




Article

# Empowering Communities on the Margins: Participatory Design in Environmental Education

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## Abstract

Within a global landscape characterised by increasing fragmentation, community empowerment requires interdisciplinary, evidence-based and validated methodology for assuring collaborative and transformative action. This research addresses the need for equity and inclusion in underserved rural areas by investigating the CleanAir@Schools initiative in Romania. The study employed a human-centred, multi-stakeholder methodology, utilising exploratory workshops with educators and pilot implementations to develop a learning framework on Sustainability Education, in which students used passive sensors to measure local air quality. Results indicate that the project successfully mobilised entire school communities, catalysing a pedagogical shift from passive reception to active, inquiry-based environmental education. Furthermore, the strategic use of both digital and analogue technologies ensured accessibility for communities facing digital divides. The research concludes that participatory design acts as a catalyst for long-term community empowerment and social transformation by addressing localised challenges through inclusive, restorative practices. By intentionally centring society's margins, design research fosters regeneration and care, serving as an essential resource for social innovators and policymakers.

**Keywords:** participatory design; sustainability education; community empowerment; inquiry-based learning; green future

## 1. Introduction

When design is thought of as a social cohesion strengthener, it aims to do so by better including fragile people, especially those seeking reintegration into social, emotional, or working life after being marginalised for lack of competencies, abilities, or information, or for reasons related to their personal history [1,2]. Design is thus seen as the means to approach the status quo with a different mindset [3] and, in particular, as a means to establish a novel way of thinking for problem-solving, distinct from the one that spread when the problem originated.

Sensitivity towards intersectionality, creative transformation, and the capacity for community mobilisation make design a resource for social innovators and policymakers [4,5]. The emergence of “values in design” constitutes an essential shift in design thinking and practice, but equitable design goes further [6] to consider not only the ways that we hard-code oppressive values and norms into design solutions but also the transformative potential of broader participation in the design process, as well as ownership and stewardship of the results [7].



Academic Editor: Rosabel Roig-Vila

Received: 22 March 2026

Revised: 16 May 2026

Accepted: 28 May 2026

Published: 2 June 2026

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The contemporary global landscape is increasingly characterised by disconnections, fragmentation, and conflict, underscoring an urgent imperative for design to serve as an agent of peace, dialogue, and coexistence [8,9].

In particular, the participatory and collaborative approach to design, namely participatory design (PD), emerges as a critical methodological framework within this context, offering a language, a syntax, and a set of tools to foster shared understanding and collaborative action. A core tenet of effective PD, particularly in achieving systemic and long-term transformations, is the explicit centring of marginalised communities and vulnerable groups, such as teens from rural areas and migrant groups [10,11], due to existing vulnerabilities, e.g., poverty and lack of access to education, which hinder effective research participation.

Engaging communities in sustainability transformation processes has been acknowledged as essential, as they play a significant role, e.g., by changing their attitudes, values, and behaviours, and by adopting more sustainable ways of living, technologies, and consumption [12]. The literature suggests that participatory design can also be empowering, as it allows marginalised individuals to shape the design of the technologies they use [13–15].

This approach is fundamental to embracing diverse voices and fostering inclusion, equity, and resilience. The focus on marginalised communities extends beyond traditional socio-economic classifications to encompass populations marginalised by limited access to opportunities or disproportionate exposure to environmental injustices [16,17]. The present research considers small rural communities, where opportunities to participate in European and international projects rarely arise. It directly addresses this imperative, highlighting an intentional effort to reach underserved populations and making it a compelling case study for fostering equity and inclusion.

This article investigates a pivotal research question: how might Sustainability Education demonstrate strengthening participants and the communities to which they belong? How might a Sustainability Education intervention in a local community change the perspective on socio-economic issues?

This research focuses on understanding and addressing Sustainability Education challenges and knowledge needs, and on identifying strategies and technologies to support efforts to deliver high-quality education to marginalised communities.

To explore this question, the CleanAir@Schools initiative is presented as a relevant case study within the GreenSCENT project, Smart Citizen Education for a Green Future, which aims to educate and empower Europeans towards environmental behavioural change through a transformative learning approach [18]. GreenSCENT, funded by the European Commission Horizon 2020 program, aims to design and deliver Sustainability Education methods and interactive technologies, as well as a competence framework to educate and empower citizens, institutions, and especially students, to change their behaviour towards the environment by fostering respect and empathy for the planet through transformative learning.

The CleanAir@Schools initiative provides an empirical lens for exploring the empowering potential of sustainability technology-based education within marginalised Romanian communities. The case study immediately gains theoretical grounding and demonstrates a deliberate operationalisation of empowerment and participatory engagement philosophy, reinforcing its direct relevance to the stated research question.

## 2. Literature

The ACM Future Computing Academy (FCA) recently highlighted the need to address the potential negative impacts of new computing technologies we introduce to society [19]. The emphasis of the FCA's argument was on the effects of the innovations themselves on

the need to assess the potential harm that computing research may have on our participants and their respective communities [7] and on the need to rethink and learn from participative practices with marginalised communities [20].

This work posits that design research, when intentionally focused on individuals situated at society's margins—whether due to age, racial representation, disability, or other forms of systemic disadvantage—can actively foster regeneration and care for entire communities. Empowerment, as a process that enables people, organisations, and communities, emphasises gaining agency and control to take action and effect positive change, beyond power imbalances [21–23]. In this study, empowerment is operationally defined as the observable process through which participants and their communities gain control over the decisions, knowledge, and resources that shape a locally relevant issue. It is treated not as a generic disposition but as three observable shifts: from passive recipient to active knowledge-producer, from individual gain to collective capacity, and from external dependence to autonomous continuation of the practice.

This framework raises critical issues regarding inclusivity and the ethical dimensions of design research in these contexts. The concept of “margins” encompasses traditionally marginalised groups and communities affected by environmental conflicts or those lacking access to broader education opportunities.

The traditional research activities conducted in these communities have strained relationships between community members and researchers. Low-resource and marginalised communities often possess limited technical expertise and lack the means to successfully implement the projects [24]. As interest in using PD practices in these contexts continues, it is valuable for PD researchers and practitioners to be more critical of how current methods align with PD's original theoretical commitments to empowerment, democracy, and equality [25,26].

Design can catalyse self-awareness, active participation in social generativity, creative empowerment options, and future-oriented transformations within these marginalised populations [7,27]. Generativity is here considered as the relational process of recreating life in a variety of existential forms, from the biological to the anthropological dimensions, until human individuation.

As part of regenerative dynamics, the establishment of trust is the prerequisite for every community empowerment outcome, especially in the case of language and health-literacy barriers and prior adversarial encounters with public institutions that represent compounded individual and structural barriers to participation [28,29]. Trust is therefore neither a baseline the researcher can presume nor a by-product of good intentions: it is built incrementally—typically over months or years—through trained cultural mediators, NGOs, charities, religious leaders and informal networks acting as brokers between institutional projects and community members [30,31].

Empowerment is then considered a means of redistributing epistemic and material power. A unifying thread across the reviewed studies is that empowerment in PD is not co-extensive with information delivery or consultation. Several studies report that interviews and surveys conducted without subsequent participation in design decisions produce a sense of “inconsequentiality” in participants, even when the disclosed content is intimate and analytically valuable [32]. Conversely, empowerment is empirically documented when participants receive preparatory training that mitigates technical asymmetries (e.g., in AI fairness or photographic methods) before co-design begins [33], and when their experiential knowledge is translated into the final artefact. This evidence operationalises Arnstein's classical distinction between non-participatory rungs of the citizen-participation ladder (manipulation, therapy, tokenism) and the upper rungs of partnership and citizen control.

A third recurring finding is that community empowerment is rarely effective when confined to individual members alone. The institutional environment—industrial workers, administrative staff, educators—itself requires preparatory training in cultural sensitivity, anti-discriminatory practice and the methodological logic of participation. Community-led design designates an arrangement in which the affected community holds substantive control over problem framing, design decisions, and the stewardship of outcomes, rather than being consulted within an agenda set elsewhere.

This research foster community-led design as a mechanism for redistribution of epistemic authority: in a first step, by getting control over the problem (what is investigated), in a second one, by getting control over interpretation (what the evidence means locally), and, finally, by getting control over use (what is done with it), each of which able to convert environmental data into community-relevant evidence.

Across the reviewed corpus, most studies measure changes in knowledge, attitudes, and intended behaviours rather than in enacted, sustained change. These findings consolidate the theoretical premise underlying the case study presented in the next sections: empowerment through PD is contingent on time, on trust mediated by recognised local actors, on a redistributive treatment of knowledge and resources, and on a critical reflection on what counts as a transformative outcome [34].

In particular, these principles offer a robust theoretical lens through which to analyse the CleanAir@Schools project [35], particularly its capacity to empower participants and their communities. The brokerage role played in the present case study by researchers and, within each school, by educators already embedded in pupils' family networks, aimed at reaching community resonance rapidly despite a historically contentious industry–community landscape.

### 3. Research Methodology

#### 3.1. The Educational Framework for Sustainability Education

The research methodology is grounded in the GreenSCENT educational framework (Figure 1), an instructional design framework that enables educators to integrate Sustainability Education principles [36–38] into their traditional curriculum and help their learners acquire literacy and Green Deal competencies by adopting learning experiences and technology-enhanced learning solutions developed in the project.

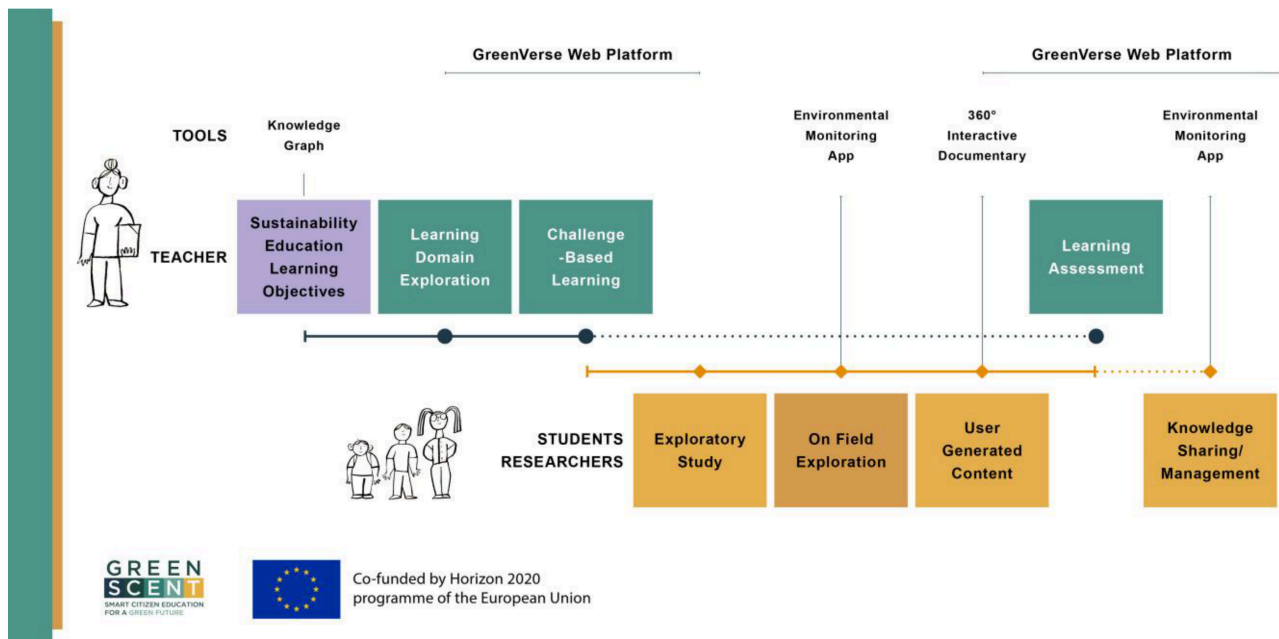
Specifically, the educational framework established an operational learning methodology to validate the GreenSCENT Competence Frameworks [39–42], a learning tool that helps educators translate European green policy objectives into learnable outcomes and assessable performance. Successively, the scope of this research was to develop a series of training kits and learning use cases on Sustainability Education, all based on a unified, structured instructional design protocol.

The most commonly used methods embodied in the educational framework to design the learning experiences were learning-by-doing design-based approaches and inquiry-based learning [43–47], in which people, especially students, learned about environmental phenomena, such as biodiversity loss or air pollution, from a multidisciplinary and interdisciplinary perspective, identified problems, and proposed solutions accordingly [48].

The educational protocol focused on teachers' design of experiences based on challenge-based learning [49,50]. This protocol, depicted in Figure 1 for a visual representation, identifies four stages:

- Stage A—Strategy: We identify learning needs and objectives related to a specific learning domain based on one of the macro areas of the Green Deal.
- Stage B—Planning: We define the competencies the learner is expected to acquire in accordance with the learning objectives that characterise the selected domain.

- Stage C—Execution: We set up the entire practical educational experience and its corresponding expected outcomes, which will be conducted with the learners' involvement.
- Stage D—Evaluation: We assess the learners' learning performance by evaluating the learning outcomes developed during the educational activities proposed in the execution stage.



**Figure 1.** GreenSCENT educational protocol, which was designed to foster Sustainability Education in future learning scenarios. Source: Authors.

In this scenario, the technology-enhanced learning solutions (in the form of interactive demonstrators) were intended to facilitate Sustainability Education through experiment-based activities targeting different Green Deal competence areas and educational proficiency levels.

Beyond community empowerment, a further objective of the research was to co-design appropriate and accessible educational technologies for a specific educational context, including a focus on their contextual adaptation and response to resource limitations of heterogeneous learning scenarios [24,51]. Experimenting with digital and analogue materials also served to assess the sustainability of the proposed technology [52,53], allowing to collect feedback from educators and learners to develop technologies for resource-limited conditions, such as paper-based documents and analogue prototypes.

### 3.2. Procedure

The following two-step procedure has been implemented to accomplish research objectives:

- A co-design workshop has been carried out as an exploratory and training session, only with educational managers and educators, to set the stages A and B and to understand the main contextual challenges and needs in Sustainability Education. The aim was to prepare them to conduct inclusive activities on environmental issues with their students in their local context. Methods and tools were provided by researchers to develop effective class orchestration, define educational challenges, and operationalise learning technologies to be inclusive.
- An educational intervention, the CleanAir@School, set the stage for C and D, in which the educators tested and validated the effectiveness of the learning experiences,

materials, and technologies (as structured during the co-design workshop) with their students in the ecological setting. The CleanAir@School objective is to involve the community in conducting air-quality measurements around schools and analysing the results obtained so that students, teachers, and parents become aware of environmental issues and how our habits, mainly mobility, influence them.

The activities were ethically approved by the Comisión de Ética en la Experimentación Animal y Humana (CEEAH) under the EU H2020 GreenSCENT project at the Universitat Autònoma de Barcelona. All participants provided informed consent to participate in the research activities voluntarily; for minors, permission was obtained from their parents or guardians.

### 3.3. Participatory Design Workshop Methodology

As educators were key to mobilising the local community by engaging students and their families, they have been involved in exploring a specific environmental topic and proposing a particular educational challenge, while also considering the available resources and contextual factors presented in the pilot site.

The PD workshop was entirely designed to allow them to define the expected pro-environmental competencies for learners and the measurement indicators to assess learners' learning performance.

In particular, the objectives of the PD workshop were:

1. Basic knowledge acquisition about Sustainability Education by defining pro-environmental behaviours related to the Green Deal objectives.
2. Understanding what the educational training kit (materials and digital technologies) might conceive and use for the proposed green education.
3. Definition of learning assessment methods for evaluating the effectiveness and value of the activity.

In order to accomplish these objectives, the educators were engaged in:

- Selecting specific learning objectives and outcomes for Sustainability Education and green competencies on a specific Green Deal macro area using the GreenSCENT Competence Framework.
- Setting and exploring the proposed challenge and class orchestration by designing a dedicated class orchestration and adopting CleanAir@School.
- Acknowledging the learning assessment methods in accordance with the proposed learning objectives.

An additional goal of the PD workshop was to enable educators to become familiar with the selected digital technology, learn autonomously how to implement the co-designed learning experience directly in their educational environments, and prepare to conduct the activities independently without the authors' intervention.

### 3.4. CleanAir@School Methodology

The CleanAir@School aimed to foster deep learning and critical engagement on air pollution through air-quality measurement. The demonstrator's objectives included learning and understanding the fundamental aspects of this environmental phenomenon, including its signs, types, sources, and impacts on human health.

Participants were also familiarised with a scientifically based analysis approach, encompassing documentation, analysis, measurement, evaluation, and improvement. Furthermore, CleanAir@School aimed to enable participants to contextualise numerical data and to connect air quality to various real-world influences, such as geographical location, traffic, and industrial activity.

This structured approach brought together a diverse array of key stakeholders, including data analysts, educators (the orchestrators), students from high and secondary schools (the primary participants), and parents and rural communities from the pilot sites.

This multi-stakeholder collaboration, encompassing diverse groups from international experts to local parents, exemplifies the comprehensive nature of the participatory approach applied and demonstrates how a carefully designed intervention can bring together various actors to achieve social transformations.

The pilot activity focused on collecting and measuring data using analogue passive sensors over four weeks to highlight the actual air-quality situation across the selected pilot site.

The demonstrator activity followed a structured timeline, indicating a deliberate and systematic application of participatory methods, as outlined below:

- Sensor placement and measurement strategies include educators collaborating with 4Sfera to choose key urban and busy areas with high traffic for air-quality assessments, using a nearby reference station to ensure accuracy.
- Exposure time refers to the period when participants await passive measurements from the samplers, during which they regularly check for damage or theft caused by external factors and learn about air pollution.
- Sensors and data collection involve educators and students resampling and sending these samples to 4Sfera's laboratory for analysis.
- Data analysis and presentation are conducted using 4Sfera, which provides educators and students with an air-quality report to analyse data quantitatively and develop informative documents to raise awareness of air quality around the local communities.

### 3.5. Educators' Voice Memos as Ethnographic Reflective Practice

To complement the structured PD activities and the CleanAir@School pilot implementation, an ethnographic strand of qualitative data collection was conducted in parallel throughout the entire research process. Drawing on traditions that recognise reflective practice and lived experience as legitimate sources of knowledge in field-based educational research [46,54], educators were invited to record short voice memos at moments they considered meaningful, both during the co-design workshop and across the four-week CleanAir@School implementation campaign. The voice-memo protocol was deliberately low-threshold and asynchronous, in line with the methodological accessibility principles that animate the broader PD framework: educators were not required to follow a fixed interview schedule but to capture, in audio form, their personal and shared reflections as they emerged in everyday teaching activity.

The reflections clustered around three macro-areas: (i) the co-design workshop experience and the operational translation of the GreenSCENT Competence Framework into class orchestration; (ii) the implementation of the CleanAir@School pilot, including sensor placement, integration of measurement into the curriculum, and student response; and (iii) the wider dynamics emerging with parents, school management, and the local industrial actor. Voice memos typically lasted between two and five minutes and were recorded in the educators' native language (Romanian).

All recordings were transcribed verbatim and subsequently translated into English, with cultural and contextual annotations applied where idiomatic expressions required clarification, following established protocols for cross-language qualitative research [55]. Transcripts were then analysed through an inductive thematic analysis [56], following the recursive phases of familiarisation, initial coding, theme construction, theme review, and theme definition.

Audio voice memos were collected as time-stamped reflective recordings and were transcribed verbatim, including audible paralinguistic features (pauses, emphasis, laughter) where analytically relevant, with non-native recordings translated using a back-translation procedure to preserve semantic equivalence. The corpus was analysed using reflexive thematic analysis [56], operationalised through the six recursive phases of data familiarisation, generation of initial codes, theme construction, theme review, theme definition, and reporting. Coding combined an inductive, data-driven pass with a subsequent deductive pass structured by the study's a priori conceptual lenses, and this hybrid orientation was declared in advance to make the analytic logic transparent.

The researchers acted as independent coders to ensure team-based analytic rigour against trustworthiness criteria, such as credibility, transferability, dependability and confirmability. One of the analysts resolved coding divergences through documented reflexive dialogue, with the rationale for final decisions recorded. In this process, the researchers' positionality was explicitly stated, since in reflexive thematic analysis the analyst is treated as an interpretive instrument whose assumptions must be auditable rather than neutralised.

The analytical lenses introduced in Section 2—empowerment, community-led design and social generativity—informed the interpretive phase without imposing a deductive coding frame. The themes that emerged from this process triangulate the quantitative air-quality findings reported in Section 6.1, ground the qualitative findings reported in Section 6.2, and inform the integrated discussion presented in Section 6.3.

## 4. Participatory Design Workshop

### 4.1. Context and Participants

The PD activities were organised and coordinated by the authors in collaboration with Volens Association, a Romanian non-governmental organisation that promotes Sustainable Development Education in marginalised communities.

The co-design workshop was held on 10 November 2023 and involved many secondary school educators from different educational institutions across the Fieni region who were very interested in exploring Sustainability Education in rural areas (Figure 2). In particular, the involved educators came from these five Romanian educational institutions: Aurel Rainu High School and Diaconu Coresi Secondary School in Fieni, Ion Ciorănescu Secondary School in Moroeni, Elena Donici Cantacuzino Secondary School no. 4 in Pucioasa, and Lucieni Secondary School in Lucieni. The educators' engagement was voluntary and coordinated by Volens. Those activities were conceived to be carried out through a full-day co-design workshop in the native language of the involved educators, held at Diaconu Coresi Secondary School in Fieni, Romania.

The activities involved 12 educators collecting qualitative data, assessing the clarity of the proposed GreenSCENT educational framework, and understanding the accessibility of adopting the related technological demonstrators in their local educational environments.

Following the agenda described in Table 1, the authors first introduced the research objectives and expected results, then guided them through a step-by-step process to create their learning experience for the pilot implementation.

The authors used the co-design session to help educational managers and educators to:

- Define the Green Deal domain and learning objectives in relation to their needs by exploring the GreenSCENT Competence Framework—as a Knowledge Graph ([https://publish.obsidian.md/greenscent/\\_START+HERE\\_](https://publish.obsidian.md/greenscent/_START+HERE_) (accessed on 29 April 2026))—and selecting the competencies to evaluate their students' learning performance.
- Understand the use of CleanAir@School to facilitate its implementation in the proposed class orchestration.

- Co-design and present several class orchestration frameworks—based on a common design challenge set up as a general quest to launch the activity—as potential use cases to be implemented as a pilot in their local context, based on a general common design challenge.
- Define a qualitative learning assessment to evaluate students’ performance against the green competencies selected in the first step.



**Figure 2.** Educators engaged by the Volens Association define educational use cases in Sustainability Education during the PD workshop held on 10 November 2023, at Diaconu Coresi Secondary School, in Fieni, Romania. Source: Authors.

After all the steps, the authors organised an open discussion session to evaluate the use cases and gather feedback from educators’ perspectives. Moreover, before and after the co-design workshop, the authors administered a Competence Assessment questionnaire [57], ex-ante and ex-post, to evaluate the impact on the activity, especially the attitude–behaviour link in the sphere of environmental issues among the educators.

**Table 1.** Description of the ‘Impact of Air Pollution on plants in the Fieni Area’ use case learning scenario, co-designed by Romanian teachers during the first PD workshop, which involves implementing the CleanAir@School technology within the course orchestration.

Time Schedule	Activity Description
15 min before starting	Competence Assessment questionnaire ex-ante.
8:20–8:30 WARM-UP & INTRODUCTION	Research general presentation; Workshop objectives and agenda.
8:30–9:30 SUSTAINABILITY EDUCATION LEARNING OBJECTIVES	GreenSCENT Competence Framework presentation through the Knowledge Graph exploration.

Table 1. Cont.

Time Schedule	Activity Description
9:30–10:30 DIGITAL DEMONSTRATORS	Technology presentation and test: <ul style="list-style-type: none"> <li>• Environmental Monitoring App</li> <li>• 4SFERA CleanAir@School</li> </ul>
10:30–10:50	COFFEE BREAK
10:50–12:30 INSTRUCTIONAL DESIGN 1/2	Define the educational challenge. Ex. Challenge-based learning activity: “Make visible the invisible”. Create a use case scenario: <ul style="list-style-type: none"> <li>• Learning Challenge</li> <li>• Instructional design details</li> <li>• Digital Technology</li> <li>• Outcomes</li> <li>• Implementation</li> </ul>
12:30–13:40	LUNCH
13:40–15:00 INSTRUCTIONAL DESIGN 2/2	Define learning assessment according to the selected domain and learning objectives.
15:00–15:50 USE CASES PRESENTATION & DISCUSSION	Get Feedback and open discussion on: <ul style="list-style-type: none"> <li>• How student respond to the educational challenge?</li> <li>• How student document themselves on an environmental topic?</li> </ul>
After Closing	Competence Assessment questionnaire ex-post

#### 4.2. Participant Profiling

The project involved educators in various subjects, such as literature, mathematics, and natural science, including geography and biology, all closely supervised by their principals. As reported, this was the first non-formal project to mobilise the entire school community—from management to teaching and administrative staff, parents, and students—marking a milestone in these institutions’ extracurricular portfolios. To understand how tech-savvy educators can adapt educational activities to their technological backgrounds, they used a questionnaire based on the European DigComp Conceptual Framework [58] to evaluate their digital competencies.

The results showed a high standard of digital literacy across all five dimensions utilised in the framework: information and data literacy, communication and collaboration, digital content creation, safety, and problem-solving.

#### 4.3. Co-Design Output

CleanAir@School situated the learning scenario within the Zero Pollution macro-area of the European Green Deal. Consequently, the educators established the educational activity as a mobile technology-enhanced learning and citizen science initiative.

The PD workshop enabled educators to conceive the ‘Impact of Air Pollution on plants in the Fieni Area’ use case (Table 2) to mobilise students to use empirical data to examine the impact of air pollution on biodiversity, especially on vegetation.

**Table 2.** Description of the ‘Impact of Air Pollution on plants in the Fieni Area’ use case learning scenario, co-designed by Romanian teachers during the first PD workshop, which involves implementing the CleanAir@School technology within the course orchestration.

Items	Definition
Organisation name	HIGH SCHOOL “AUREL RAINU” FIENI
Country	Romania
Project title	IMPACT OF AIR POLLUTION ON PLANTS IN THE FIENI AREA
Description of the learners	The project will involve 20 students from the lower secondary school specialising in mathematics and computer science, real profile, theoretical stream, aged between 14 and 17, who have studied physics, chemistry, biology, geography and information and communication technology.
EQF level	Level 4
Pre-requisites	Students need a basic knowledge of physics, chemistry, biology, geography and information and communication technology. Skills required include working with the camera, using online filmmaking applications, and working in a team.
Challenge	NATURE EXPLORATION
Learning objectives	Identify air pollutants; identify indirect links between actions and impacts on biodiversity; demonstrate accountability even when the direct effect is not visible.
Learning methodologies	Inquiry-based Learning is guided by questions and the search for answers to them, involving inquiry-type activities in the study of science subjects. Students acquire a complex set of specific scientific investigation skills, such as: <ul style="list-style-type: none"> <li>• identify questions and concepts that can guide scientific investigations,</li> <li>• designing and conducting scientific investigations,</li> <li>• using technology and mathematics to extend investigations and communicate results,</li> <li>• formulating and reviewing scientific explanations and models using evidence and logical thinking,</li> <li>• recognising and analysing alternative explanations and models,</li> <li>• communicating and supporting scientific arguments.</li> </ul>
Understanding the process of scientific investigation	Faced with an unknown fact/phenomenon, scientists ask questions; use knowledge and questions to design and carry out scientific investigations; use investigations for different purposes; use mathematical and technological background as a tool for learning and communication; formulate logical explanations and arguments based on evidence; share information on results and procedures with the scientific community, etc. Familiarity with the process of scientific inquiry facilitates students’ acquisition, through their own effort, of both scientific knowledge and an understanding of how scientific knowledge progresses. Grounding lessons in Inquiry-based Learning involves a sequence of activities. These are presented below in an adapted version. Thus, students:

Table 2. Cont.

Items	Definition
Understanding the process of scientific investigation	<p>(a) Engage in learning through guided scientific questions (questions that can be answered through investigation). Questions can be generated by observations, data analysis, or explicitly formulated by students. The questions' wording and attempts to answer them highlight the misleading, incomplete/limited representations students acquire from life experience.</p> <p>(b) Prioritise evidence, which helps them formulate and evaluate preliminary explanations that can answer questions. To this end, they observe, document, study, and experiment, collecting and analysing information to sort it and identify evidence that supports their scientific explanations.</p> <p>(c) Rephrases previous explanations and develops new explanations, based on the evidence, to answer the questions posed.</p> <p>(d) Communicates explanations to colleagues, confronts them, evaluates them (also considering alternative explanations) and justifies/argues their explanations.</p> <p>(e) Connects their explanations to scientific knowledge.</p> <p>(f) Apply acquired knowledge to new situations.</p> <p>(g) Evaluates the new knowledge and the approach to its acquisition (difficulties encountered, how to overcome them, good practices, what to remember, etc.).</p> <p>Technologies in the learning experience: the greenscent-app.net application and image-processing applications known to the students: Google Photos, Microsoft Photos; presentation applications: PPT, Canva.</p> <p>Foreseen implementation details imply a course/module duration of 10 weeks, with the following course schedule.</p> <p>Activities will be carried out flexibly, depending on the availability of the people involved, the season, the weather conditions and the structure of the school year.</p>
Course Orchestration	<p>Week 1: Giving students the challenge: Why do white spots appear on tree leaves after rain? Watch the documentary "Acid Rain" and identify the factors that can affect plants in the Fieni area.</p> <p>Weeks 2, 3 and 4: Investigation and exploration: (1) Observations made on the leaf cover of plants in the Fieni area; (2) taking photographs of affected leaves and unaffected leaves (with white spots or with numerous holes or other inconsistencies).</p> <p>Week 5: Analyse the photographs and draw conclusions based on indirect links between actions and impacts on biodiversity.</p> <p>Week 6: Making a map of the town of Fieni, marking the areas with affected and unaffected leafy plants. Produce a report specifying the links between air pollutants and pollution effects.</p> <p>Weeks 7, 8 and 9: Making a documentary film presenting the effects of pollution and proposing measures to reduce air pollution in Fieni, and presenting it at the local and regional levels.</p> <p>Week 10: Project evaluation and feedback.</p>
Assessment methodology	<p>The initial assessment will be completed after the film has been viewed via an online questionnaire, without supervision.</p> <p>The final evaluation will be carried out offline, without supervision, by producing a catalogue describing the impact of air pollution on plants.</p>

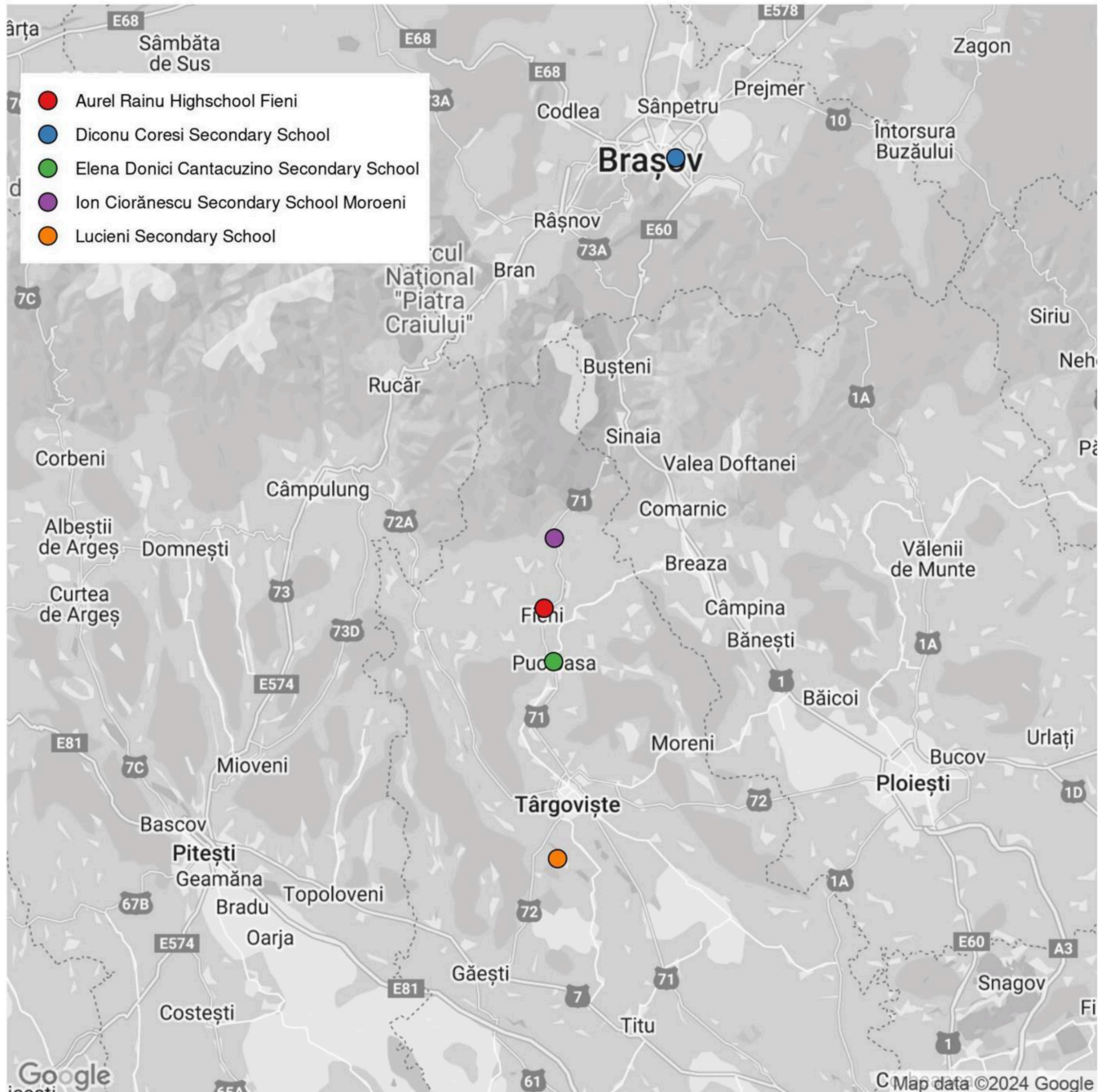
## 5. CleanAir@Schools Implementation

### 5.1. Context and Participants

The CleanAir@Schools initiative was implemented again in Romania, specifically across Dâmbovița County, encompassing two cities (Fieni and Pucioasa) and two rural communities (Lucieni and Moroeni). The Volens Association mobilised the five schools already involved during the PD workshop to conduct the pilot activities autonomously:

Aurel Rainu High School and Diaconu Coresi Secondary School in Fieni, Ion Ciorănescu Secondary School in Moroeni, Elena Donici Cantacuzino Secondary School no. 4 in Pucioasa, and Lucieni Secondary School in Lucieni. The institutions comprised one high school (Aurel Rainu High School) and four secondary schools, all of which actively monitored air quality in their surrounding areas (Figure 3).

### Educational centres locations



**Figure 3.** Map of the five selected schools in Dâmbovița County, Romania, where the air-quality samples were placed by students who participated in the pilot with the support of their educators and parents. Source: Authors.

The citizen science project engaged 179 participants, with each school involving about 25 to 40 students and two to three educators, including teachers, educational managers and school directors. The students' engagement was voluntary and coordinated by Volens, in

collaboration with their educators. The authors provided the materials and technology to conduct the activity and coordinated the data analysis stage, transforming the data into a readable report.

Aware of its potential social impact on the rural community, a local multinational building materials corporation has been involved by the school directors and decided to sponsor the CleanAir@School implementation in full with the aim of fostering dialogue and trust between the company and local communities, demonstrating its commitment to local environmental protection and to lowering its carbon footprint.

The overall demonstrator activity at the pilot site spanned from 23 January 2024 to 31 May 2024. The distribution of participants among the five schools is shown in Table 3.

**Table 3.** The number of participants involved in the implementation activities was distributed among the five Romanian schools. Educators are designated as educational managers or directors with D, and teachers with T.

School	Educators	Students
Aurel Rainu High School, Fieni	1 (D) 2 (T)	40
Diaconu Coresi Secondary School, Fieni	1 (D) 2 (T)	31
Ion Ciorănescu Secondary School, Moroeni	1 (D) 1 (T)	25
Elena Donici Cantacuzino Secondary School no. 4, Pucioasa	1 (D) 2 (T)	34
Lucieni Secondary School, Lucieni	1 (D) 2 (T) 3 (T)	35
Total	14	165

This pilot implementation was integrated into a larger Romanian initiative titled “The Living Treasures Near Us,” coordinated by the Volens Association in Dâmbovița County, Romania, to support a concept of non-formal education that combines the development of green skills and the valorisation of local heritage among young people. The broader aim of this project was to encourage and guide children and teenagers to understand, protect, and promote local biodiversity.

### 5.2. Participant Profiling

CleanAir@School involved students as primary participants in the learning activities, drawn from primary and secondary schools in the localities of Lucieni and Pucioasa, Dâmbovița County. As for the adaptation needed to accommodate different educational levels, learners’ needs were collected through a qualitative questionnaire, and the results were used to support educational pilot activities. The socio-cultural background and training needs of students were thus considered to conduct Sustainability Education effectively.

The results of participants’ profiling outlined the following students’ needs:

- For exploring natural environments and biodiversity through concrete examples and hands-on activities;
- For getting engaged through digital materials and practical experiences.

And educators’ needs:

- To get support in effectively using digital platforms to create accessible learning experiences in both digital and natural environments;

- A need emerged for clear guidance on learning outcomes, logistical support for transportation, and resource allocation to coordinate activities.

### 5.3. Implementation Plan

Romanian educators were granted access to CleanAir@School's technology, digital resources and guidelines on 22 February 2024. On 27 February 2024, Volens Association held an online briefing session with the teachers to coordinate and launch the pilot activity across the five schools.

Pollution levels were measured through passive sensors placed at strategic points around the school environment. The concentrations of NO<sub>2</sub> have been measured as an indicator of air quality using the passive dosimetry technique of NO<sub>2</sub> type Palmes.

To do so, students carried out the installation under the guidance of educators to start measuring air pollution levels in their residential areas. This practical phase of placing diffusion tubes began from 4 to 19 March 2024.

Educators completed a preliminary virtual mapping of the sensors using a dedicated digital application (<https://greenscent.4sfera.eu/> (accessed on 29 April 2026)) to facilitate geolocalization and exposure tracking of the passive sensors.

Then, the students, through local and collaborative educational initiatives organised and carried out by the educators, manually installed the sensors directly in the selected Romanian area (Figure 4). To assess air quality, the activity chose the following types of points:

- Interior points in a classroom near the main traffic roads.
- Exterior points in the main playground.
- Point at the main entrance of the school.
- Urban background: Points from sources away from traffic.
- Urban traffic: Points near busy roads.

The CleanAir@School campaigns in the five schools were reinforced by the automatic reference stations located in Brasov and Prahova to better contextualise the results and add value to the gathered data. The practical activities, data collection and interpretation were conducted following the 'Impact of Air Pollution on plants in the Fieni Area' described in Section 4.1. Students could then study the impact of air pollution on local biodiversity during the sampling campaign in the local territory (Figure 4).

Each dosimeter was registered in the digital application's virtual map by scanning its QR code, photographing the device, and assigning an identification code along with the initial date and time of exposure. The sampling period lasted four weeks, followed by weekly dosimeter checks, and finally, the collection of the tubes from 4 to 19 April 2024. During that period, educators integrated air pollution principles into regular lessons to prepare students for data interpretation and analysis.

At the conclusion of the sampling period, students and educators collected the dosimeters, then scanned the QR codes in the mobile app to verify their correspondence with the digital map and to record the end time of exposure. Then, the passive sensors were stored and sent to 4Sfera's laboratory for analysis. Specifically, the NO<sub>2</sub> measurements for the final report were taken from 14 March to 15 April 2024.

The pilot activities concluded with the delivery of the final report by 31 May 2024. The results were subsequently analysed and interpreted by the students to collaboratively produce scientific artefacts, such as PowerPoint presentations, visual posters, and social media content, to represent their findings and share them with local communities.



**Figure 4.** Students are actively participating in the CleanAir@Schools pilot initiative, implemented specifically in Dâmbovița County, Romania. (a) Students are analysing the impact of air pollution and climate change on local biodiversity, and taking the opportunity to better study the differences between endemic and invasive species. (b) Students are recording and mapping the passive dosimeter's location during the sensor placement phase. Source: Authors.

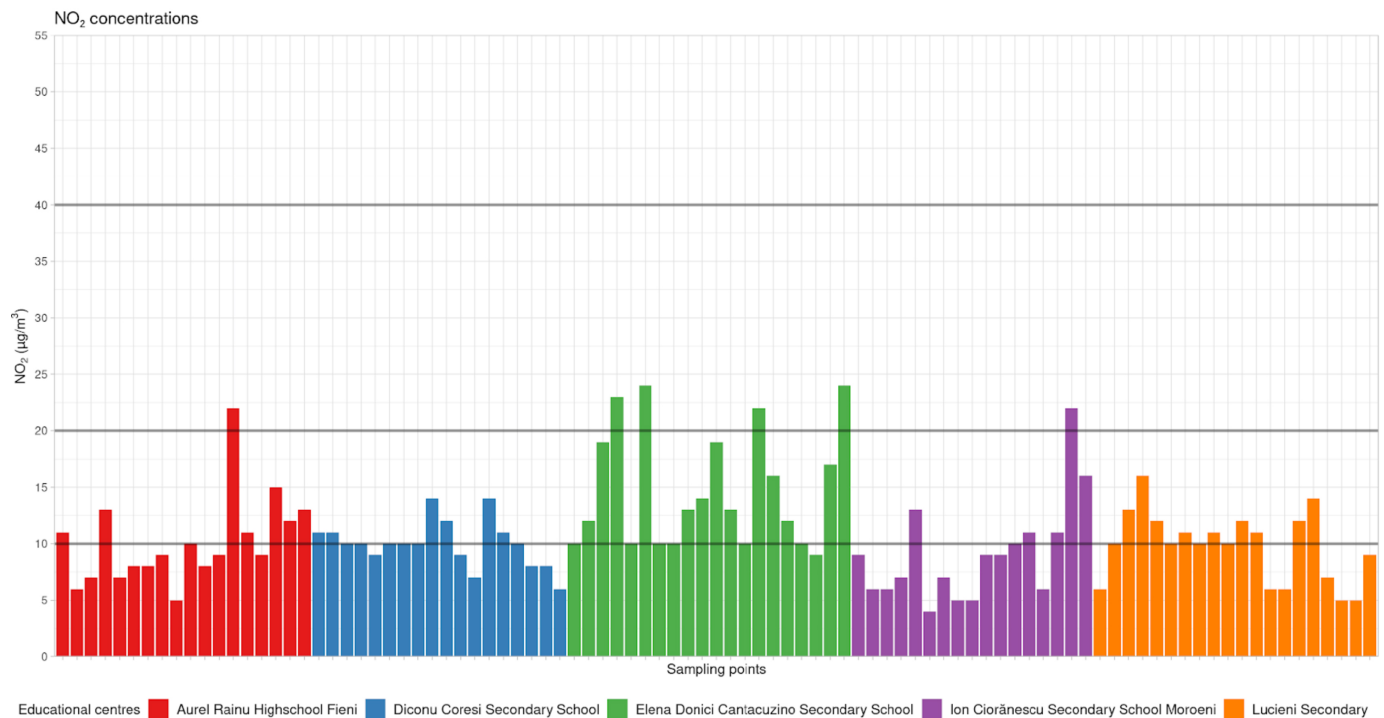
## 6. Results and Discussion

### 6.1. Air-Quality Data Analysis

Air-quality sampling in Dâmbovița County provided 93 measurement points. The study included 75 background points (parks and school yards) and 15 traffic points on internal roads and roads crossing the city. Additionally, measurements were taken at three points inside the classrooms of the studied educational centres. As shown in Figure 5, this variety of points helped the investigation to improve the understanding of air quality in specific urban and rural areas of Romania.

The results from the CleanAir@School activity indicate that  $\text{NO}_2$  concentrations in Romania range from 4 to 24  $\mu\text{g}/\text{m}^3$ , with an average of 10.9  $\mu\text{g}/\text{m}^3$ . Specifically, the urban background of the city ranges from 4  $\mu\text{g}/\text{m}^3$  to 24  $\mu\text{g}/\text{m}^3$ , with an average of 11  $\mu\text{g}/\text{m}^3$ . Therefore, all analysed background points are below the 40  $\mu\text{g}/\text{m}^3$  limit, as defined by the European air-quality standards [59]. The concentrations in the traffic zones range from 5  $\mu\text{g}/\text{m}^3$  to 24  $\mu\text{g}/\text{m}^3$ , with an average of 13  $\mu\text{g}/\text{m}^3$ . Therefore, all traffic points are below the 40  $\mu\text{g}/\text{m}^3$  limit.

However, the impact on indoor air-quality levels is lower. The  $\text{NO}_2$  levels in the classrooms of all studied schools range from 6  $\mu\text{g}/\text{m}^3$  to 13  $\mu\text{g}/\text{m}^3$ , with an average of 10  $\mu\text{g}/\text{m}^3$ . The highest concentrations in traffic areas have been measured at Elena Donici Cantacuzino Secondary School no. 4 at 24  $\mu\text{g}/\text{m}^3$ , followed by the point measured at Aurel Rainu High School Fieni at 22  $\mu\text{g}/\text{m}^3$ . The highest background levels in Romania are at Elena Donici Cantacuzino Secondary School no. 4, at 24  $\mu\text{g}/\text{m}^3$ , followed by the point at Ion Ciorănescu Secondary School, Moroeni, at 22  $\mu\text{g}/\text{m}^3$ .



**Figure 5.** Average NO<sub>2</sub> concentrations over the exposure period for all sampling points in Dâmbovița County, Romania. Source: Authors.

With the guidance of educators, students made quantitative measurements that enabled them to gain a better understanding of air quality in their local area, noting excellent environmental conditions across Dâmbovița County.

This emphasis on quantitative data highlights the project's primary goal as educational and empowering rather than regulatory. It frames citizen science as a tool for knowledge generation and community agency, not solely for technical measurement. By explicitly stating the data's declarative role, the project effectively managed expectations and prioritised the learning process and community engagement, aligning with the research question's focus on empowerment.

The environmental data-collection activities raised ethical issues and highlighted disparities in environmental quality and its impact on different communities. The concentration of NO<sub>2</sub> significantly varies between areas of different socio-economic status. Students from wealthier neighbourhoods needed to debate where to place data-collection tubes in regions with lower NO<sub>2</sub> levels, where more green spaces and better environmental conditions prevailed, while students from poorer neighbourhoods could collect data in areas with higher NO<sub>2</sub> levels, where pollution from anthropogenic activities was prevalent.

The quantitative evidence has been considered by teachers as a learning object rather than a mere finding. In particular, the unexpectedly low concentrations near the industrial plant and the socio-spatial gradient observed across measurement points transform data into a locally legible account of the environmental debate, through which both parties involved, the local association and the company, took a leap of faith in continuing the collaboration.

## 6.2. Qualitative Findings: Educators' Voice Memos

The thematic analysis of the voice-memo (VM) corpus surfaced four interrelated themes that organise the qualitative evidence below. To preserve participants' anonymity, educators are identified by code (T = teacher; D = director/educational manager) followed by their school of affiliation. All quotations are translated from the original Romanian.

**Requirement of educators' preparatory training:**

VM1 "Honestly, before the November workshop, I had no clue how to bring the Green Deal competences into a class lesson. Two full days working through the framework with the others, and suddenly I had something solid to lean on. Without those pre-structured materials, I would have spent the whole spring just figuring out where to start."—T1, Aurel Rainu High School, Fieni.

VM2 "I have been teaching for almost twenty years, and I rarely feel I need new training. This was different—the digital tools, the QR codes, the dosimeters, the mapping app. If we had not gone through it together first, I would not have managed alone. I think this is the part nobody talks about enough in our profession."—T3, Diaconu Coresi Secondary School, Fieni.

VM3 "What I appreciated as a school director was that, after the workshop, my teachers did not come to me asking for instructions—they came with proposals. That shift, from instruction-seekers to proposal-makers, is what professional agency looks like in practice. The training did that, not me."—D1, Elena Donici Cantacuzino Secondary School no. 4, Pucioasa implementation.

VM4 "The first day of the workshop, I was confused. On the second day, something clicked—the framework was not a constraint; it was scaffolding. Now, when colleagues from other schools ask me how to start, I tell them: start from your own competence map, not from the technology."—T5, Lucieni Secondary School.

VM5 "I want to record this while it is fresh. We just finished the online briefing session, and I realised that the months we spent in the workshop made this morning easy. The students arrive in twenty minutes, and I am not anxious. That is new for me."—T2, Ion Ciorănescu Secondary School, Moroeni.

**Enhanced competencies through technology:**

VM6 "The kids are fascinated by the dosimeters. They keep asking how something so small can measure something so invisible. Today, while explaining how passive sampling works, I realised I was teaching diffusion, kinetics, and atmospheric chemistry at once, without opening a textbook. The technology became the textbook."—T4, Aurel Rainu High School, Fieni.

VM7 "We were finishing mapping the points, and something uncomfortable came up. The students from the neighbourhood near the park argued we should put more tubes there because 'it is nicer'. The students from the lower part of town, near the road, said: 'No, put them here, because here it is actually bad'. I let them debate. That debate alone was a lesson on environmental justice that I could not have planned."—T6, Elena Donici Cantacuzino Secondary School no. 4, Pucioasa.

VM8 "The result that surprised everyone—including me—is that the area around the cement plant is not the worst. We were prepared for the opposite. The students keep returning to that finding, asking 'So where does the pollution come from?' That question, that they are asking themselves, is worth more than the numbers."—T7, Diaconu Coresi Secondary School, Fieni.

VM9 "I uploaded the photos and the QR codes today. The eighth-grade girls are now teaching the boys how to use the app. I did nothing—I just gave them access. Citizen science with adolescents works because it is real."—T8, Ion Ciorănescu Secondary School, Moroeni.

VM10 "What this project gave us, that the curriculum does not, is data density. Ninety-three measurement points in our county, when the official network has only a few. The kids now intuitively understand what 'granularity' means. You cannot teach that with a slide."—D2, Lucieni Secondary School.

**Transformative pedagogy:**

VM11 “For the first time in my career, the students walked out of the classroom and into the street holding measuring instruments. The corridor between the school and the world—that corridor was always there, but we never crossed it. CleanAir made us cross it.”—T9, Aurel Rainu High School, Fieni.

VM12 “I had to learn, with my students, to ask better questions. ‘Why are there white spots on these leaves after the rain?’ is not a textbook question. It became our research question. Once they had a real question, the lesson taught itself.”—T10, Elena Donici Cantacuzino Secondary School no. 4, Pucioasa.

VM13 “I keep hearing colleagues complain that today’s students do not pay attention. I would invite them to spend a Tuesday afternoon with me, in front of the dosimeters. The attention was complete. Maybe the problem was never the students.”—T11, Diaconu Coresi Secondary School, Fieni.

VM14 “What changed is not what they know—it is what they do with what they know. After we got the report, three students went home and convinced their parents to walk them to school instead of driving. I did not ask them to do that. They decided.”—T12, Lucieni Secondary School.

VM15 “This morning, a child came to me and asked: ‘Teacher, can we do another project like this next year, but about water?’ That question, more than any evaluation grid, tells me that something happened in their relationship with science. They want more—and they want to choose what ‘more’ means.”—T13, Ion Ciorănescu Secondary School, Moroeni.

#### **Strengthened industry–community relationships:**

VM16 “In thirty years at this school, I have never seen the entire institution mobilise around a single project—management, teachers, administrative staff, parents, even the night caretaker who helped us secure the dosimeters at the entrance. CleanAir did this. I am still trying to understand how.”—D3, Aurel Rainu High School, Fieni.

VM17 “The day we visited the cement plant with the technical director was a strange day. There has been so much suspicion about that company in our community. The director did not deflect any question—not even the harshest ones. I think the students learned that day that adult conflicts can also be addressed through conversation, not only through accusation.”—T14, Diaconu Coresi Secondary School, Fieni.

VM18 “Parents who had not set foot in the school in years came to ask what we were doing. The project gave us a reason to bring them back, and a topic on which they had something to contribute—because air is everyone’s problem, regardless of education or income.”—D4, Elena Donici Cantacuzino Secondary School no. 4, Pucioasa.

VM19 “The fact that the company sponsored the activity caused real debate among us teachers—was this independent science or not? We decided to be transparent about it and to discuss it openly with the students. They were the ones who concluded that the data is the data, regardless of who paid for the dosimeters. That, too, is empowerment.”\*—T16, Ion Ciorănescu Secondary School, Moroeni.

### *6.3. Discussion*

The integrated reading of the quantitative air-quality dataset (Section 6.1) and the qualitative voice-memo corpus (Section 6.2) addresses the two axes of the research question: how a Sustainability Education intervention can strengthen participants and the communities to which they belong, and how it can shift collective perspectives on a localised socio-economic issue. Quantitative measurements alone document a state of the environment; qualitative reflections alone document a state of mind. Read together, the two strands disclose the pedagogical intervention by which a citizen–science framework operationalised through PD redistributes epistemic authority, from researcher to educator,

from educator to student, from school to community, and converts environmental data into community-relevant evidence.

The most challenging question is by what mechanisms participatory design produces engagement and what is likely to persist. The evidence indicates that empowerment operated through a stepwise transfer of control, over the problem, its interpretation, and its use, rather than through participation per se, aligning this case with the upper rungs of citizen participation while exposing the limit that the projects were still externally initiated [6]; the authority to convene remained with the researchers and the NGO, a tension consistent with critiques of PD's democratic commitments [14,15,25]. Compared with prior community-based participatory studies in marginalised contexts, the results corroborate the trust-mediation finding (NGOs and embedded educators as brokers) reported across the migrant-PD literature, but diverge in that here the quantitative artefact itself—granular air-quality data—became the instrument of power redistribution, a mechanism less emphasised in studies centred on deliberative or narrative methods [30,60,61].

This also supports a transferable proposition: in contested industrial contexts, evidentiary participation may reconfigure community–industry relations more durably than discursive participation alone. The contribution is therefore not that PD empowers, which the literature already establishes, but that the locus of empowerment shifts when participation is organised around co-produced quantitative evidence—a hypothesis substantiated here but requiring a longitudinal design, tracking whether the redistributed control survives the withdrawal of external convening, to confirm.

The four themes discussed below articulate this mechanism along the dimensions of professional capacitation, scientific literacy, pedagogical transformation, and structural community change, drawing on triangulated evidence from both data sources.

**Requirement of educators' preparatory training:** The project, as evidenced by the professional development PD workshop, demonstrated that educators require comprehensive preparatory training to equip them for complex experiential learning and to enhance their digital proficiency. Such proficiency is a prerequisite for enabling students to effectively utilise emerging technologies in Sustainability Education, a necessity exemplified by the CleanAir@School initiative. The notable success of this project across the five participating Romanian schools was largely attributable to the pre-structured nature of the activities. This proactive preparation streamlined the implementation process, conserved critical institutional resources, and enabled educators to dedicate more time to the primary air-quality measurement campaign with their students.

Furthermore, preparatory training serves as an essential mechanism for empowering educational communities by enhancing their decision-making and operational capabilities. By entrusting educators with full autonomy over the learning activities co-designed during the PD workshop, the authors fostered a sense of professional agency. This pedagogical approach focused on the acquisition of fundamental skills, thereby providing the necessary scaffolding for educators to initiate and sustain the educational experience independently.

**Enhanced competencies through technology:** The CleanAir@School citizen science project significantly enhanced students' environmental awareness, scientific literacy, and competencies in Sustainability Education through a technology-integrated learning framework. By implementing an NO<sub>2</sub> measurement campaign utilising passive dosimeters, educators and students employed a bottom-up methodology to visualise NO<sub>2</sub> concentrations and map their spatial distribution across five educational centres in Romania. The integration of geolocation and quantitative air-quality measurements fostered a collaborative, democratised understanding of atmospheric pollution. Notably, the high density of locally positioned measurement points yielded more granular air-quality data across Dâmbovița County than the limited number of official municipal reference stations. This data gran-

ularity, however, surfaced critical ethical considerations regarding socio-environmental disparities. The findings highlighted significant variations in NO<sub>2</sub> levels correlated with socio-economic status: students in more affluent neighbourhoods engaged in debates regarding tube placement in areas characterised by higher proportions of green space and lower pollution levels. In contrast, students from lower socio-economic backgrounds collected data in environments with elevated NO<sub>2</sub> concentrations resulting from intensive anthropogenic activities. Conversely, the empirical data revealed unexpectedly high air quality in the vicinity of the industrial batch plant, suggesting that the facility's environmental impact was less pronounced than the local community had previously perceived.

**Transformative Pedagogy.** Educators observed that the CleanAir@School initiative effectively bridged the gap between the classroom and the natural environment, catalysing student enthusiasm for environmental stewardship through a synthesis of traditional and contemporary pedagogical methods. Students engaged with the complexities of air pollution from a multidisciplinary perspective, moving beyond theoretical understanding to actively identify localised environmental challenges and propose viable solutions.

The project's inquiry-based framework was instrumental in advancing students' scientific literacy and their comprehension of the iterative nature of scientific inquiry. This approach served as a catalyst for pedagogical innovation, transitioning the learning experience from passive reception to active, collaborative, problem-solving engagement. Such a shift fostered critical thinking and agency, transforming the classroom into a participatory environment in which inquiry is individualised. This fundamental transition directly addresses the objective of empowering participants, as students were repositioned from observers to active knowledge-creators.

**Strengthen industry–community relationships.** The CleanAir@School initiative was frequently cited by educators as a seminal non-formal project, distinguished by its capacity to mobilise the entire school ecosystem—including management, faculty, administrative personnel, students, and parents—while simultaneously extending its reach into the broader local community. The achievement of such collective mobilisation reflects the initiative's strength in cultivating a shared sense of purpose and collective ownership.

In rural settings, this mobilisation achieved significant resonance by facilitating an unprecedented dialogue between the community and the local multinational building materials corporation.

The collaboration was operationalised through direct communication between the company's batch plant and the implementing school communities. This involved a series of transparent engagement activities, including guided technical tours of the plant, scholarly debates with the technical director, and a collaborative exploration of potential pollution sources alongside the specific mitigation actions taken to achieve sustainable operations. Ultimately, the project effectively repositioned schools as central hubs for community engagement and reconciled rural communities with the industrial sector, increasing trust-building, transparency, and social mediation, as documented in the educators' reflections.

## 7. Conclusions

This research argues for the regenerative potential of participation [62] by critically examining a case. The aim is to identify whether participatory approaches might be considered validated instruments for achieving empowerment and dialogue, and for fostering respectful and equitable relationships within vulnerable communities.

Indeed, the case study presented here can be considered capable of strengthening and empowering participants and their communities. This is achieved through implementing inclusive methodologies, fostering active engagement, promoting inquiry-based learning, and building cross-sectoral collaborations.

The case highlights several crucial implications for future participatory design practices in marginalised contexts. In particular, the following actionable recommendations are for designers interested in replicating similar initiatives.

First, the case underscores the importance of context-sensitive, flexible design approaches that acknowledge and proactively address local ethical complexities, as demonstrated by successfully investigating the Fieni situation.

**Recommendation 1.** Embrace inclusive, flexible methods: Use both digital and analogue tools to engage communities facing a digital divide. This adaptability in design choice ensures that PD methodologies are equitable and accessible to diverse groups.

Second, the case accentuates the transformative potential of integrating citizen science with formal and non-formal education to foster environmental stewardship and community resilience, particularly in underserved rural areas.

**Recommendation 2.** Integrate citizen science with education to foster environmental stewardship and community resilience. The approach shifts learning from passive reception to active and problem-solving engagement, empowering participants to become “active knowledge constructors”.

Lastly, the project’s success in mobilising entire school communities suggests a viable model for broader institutional and social change, demonstrating how educational institutions can become pivotal hubs for community empowerment.

**Recommendation 3.** Foster collective change: Go beyond a single group by mobilising the entire organisation or community, including all stakeholders and users. This whole-organisation and community-wide mobilisation is required to feed the long-term transformative process.

Additionally, investigating the replicability of this model in other marginalised contexts with diverse conditions and challenges would be valuable. The authors refer here to various environmental, societal, and technological challenges. Further analysis of the specific mechanisms through which participatory design fosters trust and reconciliation in contentious community–industry relationships could yield deeper theoretical insights.

**Author Contributions:** Conceptualization, A.P. and G.A.G.; methodology, A.P. and G.A.G.; validation, A.P., G.A.G. and A.I.L.; formal analysis, A.P., G.A.G. and A.I.L.; investigation, A.P., G.A.G. and A.I.L.; resources, A.P., G.A.G., and A.I.L.; data curation, G.A.G.; writing—original draft preparation, A.P. and G.A.G.; writing—review and editing, A.P., G.A.G. and A.I.L.; visualisation, G.A.G. and A.I.L.; supervision, A.P.; project administration, A.P.; funding acquisition, A.P. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the European Union’s Horizon 2020 research and innovation programme (GreenSCENT project), grant agreement No. 101036480.

**Institutional Review Board Statement:** The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee on Animal and Human Experimentation of the Universitat Autònoma de Barcelona (CEEAH; protocol code 5712 (2021)); date 23 July 2021).

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study. Permission to conduct the participatory design activities for the purposes of this research was obtained from all respondents, who were fully informed about the purposes of this study and how their data would be used and stored.

**Data Availability Statement:** The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

**Acknowledgments:** The authors wish to thank all the staff of the associations and educational institutions that contributed to making the research activities possible, meaningful and successful: Asociația Volens in Bucharest, Romania; Maria Mădălina Mocanu, Lidia Vatavu, and Elena Leotescu—Aurel Rainu High School, Fieni; Maria Gizela Aldica, Lăcrămioara Prundaru, and Dana Negulescu—

Diaconu Coresi Secondary School, Fieni; Oana Popa and Vasilica Simona Zamfir—Ion Ciorănescu Secondary School, Moroeni; Elena-Alina Gealepu, Daniela-Maria Anastase, and Ramona—Mihaela Buzatu—Elena Donici Cantacuzino Secondary School no. 4, Pucioasa; Felix Dan Stan, Nicoleta Stan, Loredana Stan, Rodica Pătulea, George Badea—Lucieni Secondary School, Diaconu Coresi Secondary School, Aurel Rainu High School, Fieni, Lucieni Secondary School, Ion Ciorănescu Secondary School, Moroeni, and Elena Donici Cantacuzino Secondary School, Pucioasa, all in Dâmbovița county, Romania. They provided valuable support in organising and conducting the entire educational journey at their venues, dedicating their time and resources to coordinating the activities with their students and local communities. The authors also wish to thank 4Sfera for providing the educational materials and guidance for the learning activities, the schools, and Heidelberg Materials Romania for supporting the project's implementation in Romania.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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