Smart Monitoring and Climate Resilience in African Ecosystems: Inclusive Innovation through International Collaboration

Tom Peeters[1], Jeroen De Vos[1], Nelson Neves[2], Eunice Likotiko[3], Geoffrey Andogah[4], Khamis Said[5]

[1] AP University of Applied Sciences and Arts (Belgium)
[2] ISPGAYA – Instituto Superior Politécnico Gaya (Portugal)
[3] Ardhi University (Tanzania)
[4] Mbarara University of Science and Technology (Uganda)
[5] Karume Institute of Science and Technology (Tanzania)

Abstract

This paper explores a multidimensional approach to sustainability and climate resilience in African ecosystems through the convergence of inclusive international collaboration, IoT-enabled smart monitoring, and context-sensitive educational innovation. The study draws on the Blended Intensive Program (BIP), a European Erasmus+ initiative, and IoT-integrated field trials in Tanzania and Uganda to examine how cross-border academic cooperation can strengthen technological capacity and co-designed environmental solutions.

The methodology combines hybrid learning between African and European institutions with applied fieldwork. The BIP model engaged students and educators in joint projects on smart cities, sensor-based monitoring, and low-cost deployable hardware. Parallel field implementations tested IoT systems in real contexts, linking classroom knowledge to environmental challenges.

Results include three case studies: (i) automated water quality monitoring for fishponds in Uganda, (ii) real-time salinity and nutrient tracking in women-led seaweed farming in Zanzibar, and (iii) air quality monitoring in Dar es Salaam to inform public health policies. These outcomes illustrate how digital tools can address both rural and urban sustainability issues while fostering innovation pipelines that integrate pedagogy, entrepreneurship, and capacity building.

The findings show that African universities, supported by international networks, are shaping smart city models and environmental strategies adapted to local realities. These initiatives contribute directly to the UN Sustainable Development Goals, particularly education (SDG 4), infrastructure (SDG 9), sustainable cities (SDG 11), climate action (SDG 13), ocean health (SDG 14), and land ecosystems (SDG 15). The paper argues that IoT and education-driven partnerships can advance climate resilience, environmental stewardship, and equitable development across the Global South.

Keywords: IoT; Smart Monitoring; Climate Resilience; Sustainability; International Collaboration; Africa.

Introduction

The integration of Internet of Things (IoT) and Artificial Intelligence (AI) education into East African universities has become a pivotal strategy to bridge the technological gap and foster innovation. Institutions like Makerere University in Uganda have established specialized labs and curricula focusing on IoT and AI, aiming to equip students with the necessary skills to address local challenges through technology. For instance, Makerere University launched the Centre for Artificial Intelligence and Data Science (Mak-CAD) in March 2025, dedicated to advancing AI research and innovation for Africa's development (Makerere University, 2025). Similarly, the Uganda Institute of Information and Communications Technology (UICT) offers practical-oriented ICT training at certificate and diploma levels, specializing in emerging technologies such as AI and IoT (International Telecommunication Union [ITU] Academy, 2024). These academic emphases are complemented by regional initiatives like the East African Community's digital skills training programs, which have seen participation from staff across 100 universities, highlighting a collective effort towards enhancing technological competencies (East African Community, 2024).

However, the successful integration of these technologies into educational frameworks is not without its challenges. Factors such as limited infrastructure, inconsistent internet connectivity, and a shortage of qualified instructors hinder the effective delivery of IoT and AI education. A study published in the *Journal of Higher Education Policy and Management* (2025) reports that many students lack access to reliable and affordable digital facilities, which are prerequisites for effective technology integration in higher education. Despite these obstacles, the commitment to advancing digital education is evident, with institutions striving to overcome these barriers through innovative approaches and collaborations. For example, the dSkills@EA initiative has strengthened digital skills for employment and innovation among young professionals, students, and entrepreneurs in the East African Community (EAC Germany, 2024). These ongoing efforts underscore the critical role of higher education in driving technological advancement and addressing the region's development needs.

.

Justification for the integration of the projects

This proposal is the result of the convergence of two complementary projects: the Blended Intensive Programme (BIP), under the Erasmus+ programme, focused on inclusive internationalisation through hybrid learning experiences and urban innovation (European Commission, 2025); the Belgian VLIRUOS International Training Program (ITP) Expert training in AI and IoT for product development (https://kih.kist.ac.tz), the cofounded Erasmus+ programme AHUMAIN (https://ahumain.africa/) and a set of applied IoT-based environmental monitoring trials, developed in sensitive African ecosystems, namely in Tanzania and Uganda (Mulume, 2025; Popoola et al., 2024). Though these projects come from different starting points, they're united in their goals: sharing knowledge, sparking local innovation with a global reach, and tackling sustainability challenges head-on. The integration of these initiatives allows for a holistic analysis of how international collaboration can drive sustainable environmental solutions anchored in technology, education and intercultural co-creation (López-Vargas et al., 2021).

Educational, technological and climate objectives

From an educational perspective, the projects aim to strengthen technical and transversal skills in multidisciplinary and transnational contexts, with an emphasis on the development of active learning methodologies, pedagogical innovation and increased employability (Ignacio Martínez et al., 2021). From a technological perspective, the implementation of IoT-based monitoring systems stands out, capable of collecting, processing and transmitting environmental data in real time, even in contexts with limited infrastructure (Salam, 2019; Adebayo et al., 2024). In terms of climate, the interventions focus on sectors vulnerable to climate change, such as aquaculture, urban air quality and regenerative agriculture, demonstrating how digital approaches can support ecological resilience, food security and sustainable resource management in African territories (Mulume, 2025; Ooko & Rweyemamu, 2024). Furthermore, the intention is that universities, through capacity building and the integration of local knowledge, can assume the role of expert advisors, collaborating closely with government bodies to inform evidence-based policy decisions. This collaboration is grounded in real-life, locally anchored projects, enabling universities to act as key actors in shaping sustainable urban development.

Alignment with the Sustainable Development Goals (SDGs)

The articulation between the projects explicitly responds to several United Nations Sustainable Development Goals (SDGs). The following stand out:

- SDG 4: Quality Education, by promoting inclusive and cooperative learning between global regions (European Commission, 2025);
- SDG 9: Industry, Innovation and Infrastructure, by developing robust and adaptable technological systems (Ignacio Martínez et al., 2021);
- SDG 11: Sustainable Cities and Communities, through smart monitoring for mobility and the urban environment (Salam, 2019);
- SDG 13: Climate Action, with solutions for mitigating and adapting to climate change (Popoola et al., 2024);
- SDGs 14 and 15: Life Below Water and Life on Land, by protecting aquatic and terrestrial ecosystems based on data (Mulume, 2025; López-Vargas et al., 2021).

By blending education and technology with a focus on climate justice, these efforts are key to building a stronger, fairer, and more sustainable future worldwide.

this paper is structured as follows. Section 2 reviews the state of the art on sustainability, smart monitoring, and IoT-enabled environmental innovation in African contexts. Section 3 introduces the methodology, outlining the blended learning approach of the Erasmus+ BIP model and the design of field-based IoT trials. Section 4 presents the applied case studies in Uganda and Tanzania. Section 5 discusses the results, highlighting their implications for sustainable development and international collaboration. Finally, Section 6 concludes with reflections on the contributions, limitations, and future directions of this work.

Theoretical Framework and State of the Art

Smart Monitoring and Sustainable Cities

Smart monitoring is transforming how we build sustainable cities, acting as a key tool to create urban spaces that are more efficient, resilient, and inclusive. By using sensors, communication networks, and data analysis platforms, cities can better manage resources like energy, water, transportation, and waste (American Planning Association, 2015).

These technologies, often seen in smart cities, aim to improve residents' quality of life, cut down emissions, and encourage community involvement. However, for these solutions to truly work, they need to be tailored to local needs, especially in areas with limited infrastructure (Kitchin, 2014). For instance, environmental monitoring helps spot pollution trends, enabling city leaders to craft policies based on solid evidence (López-Vargas et al., 2021).

Ultimately, smart monitoring supports the Sustainable Development Goals, particularly SDG 11—Sustainable Cities and Communities—by fostering more connected and sustainable urban management (Ignacio Martínez et al., 2021).

IoT in Agriculture and Aquatic Ecosystems

The Internet of Things (IoT) is transforming agriculture and aquaculture, making them more efficient, sustainable, and resilient to climate challenges. In farming, IoT sensors track soil moisture, temperature, and nutrients, helping farmers use water and fertilizers more effectively (Liu et al., 2025).

In aquaculture, smart systems monitor water quality—measuring pH, oxygen, and salinity—to boost the health and productivity of aquatic species (Singh et al., 2024).

These innovations are especially vital in places like East Africa, where agriculture and aquaculture are critical for livelihoods and food security.

International Learning and Digital Inclusion

International learning and digital inclusion are key to ensuring everyone shares in the benefits of digital transformation. By fostering global knowledge exchange and making digital tools accessible to all, we can create a more equitable world where technology uplifts everyone, regardless of background or location. Programs such as Blended Intensive Programmes (BIP) promote cooperation between institutions from different countries, enabling the co-creation of technological solutions with local impact and global relevance (European Commission, 2025).

Digital inclusion, in turn, refers to the ability to ensure access, skills and active participation of all social groups in the digital ecosystem. In African contexts, the combination of blended learning, access to devices and digital skills training has demonstrated positive impacts on employability, local innovation and civic participation (Hockings, 2010; Gurin et al., 2002).

Intercultural learning helps us connect on a deeper level, building empathy, teamwork, and a shared global perspective. These qualities are crucial for working together to solve big challenges like climate change and environmental justice (Arvanitakis & Hornsby, 2016).

Methodology

This study employs a qualitative, multiple-case study methodology, which is appropriate for investigating complex, context-dependent phenomena in real-world settings (Yin, 2018). The focus is on applied IoT-based monitoring projects implemented in East Africa, specifically in Tanzania, Uganda, and Zanzibar. Case studies were selected purposively based on their environmental, socio-economic, and technological significance.

The research integrates participatory action and observational methods to collect rich, contextualized data. Stakeholders—including students, academic staff and local authorities—were actively involved in co-designing project interventions, in alignment with participatory design principles (Spinuzzi, 2005). Project deliverables (prototypes, dashboards, reports), and digital collaboration artifacts generated during both virtual and physical phases of the BIP.

The methodology emphasizes experiential and interdisciplinary learning, reflecting the educational objectives of the BIP. Students from information technology and electronics backgrounds collaborated in heterogeneous teams, undertaking the full project lifecycle, from planning and prototyping to evaluation and reporting. Pedagogical outcomes were assessed through direct observation, analysis of technical artifacts, and structured reflection, allowing evaluation of both cognitive and practical skill acquisition.

By combining participatory, field-based research and analysis, the study provides empirical evidence on the effectiveness of integrating IoT technologies into educational curricula, fostering both technological competence and societal impact.

This project was made possible through the combined support provided by three key initiatives. The Erasmus+ Blended Intensive Programme (BIP) served as the foundation for the development and implementation of our capacity building and learning methodology, fostering international collaboration and active learning across institutions. The Erasmus+ AHUMAIN project (AHUMAIN, undated) and the VLIRUOS International Training Programme (ITP) (*Karume innovation hub*. Undated) provided critical funding and logistical support, making it possible to bring this program to life. These initiatives enabled a diverse group of learners and experts to come together, fostering a vibrant, cross-cultural, and interdisciplinary educational experience rooted in innovation and sustainability.

Description of the AHUMAIN project

The world is experiencing a technological revolution with Internet Of Things (IoT) and Artificial Intelligence (AI). Governments are investing in AI to stay competitive, and African companies need to adopt AI to reduce costs and attract global partners. The AHUMAIN project seeks to address local IT needs, offer up-to-date AI and Data Science courses, and build an international network for knowledge exchange to promote useful and commercially viable AI systems.

All supported by digital tools for project management, course development & quality assurance Key ideas are openness, collaboration, synergy and respect.

Description of the ITP project

The goal of the International Training Program (ITP) is to implement an innovation hub, which can act as the central point of a new business ecosystem. This ecosystem will enhance the collaboration between all innovative parties in Zanzibar, will create a multidisciplinary community for learning and research and will act as an incubator to facilitate start-ups and product development for new and sustainable (digital) products.

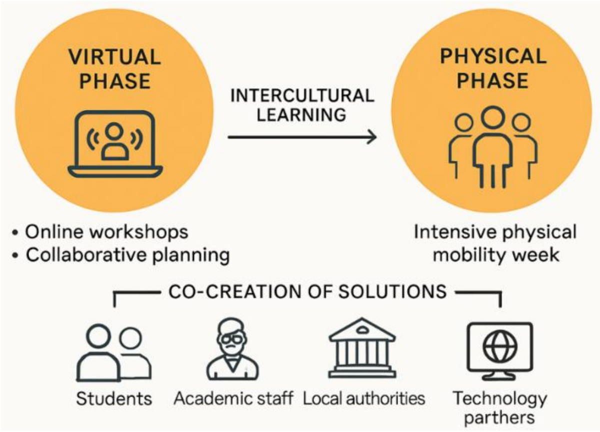
Description of the BIP: Blended Approach, Stakeholders and Partners

The Blended Intensive Program (BIP) implemented under the Erasmus+ framework adopts a hybrid model that combines short-term physical mobility with virtual collaboration, enabling inclusive participation across institutions and geographies (European Commission, 2025). The program was co-organized by a consortium of higher education institutions from Europe and East Africa, which involved faculty and students from cities/countries such as Antwerp/Belgium, Vila Nova de Gaia/Portugal, Chania/Greece, Kampala, Arua, Mbarara /Uganda, and Dar es Salaam and Zanzibar/Tanzania, which, as shown in Figure 1, covers a large geographic area, promoting real inclusion for cultures and religions.

Fig 1. BIP2025@Antwerp. Source: Prepared by the authors.

As show in Figure 2., The Blended Intensive Program (BIP) is a learning program that combines virtual and physical phases to promote intercultural learning and the co-creation of solutions; a Virtual Phase that, includes online workshops and collaborative planning, allowing remote participation. a Physical Phase that consists of an intensive week of physical mobility, facilitating face-to-face interaction; a Intercultural Learning where the program aims to promote the exchange of knowledge and experiences between different cultures; a Co-creation of Solutions that involves the collaboration of students, academic staff, local authorities and technology partners in the development of solutions.

Fig 2. Blended Intensive Programme. Source: Prepared by the authors.



Stakeholders included students, academic staff, local authorities, NGOs, and technology partners, ensuring a transdisciplinary and intercultural learning environment. The program emphasized challenge-based learning, where mixed teams tackled issues aligned with the UN Sustainable Development Goals (SDGs), particularly in the domains of environmental monitoring and digital inclusion (ISCTE, 2024; Blended Intensive Programs, 2024).

The International Project for IT Students is a dynamic, hands-on course that brings together students from varied academic and cultural backgrounds to tackle real-world challenges. Running during the spring semester and worth 3 ECTS (European Credit Transfer and Accumulation System), with the possibility of more depending on each institution's rules, this program encourages teamwork across disciplines to address meaningful social issues.

At the start, students dive into the essentials of project management, with a focus on Agile methods, and take part in sessions on intercultural communication to help them collaborate effectively in global teams. English is the common language, ensuring everyone can connect and contribute seamlessly, no matter their background.

Each project is commissioned by an external field partner, which may include private companies, non-governmental organizations, public sector bodies, or academic research groups. These partners play an active role in the formulation of the problem and the validation of the proposed solution. Teams consist of four to six students, carefully composed to ensure a mix of nationalities and disciplines. The project runs from February to June, and students are expected to dedicate at least one full day per week to the project. This includes team coaching, independent and collaborative work, interaction with the field partner, and engagement with theoretical frameworks.

The primary pedagogical aim is to guide students through a full project management cycle, with iterative planning, prototyping, and evaluation. Each team is assigned a project coach who meets with the students weekly, typically via online platforms such as Microsoft Teams, and remains available throughout the semester for ad hoc support. Coaches are expected to attend both the midterm and final presentations and participate in the final evaluative discussion.

To ensure feasibility and relevance, each project must be executable within the designated timeframe and must result in a tangible product or prototype. The deliverable should address a real-world need of the partner organization and be designed with a specific target audience in mind. Students are also encouraged to think about the long-term impact of their solutions, suggesting ways to sustain or build on their ideas in the years ahead.

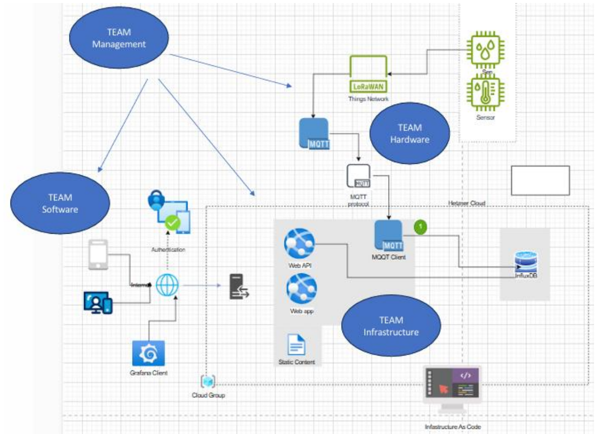
The learning outcomes associated with the project are situated in three main domains: interdisciplinary collaboration, communication and reporting, and technical problem-solving. Students work both independently and in teams, taking ownership of their contributions while boosting the group's overall success. They're encouraged to embrace the challenges of diverse, interdisciplinary settings by blending their unique skills with those of others.

Throughout the project, they sharpen their ability to tackle complex problems, manage time effectively, and keep the team running smoothly. They also build intercultural skills, which are essential in today's global workforce. Regular discussions with peers and external partners hone their communication abilities, and they learn to clearly and accurately report on processes, systems, and results. The final presentation and project report assess not just the end product but also the team's collaboration and reflective thinking.

On the technical side, students propose and develop solutions to complex problems, drawing on their existing knowledge and skills to create something impactful. This involves evaluating alternative approaches, selecting suitable technologies, and constructing a working prototype or proof of concept. Tools that support collaborative development are actively integrated into the workflow.

The group of students from information technology or electronics courses was divided into three different projects, each subdivided into three teams: hardware, infrastructure, and software. Furthermore, each project had a student responsible for project management, who could be from either information technology or electronics. Figure 3, schematically presents this division into teams within each project.

Fig 3. Team division in each project. Source: Prepared by the authors.



The table below outlines the roles assigned to each team for every project:

Table 3. The roles of each team at each project. Source: Prepared by the authors.

	Hardware Developer	**Infrastructure Engineer**	**Full-Stack Developer**	**Business Analyst & Management**
Role	Develop LoRaWan communication	Deploy backend and databases to Hetzner.	Develop RESTful APIsto handle sensor data	ScrumMaster
	Build a specific sensor module for your challenge	Configure CI/CD pipelines for automated deployment	Build a dashboard for real-time monitoring using Angular	Translates business needs and requirements into clear specifications for the IT team
		Ensure data security and cloud storage optimization.		
Skills	Electronics	DevOps	Java	Scrum
	Sensor development	Scripting	API Development	Management
	Arduino	Cloud Technology	Angular	Communication

Applied Cases: Tanzania, Uganda and Zanzibar

The field component of the project focused on three applied case studies in East Africa, each addressing a distinct environmental or socio-economic challenge through IoT-based monitoring:

– In Dar es Salaam (Tanzania): A distributed air quality monitoring system was designed to measure particulate matter (PM2.5 and PM10) and gaseous pollutants in urban areas. The system was designed to guide public health strategies and shape smarter urban planning (Popoola et al., 2024).

– In Uganda, both in Kampala and rural aquaculture sites, IoT-powered fish pond monitoring systems were set up to keep tabs on water quality factors like pH, temperature, and dissolved oxygen. These tools helped small-scale fish farmers boost productivity and keep more fish alive, making their work more sustainable and successful (Mulume, 2025).
– In Zanzibar, a pilot project centered on seaweed farming—a vital source of income for rural women—used sensors to track salinity, temperature, and nutrient levels. This technology helped fine-tune harvest cycles, boosting yields and strengthening economic stability for these communities. (Asya, 2020).

These case studies were selected for their climatic vulnerability, economic relevance, and potential for scalable impact. Each intervention was co-designed with local stakeholders to ensure contextual appropriateness and long-term sustainability.

Technologies Used (Sensors, Platforms, Renewable Energies)

The technological backbone of the project relied on low-cost, modular IoT architectures tailored to resource-constrained environments. Key components included:

– Sensors: Temperature, humidity, pH, turbidity, salinity, and gas sensors were integrated with single board computers (SBC) such as Arduino Uno and ESP32 for data acquisition (Singh et al., 2024). The following figures, from figure 4 to figure X, identifying the SBC and the sensors used at the projects at BIP2025@Antwerp:

Fig 4. – Walter ESP32-S3 IoT Development Board - Cat-M NB-IoT en GNSS - GM02SP. Source: https://soracom.io/store/walter/?srsltid=AfmBOop8Z98i2mos-lAxWZlGhtaL4mmuRK8G46vjr6T-gc3s7ONRSsY5 in 7 of July, 2025.

Fig 5. – LilyGO T-Beam V1.2 AXP2101- LoRa 868MHz - NEO-6M GNSS - ESP32. Source: [https://www.tinytronics.nl/en/development-boards/microcontrol-ler-boards/with-gps/lilygo-t-beam-v1.2-axp2101-lora-868mhz-neo-6m-gnss-esp32](https://www.tinytronics.nl/en/development-boards/microcontroller-boards/with-gps/lilygo-t-beam-v1.2-axp2101-lora-868mhz-neo-6m-gnss-esp32) in 7 of july, 2025

Fig 6. – DFRobot FireBeetle Covers - LoRa Radio 868MHz ***
DFRobot FireBeetle 2 ESP32-E IoT Development Board - Wi-Fi en Blue-tooth - met Gesoldeerde Headers. Source: https://www.dfrobot.com/product-1831.html?srsltid=AfmBOorWNxgsivpud-cbPsYi_VMMdzNeON9V4l6kdQMj0mnFFqrCdL_aG in 7 of july, 2025

Fig 7. - Gravity: 7/24 Industrial Analog pH Meter Kit. Source: https://www.dfro-bot.com/product-2069.html?srsltid=Afm-BOop9mwP0hvO9RZVOSRNki3XaQbZ79khYctILwIawf3bC3fMmrk2A in 7 of july, 2025

Fig 8. - Gravity Analog Dissolved Oxygen Sensor SKU SEN0237. Source: https://wiki.dfrobot.com/Gravity__Analog_Dissolved_Oxygen_Sensor_SKU_SEN0237 in 7 of july, 2025

Fig 9. - Gravity I2C BME680 Environmental Sensor VOC, Temperature, Humidity, Barometer SKU SEN0248. Source: https://wiki.dfrobot.com/Gravity__I2C_BME680_Environmental_Sensor__VOC,_Temperature,_Humidity,_Barometer__SKU__SEN0248 in 7 of july, 2025

Fig 10. - Analog Turbidity Sensor+module. Source: https://wiki.dfrobot.com/Turbidity_sensor_SKU__SEN0189 in 7 of july, 2025

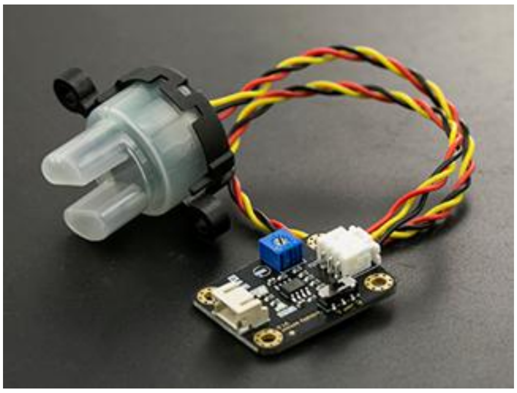


Fig 11. - Gravity IO Expansion Shield for FireBeetle 2 Series Wiki. Source: https://wiki.dfrobot.com/Gravity_Shield_for_FireBeetle_2_SKU_DFR0762 in 7 of july, 2025

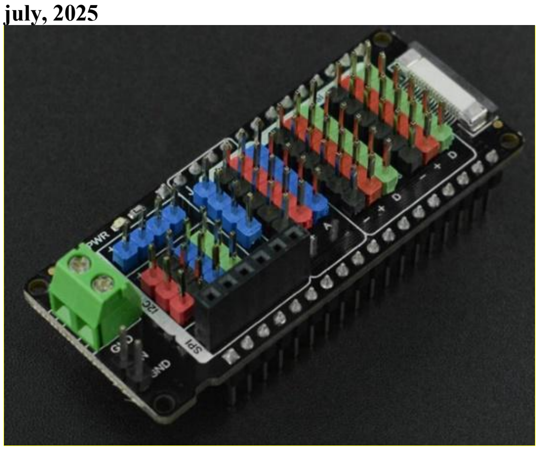
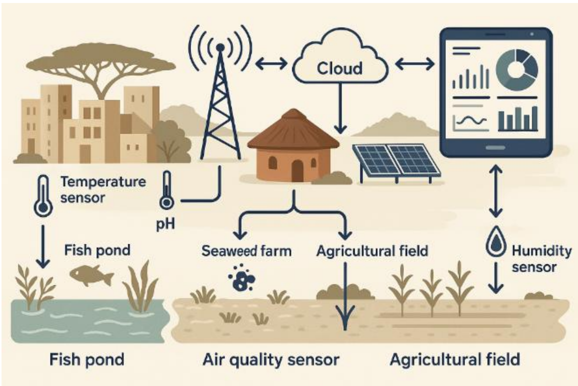


Fig 12. - Kradex Enclosure 176x126x57mm - IP65 - Grey - Transparent - Z74JPH TM ABS. Source: https://www.tinytronics.nl/en/tools-and-mounting/enclosures/universal/kradex-enclosure-176x126x57mm-ip65-grey-transparent-z74jph-tm-abs in 7 of july, 2025

– Communication Platforms: Data transmission was LoRaWAN;
– Data was visualized using custom made software components;
– Renewable Energy Integration: In off-grid areas, solar panels were used to power sensor nodes and communication modules. This approach aligns with SDG 7, Affordable and Clean Energy, ensuring energy autonomy and reducing environmental impact (Ponnalagarsamy et al., 2021).

By weaving together these technologies, the project showed how IoT systems can be tailored to different environments, enabling smarter, data-driven decisions while empowering local communities.

Fig 13. - Intelligent Monitoring System Architecture Diagram. Source: Prepared by the authors.



The diagram in Figure 13 illustrates an "IoT Smart Monitoring System for Climate Resilience in African Ecosystems," showing how:

– Sensors: These devices gather key environmental data like temperature, humidity, air pressure, air quality, and salinity.
– Communication Modules: They send the sensor data using tech like LoRa, Bluetooth, or other network connections.
– Cloud Platform: Data flows from edge devices to a cloud platform, where it's processed and stored.
– User Applications: People can access this data through a web dashboard, mobile app, or even Telegram, making it easy to monitor conditions in real-time and make smart, informed decisions.
– Objective: The system aims to improve environmental monitoring and climate change responsiveness in African ecosystems, providing crucial data for climate resilience and sustainable resource management.

From a software perspective, the system integrates sensor data collection, secure communication, scalable data processing, and user-friendly web access through a modular, cloud-native architecture.

The backend was implemented using Spring Boot with RESTful API endpoints and integrated PostgreSQL and InfluxDB for structured and time-series data management, respectively. The system architecture followed microservice principles with containerization and service routing handled via Traefik, ensuring horizontal scalability and simplified deployment. Authentication and authorization were implemented using JWT and OAuth 2.0 protocols, while Firebase integration enhanced user identity management and role-based access control.

Sensor data, transmitted via MQTT from deployed edge devices, was successfully ingested, parsed, and stored with high temporal resolution, supporting near real-time monitoring. A user-friendly single-page app, created with Angular, gave end-users an easy-to-navigate interface to view and analyze key data like pH, temperature, and salinity. Robust security measures were embedded throughout the system, including HTTPS transport, backend route protection, and secure token handling.

Data is transmitted through The Things Network (TTN) to a Hetzner-hosted cloud server, where it is ingested into InfluxDB for timeseries analysis and PostgreSQL for configuration and user management. The system employs a microservices architecture managed via Docker Compose, enabling modular deployment and automated updates through a GitLab CI/CD pipeline. Observability is achieved using Prometheus, Grafana, and OpenTelemetry, ensuring system performance, traceability, and alerting. To keep communications secure, the system uses TLS encryption and controls who can access each part of the platform through role-based permissions. Reliability is ensured through persistent data volumes that preserve important information and continuous monitoring of system resources.

Although we initially considered using Docker Swarm for container orchestration, we ultimately decided against it due to limited resources. This decision highlights how crucial it is to properly scale infrastructure when designing cloud-native solutions.

The project is based exclusively on open-source tools, which ensures cost efficiency and facilitates future growth. Essentially, it demonstrates how it is possible to practically integrate IoT technologies, cloud infrastructure, and DevOps methodologies for environmental monitoring, even when working with limited resources.

Results and Discussion

Lessons from International Collaboration

To keep communications secure, the system uses TLS encryption and controls who can access each part of the platform through role-based permissions. Reliability is ensured through persistent data volumes that preserve important information and continuous monitoring of system resources. Although we initially considered using Docker Swarm for container orchestration, we ultimately decided against it due to limited resources. This decision highlights how crucial it is to properly scale infrastructure when designing cloud-native solutions. The project is based exclusively on open-source tools, which ensures cost efficiency and facilitates future growth. Essentially, it demonstrates how it is possible to practically integrate IoT technologies, cloud infrastructure, and DevOps methodologies for environmental monitoring, even when working with limited resources. (Thompson, 2006).

Participants reported significant gains in intercultural skills, scientific communication, and collaborative problem-solving, aspects often highlighted as central benefits of transnational research (Dusdal & Powell, 2021). Furthermore, the sharing of resources, methodologies, and infrastructure between African and European institutions has increased the efficiency and quality of the results obtained (APA, 2015).

Collaboration has also facilitated the creation of lasting networks between researchers, students, and policymakers, promoting the continuity of projects and the scalability of solutions. However, challenges such as language differences, time zones and institutional asymmetries required careful management strategies and constant communication (Rigby & Edler, 2005). To overcome these obstacles, the project required the development of very well-thought-out management strategies and constant, transparent communication between everyone involved.

Environmental, Educational and Social Impacts

The environmental results of the projects were remarkable and visible from the beginning. We were able to significantly improve the monitoring capacity of vulnerable ecosystems, especially coastal zones and densely populated urban areas, which are particularly vulnerable to climate change.

The ability to collect data in real time completely changed the way we respond to environmental problems. Instead of discovering problems weeks or months later, we can now intervene quickly and much more effectively, helping to reduce environmental risks and better adapt to climate change (Salam, 2019).

Educational-wise, participants developed a powerful combination of technical and soft skills. On the technical side, they learned about IoT, data analytics, and sustainability, areas that are increasingly important in the job market. But equally valuable was the development of skills such as teamwork, critical thinking, and digital literacy (Zee-shan et al., 2022). These skills are essential for preparing a new generation of professionals who can tackle global challenges with sustainable technological solutions. It's not just about knowing how to use technology, but about using it intelligently and responsibly.

From a social perspective, the projects had a transformative impact on local communities. It was particularly gratifying to see how we were able to include local communities, especially women, in activities such as seaweed aquaculture. This not only strengthened gender equity but also promoted these women's economic autonomy (Ganancias et al., 2024).

Furthermore, by using accessible technologies adapted to the local context, we were able to bridge the digital divide and increase citizen participation. People felt more engaged and empowered to actively participate in monitoring and protecting their environment (Bustami & Suzanna, 2025).

Limitations Faced and Replicability

Despite the positive results, the projects faced several limitations, as limited connectivity in rural areas made continuous data transmission difficult, requiring hybrid solutions with local storage and periodic synchronization (Ponnalagarsamy et al., 2021).

Device maintenance also proved to be a challenge, especially in environments with high humidity, salinity, or dust. Local technical training was essential to ensure the sustainability of the infrastructure, but it was not always possible to ensure continuous technical support (Guttinger, 2020).

Regarding replicability, the results demonstrate that the implemented models are scalable, as long as they are adapted to the sociotechnical realities of each region. Successful replication requires community involvement, adequate funding, and public policies that encourage local innovation (Dusdal & Powell, 2021). True replicability goes far beyond simple technical reproduction. It involves a careful and contextualized reinterpretation of proven effective solutions, adapting them to the specificities of each new application environment (Guttinger, 2020).

Conclusion and Future Perspectives

Openness to New BIP and Expansion to Other Regions

The extremely positive experience of the Blended Intensive Program (BIP) clearly demonstrated its potential as a replicable and scalable model, capable of being successfully adapted to other regions and diverse contexts. The combination of short-term physical mobility with virtual collaboration allows institutions from different geographies to be involved, promoting inclusive internationalization and learning based on real challenges (European Commission, 2025).

Expansion to other regions, such as Latin America, Southeast Asia or Southern Africa, can benefit from existing networks within the framework of Erasmus+ and strategic partnerships between higher education institutions, local governments and civil society organizations (STARS EU, 2023). Furthermore, the flexibility of the BIP model allows content to be adapted to local needs, while maintaining the pedagogical structure focused on co-creation, interdisciplinarity and social impact (Klavina et al., 2023).

The opening of new BIP programs must be accompanied by sustainable financing mechanisms, teacher training in hybrid methodologies, and continuous impact assessment, ensuring the quality and relevance of training experiences.

Potential of Educational IoT as a Tool for Scientific Diplomacy and Social Innovation

The use of the Internet of Things (IoT) in educational contexts transcends the technical dimension, positioning itself as a powerful tool for scientific diplomacy and social innovation. By involving students, researchers, and local communities in the design and implementation of technological solutions, educational projects with IoT promote intercultural dialogue, knowledge transfer, and international scientific cooperation (Martinez et al., 2023).

Science thus becomes an instrument for building bridges between countries and cultures, contributing to the joint resolution of global challenges such as climate change, food security, and environmental justice (Ziegler et al., 2023). On the other hand, the local appropriation of IoT technologies, especially in vulnerable communities, stimulates basic social innovation, reinforcing autonomy, digital literacy and citizen participation (Vasconcelos, 2022).

This potential should be explored through public policies that encourage open science, South-South and North-South cooperation, and the formation of inclusive innovation networks.

Continued Alignment with the SDGs

The continuity of the projects described in this article must remain firmly aligned with the Sustainable Development Goals (SDGs) of the 2030 Agenda. The integration of digital technologies, such as IoT, in sectors such as education, agriculture, energy and environment, directly contributes to SDGs such as:

- SDG 4 - Quality Education,
- SDG 7 - Affordable and Clean Energy,
- SDG 9 - Industry, Innovation and Infrastructure,
- SDG 11 - Sustainable Cities,
- SDG 13 - Climate Action,
- SDGs 14 and 15 - Life Below Water and Life on Land (Martínez et al., 2021; Springer Handbook, 2023).

Continuous monitoring of impact indicators, adaptation to local realities and multi-sectoral cooperation are essential to ensure that projects not only contribute to the SDGs, but also evolve with them. IoT, when guided by ethical and sustainable principles, can be a transformative vector in building more just, resilient and inclusive societies.

General conclusions

This study highlights the growing importance of IoT and AI technologies in East Africa, particularly in sectors such as agriculture, health, and education. The findings indicate that while technological adoption is progressing, its effectiveness is closely tied to the availability of skilled human resources, infrastructure, and supportive policies.

Contribution to management, society and literature

From a managerial perspective, this research provides insights for organizations and institutions seeking to implement IoT monitoring systems efficiently. Socially, the study underscores the role of education in empowering local communities and fostering innovation. Academically, the work contributes to the literature by integrating technology adoption, educational initiatives, and regional development within the East African context, offering a framework for future studies.

Limitations

The study acknowledges certain limitations, including the availability of up-to-date data, the diversity of contexts within East Africa, and the focus on selected case studies and universities. These constraints may affect the generalizability of the findings.

Future Investigation

Future research could explore longitudinal studies on the impact of university-led IoT and AI programs on regional technological ecosystems. Comparative analyses between countries in East Africa, as well as the examination of additional sectors such as urban management and energy, could further deepen understanding and provide actionable recommendations.

References

East African Community. (2024). Over 200 participants from 30 universities in EAC graduate in digital skills training. https://www.eac.int/tb2/2-uncategorised/2607-over-200-particiapnts-from-30-universities-in-eac-graduate-in-digital-skills-training

EAC Germany. (2024). Empowering East Africa's digital future: dSkills@EA lays the groundwork for the EAC regional AI alliance. https://www.eacgermany.org/news/empowering-east-africa-s-digital-future-d-skills-ea-lays-the-groundwork-for-the-eac-regional-ai-alliance

International Telecommunication Union (ITU) Academy. (2024). Uganda Institute of Information and Communications Technology (UICT). https://academy.itu.int/uganda-institute-information-and-communications-technology-uganda-uict

Makerere University. (2025). Makerere launches AI and Data Science Centre to drive Africa's technological development. https://cocis.mak.ac.ug/makerere-launches-ai-and-data-science-centre-to-drive-africas-technological-development

Journal of Higher Education Policy and Management. (2025). Digital technology integration in East African higher education: Challenges and opportunities. https://www.tandfonline.com/doi/full/10.1080/1475939X.2025.2520589

Adebayo, A., Popoola, O. V., & Oyedeji, O. C. (2024). Climate change effect in Nigeria: Mitigation, adaptation strategies and the role of IoT. ResearchGate. https://www.researchgate.net/publication/380615790

AHUMAIN – AI on the revolution. (undated). Ahu-main.Africa. 02 de julho de 2025, de https://ahumain.africa

American Planning Association. (2015). Smart Cities and Sustainability Initiative. https://www.planning.org/knowledgebase/resource/9165048

American Psychological Association. (2015). Engaging in international collaborative research. https://www.apa.org/international/resources/publications/research

Arvanitakis, J., & Hornsby, D. J. (Eds.). (2016). Universities, the citizen scholar and the future of higher education. Palgrave Macmillan.

Asya, S. M. (2020). Development of IoT-based solution for small sailing boat monitoring and tracking: A case of Zanzibar [Master\'s thesis, State University of Zanzibar]. http://hdl.handle.net/123456789/1391

Blended Intensive Programmes - Erasmus+ & European Solidarity Corps guides - EC Public Wiki. (2024). Europa.eu. https://wikis.ec.europa.eu/spaces/NAITDOC/pages/95553249/Blended+Intensive+Programmes

Bustami, M. F., & Suzanna, E. (2025). IoT-based environmental monitoring and its implications for student mental health. Revista de Gestão Social e Ambiental, 19(2). DOI: 10.24857/rgsa.v19n2-022

Dasgupta, S., Lall, S. V., & Wheeler, D. (2020). Traffic, air pollution, and distributional impacts in Dar es Salaam: A spatial analysis with new satellite data. World Bank Policy Research Working Paper No. 9185. https://ssrn.com/abstract=3554094

Dusdal, J., & Powell, J. J. W. (2021). Benefits, motivations, and challenges of international collaborative research: A sociology of science case study. Science and Public Policy, 48(2), 235-245. DOI: 10.1093/scipol/scab010

European Commission. (2025). Erasmus+ Programme Guide 2025. https://erasmus-plus.ec.europa.eu

Farooq, Q. U., Lavanya, A., Ali, W., Ali, S. M., & Bhavsingh, M. (2024). AgriAqua intelligence: Advancing smart farming with ecosystem-based water management solutions. International Journal of Computer Engineering in Research Trends, 11(1), 51-60. DOI: 10.22362/ijcert/2024/v11/i1/v11i17

Ganancias, F. M., Tayo, C. O., Plaza, L. Y., & Mylene, F. (2024). IOT - CONTROLLED SEAWEED MONITORING SYSTEM. 36(6), 415-419. https://www.researchgate.net/publication/388656466_IOT_-CONTROLLED_SEAWEED_MONITORING_SYSTEM.

Gurin, P., Dey, E., Hurtado, S., & Gurin, G. (2002). Diversity and Higher Education: Theory and Impact on Educational Outcomes. Harvard Educational Review, 72(3), 330-367. DOI: 10.17763/haer.72.3.01151786u134n051

Guttinger, S. (2020). The limits of replicability. European Journal for Philosophy of Science, 10, Article 10. DOI: 10.1007/s13194-019-0269-1

Hockings, C. (2010). Inclusive Learning and Teaching in Higher Education A Synthesis of Research. York Higher Education Academy. - References - Scientific Research Publishing. (n.d.). Www.scirp.org. https://www.scirp.org/reference/referencespapers?referenceid=2937174.

Ignacio Martínez, I., Zalba, B., Trillo-Lado, R., Blanco, T., Cambra, D., & Casas, R. (2021). Internet of Things (IoT) as Sustainable Development Goals (SDG) enabling technology. Sustainability, 13(14), 7647. DOI: 10.3390/su13147647

Ineza, Y. (2022). IoT monitoring systems in aquaculture: Case study of University of Rwanda Fish Farming and Research Station (UR-FFRS) [Master\'s dissertation, University of Rwanda]. https://dr.ur.ac.rw/handle/123456789/1755

International Energy Agency - Photovoltaic Power Systems Programme (IEA-PVPS). (2023). Dual land use for agriculture and solar power production: Overview and performance of agrivoltaic systems. https://iea-pvps.org/key-topics/dual-land-use-agriculture-solar-power-production/

Iscte - Instituto Universitário de Lisboa. (2024). Erasmus+ Blended Intensive Programmes. https://www.iscte-iul.pt/conteudos/internacional/mobilidade/2570

Karume Innovation Hub. (undated). Kist.Ac.Tz. 02 de julho de 2025, de https://kih.kist.ac.tz

Karume Innovation Hub. (2025). Monitoring air quality in Dar es Salaam. https://kih.kist.ac.tz/2025/04/01/monitoring-air-quality-in-dar-es-salaam/

Klavina, A., Ferreira, J., Dadová, K., & Reina, R. (2023). Inclusive and adapted physical activities: Reflections from a Blended Intensive Programme. European Federation of Adapted Physical Activity. https://eufapa.eu/recap-blended-intensive-programme-in-apa

Kitchin, R. (2014). The real-time city? Big data and smart urbanism. GeoJournal, 79(1), 1-14. DOI: 10.1007/s10708-013-9516-8

Kunapinun, A., Fairman, W., Wills, P. S., Hanisak, D., & Ouyang, B. (2024). Advancing seaweed cultivation: Integrating physics constraint in machine learning for enhanced biomass forecasting in IMTA systems. Remote Sensing, 16(23), 4418. DOI: 10.3390/rs16234418

Liu, L., Cheng, W., & Kuo, H.-W. (2025). A narrative review on smart sensors and IoT solutions for sustainable agriculture and aquaculture practices. Sustainability, 17(12), 5256. DOI: 10.3390/su17125256

López-Vargas, A., Ledezma-Espino, A., Bott, J., & Sanchis-de-Miguel, A. (2021). IoT for global development to achieve the United Nations Sustainable Development Goals. IEEE Access. DOI: 10.1109/ACCESS.2017.Doi

Ludzuweit, A., Paterson, J., Wydra, K., Pump, C., Müller, K., & Miller, Y. (2025). Enhancing ecosystem services and biodiversity in agrivoltaics through habitat-enhancing strategies. Renewable and Sustainable Energy Reviews, 212, 115380. DOI: 10.1016/j.rser.2025.115380

Martinez, I., Zalba, B., Trillo-Lado, R., Blanco, T., Cambra, D., & Casas, R. (2021). Internet of Things (IoT) as Sustainable Development Goals (SDG) enabling technology. Sustainability, 13(14), 7647. DOI: 10.3390/su13147647

Mulume, D. M. (2025). Michael: An innovative disaster management solution for climate resilience in Africa. Academia.edu. https://www.academia.edu/129169921

Ooko, S. O., & Rweyemamu, E. (2024). Monitoring and predicting African rural household air pollution using IoT and AI. Pan-African Journal of Health and Environmental Science, 3(1). DOI: 10.56893/ajhes2024v03i01.06

Overview and performance of agrivoltaic systems. IEA-PVPS Task 13 Report. https://iea-pvps.org

Ponnalagarsamy, S., Geetha, V., Pushpavalli, M., & Abirami, P. (2021). Impact of IoT on renewable energy. In I. Singh et al. (Eds.), IoT Applications Computing (pp. 1-20). IntechOpen. DOI: 10.5772/intechopen.98320

Popoola, O. V., Adebayo, A., & Oyedeji, O. C. (2024). Climate change effect in Nigeria: Mitigation, adaptation strategies and the role of IoT. ResearchGate. https://www.researchgate.net/publication/380615790

Rigby, J., & Edler, J. (2005). Peering inside research networks: Some observations on the effect of the intensity of collaboration on the variability of research quality. Research Policy, 34(6), 784-794. DOI: 10.1016/j.respol.2005.02.004

Salam, A. (2019). Internet of Things for environmental sustainability and climate change. In Internet of Things for Sustainable Community Development (pp. 33-69). Springer. DOI: 10.1007/978-3-030-35291-2_2

Singh, M., Sahoo, K. S., & Gandomi, A. H. (2024). An intelligent-IoT-based data analytics for freshwater recirculating aquaculture system. IEEE Internet of Things Journal, 11(3), 4206-4218. DOI: 10.1109/JIOT.2023.3312345

Springer Handbook of Internet of Things. (2023). IoT for SDGs. In C. Martinez et al. (Eds.), Springer Handbook of Internet of Things (pp. 763-786). Springer. DOI: 10.1007/978-3-031-39650-2_31

STARS EU. (2023). Blended Intensive Programs. https://starseu.org/blended-intensive-programs

Thompson, D. R. (2006). International collaboration and sharing lessons learned. Journal of Research in Nursing, 11(4), 285-287. DOI: 10.1177/1744987106066967

Trommsdorff, M., Campana, P. E., Macknick, J., Solas, A. F., Shiva Gorjian, & Ioannis Tsanakas. (2025). Dual Land Use for Agriculture and Solar Power Production: Overview and Performance of Agrivoltaic Systems. DOI: 10.69766/xaeu5008

Vasconcelos, M. C. P. S. J. (2022). How Internet of Things can contribute to the United Nations Sustainable Development Goals [Master\'s thesis, Nova School of Business and Economics]. https://run.unl.pt/handle/10362/172087

Zahrawi, A. A., & Aly, A. M. (2024). A review of agrivoltaic systems: Addressing challenges and enhancing sustainability. Sustainability, 16(18), 8271. DOI: 10.3390/su16188271

Zeeshan, K., Hämäläinen, T., & Neittaanmäki, P. (2022). Internet of Things for sustainable smart education: An overview. Sustainability, 14(7), 4293. DOI: 10.3390/su14074293

Ziegler, S., Grimm, C., Bueti, C., & Brékine, A. (2023). The role of IoT in supporting the UN Agenda 2030: A science diplomacy perspective. In Springer Handbook of Internet of Things (pp. 775-786). Springer.