African School on Air Quality and Pollution Prevention
1st – 10th December, 2025

Challenges Related to Air Quality Monitoring using LCS

Presentation by:

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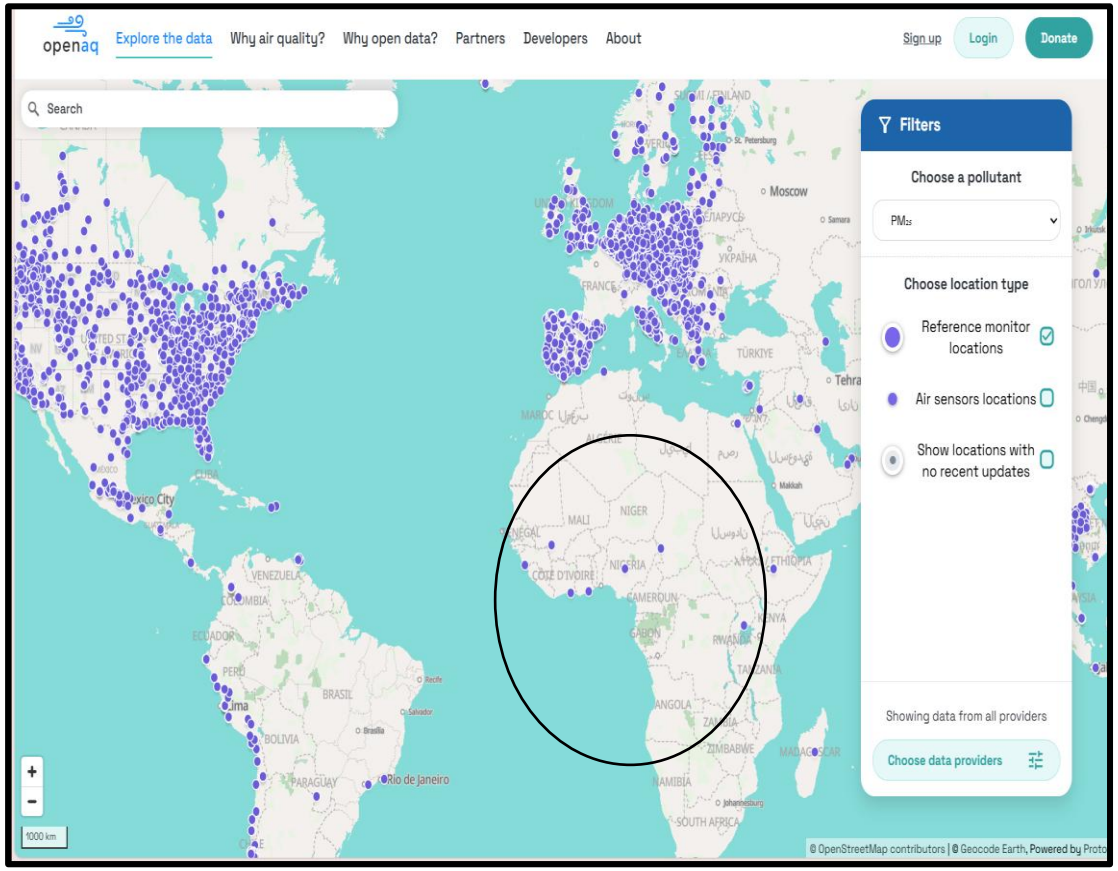
Date: Tuesday, December 2, 2025
Venue: Kwame Nkrumah University of Science and Technology, Kumasi

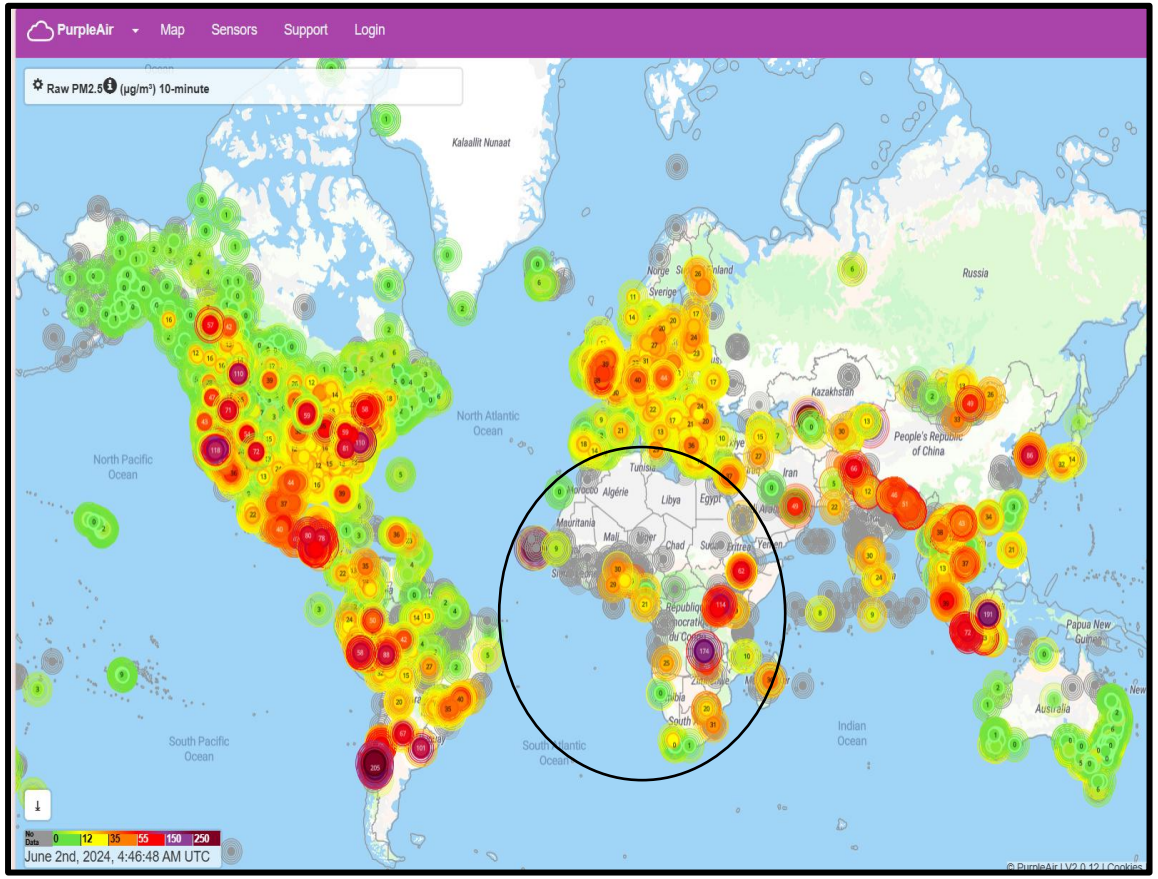
The Air Pollution Challenge in Sub-Saharan Africa

Reference monitors



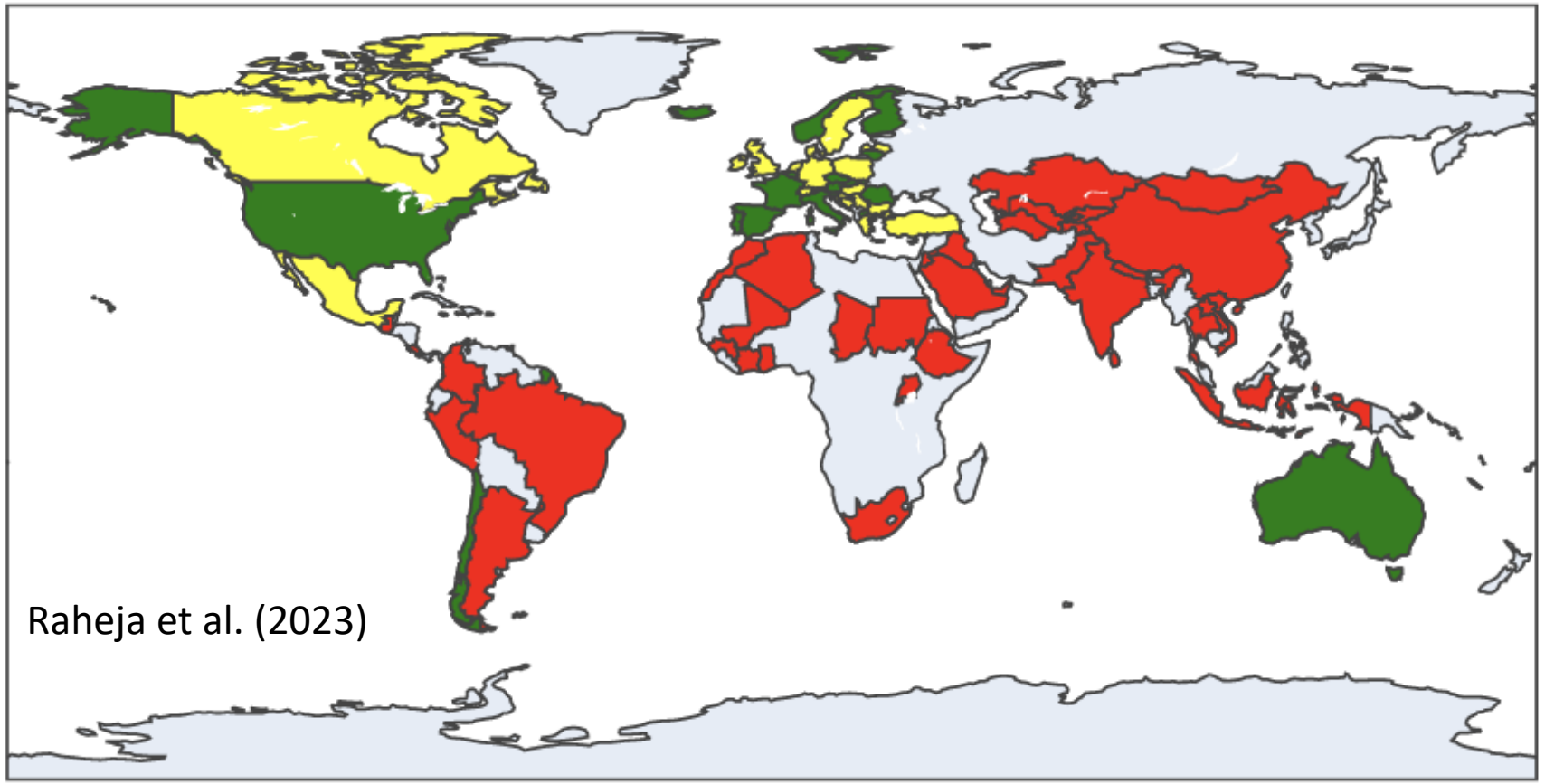
https://explore.openaq.org/#1.2/20/40 (Accessed 2024)

Low-cost sensors



https://map.purpleair.com/ (Accessed July, 2025)

Traditional Air Pollution Data is Sparse in Africa



- About 80 FEM/FRM at US Embassies worldwide
- About 8 in African countries

FEM/FRM $PM_{2.5}$ monitors per million people, 2022 (Data from OpenAQ)

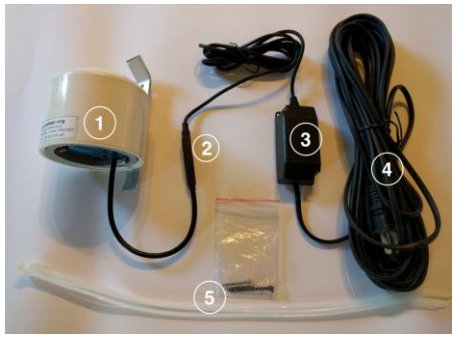
Different Types of Air Quality Monitoring

- Low-cost sensors (LCSs) that measure PM2.5 are becoming increasingly popular because of their **low cost**, **ease of use**, **and portability**.
- Portability and low cost comes at the expense of data quality, reliability, and the durability of the sensors
- The typical lifespan of LCSs is 1-2 years
- Raw data from these LCSs need to be corrected or calibrated

Air Quality Egg

AirQo

Real-time Affordable Multi-Pollutant (RAMP) sensor



PurpleAir PA-II

Reference Monitors vs Low-Cost Sensors

	Reference Monitors	Low-Cost Sensors
Typical Purchase Cost	$15,000 to $40,000 (USD)	$200 to $5,000 (USD)
Staff Training	Highly trained technical staff	Little or no training to operate. May need more training to interpret data
Operating Expense	Expensive – shelter, technical staff, maintenance, repair, quality assurance.	May be less expensive – replacement, data streaming, data management.
Siting Location	Fixed Location. (climate controlled building/trailer needed)	More portable. May require weather shielding. Siting can be easier due to lower flow rates but more tricky because of data streaming.
Data Quality	Known and consistent quality in a variety of conditions.	Unknown. Can vary from sensor to sensor, in different weather conditions, and in different pollution environments.
Operating Lifetime	10+ Years (calibrated and operated to maintain accuracy).	Short (1 year) or Unknown (may become less sensitive over time).
Regulatory Monitoring?	Yes	No

US EPA Office of Research and Development, 2019

When should you use monitors or low-cost sensors?

FRM/FEM Monitor

- Regulatory
- Compliance
- High data quality
- Establishing new system
- Sufficient funding
- Sufficient space

Low-Cost Sensor

- Non-regulatory
- Informational
- Limited by cost or infrastructure needs
- Need smaller or portable options

Considerations before choosing an LCS

- Sensor selection is determined by the objectives of the project, field conditions, and the following factors:

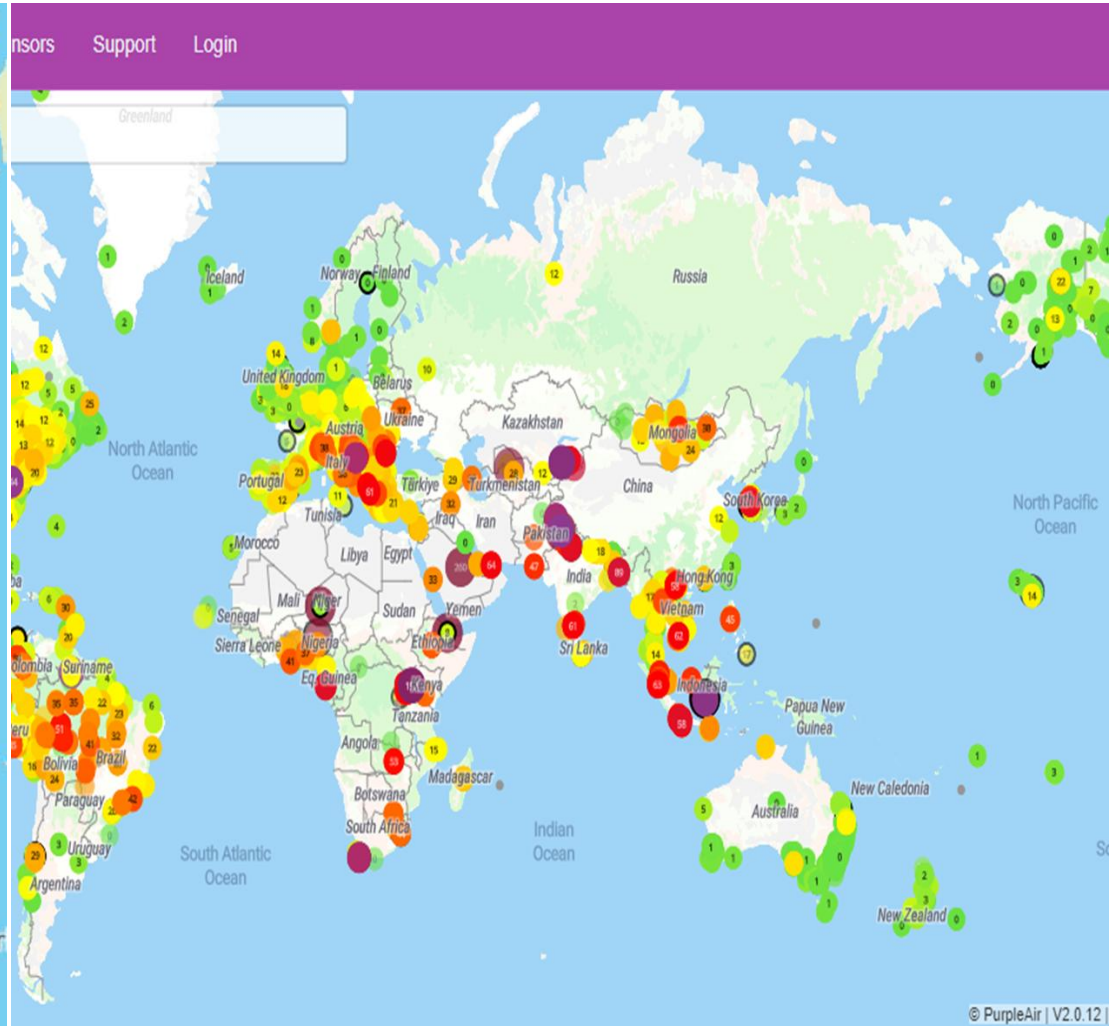
- ✓ Cost
- ✓ Type of sensor (Plantower or Optical particle counter)
- ✓ Ease of installation
- ✓ Portability
- ✓ Precision and accuracy of the sensor measurements
- ✓ Temporal resolution of the output data by the LCS
- ✓ Wi-Fi/cellular module availability
- ✓ Meteorological sensor availability
- ✓ Solar panel availability
- ✓ Online dashboard facility

- ✓ Global Positioning System (GPS) module availability
- ✓ Battery backup
- ✓ Dual laser counters
- ✓ Internal storage (SD card) facility
- ✓ Lifetime of the sensors
- ✓ Back-end and technical support by the vendor

Availability of Air Sensors in Africa

https://analytics.airqo.net/map

https://map.purpleair.com/



Why The Need For Air Sensor Evaluation Centre In Africa?

- **Improving air quality in Africa faces two main obstacles:**

1) **A lack of monitoring equipment due to high capital cost and**
2) **A lack of trained personnel to run or operate these instruments.**

- The use of low-cost air quality sensors (LCS) is a promising avenue to address at least the first of these obstacles.
- Unfortunately, LCS face a few key problems:

1) **LCS are not as plug-and-play as most manufacturers suggest; they always requires multiple data quality and calibration steps.**
2) **When examining how well these sensors perform or how they should be calibrated, there is a strong mid-latitude, Global North bias.**

Afri-SET: The Air Sensor Evaluation and Training centre for West Africa

Genesis of Afri-SET

The World Bank Pollution Management and Environmental Health Multi-Donor Trust Fund (PMEH)

- PMEH technical assistance was launched in April 2015 with an initial duration of 5 years (2015-2020)
- Countries eligible for PMEH were: China, South Africa, Nigeria, Egypt, Vietnam, **Ghana**, and India
- Formulation of AQM plans that identify cost-effective abatement options
- ***Establishment and strengthening of air quality monitoring networks in large urban areas***

Installation of Reference Monitors and MET Stations

Installation of Reference Monitors

First Pilot Collocation Publication

Environmental Science & Technology

pubs.acs.org/est

Article

Low-Cost Sensor Performance Intercomparison, Correction Factor Development, and 2+ Years of Ambient $PM_{2.5}$ Monitoring in Accra, Ghana

Garima Raheja,* James Nimo, Emmanuel K.-E. Appoh, Benjamin Essien, Maxwell Sunu, John Nyante, Mawuli Amegah, Reginald Quansah, Raphael E. Arku, Stefani L. Penn, Michael R. Giordano, Zhonghua Zheng, Darby Jack, Steven Chillrud, Kofi Amegah, R. Subramanian, Robert Pinder, Ebenezer Appah-Sampong, Esi Nerquaye Tetteh, Mathias A. Borketey, Allison Felix Hughes, and Daniel M. Westervelt*

AFRI-SET

Establish to evaluate low-cost air sensors and training facility in Ghana (January 2023)

Facilitate the capacity building of students and air quality practitioners in Africa

Promote long-term sustainability and replication of the centre

Activities of Afri-SET

1. Establish a low-cost air sensor evaluation and training hub in Ghana-West Africa.

   i. Develop Standard Operating Procedures (SOPs) (vetted by AirParif, NILU & AQ-SPEC)

   ii. Evaluate 10 sensor types in Year 1.

   iii. Build a website to host reports, calibration protocols/correction factors and other training materials in both English and French.

Standard Operating Procedure (SOP)

- Number of sensors (at least 3 identical sensor units)
- Period of evaluation (6 weeks in dry season (include Harmattan period) and 6 weeks in wet season)
- Sensor pre-deployment before installation
- Data analysis and evaluation

13 LCS installed at Afri-SET Facility

Airbeam3

Airly

Modulair

Airgradient

Kunak

Clarity

Praxis

Atmos

IQAir

Airqo

SensorAfrica

Air Quality EGG

TSI-Bluesky

List of manufacturers

IQAir
First in Air Quality

airly

atmos
real-time air quality
Respirer Living Sciences

sensors.AFRICA

airgradient

airqo
Breathe Clean

South Coast
Precision Air Quality Monitors

QUANTAQ

clarity

AIR QUALITY EGG

kunak®
SENSING ANYWHERE

Reference Grade Instruments

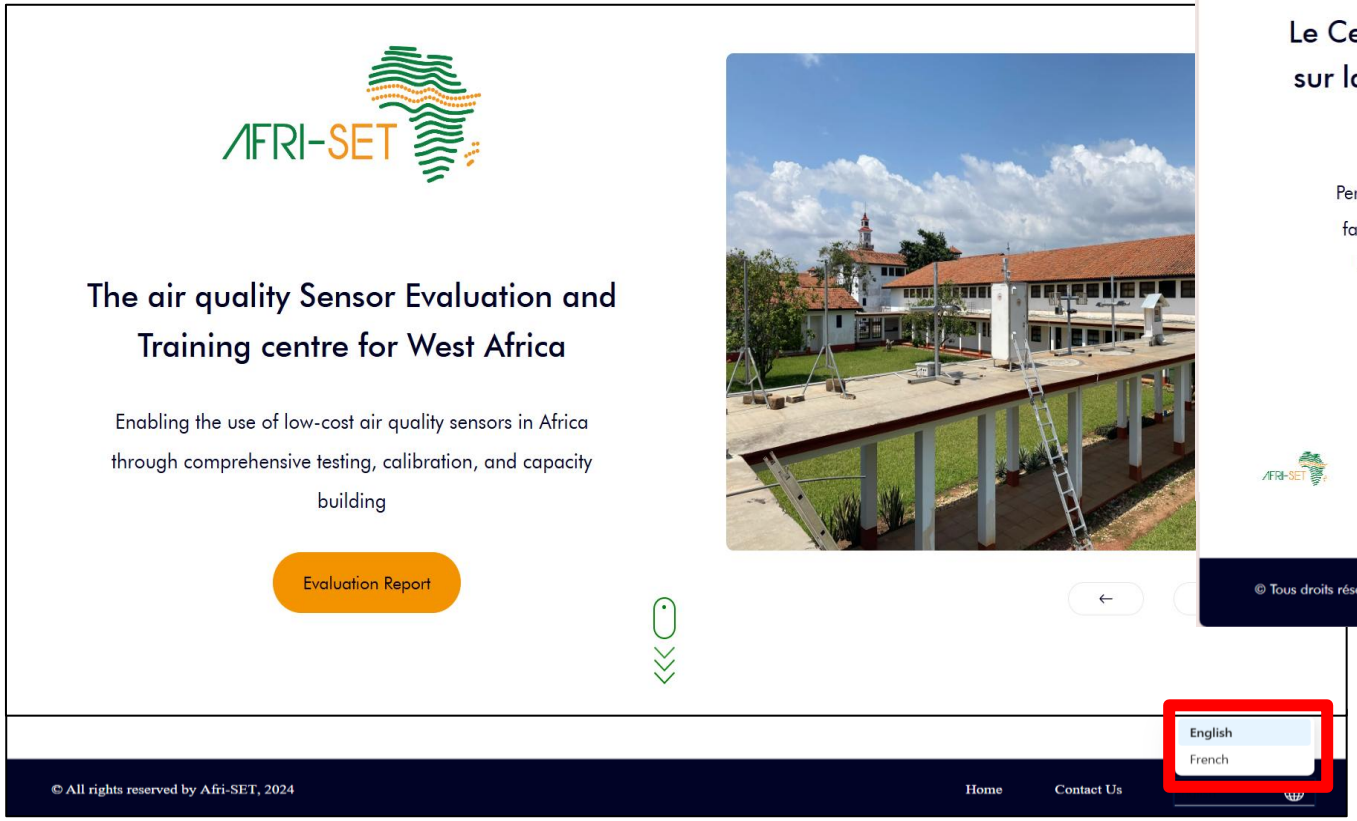
What Afri-SET has done so far?

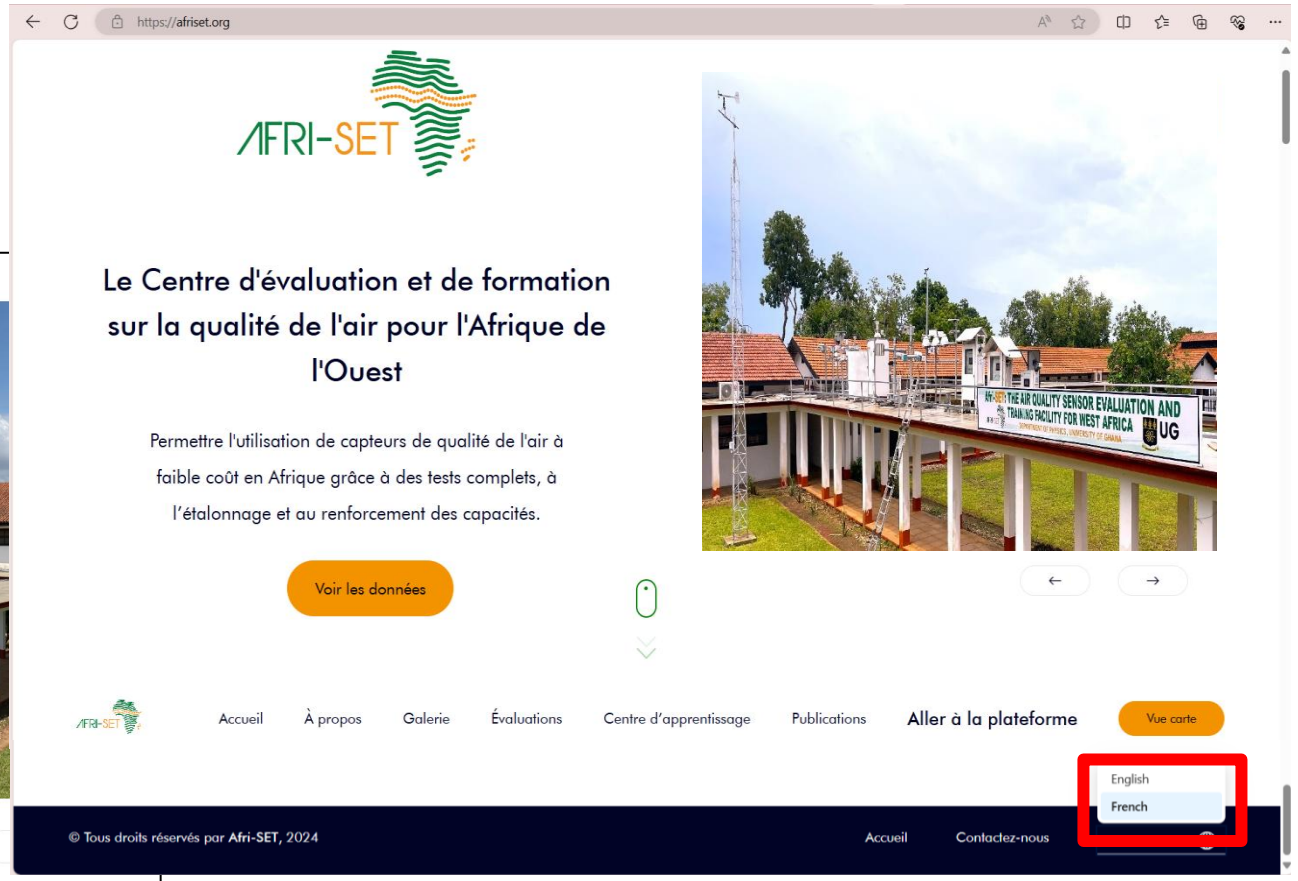
- Some air quality sensors at the facility

What Afri-SET has done so far?

What Afri-SET has done so far?

Afri-SET Website





https://afriset.org/

Reports available for download

Home About Gallery Evaluations Learning Center Publications Go to platform Map View

Manufacturer	Model Name	PM2.5 Report	Manufacturer Website
Air Quality Egg	Air Quality Egg	Air Quality Egg Report	https://airqualityegg.com/
AirGradient	Outdoor Air Sensor	AirGradient Report	https://www.airgradient.com/
Airly	Airly PM	Airly PM	https://airly.org/en/

Activities of Afri-SET

2. To facilitate capacity building of students and air quality practitioners in Africa

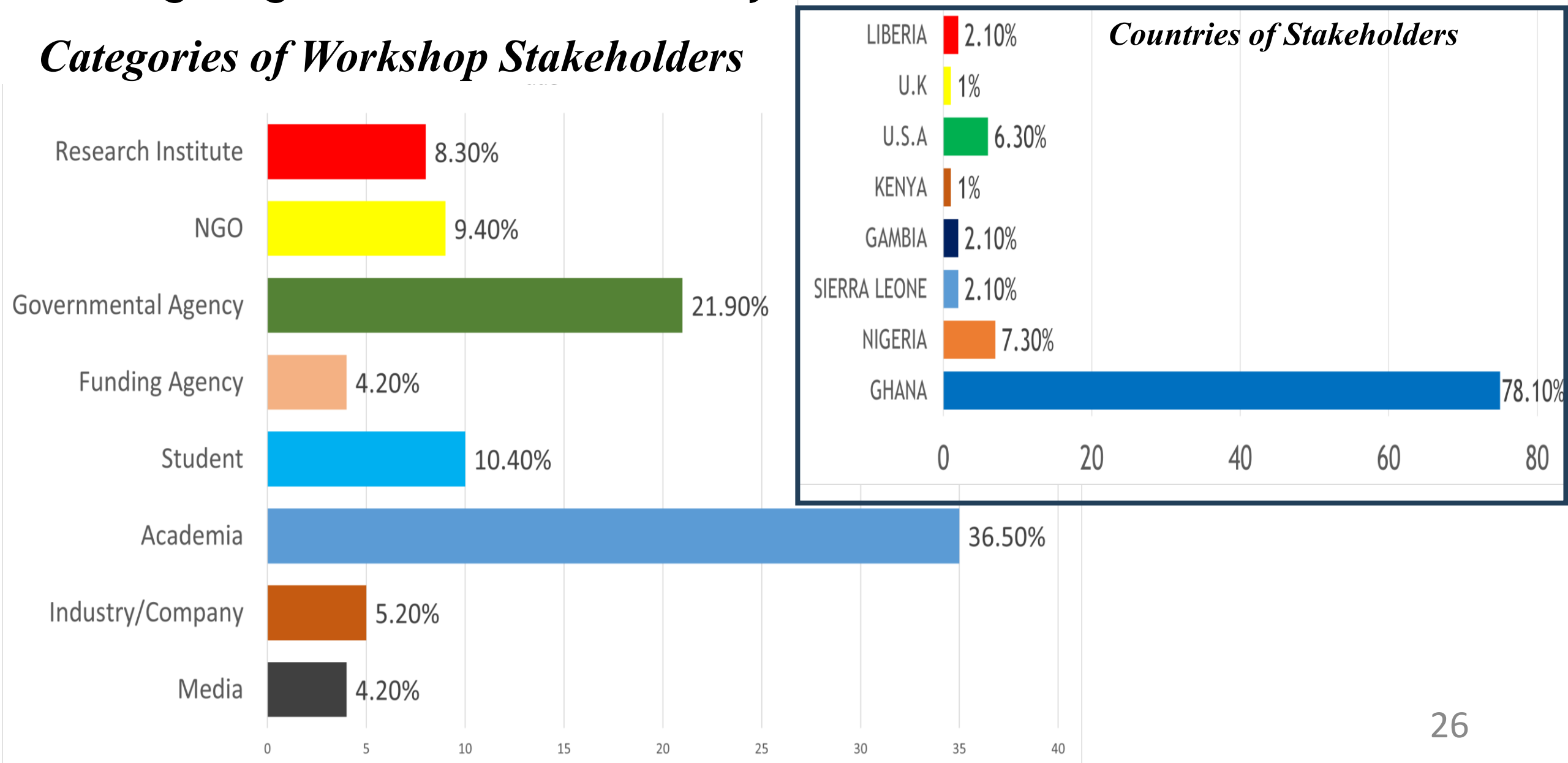
i. In-person, hands-on, training sessions – "training the trainers" (~25+ practitioners from at least 5 West African countries each year)
   - **Low-cost sensors installation and usage, reference monitors, data analysis and modelling, and various value-added products for LCS**

ii. Organize virtual trainings using webinars and self-paced training materials (~50 practitioners and students from W. Africa and other regions)

1. To facilitate capacity building of students and air quality practitioners in Africa - 1st Air Quality Training Workshop, Carnegie Mellon University Africa, Kigali, Rwanda 7th to 10th March 2023

University of Ghana + Columbia University Air Quality Certification Training Program 15th to 19th January 2024, Legon, Accra

University of Ghana + Columbia University Air Quality Certification Training Program 15th to 19th January 2024



3. Air Quality Data Analysis Workshop for Students and Air Quality Professionals in West Africa, 27th to 31st January 2025

Capacity building by Afri-SET
Hands-on training and Webinars

Activities of Afri-SET

Tour of Afri-SET facility by participants of the Air Sensors International conference (ASIC) held in Accra, October 2023

DATA CLEANING

date format
(POSIXct, chr, etc)

```
tibble [52,516 × 41] (S3: tbl_df/tbl/data.frame)
 $ date           : POSIXct[1:52516], format: "2023-10-01 00:04:00"
 $ RHa            : num [1:52516] 85.4 85.3 85.4 85.4 85.4 ...
 $ Tempa          : num [1:52516] 27 27 27 27.1 27.1 ...
 $ Otempa         : num [1:52516] 32.1 32.1 32.1 32.2 32.2 ...
 $ ORHa           : num [1:52516] 64.4 64.2 64.3 64.3 64.3 ...
 $ OPM1a          : num [1:52516] 2.83 2.78 2.63 2.56 2.72 ...
 $ OPM25a         : num [1:52516] 9.73 10.12 9.96 9.08 9.99 ...
```

0s , NAs, null values

```
      date                          RHa             Tempa           Otempa
in.   :2023-10-01 00:04:00.00   Min.   :11.33   Min.   :23.17   Min.   :25.13
st Qu.:2023-11-15 19:22:45.00   1st Qu.:51.62   1st Qu.:28.36   1st Qu.:33.52
edian :2023-12-31 13:56:30.00   Median :72.56   Median :29.87   Median :35.13
ean   :2023-12-31 11:28:31.67   Mean   :65.83   Mean   :31.76   Mean   :37.08
rd Qu.:2024-02-15 03:50:15.00   3rd Qu.:79.59   3rd Qu.:35.13   3rd Qu.:40.53
ax.   :2024-03-31 23:59:00.00   Max.   :92.37   Max.   :44.15   Max.   :49.98
                                NA's   :78      NA's   :78      NA's   :78
```

Outliers, extreme values
min & max

```
      PM1c              PM25c             PM10c
Min.    :   0.000   Min.    :   0.00   Min.    :   0.00
1st Qu.:   7.817   1st Qu.:  11.37   1st Qu.:  11.68
Median :  14.083   Median :  20.53   Median :  21.03
Mean   :  19.432   Mean   :  27.68   Mean   :  30.21
3rd Qu.:  23.633   3rd Qu.:  35.90   3rd Qu.:  41.13
Max.   :3288.717   Max.   :3289.07   Max.   :3289.07
```

data types & format

```
bble [52,516 × 41] (S3: tbl_df/tbl/data.frame)
 $ date           : POSIXct[1:52516], format: "2023-10-01 00:04:00"
 $ RHa            : num [1:52516] 85.4 85.3 85.4 85.4 85.4 ...
 $ Tempa          : num [1:52516] 27 27 27 27.1 27.1 ...
 $ Otempa         : num [1:52516] 32.1 32.1 32.1 32.2 32.2 ...
 $ ORHa           : num [1:52516] 64.4 64.2 64.3 64.3 64.3 ...
 $ OPM1a          : num [1:52516] 2.83 2.78 2.63 2.56 2.72 ...
 $ OPM25a         : num [1:52516] 9.73 10.12 9.96 9.08 9.99 ...
```

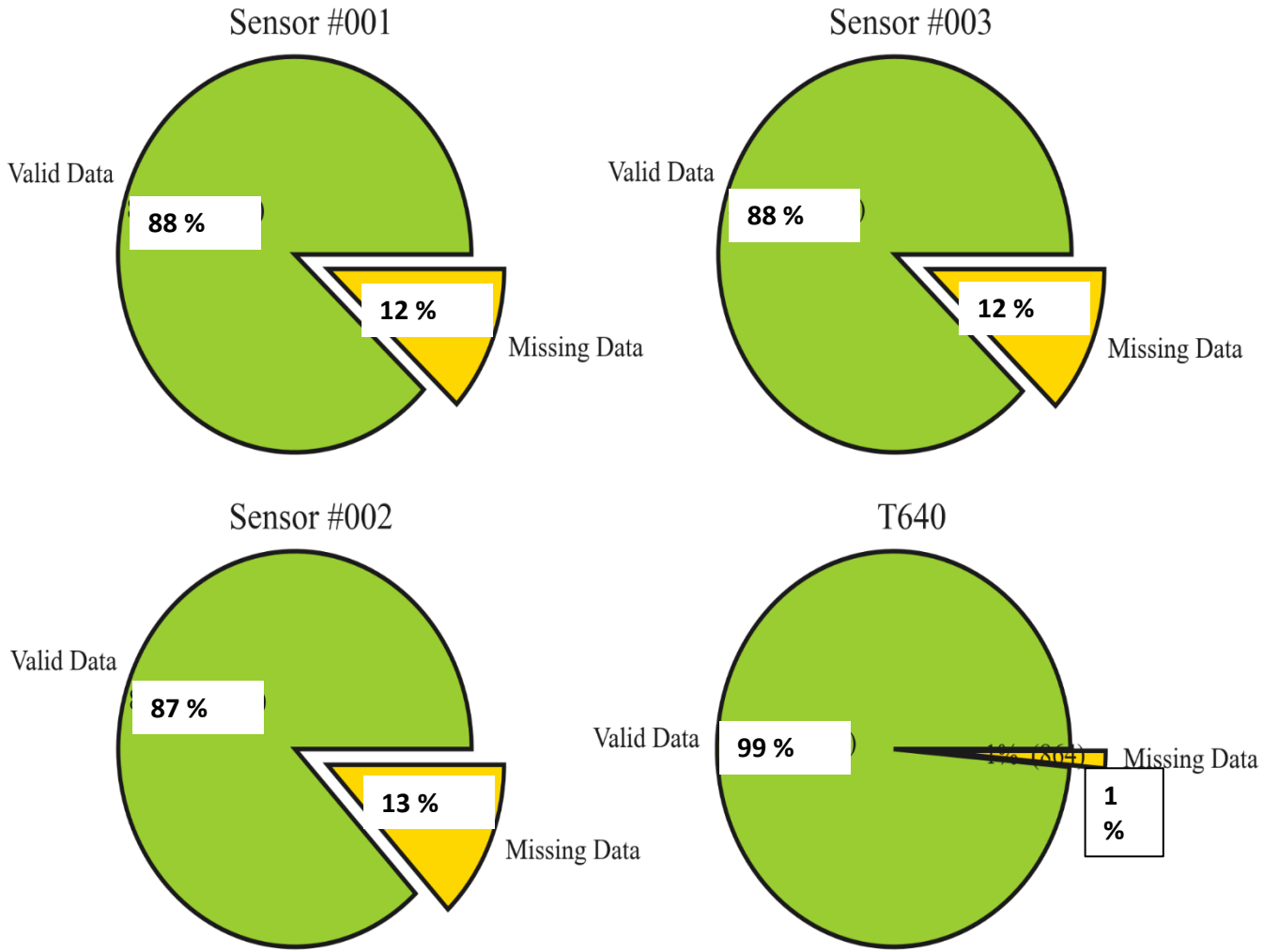
Data recovery

Cleansed data

$$\text{Data recovery (\%)} = \frac{N_{valid\ data}}{N_{test\ period}} * 100$$

six weeks – wet season

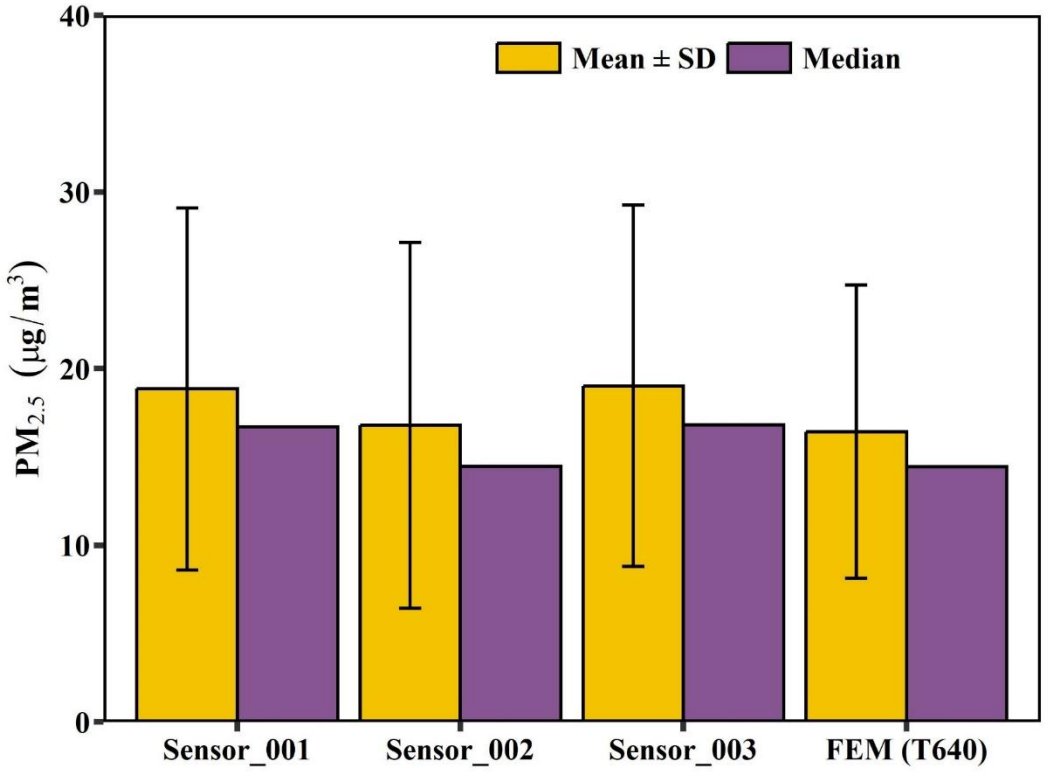
six weeks – dry season



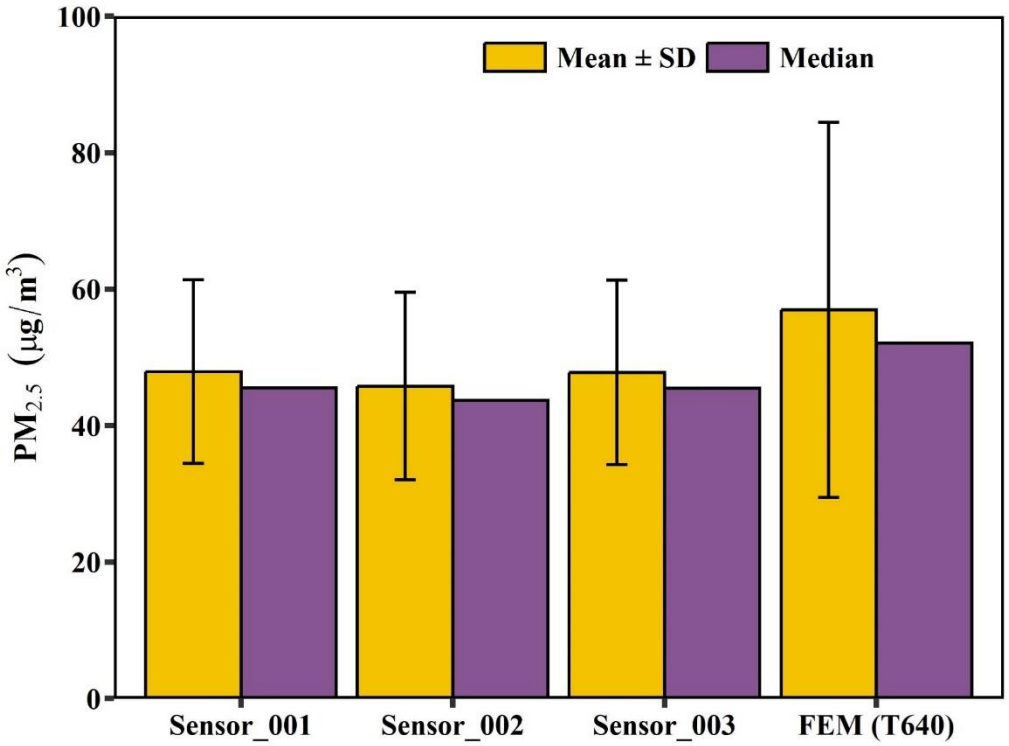
Sensor Performance

- Intra-unit measurement variability
- Inter-unit measurement variability in PM levels when compared to the FEM T640

Wet Period

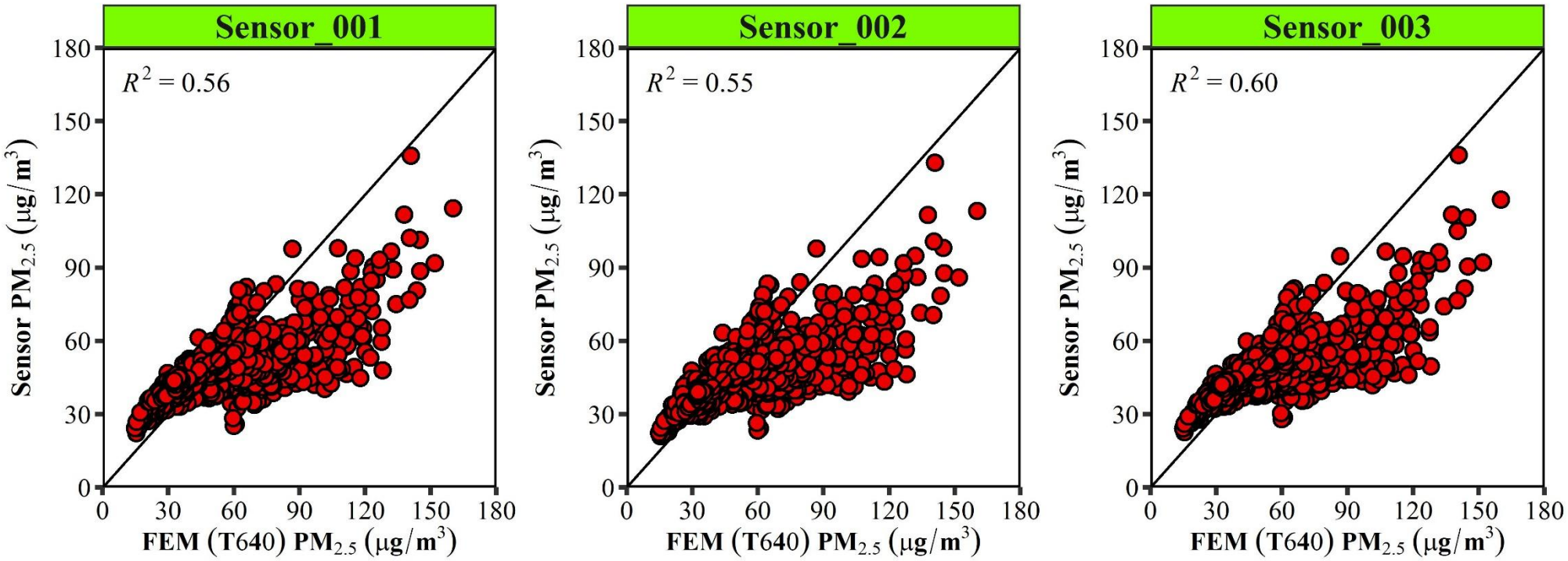


Dry Period



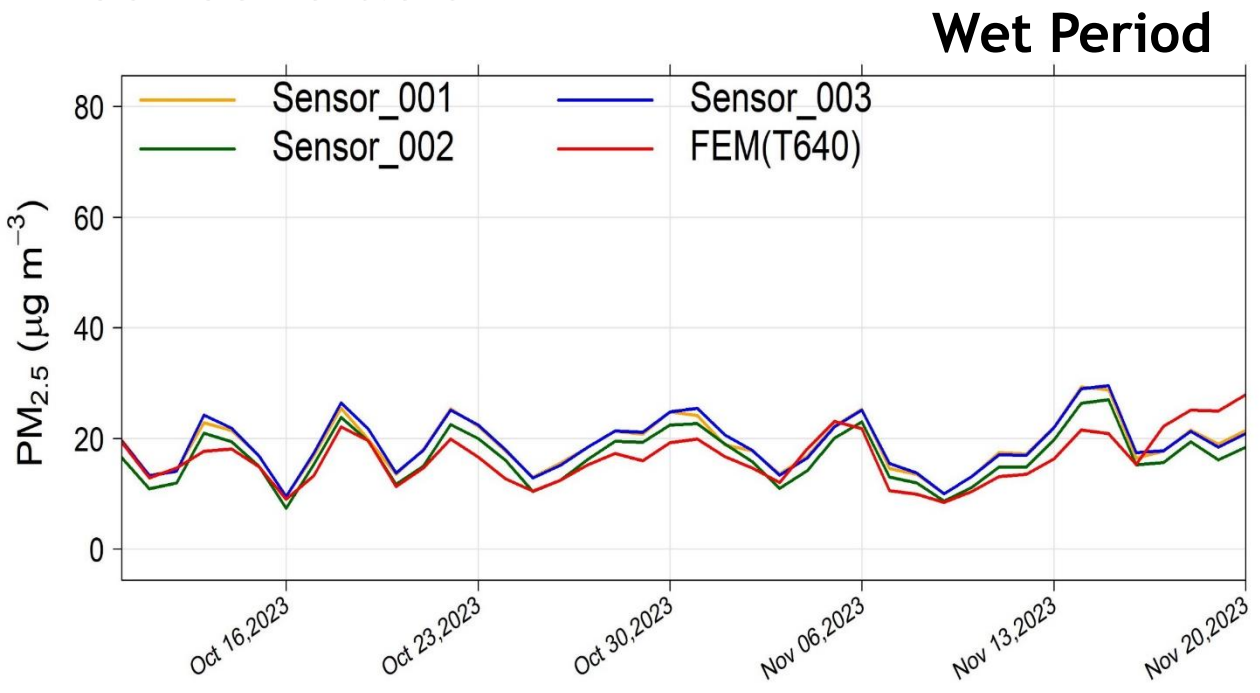
Sensor Performance

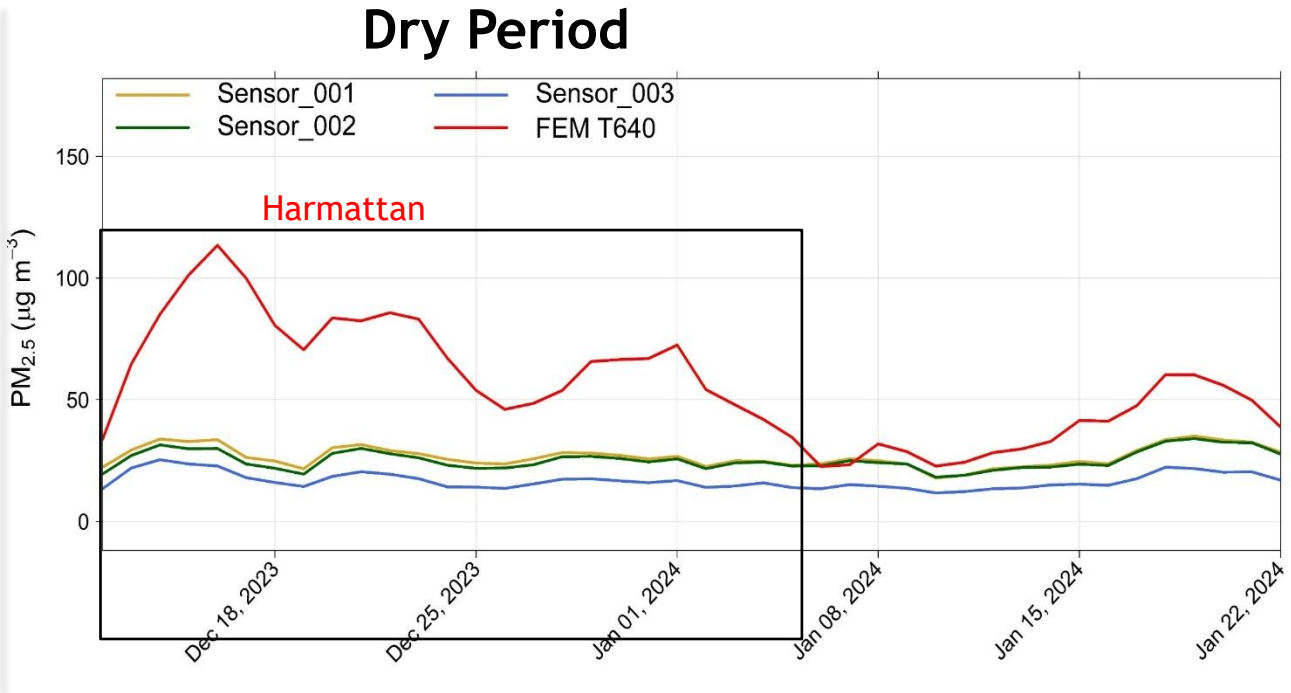
- Determine relationship between sensors data and FEM T640 data
- Calculate measurement errors from sensors to compare with FEM T640



Diurnal variation

- The tendency of the sensors to underestimate or overestimate $PM_{2.5}$ concentration





The sensors seem to track the diurnal $PM_{2.5}$ variations of the FEM T640 in both period

Summary Statistics

	WET PERIOD (1-hour mean)				DRY PERIOD (1-hour mean)			
	R^2	MAE	MBE	RMSE	R^2	MAE	MBE	RMSE
Sensor_001	0.74	4.19	2.35	5.47	0.55	15.86	— 9.00	21.22
Sensor_002	0.71	3.87	0.21	5.27	0.56	16.27	—11.16	22.24
Sensor_003	0.74	4.28	2.46	5.53	0.60	15.42	—9.16	20.79

Future Activities of Afri-SET

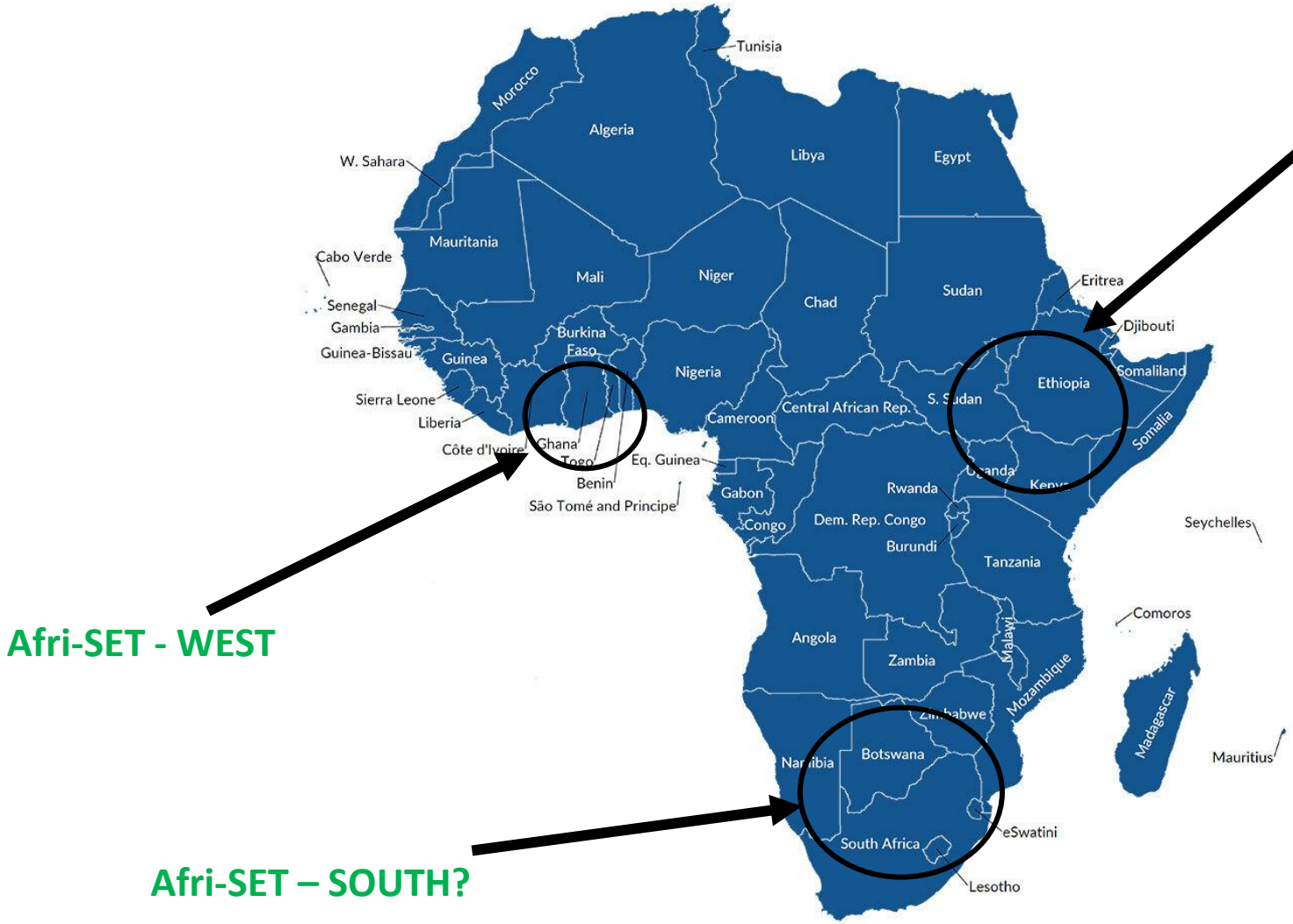
To promote long-term sustainability and replication of the center

i. Explore funding, partnership, and other opportunities to replicate the centre in other regions of Africa.

ii. Monetizing training services (in-person and virtual).

iii. Establishing consulting service for LCS (e.g. analyzing other users' data, deployments, etc.).

Future Activities of Afri-SET



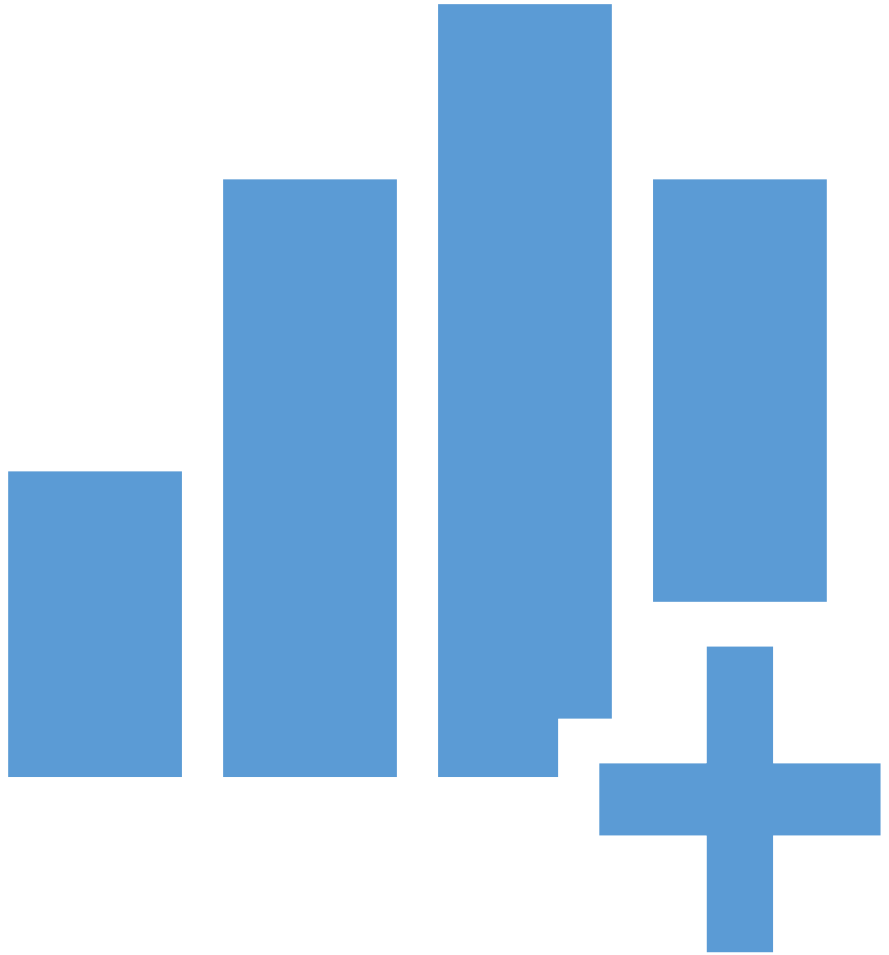
Afri-SET – EAST?

Afri-SET - WEST

Afri-SET – SOUTH?

Conclusion

- Reports are generated after each season (rainy or dry)
- All reports and data are available at the Afri-SET website -www.afriset.org
- All models created to calibrate low-cost sensors are available for download



Next Steps

- Develop calibration factors for each sensor unit and comparison after calibration

Acknowledgement

Norsk institutt for luftforskning
Norwegian Institute for Air Research

Thank you

Come talk to us, or reach us by email if you want to learn more!

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Scan to https://afriset.org/

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