, each corresponding to an individual air quality measurement at a specific location, and covered 33 km², corresponding to a data density of 5,545 data points/km². During this study, the users mostly used their monitoring devices in the morning hours to early afternoon, between 8 am and 1 pm local time. However, it shall be noted that during the deployment in Quito, the sensors were not used mainly during the weekends, or at least were not connected to the app, which resulted in data lacking for some periods, as shown in Figure 18. All data has been forwarded to the University of Helsinki's Mega Sense platform to validate the simulations on the Ecuadorian City.



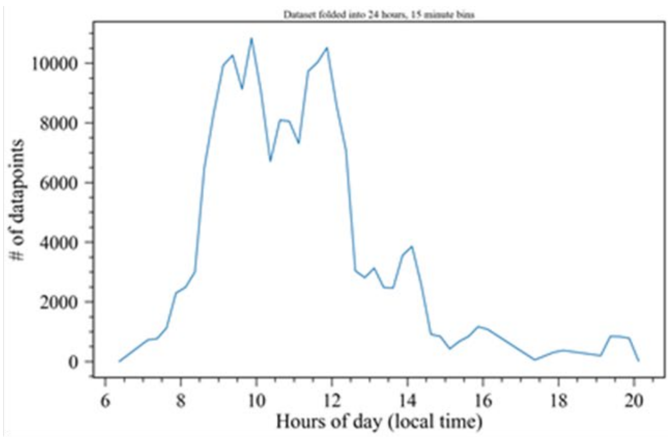
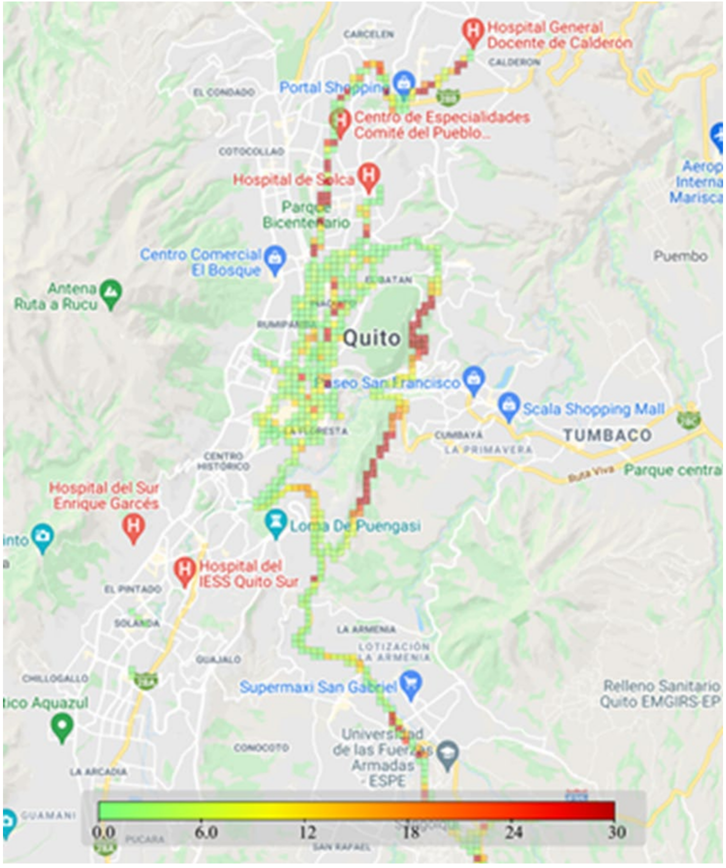




Figure 18. Left: Histogram of average PM pollution during the four-week monitoring period. The median baseline of the city is depicted as a dashed line at 6.70 μg/m³. The open-seneca monitors were not used or not connected to the data transmission smartphone app, leading to gaps in the dataset and potentially skewing the baseline calculations. Right: User active by day graph, highlighting days without any sensor active contrasted by days with five sensors active.

Despite the lower data quantity in comparison to the other cities, some areas with higher levels of air pollution were highlighted in the aggregated dataset. The complete aggregated baseline removed map of the data collected in Quito, without any filtering for number of points per grid tile, is shown in Figure 19. One possible hotspot region was seen nearby "Universidad Técnica Particular de Loja/UTPL Quito Regional centre", where a mean value of 20 μg/m³ above the baseline was recorded in a 250m*250m tiled region. The source of pollution experienced in this region was unclear from satellite or street view imagery, but traffic is thought to be the likely source. It is recommended to aggregate a larger dataset before concluding any hotspot regions.




**Community Engagement and Education**

As mentioned above, the focus of this project was put on community engagement, informing citizens and outreach. Therefore, a public distribution event was organised by the local stakeholders to initiate the formation of an air quality monitoring community in and around Quito. The event was perceived very positively, as various participants shared their opinions through Twitter and in private communications. For example, a local stakeholder and member of Fondo Ambiental: "Happy with yesterday's distribution event!!! Everyone is happy and encouraged to participate in the project." On the same note, Ambiente Quito produced and shared an informational video on Twitter about the launch of the project, which can be accessed here. During the data collection period, many users posted on various social media channels about their collection process and shared their personal exposure during commuting or exercising, see Figure 20. For example, one of the bike messenger cyclists shared a video of them collecting data with the sensor while being stuck behind an old bus emitting black smoke in his Instagram story. In a short questionnaire conducted the week beginning 11th October,

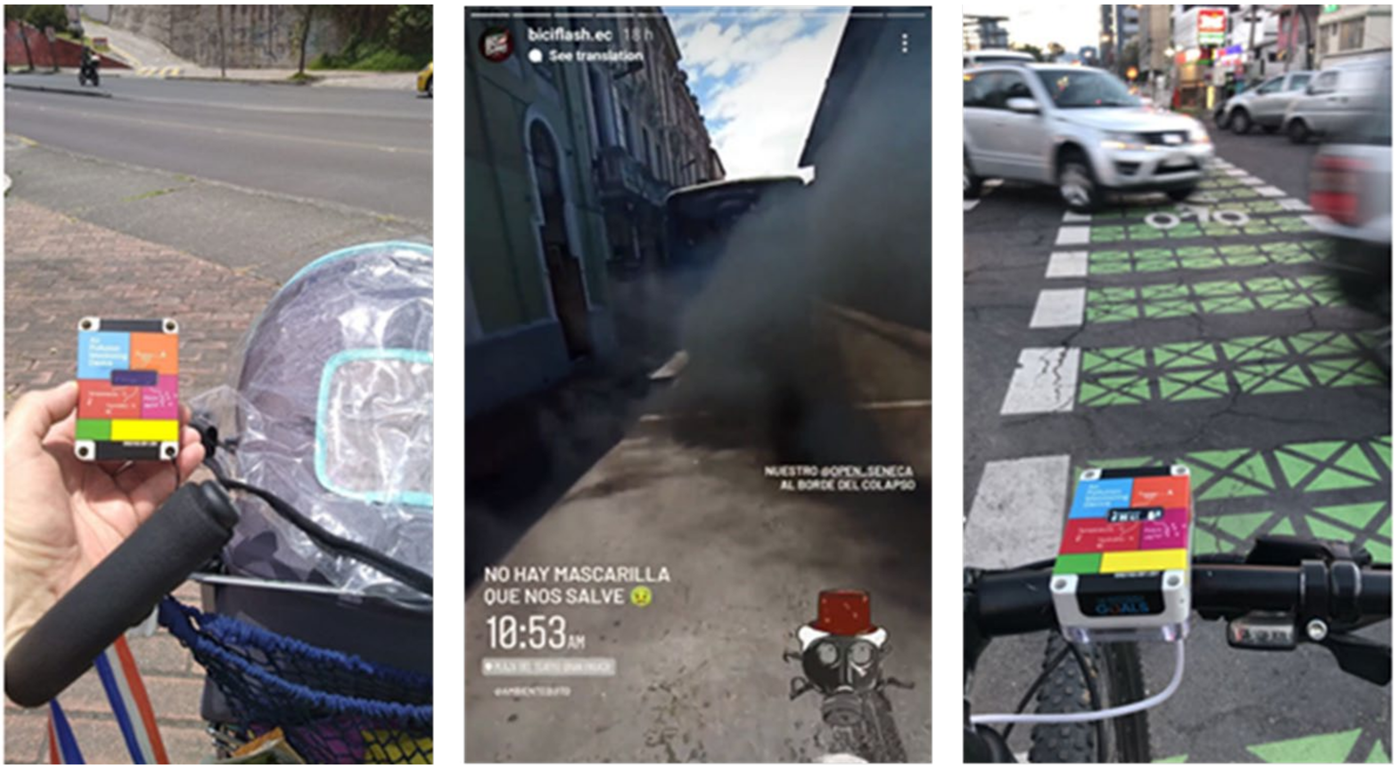



Figure 20. Various social media posts and images shared by volunteers using the open-seneca sensor on their commutes or daily outings.

# DELIVERABLES

The main objective of this project was to set up the infrastructure and build local capacity to deploy and maintain low-cost air quality sensor networks with a citizen science approach. The implementation in all three cities is agreed to continue with the local stakeholders beyond the completion of this project and long-term impact resulting from this initial progress is expected.

Table 1: Activities, KPI and achieved values during the deployments in Kigali, Kathmandu, and Quito.

| No | Activity | KPIs (projected value) | Values achieved |
|---|---|---|---|
| 1 | Deployment of network | 1. Number of cities where a network is deployed (3)<br>2. Number of local stakeholders active in each city (>2)<br>3. Number of sensors deployed (60, 20 per city) | 1. 3 cities: Kigali, Quito, and Kathmandu<br>2. Total: 19. Kigali: 5, Quito: 8, Kathmandu: 6<br>3. 60 sensors delivered in total, 20 to each city. Deployed in total: 57. Kigali: 20, Quito: 20 (10 since 06/09/21, 10 on 18/10/21), Kathmandu:17 (rest used as back-ups) |
| 2 | Data collection with citizen science approach | 1. Number of users (60, one per sensor)<br>2. Total average of data points collected per square kilometre (2000 points/km2)<br>3. Coverage of the city in square kilometres (40 km2)<br>4. Total number of data points fed into University of Helsinki's platform (4M data points) | 1. 57 users (one per sensor deployed). Kigali: 20, Quito: 20, Kathmandu: 17<br>2. Kigali: 40740 points/km2, Quito: 5512 points/km2, Kathmandu: 9640 points/km2<br>3. Kigali: 162 km2, Quito: 33.2 km2, Kathmandu: 41.5 km2<br>4. 7.14M data points |
| 3 | Community engagement and education | 1. Usefulness of step-by-step guides, webinars and learning materials (>50% report 4-5 in 1-5 Likert scale)<br>2. Average number of posts per user in the app or forum (3)<br>3. Number of solutions suggested by users (5)<br>4. Number of users that report changing behaviour (10%) | 1. 90%<br>2. Kigali: 0 (app not used), Quito: 1 post in app, 5 in forum, daily posts on social media, 2 media interviews; Kathmandu: 2 posts (most users did not use the app i.e., bus sensors)<br>3. Pending presentation of results to cities and longer impact timeframe<br>4. 7% so far - need longer time frames for impact assessment |
| 4 | Cities and individuals informed | 1. Number of individuals participating the capacity building programme (>15, 5 per city)<br>2. Number of cities participating in the capacity building programme (3) | 1. Kigali: 27, Quito: 17, Kathmandu: 21<br>2. 3 cities: Kigali, Quito, and Kathmandu |
| 5 | Impact in reducing air pollution | 1. Number of success stories: identified hotspot and action taken to improve air quality (3) | 1. Pending presentation of results to city policy makers to find solutions, and longer impact timeframe |

# CONCLUSIONS

The aim of this project was to build local capacity and provide tools that improve the air quality monitoring and management system of three Urban Pathways partner cities (Kigali, Quito, Kathmandu), in order to support evidence-based decision-making processes related to reducing air pollution. To achieve this, a network of 20 open-seneca low-cost air quality monitors was deployed in each city in a mobile and citizen-based setting, and high-resolution PM2.5 city maps were generated that highlight hotspots of air pollution and provide evidence for a data-driven transition towards cleaner transport systems.

Capacity building and knowledge transfer were at the core of the activities. Partnerships were established with local stakeholders to ensure local appropriateness of the implementation, and multiple workshops were conducted so that local stakeholders would learn how to assemble, operate, deploy, manage, and maintain the network of open-seneca's low-cost air quality monitors.

Some of the main conclusions of this project are:

- The identification of "local champions" that lead the local implementation in each city was key for the success of the project. Local champions understand the local context and needs, help to establish partnerships with relevant local stakeholders and lead the activities on the ground. Knowledge was transferred to them via online workshops and then distributed locally to a wider audience.
- The use of good quality low-cost sensors in a mobile setting (i.e., the sensors are mounted on vehicles and move around the city, mapping air pollution street-by-street) is a very powerful tool. Open-seneca sensors show excellent inter-sensor comparability (measurements within ±0.6 $\mu g/m^3$ when placed in the same location), which enables to compare PM2.5 readings between sensors that are moving around the city. Within a month of data collection, air quality city maps covering most of the city area were obtained that help understand spatial variations of PM2.5 with a resolution unachievable by stationary sensors.
- Although calibration of the low-cost sensors with a reference-grade monitoring station is necessary to provide accurate absolute PM2.5 values, uncalibrated measurements can still be used to provide evidence for decision-making by doing relative comparisons. Hotspot maps highlight areas in the city that are more polluted than others, independently of the actual PM2.5 value. Once a hotspot is identified, understanding what is causing that relative increase in PM2.5 compared to other parts of the city is key to inform good and bad practices in urban planning, as well as identifying priority areas for intervention activities. Hotspot maps were successfully generated for the three cities of this project.
- Collecting air quality data and producing city maps is only the first step. Local expertise about the city dynamics is essential

to bring meaning to the data and turn the maps into actionable tools. Hotspot maps highlight areas that have higher PM2.5 pollution than others and local knowledge helps identify sources of pollution in those hotspots. When sources are identified, the right solutions and interventions can be applied. The contribution of local knowledge does not need to be limited to air quality experts and additional datasets (such as traffic flow data or data about road conditions): this project shows that citizens using the low-cost air quality monitor gain valuable insights about what is causing higher PM2.5 values in the city and are happy to share their experiences. Indeed, the interpretation of the air quality city maps could be crowdsourced to the general public for much more granular input. In order to trigger behaviour change in citizens towards reducing their personal exposure and emissions, a strong focus on community education is important to ensure that they understand the impact of high PM2.5 concentrations on their health.

- The communities that participated in the project report being much more aware of the air pollution they are exposed to after engaging with the air quality sensors. Citizen engagement is a powerful complementary tool to facilitate the adoption and transition to cleaner mobility.
- There is a trade-off in the deployment strategy of collecting air quality data with a citizen science approach: the amount, spatial and temporal coverage of data collected; and the impact on raising awareness among citizens. In this project, Kigali deployed sensors on electrical moto-taxis with little engagement from the drivers: the coverage of the city was excellent (162 km2, 40740 data points/km2 in 1 month), but the drivers did not learn as much about their personal exposure and the meaning of the data they were collecting, and the awareness did not spread to the wider public. On the contrary, Quito distributed sensors to cycling citizens that were very active about sharing their experience and measurements on social media and other media outlets, having a much bigger impact on the general public, but however these cyclists only collect data in their daily commutes and the city coverage was much lower in the same time period (33.2 km2, 5512 data points/km2 in 1 month). In order to make the most of both aspects, a mixed strategy might be the best approach (Kathmandu model: half of the sensors on buses, half distributed to citizens).

**Challenges**

The implementation of this project encountered some challenges that are important to keep in mind:

- Access to reference grade air quality monitoring stations: performing co-localisation studies to calibrate the low-cost sensors with reference stations is not always possible if access to these stations (if existing at all) is not granted. In that case, the absolute values of PM2.5 reported by the low-cost sensors might not be accurate. However, hotspot maps that perform comparative measurements can still be used and are a powerful tool to support decision-making. Moreover, previous open-seneca calibration studies with reference stations show that open-seneca low-cost sensors follow the same trend as the reference station, but with a slight offset (underreports PM2.5 absolute concentrations).

- Cultural and language barriers: it is important for the community engagement activities to be organised by the local champion in the local language and most culturally suitable format, in order to minimise potential cultural and language barriers. Workshops provided by open-seneca remotely in English do not achieve the same level of impact. Therefore, the step of knowledge transfer to the local champion is key for successful posterior impact in engaging local communities. This was successfully achieved in all three cities of this project.
- Citizen engagement in LMICs has different challenges than in high income countries. Unless explicit high value is provided to the citizens with their participation in the project, volunteering in most cases requires monetary compensation in order to ensure high commitment levels. In Kigali, motorbike drivers were economically compensated by Ampersand for participating in the data collection, whereas in Quito cyclists volunteered without asking for monetary compensation.

**Project sustainability**

One key reason for focusing on local capacity building in this project is to ensure long-term impact and project sustainability beyond the timeframe of this project. Open-seneca has successfully established the necessary infrastructure in all three cities to ensure sustainability of the project. It was agreed with the local stakeholders in Kigali, Quito, and Kathmandu that the data collection is going to continue in the next months. The local champions are completely enthusiastic about and committed to the continued use of low-cost sensor networks and initial discussions have been held to further expand the network in some of the cities.

Urban Pathways

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