ACADEMIC PAPERS

Proceedings of the Second International Conference on Sustainable Energy Education (SEED 2026)

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Martijn Rietbergen • Lenny van Onselen

SEED
sustainable energy education

Academic Papers

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Scientific Editors: Martijn Rietbergen, Lenny van Onselen

Texts: By the authors

University of Applied Sciences – Utrecht

Center of Expertise Smart Sustainable Cities

Padualaan 99 – 3584 CH Utrecht – The Netherlands

smartsustainablecities@hu.nl

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Prologue SEED Proceedings 2026

This volume presents peer-reviewed **academic papers** from the Second International Conference on Sustainable Energy Education (SEED 2026) held in Utrecht, the Netherlands, 24-25 March 2026. The conference was hosted by the Centre of Expertise Smart Sustainable Cities at Utrecht University of Applied Sciences.

Since its inception, the SEED conference has established itself as an international forum for lecturers in vocational training and higher education, researchers, policymakers, and practitioners. SEED provides a platform for exchanging ideas, sharing experiences, and collectively addressing the challenges of the energy transition. Central to this mission is the preparation of well-equipped learners, students, and professionals, and the development of sufficient and future-ready labour capacity in the context of the energy transition.

The 2026 conference focused on four interrelated themes: the energy sector labour market, innovative energy education, the region as a university campus, and skills for the sustainable energy transition. Together, these themes framed discussions on how education systems, regions, and industries can collaborate to address current and future societal needs.

The conference programme combined academic rigour with practical engagement and included a dedicated student track, as well as sessions connected to the CoVE SEED project. Over the course of two days, the conference welcomed more than 200 participants from 25 countries worldwide. The programme featured 30 academic papers, 35 expert papers, and 20 poster presentations, alongside 23 workshops, several student contributions, excursions, and exhibitions showcasing innovative practices and regional initiatives.

Keynote speeches were delivered by Arash Aazami, who spoke on *Trends and innovations in the field of the energy transition*, and Marcel Koenis, who addressed the topic of *Strategic regional collaboration in the energy transition*. A panel discussion, moderated by Remko van der Lugt, brought together perspectives from education (Mark Tammer), policy (Marsha Wagner), and industry (Jop Amelsfoort) exploring the topic *Aligning energy education and training with evolving energy labour market needs*. The conference concluded with a reflective wrap-up by Marsha Wagner, synthesising key insights and outlining directions for future collaboration.

The SEED Conference is a platform for transnational learning and cooperation within the CoVE SEED project (Centre of Vocational Excellence – Sustainable Energy Education). CoVE SEED is funded by the European Union through Erasmus+ and the European Solidarity Corps (grant agreement No. 101056147). The CoVE SEED consortium consists of educational providers (EQF levels 2-7), working professionals, and policymakers from Spain, the Netherlands, Greece, Germany, and Finland. The project focuses on delivering high-quality, innovative education to support the energy transition. The project aims to equip learners and

professionals with the skills needed to accelerate the energy transition; strengthen regional innovation through stakeholder collaboration; share and scale best practices in sustainable energy education; build an international learning community; and ultimately establish a Centre of Vocational Excellence in each participating region.

The organising committee would like to thank our supporters and sponsors, including the Province of Utrecht and Rabobank, whose contributions were essential to the success of the conference. We also warmly thank the keynote speakers, authors, programme committee members, reviewers, session chairs, presenters, supporters, and all participants for their engagement and commitment. Finally, our appreciation goes to Utrecht University of Applied Sciences for its support and for helping to make SEED 2026 a truly impactful event.

Martijn Rietbergen & Lenny van Onselen

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Success Stories In Renewable Energy: Birzeit University

Ahmed Abu Hanieh[a] and Afif Akel Hasan[a]

[a] Department of Mechanical and Mechatronics Engineering, and Ph.D Program in Energy and Environment Technology, Birzeit University, Palestine

Abstract

Birzeit University, as Palestine's leading academic institution with the aim of education and research excellence, as well as community interaction and services, is committed to achieving sustainable development. Greening its campus through water efficiency, use of renewable energy, and wide greener areas. At the same time, developing academic programs at the bachelor, master and PhD levels to advance technical capacity for sustainability awareness and research. Birzeit University experience with MS in Renewable Energy Management program is explained in this paper including its national and international cooperation in research and student MS thesis. Feedback of program graduates through a survey is analysed, indicating how the programme is in line with national strategies, and the benefits of programme to graduates in advancing their career and prospect for graduate studies. Cooperation with EU research centres showed our student ability to carry out advance research and gain international cultural experience. Cooperation with government such as Palestinian Energy and Natural Resources Authority (PENRA) showed program capability to help solve local energy problems and provide opportunities to government employee to develop their technical and research capability. The new PhD in Energy and Environment Technology program at Birzeit University is introduced as well in this paper, and its first enrolled student cohort is analysed with prospect to achieve program objectives.

Keywords: green campus; renewable energy; sustainability; environment; sustainable education.

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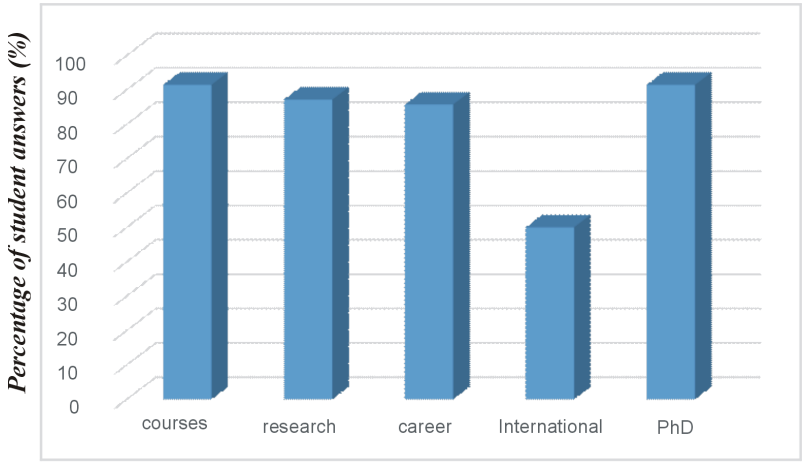
1 Introduction

Birzeit University developed from community college to university in 1974 since then it has been growing in terms of programs, student number and campus. Currently around 14000 students enrolled in 83 BS programs, 45 MS programs and 5 PhD programs. Females form 64% of enrolled students. University campus covers 200 acres with green gardens and open areas forming 70% of the campus area (Birzeit University, 2025). A solar PV field of 1.7 MW grid connected system supplies most of electric loads to the University, and exceeding its loads in the summer days.

The Graduate School offers a program leading to a master's degree in Renewable Energy Management. The program aims to develop graduates who will contribute to developing the renewable energy profession, managing its projects, and enriching it with modern and advanced technological developments. It also qualifies them to complete doctoral studies, conduct research in the field of renewable energy and manage its projects. The program offered by the Graduate School is interdisciplinary in nature, combining concepts from the fields of Chemistry, Physics, Mechanical, Electrical and Information Engineering, Economics, Administration and management. The clear focus of the program is to produce theoretical and applied research in renewable energy engineering and management.

A survey of program graduates and students shows that program succeeded in providing graduates additional skills and knowledge that enhanced their qualification in their current career and carrying out research as well as preparing them for PhD studies. Survey results showed that program courses and content is in line with community needs and strategies, see (Figure 1). On the other hand, it only succeeded moderately in strengthening cooperation with international institutions.

Fig. 1 - Benefits evaluation of the M.Sc. program for local and international cooperation, career and Ph.D study



2 Prospects of cooperation

In the frame of enlarging the pool of scientific cooperation, the Renewable Energy Management Master program at Birzeit University started making a network of relationships with local and international institutes and associations related to renewable energy. Cooperation agreements have been signed with international institutes like Julich research centre in Germany, to work on research in the field of partial shading of road-integrated photovoltaic cells that lead to a master thesis in the field, co-supervised by a professor from Birzeit University and a professor from Julich.

The local cooperation was distributed to three levels: government, higher education institutions and local industry. A memorandum of understanding has been signed with the Palestinian Energy and Natural Resources Authority (PENRA). Besides to other cooperation issues, the agreement includes starting a research and Master thesis in the field of investigating the possibilities of implementing ISO 50001 energy conservation system to one of the biggest food companies in Palestine.

2.1 International cooperation

Globalization has a great social, environmental and economic impact on developing countries (Lee and Vivarelli, 2006). Palestine needs to enhance its integration in the global society for building a long living state and strengthening a prosperous society. A research topic has been held between Birzeit and Julich research center in Germany in the frame of the Palestinian-German research Bridge. A female student conducted student mobility at Julich to work on her Master thesis in the field of Bypass diodes and shade tolerance of the road integrated photovoltaic analysis. The main objectives behind this agreement are: Enhancing inter-cultural mobility between Palestine and Germany, involving females to enhance gender participation in renewable energy field, transferring knowledge from highly developed center (Julich) in a developed country (Germany) to implement globalization on ground, qualification of researchers and experts who can take the lead of technology in renewable energy and improve it in Palestine and opening the gates for future cooperation in other fields and with other international research institutions.

2.2 Cooperation with government

It is one of the most important goals to enhance relationships with the different departments of the Palestinian Authority. PENRA is the energy authority mostly relevant to this program. A cooperation agreement is signed with PENRA that includes training of Bachelor engineering students in the authority and partially funding PENRA employees to pursue their PhD and Master studies at Birzeit University. One of the projects connecting the three pillars; university, government and industry, is a project to investigate the feasibility to implement

the ISO 50001 for energy efficiency and sustainable development in one of the most famous food producing companies. The research will be based on Plan-Do-Check-Act (PDCA) methodology. Where the student will start in planning by doing simulations for the impact of ISO system on energy efficiency. The next step is to install measurement equipment to test the energy consumption. The third step is to check the influence and compare the results before and after implementation. The last step is to take the required actions to obtain the ISO accreditation. The cooperation with PENRA is further enhanced as three of its staff is enrolled in the newly launched PhD program. The MS program was involved in devising solutions for some of energy related problems at Al-bireh municipality which adjacent to the university.

2.3 Cooperation with industry

Adoption of electric vehicles (EVs) and Hybrid electric vehicles (HEV) in Palestine tripled in 2023 due to the entry of more than five fully electric vehicle brands into the market. This growing market led to the appearance of a few local companies in this field for importing these vehicles and carrying out after-sales services. Through one of MS students, employed by one of the EV & HEV companies, cooperation was established to support such market and deal with challenges it faces, especially with weak electric grid and the increased penetration of PV electricity in the grid.

Modelling of EV battery charging and discharging processes, in addition a bidirectional charging- discharging, to be installed and tested in actual EV car. The main objective of the student thesis is to find out if the Palestinian grid could cover the rapid increasing load of EVs along with other electricity demands, and the ability to use vehicle to grid V2G technology to help the grid, specially at peak time. Also, to study the possibility of integrating the electric vehicle to the grid alongside with solar PV system. Simulation models were developed to analyse grid performance under different scenarios as well as systems integrated with photovoltaic (PV) panels. The results demonstrate that V2G technology can effectively reduce peak demand, enhance energy resilience, and enable peak shaving in Ramallah, particularly during winter months when grid demand is highest (Nazzal, 2025). There is a vast potential of cooperation with many of the renewable energy developing and installing companies, such as Qudra which is currently developing a 6 MW of PV field as car parking shading roofs on the university campus.

3 Research topics

3.1 Road integrated PV panels

One of the main research topics in renewable energy has been held through a Master thesis in the field of Bypass diodes and shade tolerance of the road integrated photovoltaic analysis

(Sara Rajab, 2024). The student spent three months in Julich research center to work on the topic. The research found out that using a series of bypass diodes can reduce the effect of soil or tree leaves which cause partial or complete shading on the PV cells (Sara Rajab et al., 2024).

3.2 Vertical-axis wind turbine

Wind energy is rarely used in Palestine because of low wind speeds which makes horizontal-axis wind turbines inefficient. This research focuses on using vertical-axis wind turbines for domestic power generation at small scale (Hamza Ahmad, 2024).

The experiments were based on exposing the vertical-axis savonious wind turbine to a wind tunnel and measuring the output power from the turbine. The produced turbine power was very low; thus results assured the idea that wind energy is not feasible in Palestine. (Hamza Ahmad and Ahmed Abu Hanieh, 2025).

3.3 Batteries and energy storage

With increased adoption of EV and HEV in Palestinian market in addition to other usages of batteries such as autonomous PV systems, number of batteries of different types and capacities is increasing enormously in the last few years. The End-of-life battery research aim is to assess the life cycle and the environmental implications of future use of EV & HEV batteries in Palestine. Number of EV & HEV are forecasted till 2035 then number and capacity of batteries reaching their end of life are estimated, management options were explored based on best practice and local conditions. Management options included reuse, repurposing, remanufacturing, and recycling. Research proposed business model, technical capacity building, and government regulations to accomplish such task (Zawahrah, 2025).

The research on vehicle to grid model of EV and HEV involve developing a model for a typical home load and evaluating the V2 G option. Another model included integration of the V2G with PV grid system. Modelling results indicated feasibility for implementing the model in certain locations in West Bank (Nazzal, 2025).

Table 1 summarises the main research topics of the students' thesis, their status and cooperation models. Thesis showed a wide range of renewable energy and energy management topics as well as a wide spectrum of local and international cooperation.

Table 1 - Main research and thesis of the program during the last three years

Topic	Status	Comments
Road integrated PV system	completed	International cooperation
Vertical wind axis turbine	completed	Experimental –using University labs
End of life EV battery management	completed	Modelling
Vehicle to grid battery storage	completed	Modelling – cooperation with EV vehicle company
Impact of Electric Vehicle Charging Stations on the Performance of Active Electrical Distribution Grid	completed	In cooperation with electricity distribution company
Implementing ISO 50001 system for energy in food industry	Ongoing	In cooperation with government energy authority and local industry
Green hydrogen potential in Palestine	Ongoing	Modelling

4 PhD in Energy and Environment Technologies

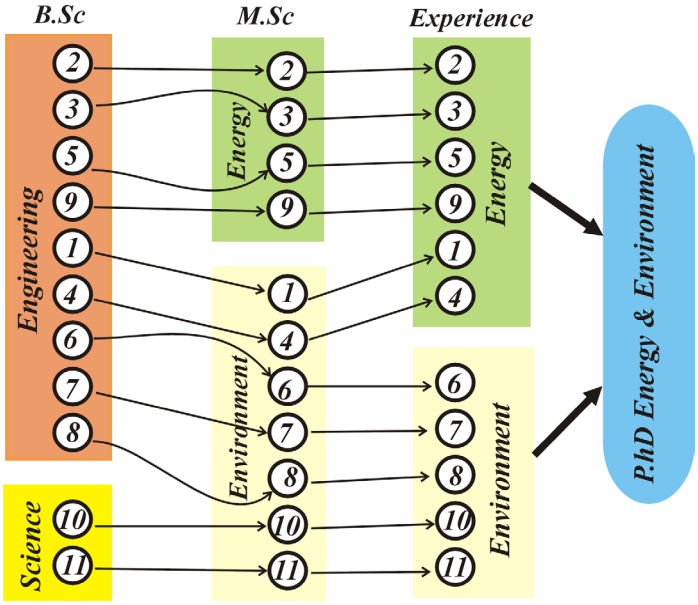
As a continuing process of supporting sustainability, environmental issues, energy and renewable energy technologies, BZU has recently started a PhD program in energy and environmental technologies. The program focuses on both energy and environment aspects in courses and research topics. The program has the following objectives: qualifying researchers capable of understanding all energy, environment and climate change challenges; locally and internationally, preparing scientists who can participate in the global knowledge awareness, graduating experts to transfer and share knowledge between universities and providing the society with leaders who can put forward and modify energy and environmental policies and regulations.

Engineers from almost all engineering disciplines, biologists, physicists and chemists can be admitted in the program if they satisfy the admission requirements. A student must follow 9 advanced courses related to energy and environment and succeed the qualification exam to be considered as a PhD candidate. After being candidate, a student can start working on his dissertation under the supervision of one or more of the existing professors and, preferably, co-supervision by external supervisors.

The program admitted this year 11 students as a first cohort. There is a good geographical distribution, gender ratio (50% are females) and association variation for the students. Enrolled students in the first cohort 2025-2026 reflected the interdisciplinary nature of the program. As shown in figure 2 the enrolled students qualifications included two students with B.S in science degree, and nine with engineering degrees. At the master's degree level six

have environment degrees, two engineering degrees, and three energy engineering degrees. Concerning the current job and experience; five are in energy related positions, and six in environment related positions. Such student background will help in achieving program objectives and carrying out in energy- environment nexus.

Fig. 2 - PhD of Energy and Environment Technology cohort 2025-2026 qualifications



BZU is looking for cotutelle supervision for the coming dissertations and partnership with international higher education institutions. Cooperation with international universities can provide the program with external knowledge and global experience. It can also help students to be open-minded with multi-cultural thoughts that help them to be well-integrated in the global societies and participate in the international knowledge awareness.

5 Conclusions

This article presents an overview of the previous and recent expertise of BZU team in the fields of sustainability, energy, renewable energy and environment education. Paper presents the MS program of renewable energy management, and its ability to enhance sustainable energy education, as well as the local and global cooperation activities. Among program projects was an international cooperation with the German Julich research center while the other projects were with local parties. Locally, the cooperation varied between working with local industry and government bodies. The paper presented some of the research topics tackled by the students and their supervisors. Research carried out in cooperation with Julich center, is road-integrated solar PV panels and the problems of soil and shading with some practical solutions. Vertical-axis wind turbines have been studied and proved having very low efficiency. Batteries for energy storage have been studied showing the possibilities of sustainable management of EV batteries. Based on these research three

papers have been published in international journals. This paper presents, at the end, a summary about the recent PhD program of Energy and Environment Technologies and calls for partnership and cotutelle thesis supervision in cooperation with international universities.

Acknowledgements

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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A Challenged-Based Learning Community For Hydrogen Development, Applications And Education

Hans Gelten[a], Benno Aalderink[a], Richard van Leeuwen[a], Mirte Disberg-van Geloven[b], Stephan Corporaal[b] and Yashar Hajimolana[c]

[a] Department of Sustainable Energy Systems, Saxion University of Applied Sciences, The Netherlands
[b] Department of Human Capital, Saxion University of Applied Sciences, The Netherlands
[c] Department of Thermal and Fluid Engineering, University of Twente, The Netherlands

Abstract

The University of Twente, Saxion University of Applied Sciences, ROC van Twente (vocational education), centre of expertise TechYourFuture and H_2Hub Twente work together to shape a Learning Community (LC) for the development of hydrogen technology. In the LC decentralized hydrogen production, storage, application and education plays a central role. The main question of the cooperation is how we can design and perpetuate a successful challenge-based LC in which students, company employees (specialists) and researchers can learn, innovate, build-up knowledge and benefit together? Human Resource Development-specialists (HRD), engineers and researchers explored the important factors for a LC, resulting in a blueprint with agreements and commitment. The LC blueprint served as a guideline for the RAAK MKB project HYGENESYS (2022 – 2024). Impact interviews reveal that the LC is very beneficial. For companies it increases overall knowledge on hydrogen systems, promotes cooperation and connection with other companies and aids to their market position as well. Students get the opportunity to work in close contact with multiple company professionals and build-up a network of their own. Output of the LC can serve as educational material for businesses and companies. Insights are further improved with hands-on experimental possibilities using a small-scale test-setup, which is made available in an open-source hardware platform (*Instructables*). The LC will continue to serve as methodology for projects like HyPRO (GroenvermogenNL) or Professional Doctorate (SIA) and educational activities are expanded with courses for Lifelong Learning.

Keywords: hydrogen; applications; learning community; open-source hardware; education.

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1 Introduction

Due to worldwide climate change caused by CO_2 emissions, there is an urgency to change energy systems towards 100% renewable energy. Green hydrogen is a promising renewable energy carrier for industrial applications and heat demand. It is produced from biobased sources or by electrolysis using electricity from renewable sources (Shiva Kumar et al., 2022).

The demand for engineers with electrolyzer and hydrogen know-how is increasing, so there is a need for hydrogen related training opportunities (Tretsiakova-McNally et al., 2017). Learning Communities (LCs) have proven to be a suitable form of training, covering different engineering and societal aspects of hydrogen technology (Corporaal et al., 2021). According to 'The future of hydrogen', the creation of jobs in manufacturing, installation and maintenance of electrolyzer systems will be increasingly important (Gül et al., 2019).

The UT, Saxion, ROC van Twente, TechYourFuture and the H_2Hub Twente [1] work together to shape a challenge-based LC, where a decentralized production unit with storage of green hydrogen is designed and built. Simultaneously, educational material and courses are developed for business specialists and students from different educational levels.

2 Setting up an effective LC

LCs are public-private partnerships in which learning, working and innovation merge into a hybrid learning environment. Although there is a diversity of manifestations of LCs, a number of core dimensions can be specified (West et al., 2017). Participants in a LC work together collectively on a meaningful challenge to build on already existing knowledge and thus learn at individual and group level (Blackshaw, 2010). The interaction between participants is promoted if they feel interdependent and responsible for the problem and feel safe and familiar in the group. This learning is necessary to act and respond proactively to rapid changes in innovation processes. Learning, working and innovation are seen less and less as purely individual and isolated processes, but as a collaborative, co-creating and context-rich process covering these aspects. This context often refers to the quadruple helix in which companies, knowledge institutions (students and researchers), governments and citizens play an (active) role in creating new knowledge and technologies (MacGregor et al., 2010).

In 2019, the Dutch national top sectors program (Topsectoren) joined forces in an action-oriented Roadmap Human Capital 2020-2023. Part of the programming of this Roadmap is the weaving of LCs into the multi-year mission-driven innovation programs of the top sectors

[1] The H2Hub Twente is a cooperation located in Almelo, in which various regional corporations like Demcon, VDL, HyMatters, KIWA, Cogas, Powerspex and Waterschap Vechtstromen and knowledge institutes like Saxion, UT and ROC of Twente, are involved to perform valuable research on the value chain of hydrogen, from production to applications.

and research programs of the Dutch Organization for Scientific Research (NWO). The concept of LCs is seen as the solution to connect learning, working and innovation. LCs aim to contribute to solutions for major social or technological issues and provide insight and revenues at macro, meso and micro level:

- At the **macro** level, the central issue of the community is examined. This is a complex task and a large group of (different) parties are involved. A so-called learning ecosystem is formed by all stakeholders – companies, knowledge institutions (education and research), government – and located around a specific area, in this case the H2Hub Twente. Solving this complex issue requires cooperation with different sectors (engineering, construction, installation, safety, etc.) and involved positions are often strategic in nature (managers, management, lecturers/project leader of education and companies).
- At the meso level, the big issue is divided into the different challenges or projects. Various participants from multiple parties are involved, but the issue is less complex. Involved positions are often tactical in nature, such as the generalists/specialists from companies and researchers of knowledge institutions.
- At the micro level, a smaller group of stakeholders operates around a very specific issue. It still exists of several parties (e.g. education and companies), but from a specific sector. Involved positions at this level are often executive in nature. This is the level in which specialists from companies and researchers and students from knowledge institutions are involved as participants in the LC.

The developed LC is based on some key elements as identified and validated in previous research projects (Corporaal et al., 2021; van Rees et al., 2025):

- Multidisciplinary work: Learning within the LC is basically a social process but is closely connected with individual learning.
- Shared ownership: Learning and working is situated and integrated with daily practice.
- Facilitating meetings between stakeholders, experts and students: The LC fulfils the three main basic psychological needs - connectedness, autonomy and self-management - for intrinsically motivated participants.
- Organizing effective ways of knowledge sharing to bring the proceeds of LCs to society: The LC focuses on making the learning outcomes sustainable and continuing the LC itself.

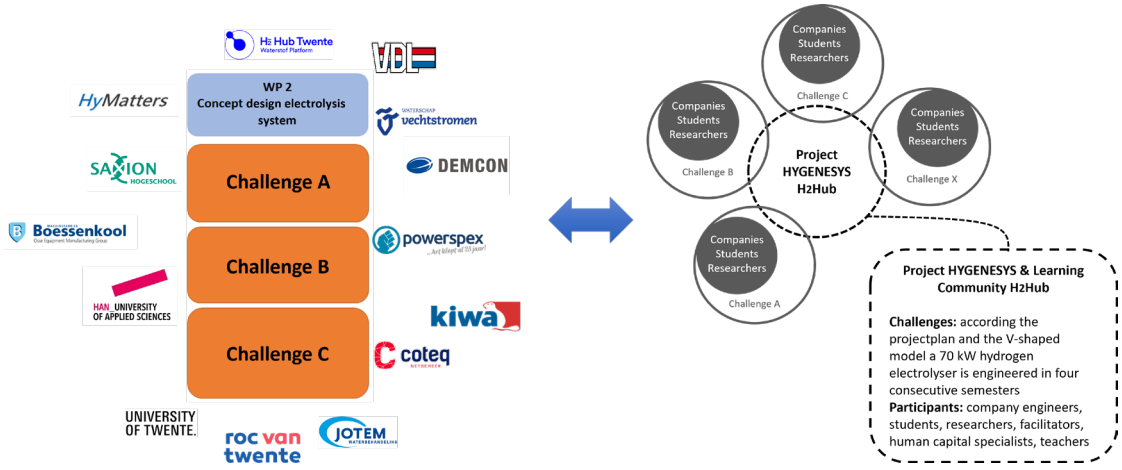
Evidence-based research about work design, workplace learning, team learning, self-directed learning and motivation convert these key elements in design principles for the LC blueprint. The RAAK-MKB project HYGENESYS (September 2022 – September 2024) is translated into a macro, meso and micro-LC based on the mentioned design principles. In the LC students, professionals and stakeholders work in teams together on challenges from the project plan.

3 Development of the challenge-based LC blueprint

Currently, there is still limited knowledge available about the realization and application of hydrogen production equipment at larger scale, both in industry and at knowledge institutes. The technological development of constructing a robust and safe hydrogen electrolyzer is a challenging multi-disciplinary engineering task. It consists of several steps, ranging from global system engineering towards drafting a detailed design, followed by manufacturing, testing and verification. This development is well written in the HYGENESYS project plan, where all the work packages are described.

The consortium of companies and knowledge institutes is a mix of specialists and generalists, each with different interests and ideas. In order to come to an operational electrolyzer system, the work packages were split into several manageable challenges and linked to specific companies, researchers and students that have the appropriate skill set to tackle the task. For WP2 these challenges are shown in figure 1 (left), resulting in the design for the challenge-based LC (right) (Corporaal et al., 2021).

Fig. 1. - Example of a WP and consortium from the project (left) versus concept design LC (right)



The main question is: how can the challenges within the WPs of a project be arranged in a challenge-based LC in which students, company employees (specialists) and researchers from the knowledge institutions can learn, innovate, build-up knowledge and benefit?

An important aspect within this LC is commitment from all involved stakeholders and to formulate working agreements. This should lead to a situation where all partners benefit from the project. To accomplish this a blueprint is developed in which LC teams are connected. The LC teams work in an equal collaboration on integrated complex issues. The teams consist of multiple stakeholders, in which the field of work, education and research are always represented. The concrete steps towards the LC blueprint are described below:

- Participating companies are approached for a LC design session. In this session, HRD specialists, engineers and researchers have an open discussion to retrieve how the business community views the development or innovation and how knowledge institutes involve students and researchers in the process.
- The results of the design session are incorporated into a blueprint (a set of agreements and commitment) for the LC by human capital specialists.
- During the kick-off of the project, the main goal is to form the LC teams for the challenges, make work agreements and streamline expectations. The most important issues are project focus, challenge coordination, concrete results or output and ways of communication.

Based upon the design principles, the development session with stakeholders and the kick-off meeting, the concrete blueprint for the challenge-based LC was developed. It includes important agreements and commitment around the challenges, participants, frequency of meetings and the role of the facilitator. The blueprint is a starting point of the collaboration within the LC but will be reviewed and improved during the course of the project.

4 Impact and progress of the Learning Community

The challenge-based LC started in September 2022 with the RAAK-MKB project HYGENESYS, which continued in four consecutive semesters till September 2024. After finishing of the project, the progress and especially the impact of the LC is significantly:

- During the kick-off, the full consortium (students, companies and knowledge institutes) was present to discuss the blueprint and make working agreements for the challenges.
- Challenges at work: The challenges follow a rhythm suitable for the activities and deliverables with frequent meetings, discussion and knowledge sharing. The participants met every Friday morning physically at the H_2Hub in Almelo for an intensive discussion and work session. Scrum sessions were coordinated for short-cycle progress updates.
- Periodical consortium meetings were planned, where the companies, knowledge institutions, students and LC coaches are invited at the H_2Hub to discuss the results of the challenges and to consider the overall state of affairs within the project.

Fig. 2 - Progress and impact of the challenge-based LC. Left: discussing work agreements during the kick-off, middle: the LC at work, right: sharing the progress and aligning challenges at a periodical consortium meeting

The impact of the challenge-based LC is evaluated with two impact interviews (midterm and at the end of the project). During an open discussion, different stakeholders from the consortium reflected on the established LC. There are several conclusions from the impact interviews which are well in line with the design principles described in this article and the observations described in literature:

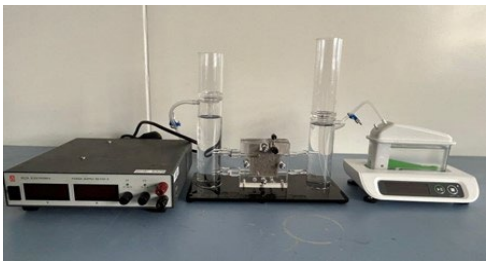
- Students stress the importance of **authentic assignments** and indicate that LCs offer students the opportunity to be educated closer to or together with practice. It is noticed that the students develop adaptive ability, self-management and collaboration.
- The involved companies express that working within a LC **increases cooperation** across the boundaries of their own organization, while on the other hand joining the LC can improve the **competitive position** of the company.
- The LC gives results on micro (highly **motivating** and build-up of knowledge and lifelong development of company employees), meso (**co-creation** and connection between education and practice) and macro scale (development of a LC as **organic ecosystem**).
- It was observed that participants feel **confidence** (self efficacy / team efficacy) and **competence**. In the LC there is involvement, connectedness and equalness.
- Working from a digital cloud environment and having both formal and informal contact between participants, leads to shared ownership, where results are directly relevant and applicable for each partner within the consortium.

The impact of the LC is well expressed in the LC promotional clip (https://youtu.be/L8GgjO90Ah8) and the after movie of the successful H_2 event on Decentral Hydrogen held at the H_2Hub Twente in September 2024 (https://youtu.be/_inm9TpDruA).

5 Development of a lab scale test set-up and implementation in open-source hardware platform

During the project HYGENESYS also a lab scale, transportable electrolyser set-up was developed, which can be used in educational institutions for practical exercises across various education levels. The electrolysis setup consists of three components, which are a power supply, an electrolyser and a gas measurement device. The user-friendliness of the setup is enhanced to ensure easy and safe transportability of all the components for demonstration, education or showcase purposes.

Fig. 3 - Development of a user friendly and transportable lab-scale electrolyser set-up



To further enhance accessibility and publicity the setup was published on an open-source hardware platform. The selected open-source hardware platform is **Instructables**. Instructables is selected due to the number of users and uploaded projects, educational purpose, the diversity of the environment and the user interface.

6 Conclusion

The energy transition requires new skills, insights and training. The LC approach is an innovative concept where students work together with professionals on real challenges. To set up a good working LC with mutual ownership between students, company specialists and researchers, theory and experience within this work conclude the following guidelines:

- Link challenges that are recognizable and attractive to all participants to the LC. A multidisciplinary and relevant project for companies is important; this ensures intrinsic motivation for all stakeholders.
- Create an equal collaboration between the participating stakeholders. This means that all participants learn from each other equally, the best condition for open cooperation.
- Create good knowledge transfer moments as participants in the LC gradually change and organize a stable and clear system for mutual communication and data storage in the LC.
- Physical contact moments to work and consult around the project or challenges are essential for mutual involvement. These sessions give motivation and energy to go further.

Although these guidelines work well within the developed LC and established engineering project and location, the authors would like to stress that setting up a LC needs also customization to the encountered situation.

7 Perpetuation of the LC and future developments

Starting September 2025, follow-up projects from Saxion and UT (for instance HyPRO and/or the Professional Doctorate) are considered as next projects, carried out within the boundaries of the designed LC. Groups of students, researchers and industry specialists will join forces at the H_2Hub Twente to gain further insights on hydrogen production (plasma decomposition of biomethane) and application (Power-to-Methanol technologies).

Educational activities are increased by developing course material from several results from the projects, for instance guidelines for HAZOP sessions or performing steps for a TEA.

Next to the development of course material effort is put in organizing a hydrogen-based theory and experimental course for companies and industries. This course contributes to Lifelong Learning and is developed in cooperation with HyMatters.

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Conflicts of interest

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Romania's contribution to the energy transition and reducing the EU's dependence on strategic raw materials

Marinela Istrate[a] and Ionel Muntele[a,b]

[a] Department of Geography, "Alexandru Ioan Cuza" University of Iasi, Romania
[b] Center of Geographical Studies, Iasi Branch, Romanian Academy

Abstract

The transition to a low-carbon economy is driving demand for critical raw materials (CRMs), such as lithium, cobalt, and rare-earth elements, which are essential for clean technologies. The EU's limited domestic capacity in mining and processing has created strong dependencies and supply risks due to geopolitical tensions and market instability. In response, the EU adopted the Critical Raw Materials Act in 2024 to boost domestic extraction, processing, and recycling. Romania has critical resources and raw materials that it can exploit both in the context of the energy transition and in response to the demand generated by global economic development. We propose integrating the concept of energy transition into the university geography curriculum, emphasizing the need to train specialists capable of analyzing the profound transformations of energy systems, evaluating resources from a geographical perspective, and contributing to sustainable territorial planning in line with the EU's climate neutrality objectives. Thus, we analyzed the 47 strategic projects approved by the EU to stimulate domestic capacities for strategic raw materials, of which 3 will be developed in Romania: copper, metallic magnesium, and graphite extraction. Inclusion on the list means that the projects will benefit from support in attracting funding and streamlined approval processes, allowing them to be completed as quickly as possible. However, implementation faces several obstacles, including public opposition to mining and limitations on recycling. In addition, we emphasize that the topic of energy transition requires an interdisciplinary approach and represents a strategic direction in student education.

Keywords: critical raw materials; sustainable mining; university curricula; Romania.

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1 Introduction

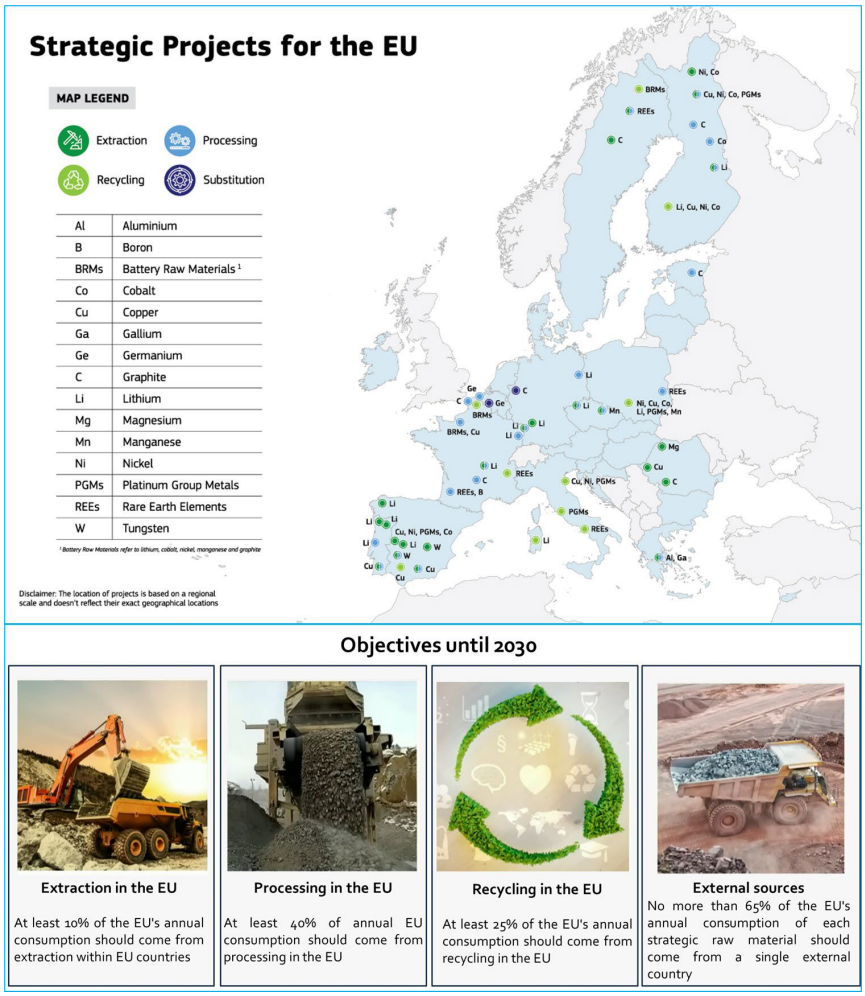
Against the backdrop of the transition to a sustainable and digitized economy, critical minerals have become strategic resources globally. They are essential for the functioning of high-tech sectors such as renewable energy, electronics, and aerospace. The transition to a low-carbon economy drives demand for critical raw materials (CRMs) such as lithium, cobalt, and rare earth elements essential for clean technologies (International Energy Agency, 2025). The EU's limited domestic capacity in mining and processing has created strong dependencies and supply risks due to geopolitical tensions and market instability. In response, the EU adopted the Critical Raw Materials Act in 2024 to boost domestic extraction, processing, and recycling.

Romania, with its geological diversity and tradition in extracting and processing mineral resources, has considerable potential for exploiting and utilizing critical minerals at the European level. The presence of these resources on national territory brings both economic opportunities and responsibilities related to environmental protection, integration into European value chains, and the security of supply of strategic raw materials (Radu et al., 2023; Drăgan et al., 2024). Thus, research and assessment of critical mineral deposits in Romania (Marincea et al., 2022) become priorities for industrial and environmental policies and for balanced regional development. Given the need for Romania's reindustrialization in the European context and the increasing use of non-energy mineral resources in industry, but also in the context of the transition from energy-intensive mining to responsible mining and circular economy, Romania has recently adopted the National Strategy for Non-Energy Mineral Resources 2025 – 2035.

In spring 2025, the European Commission adopted a list of 47 strategic projects aimed at boosting internal capacities for strategic raw materials and diversifying supply sources. The new strategic projects aim to meet the targets for the extraction, processing, and recycling of strategic raw materials in Europe, so that they meet 10%, 40%, and 25% of EU demand by 2030, respectively (Figure 1). These projects will contribute significantly to the ongoing green transition in Europe, while supporting the European defence and aerospace industries.

To become operational, the 47 strategic projects will receive support from the European Commission, Member States, and European financial institutions. The projects are distributed as follows: France (9), Spain and Finland (6 each), Germany, Italy, and Portugal (4 each), Romania and Sweden (3 each), Poland and the Czech Republic (2 each), Estonia and Greece (1 each). In the context of the European Union's intensified efforts to ensure its strategic independence in terms of critical raw materials, Romania has emerged as a significant player, having been selected as the location for three of the 47 projects considered strategic at the European level.

Fig. 1 – Strategic projects for the EU



Source: European Commission, 2025

These projects focus on the exploitation and processing of resources that are essential for the energy and digital transition—copper, graphite, and magnesium—and benefit from the European Commission's support for financing, simplification of authorization procedures, and integration into European industrial value chains. In accordance with the Critical Raw Materials Act, projects will have to meet requirements for sustainability, technical feasibility, and cross-border relevance, thereby contributing to the achievement of the EU's industrial and climate goals for 2030 and reducing the EU's dependence on imports of raw materials from outside the EU.

In this context, it is important to present to students the concepts, mechanisms, and implications of the Energy Transition on the territory, the environment, and society, with an emphasis on the spatial analysis of resource exploitation and the reorganization of energy systems at the regional and European levels. This topic can be introduced into the existing curricular components of both undergraduate and master's studies: Economic Geography, Territorial Planning, or Sustainable Development.

This article presents an exploratory assessment of Romania's situation regarding the implementation of the three mining projects, including considerations on the possibility of implementing sustainable mining and the communities' perception of the opportunity to reopen the mines. The article is structured as follows: introduction and general context, main characteristics of mining projects to be implemented in Romania, aspects related to sustainable mining, and the perception of local communities. Finally, there is a short section of conclusions, which offers some pointers on the prospects for further study of the topic.

2 Materials and methods

In this paper, an analysis of the literature and reports issued by the European Commission was used to establish the direction of the study and understand the concepts on which the paper is based. The documentary research was supplemented by descriptive statistics, with data taken from official sources published by the European Commission. The perception of local communities was highlighted by reading and summarizing articles published in the Romanian press. The three strategic projects approved by the EU in March 2025 to ensure the European Union's supply of raw materials necessary for the continuation of the energy transition were analysed (table 1): copper extraction in Rovina, magnesium metal extraction in Budureasa, and graphite extraction in Baia de Fier.

Table 1 – Characteristics of the three mining projects in Romania financed by the EU

Location (village and county)	Strategic raw material	Project type	Project promoter	Value of funding (million euros)	Estimated starting year of production	Estimated production
Rovina (Hunedoara)	Copper	extraction	Euro Sun Mining (Canada) and Samax România	300	2027	20,000 t/year of copper concentrate
Budureasa (Bihor)	Magnesium	extraction	Verde Magnesium Romania, through the Amerocap investment fund (USA)	115	2026	90,000 t/year of metallic magnesium
Baia de Fier (Gorj)	Graphite	extraction	National Salt Company (Salrom), Romania	200	2027	15,000 t/year of graphite

Source: European Commission, 2025

3 Results and Discussion

3.1 Copper mining at Rovina

The copper and gold deposit at Rovina was identified in 1973 and subsequently researched in the following decades, being considered the second largest in Europe. Three deposits were identified, two of which were mined in open pits (Rovina and Colnic) and one underground (Cireșata), with exploitable resources estimated at the time at around 100 tons of gold and 200,000 tons of copper. The mine was closed at the end of the 1990s. The authorities indicated at the time that mining had been in decline for several years, with the Romanian state considering the costs of production and operation of the mines in relation to market demand to be too high to be profitable. However, the mineral resources in the area continued to attract the interest of companies, and several mining fields were explored with a view to opening new mines. Since November 2018, the Canadian company Euro Sun has held an exploration permit and a mining license, renewable for 20 years, for the area in the Rovina Valley, covering more than 27 square kilometers. Although gold is a precious metal, it is not included on the list of critical minerals, let alone strategic minerals, at the European level. At the same time, even though it is not a rare mineral, copper is on both lists, due to the growing demand in relation to existing resources, being used in electrical infrastructure in the form of semiconductors, in new technologies such as wind turbines, and in the automotive, aerospace, and defence industries (European Commission, Rovina project, 2025). The Rovina project has been vehemently opposed over time by environmental non-governmental organizations, which have presented it as "devastating" for nature and local communities.

3.2 Exploitation of metallic magnesium in Budureasa

Prospecting for brucite limestone deposits began in 1977, with experts estimating that the Budureasa area contained the largest deposit of brucite limestone in Europe, which is extremely valuable. Between 1978 and 1989, 15 kilometers of galleries, research wells, trenches, and boreholes were dug in preparation for the exploitation of the deposit. After the fall of communism and the transition to a market economy, the mine gradually entered a phase of conservation, closing completely in 2014. Subsequently, the National Agency for Mineral Resources put the deposit up for auction, and various interested companies took it over. The current project, approved by the European Commission, includes the development of the necessary infrastructure for extraction, as well as the installation of processing equipment to transform the raw material into high-purity graphite, which is essential for the production of batteries, especially for electric vehicles and energy storage systems. The company plans to produce magnesium in aluminothermic furnaces, where temperatures of up to 2,400 degrees Celsius will melt the magnesium oxide obtained from brucite limestone. Through a process that also uses aluminium waste, the plant will obtain metallic magnesium,

which can be sold for the production of cars, rockets, airplanes, or drones. Depending on the evolution of production capacity, the operation is expected to create up to 1,000 direct jobs and around 10,000 indirect jobs. This operation could be the EU's leading producer of metallic magnesium, providing Europe with an internal supply alternative (European Commission, Verde Magnesium project, 2025).

3.3 Graphite mining at Baia de Fier

One of the priorities of Romania's non-energy mineral strategy for 2025-2035 is to ensure the superior exploitation of graphite for the production of batteries and graphene in Romania, with widespread use in the electronics, aerospace and defence, energy, automotive, and biomedical technologies industries. The presence of graphite was reported in Baia de Fier 150 years ago, and mining began in 1939 in two areas: Cătălinu (underground mining) and Ungurelașu (surface mining). In the mid-20th century, graphite from this mine provided 70% of Romania's needs. Work was challenging and dangerous in the deep mine, but wages were well above the regional average, so mining activities attracted workers from all over the country. The cessation of mining activity at the Cătălinu mine in 1994 was due to a sharp decline in economic profitability resulting from challenging deposit conditions. Nearly 800 workers were laid off. Subsequently, in 2007, due to economic losses and increasingly restrictive environmental obligations, operations at the Ungurelașu quarry were also discontinued. According to recent prospecting, the deposit in the Baia de Fier area would be sufficient for several decades of exploitation, with the application of all environmental standards agreed by the EU (European Commission, Baia de Fier project, 2025).

3.4 The long way to sustainable mining

The exploitation of critical mineral resources exerts significant pressure on the environment, manifested through severe pollution, ecosystem degradation, and the need for complex remediation interventions. In Romania, these ecological impacts are becoming significant challenges for both communities and authorities, highlighting the limitations of conventional methods and the urgent need to adopt advanced technologies designed to reduce adverse effects and facilitate sustainable management of natural resources. In Baia de Fier, the resumption of graphite mining involves extensive land interventions and considerable handling of mining waste, which significantly increases the risk of dispersion of fine dust with the potential to contaminate nearby soil and water. Although the European Union has invested millions of euros in the project, the necessary infrastructure — such as dust capture systems and continuous pollution monitoring — has not yet been implemented on site. Similarly, circular economy initiatives aimed at secondary extraction and recycling of graphite from used batteries integrate sustainability principles but require cutting-edge technologies that have not yet been implemented.

In the case of Budureasa, the European Union strategic project developed by Verde Magnesium aims to recover magnesium from tailings by processing tailings rich in magnesium, calcium, and iron. This intervention involves significant risks of groundwater contamination. Although the initiative is presented as low-carbon and part of a circular economy, there is still a lack of public information on the existence of adequate impermeable barriers and detailed hydrogeological studies to confirm the sustainability of the project. The absence of detailed hydrogeological studies compromises groundwater safety and increases the risk of inorganic and acid pollution. The Rovina mining project raises the most serious environmental concerns. The proposed open-pit mining of copper and gold involves diverting an underground stream and constructing upstream tailings ponds—considered unstable—just 1.4 km from a protected site that is part of the Natura 2000 network. The previously granted environmental permit was revoked in 2024 due to significant omissions, including the absence of a cross-border impact assessment on the rivers in the area, the existence of geotechnical risks regarding the stability of the structures, and the neglect of the effects on local biodiversity. The ecological remediation of the three mining sites requires urgent and tailored measures: in Baia de Fier, the installation of filters to reduce graphite dust; in Budureasa, the application of impermeable membranes under the tailings deposits; in Rovina, the construction of safe storage facilities and buffer basins, given the proximity of the Natura 2000 site. Complementarily, chemical neutralization and bioremediation can reduce toxicity and allow for metal recovery.

3.5 Local communities' perception of mine reopening

Despite the economic potential highlighted by the promoters of the aforementioned mining projects, a significant portion of local communities expresses reluctance towards the reopening of the mines. Closed in the early 2000s, the old mines have long been perceived as a closed chapter, and locals associate the resumption of mining activities with significant risks to the environment, health, and rural lifestyle. The prevailing perception is negative, based on previous experiences and fears that the resumption of mining will profoundly affect the natural balance regained in recent years. Criticism has also been expressed regarding the proposed mining methods—surface stripping, for example—which are considered invasive and destructive. Statements by residents, as reported in the mass media (Adevărul, 2023; Pandurul, 2025), suggest not a rejection of mining itself, but of modern industrial methods considered aggressive and environmentally irresponsible. The communities' concerns are also closely linked to the possible impact of toxic substances, especially cyanides, on the environment and health. Many locals and commentators express serious concerns about the possible consequences for the environment, especially for the sensitive ecosystems in the area and for tourism potential. They fear that processing will be moved to other counties, leaving the local community with only the waste and risks.

3.6 Developing students' theoretical and practical skills

By including a special chapter on this topic in university courses, students are offered the opportunity to have an integrated understanding of the concept of energy transition from a geographical perspective, ensuring the development of spatial analysis skills and the formation of the capacity to evaluate the socio-territorial impact of projects to reopen mining operations. At the end of the course, students will be able to identify and evaluate the resources needed for the green transition, develop models for the optimal location of projects, and interpret national and European energy policies. The theoretical analysis can be complemented by a practical application in the field, in which students assess on-site access to critical metals mines, potential conflicts, public perception, and acceptability from the community.

4 Conclusions

These projects will benefit from coordinated support from the Commission, Member States, and financial institutions to become operational, particularly in terms of access to financing and support for establishing links with relevant off-takers. They will also benefit from streamlined authorization provisions to ensure predictability for project promoters, while protecting environmental, social, and governance standards. However, implementation faces several obstacles, including a lack of funding, public opposition to mining, and recycling constraints. In addition, we emphasize that sustainable economic development comes from processing these resources and manufacturing value-added products, not just from exploiting and selling them. At the same time, public perception of projects is marked by low trust in authorities and investors, as well as a genuine concern for protecting local interests and the environment. Without a transparent and participatory effort on the part of companies and the state (Peck & Sinding, 2009), projects risk facing social resistance, even if, at the declarative level, they align with the strategic objectives of the European Union.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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An Analysis Of Skill Profiles Across Energy-Sector Occupations

Martijn Rietbergen[a]

[a] Center of Expertise Smart Sustainable Cities, University of Applied Science Utrecht, The Netherlands

Abstract

There is a pressing need to align energy curricula in vocational and higher education to the challenges of the energy transition. Therefore, this paper aims at drafting up to date skills profiles for jobs in the Dutch energy sector. Skills profiles were drafted by mapping (transversal) skills mentioned in job advertisements to predefined (transversal) skill categories by using ChatGPT. The key findings highlight the demand for installers, consultants, project and engineering professionals, with degrees in installation technology, environment/sustainability, mechanical or electrical Engineering preferred. The study results emphasize the significance of transversal skills like *planning and organizing*, *communicating*, *taking a proactive approach*, and *collaborating in teams and networks*. The list of most frequently mentioned sector specific skills consists mainly of *information-related skills* such as *documenting and recording information*, *analysing and evaluating information and data*, *interpreting technical documentation and diagrams*, and *testing electrical and mechanical systems or equipment*. Although the sector specific skills profiles need further refinement, the approach followed in this research has proven to be a promising way to develop skills profiles for jobs in a specific sector.

Keywords: transversal skills; skills profiles, energy sector.

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1 Introduction: Energy transition and labour market

In the Paris Agreement it was agreed to limit the temperature increase to maximum 2˚ and preferably below 1.5˚C in 2100. The European Union therefore aims at decreasing CO_2 emissions by 95% in 2050 compared to the level in 1990. These deep cuts in CO_2 emissions require an acceleration of the energy transition, amongst other by an increased renewable energy supply, the speeding up of energy renovations of existing building stock, and a further transition to the electrification of energy demand and supply systems (e.g. heating of dwellings, mobility and industrial processes). However, there are huge shortages on the labour market which slows down this urgent energy transition. Also, expertise, knowledge and skills are often lacking amongst employees to facilitate a speedy energy transition. The latter is often the result of lacking responsive curricula in Vocational Education Training institutes, including universities of applied Science.

2 Research objective

Given the above-mentioned need to update energy curricula in vocational and higher education, an analysis of skill profiles in energy-sector occupations is especially relevant. Previous efforts to map these skill sets—such as Heinonen & Rietbergen (2024), EUREC (2024), and Arcelay (2021)—have primarily provided qualitative insights into the types of skills required in the (renewable) energy sector. However, quantitative evidence on the relative importance of different skill categories remains limited. This paper therefore aims at drafting skill profiles for jobs in the Dutch energy sector by mapping the frequency of required skills, where job advertisements are used as the source of information.

3 Method

Job advertisements for the energy transition posted on INDEED website in August 2025 were used as the source for analysing the skills set, the job types, and education background (level & programme). First a selection was made to limit the available job posts to the energy sector. The following key words were used (in Dutch): energy transition, heat transition, sustainable energy, and energy installer. The Apify web scraper for INDEED [2] was used to web scrape the job title and description from the website. A python script was written to analyse the job description with ChatGPT model gpt-4.1-mini. The prompt (see attachment) assigned ChatGPT the task of analysing the job description to 1) match the advertised position with a predefined list of job types; 2) match the required education programme with a predefined list of education programmes; 3) identify and return the top seven most important technical skills from a predefined skills list; 4) identify and return the top seven most important transversal skills from a predefined skills list; 5) determine the required education level (MBO,

[2] https://apify.com/misceres/indeed-scraper

HBO, or WO); 6) check whether the job is in the energy sector; 7) assess the seniority level (Junior: < 5 years of experience; Senior: > 5 years). Job profiles were then created by making frequency tables of the 7 most important transversal and technical skills per job type.

4 Classifying skills

The ESCO skills & competences pillar, developed by the European Commission (2023), was used to classify skills required. This skills pillar contains a comprehensive list 'skills', 'transversal skills', 'knowledge' and 'language skills and knowledge' relevant to the European labour market. For this research we have used skills and transversal skills sets. Skills are "ability to apply knowledge and use know-how to complete tasks and solve problems" (EC, 2022). These skills are further categorized in 8 different skills groups (see S1 – S8 in Table 1) and 296 different skills types (see ESCO, 2021).

Table 1 - Description of sector specific skills

S1 - Communication, collaboration and creativity: Communicating, collaborating, liaising, and negotiating with other people, developing solutions to problems, creating plans or specifications for the design of objects and systems, composing text or music, performing to entertain an audience, and imparting knowledge to others.
S2 - Information skills: Collecting, storing, monitoring, and using information; Conducting studies, investigations and tests; maintaining records; managing, evaluating, processing, analysing and monitoring information and projecting outcomes.
S3 - Assisting and caring: Providing assistance, nurturing, care, service and support to people, and ensuring compliance to rules, standards, guidelines or laws.
S4 - Management skills: Managing people, activities, resources, and organisation; developing objectives and strategies, organising work activities, allocating and controlling resources and leading, motivating, recruiting and supervising people and teams.
S5 - Working with computers: Using computers and other digital tools to develop, install and maintain ICT software and infrastructure and to browse, search, filter, organise, store, retrieve, and analyse data, to collaborate and communicate with others, to create and edit new content.
S6 - Handling and moving: Sorting, arranging, moving, transforming, fabricating and cleaning goods and materials by hand or using handheld tools and equipment. Tending plants, crops and animals.
S7 – Constructing: Building, repairing, installing and finishing interior and exterior structures.
S8 - Working with machinery and specialised equipment: Controlling, operating and monitoring vehicles, stationary and mobile machinery and precision instrumentation and equipment.

Source: ESCO (2023)

Transversal skills are "learned and proven abilities which are commonly seen as necessary or valuable for effective action in virtually any kind of work, learning or life activity. They are "transversal" because they are not exclusively related to any particular context (job,

occupation, academic discipline, occupational sector, group of occupational sectors, etc.)" (EC, 2022). The transversal skills are further narrowed down in 6 categories (see T1 – T6 in Table 2) and 24 subcategories.

Table 2 - Description of transversal skills and competencies

T1: Core skills and competences: representing the foundation for interacting with others and for developing and learning as an individual. They comprise the ability to understand, speak, read and write language(s), to work with numbers and measures and to use digital devices and applications.
T2: Thinking skills and competences: relating to the ability to apply the mental processes of gathering, conceptualizing, analysing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication. They include the ability to evaluate and use information of different kinds to plan activities, achieve goals, solve problems, deal with issues and perform complex tasks in routine and novel ways.
T3: Self management skills and competences: requiring individuals to understand and control their own capabilities and limitations and use this self-awareness to manage activities in a variety of contexts. They include the ability to act reflectively and responsibly, to accept feedback, adapting to change and to seek opportunities for personal and professional development.
T4: Social communication skills and competences: relating to the ability to interact positively and productively with others. This is demonstrated by communicating ideas effectively and empathetically, coordinating one's own objectives and actions with those of others and acting in ways which are structured according to values, ensuring the well-being and progress of others, and offering leadership.
T5: Physical and manual skills and competences: relating to the ability to perform tasks and activities requiring manual dexterity, agility and/or bodily strength. These tasks and activities may be carried out by hand, with other direct physical intervention, or by using equipment, tools or technology (such as ICT devices, machinery, craft or musical instruments) which requires guidance, movement or force.
T6: Life skills and competences: relating to the ability to process and use knowledge and information which has transversal significance and facilitates active citizenship. They comprise the areas of health, environment, civic engagement, culture, finance and the application of general knowledge.

Source: ESCO (2023)

5 Results

5.1 Job types, education level and programmes

The Web scraping of job postings on Indeed identified 1298 open positions in the (sustainable) energy sector in August 2025. First, we will present in Figure 1 the 7 most frequently listed job types. The largest group consists of installers and mechanics/service technicians (24%), who are responsible for installing and maintaining energy-related equipment. They are followed by advisors and consultants (14%), who guide clients on

improving energy efficiency and increasing the adoption of renewable energy. Project leaders and coordinators (13%) manage the design, planning, and successful delivery of energy projects, with responsibilities and project scope varying by experience. Engineering professionals, technical designers, and specialists (12%) focus on conceptual and detailed technical design as well as feasibility assessments based on client specifications. The remaining positions fall into smaller categories (Work planner, Business Developer, Manager) or an "other" category, which includes policy makers, planners, commercial staff, cost estimators, and interns. Next, in Figure 2 the required education level mentioned in the job descriptions are shown. Over 50% of the jobs require either a lower (MBO) or higher (HBO) vocational education degree. About 34% demand at least a higher vocational (HBO) or university (WO) degree. The remaining vacancies specifically call for a lower VET (2%), higher VET (7%), or university degree (5%). As a third step, we identified the preferred educational backgrounds for the open positions. The most frequently cited fields are Installation Technology (19%), Environment/Sustainability (15%), Mechanical Engineering (14%), and Electrical Engineering (12%). In 18% of cases, any technical degree is considered sufficient.

Fig. 1 - Job types

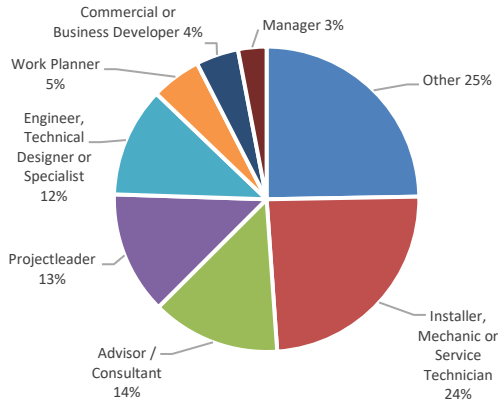
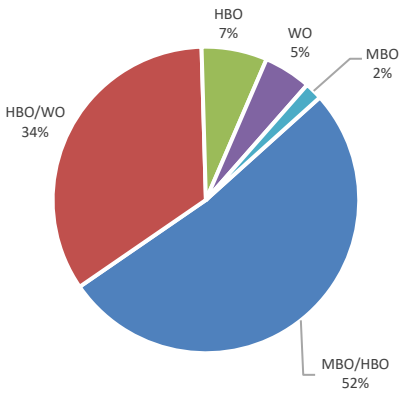


Fig. 2 - Required education levels



5.2 Transversal Skills

Table 3 lists, on the left, the most frequently mentioned transversal skills across all analysed jobs and breaks down the results for the four most common job types. The following sub-categories rank among the top seven most valued in the job postings: T2.2 - planning and organizing, T4.1 – communicating, T3.2 - taking a proactive approach, T4.3 - collaborating in teams and networks, T2.3 - dealing with problems, T3.4 - demonstrating willingness to learn, and T1.1 - mastering language. The greyed-out skills are among the top 7 of the grand total of the transversal skills. Notably, the results for the four most common job types show little variation: the top seven skills are nearly identical, though their order of importance differs slightly. This similarity is unsurprising, as these transversal skills are not tied to any specific context.

Table 3 - (Transversal) Skills profiles per job type*

Grand Total - Transversal Skills	**9086**	**Grand Total - Sector specifc skills**	**8659**
T2.2 - planning and organising	14%	S2.2.0 - documenting and recording information	9%
T4.1 - communicating	13%	S2.7.0 - analysing and evaluating information and data	7%
T3.2 - taking a proactive approach	12%	S2.1.3 - interpreting technical documentation and diagrams	6%
T4.3 - collaborating in teams and networks	11%	S2.8.1 - testing electrical and mechanical systems or equipment	6%
T2.3 - dealing with problems	9%	S2.9.0 - monitoring developments in area of expertise	6%
T3.4 - demonstrating willingness to learn	8%	S2.2.3 - preparing documentation for contracts, applications, or permits	5%
T1.1 - mastering language	6%	S2.2.5 - maintaining operational records	5%
Installer, Mechanic or Service Technician	**2135**	**Installer, Mechanic or Service Technician**	**1771**
T2.2 - planning and organising	14%	S2.8.1 - testing electrical and mechanical systems or equipment	12%
T4.1 - communicating	12%	S2.1.3 - interpreting technical documentation and diagrams	10%
T3.4 - demonstrating willingness to learn	11%	S6.7.0 - using hand tools	9%
T3.2 - taking a proactive approach	11%	S2.2.5 - maintaining operational records	8%
T2.3 - dealing with problems	11%	S6.0.0 - handling and moving	8%
T4.3 - collaborating in teams and networks	10%	S2.2.0 - documenting and recording information	8%
T3.3 - maintaining positive attitude	9%	S6.2.4 - positioning materials, tools or equipment	5%
Advisor / Consultant	**1204**	**Advisor / Consultant**	**1157**
T2.2 - planning and organising	14%	S2.7.0 - analysing and evaluating information and data	12%
T4.1 - communicating	14%	S2.2.0 - documenting and recording information	10%
T3.2 - taking a proactive approach	13%	S2.9.0 - monitoring developments in area of expertise	9%
T4.3 - collaborating in teams and networks	11%	S2.2.3 - preparing documentation for contracts, applications, or permits	8%
T2.3 - dealing with problems	8%	S2.7.5 - performing risk analysis and management	7%
T3.4 - demonstrating willingness to learn	8%	S2.4.1 - gathering information from physical or electronic sources	6%
T1.1 - mastering language	7%	S2.4 - processing information	5%
Projectleader	**1148**	**Projectleader**	**1085**
T2.2 - planning and organising	14%	S2.2.0 - documenting and recording information	10%
T4.1 - communicating	14%	S2.7.0 - analysing and evaluating information and data	9%
T3.2 - taking a proactive approach	13%	S2.2.3 - preparing documentation for contracts, applications, or permits	9%
T4.3 - collaborating in teams and networks	11%	S2.7.5 - performing risk analysis and management	7%
T2.3 - dealing with problems	10%	S2.9.0 - monitoring developments in area of expertise	6%
T4.4 - leading others	9%	S2.2.5 - maintaining operational records	5%
T3.4 - demonstrating willingness to learn	5%	S2.8.2 - monitoring operational activities	5%
Engineer, Technical Designer or Specialist	**1029**	**Engineer, Technical Designer or Specialist**	**987**
T2.2 - planning and organising	14%	S2.1.3 - interpreting technical documentation and diagrams	11%
T4.1 - communicating	14%	S2.8.1 - testing electrical and mechanical systems or equipment	11%
T4.3 - collaborating in teams and networks	11%	S2.2.6 - documenting technical designs, procedures, problems or activities	10%
T3.2 - taking a proactive approach	11%	S2.9.0 - monitoring developments in area of expertise	8%
T3.4 - demonstrating willingness to learn	9%	S2.2.0 - documenting and recording information	8%
T2.3 - dealing with problems	9%	S2.7.0 - analysing and evaluating information and data	8%
T1.3 - working with digital devices and software	5%	S2.7.5 - performing risk analysis and management	4%

* The greyed-out skills are among the top 7 of the grand total.

5.3 Sector specific skills

Table 1 also lists, on the right, the most frequently mentioned sector specific skills across all analysed jobs and breaks down the results for the four most common job types. The following sub-categories rank among the top seven most valued in the job postings (Grand Total): S2.2.0 - documenting and recording information; S2.7.0 - analysing and evaluating information and data; S2.1.3 - interpreting technical documentation and diagrams; S2.8.1 - testing electrical and mechanical systems or equipment; S2.9.0 - monitoring developments in area of expertise; S2.2.3 - preparing documentation for contracts, applications, or permits; S2.2.3 - maintaining operational records. Notably, all top seven skills fall under the S2 "Information Skills" category. The skills profiles of the four most common job types are obviously dominated by the top 7 skills in the grand total (greyed out skills) but also show a

more varied picture with the "Installer profile" the only one that also includes skills from the S6 "Handling and Moving" category. It is a bit striking that neither S1 – 'Communication, collaboration and creativity' nor S4 – 'Management skills' are ranked among the top 7 skills.

6 Discussion

This paper aimed to draft skill profiles for jobs in the Dutch energy sector by using ChatGPT to map (transversal) skills mentioned in job advertisements to predefined (transversal) skill categories. While the model produced fairly obvious skill profiles, the results should be interpreted with caution.

We repeated the analysis multiple times with *gpt-4.1-mini* to test the robustness of the model and obtained consistent outcomes. So far, the good news. Earlier runs of the python script with the older *gpt-3.5* model did not produce satisfactory results; for example, it prioritized skills (in the S1 – S8 categories) that did not appear in the actual job descriptions. To improve quality, we adapted the prompt to include text evidence from the job descriptions, which helped, but mismatches between the extracted text evidence and the assigned skill categories (S1–S8) remain. For obtaining better results in the future, it is recommended to use the full *GPT-4.1* or *GPT-5* models.

Another way to improve the quality of the outcome is to adopt a classification scheme specifically focused on energy-related skills, which could more accurately categorize the skills in job postings. In this analysis we used the ESCO skills classification to draft skill profiles for each job type. Although ESCO lists 296 distinct skills in 8 categories (S1 – S8), their descriptions are relatively short, sometimes overlapping and not specifically tailored to the energy sector. This may clarify the earlier reported mismatch between the skills categories and the provided text evidence.

Although the matching process of job advertisement and the skills categories (S1 – S8 or an alternative scheme) needs refinement, it must be mentioned that the quality of the matching of the transversal skills mentioned in the job advertisement and the transversal skills categories (T1 – T6, see Table 2) is actually quite good. A review of the text evidence and the matched transversal skill categories confirms this strong correspondence.

Finally, we based our skill profiles on job descriptions under the assumption that they provide a comprehensive view of required skills. It is however possible that these descriptions emphasize skills employers often find lacking among current employees, rather than those that are complete, and inherently critical for the role. Therefore, also here the results should be interpreted with caution.

7 Conclusions

The aim of this research was to draft skill profiles for different job categories in the Dutch energy sector. The largest group of jobs consists of installers and mechanics/service technicians (24%), followed by advisors and consultants (14%), Project leaders and coordinators (13%), and Engineering professionals, technical designers, and specialists (12%). Half of the jobs require either a lower or higher vocational education degree. About one third demand at least a higher vocational or university degree. The most frequently educational backgrounds are Installation Technology (19%), Environment/Sustainability (15%), Mechanical Engineering (14%), and Electrical Engineering (12%).

The primary added value of this research is the more quantitative insight in the importance of specific skills required for jobs in the energy sector. The most frequently mentioned transversal skills (T1-T6) are *planning and organizing*, *communicating*, *taking a proactive approach*, and *collaborating in teams and networks*. This part of the analysis delivered fairly robust results. The list of most frequently mentioned sector specific skills (S1-S8) consists mainly of *information-related skills* such as *documenting and recording information*, *analysing and evaluating information and data*, *interpreting technical documentation and diagrams*, and *testing electrical and mechanical systems or equipment*. Although the sector specific skills profile, looks quite obvious the validity of the analysis is less clear, due to limitation in the model. To achieve more reliable results that can be used for curriculum development, categorization of skill descriptions—and the underlying LLM prompting and model needs further refinement. Nevertheless, the followed research approach has proven to be a promising way to develop skills profiles for jobs in a specific sector.

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The author used ChatGPT to assist in improving the clarity and grammar of the text. The content, ideas, and conclusions are solely those of the author.

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Attachment 1: Prompt

Analyze this job description:
1. Best matching Position. Choose exactly one value from this list (do NOT invent other positions): {positions_str}
2. Best matching EducationPrograms. Choose all relevant values from this list (do NOT invent others):
- Select between 1 and 3 programs that best match the job description.
- Return them as a list.
3. Top {TOP_N_SKILLS} Technical skills from: {skills_str}.
- IMPORTANT: Always return ONLY the exact skill CODE (e.g., "S63") in the "skill" field.
- For each selected skill, provide **text evidence** from the job description (1–2 sentences) in the "explanation" field.
- Select exactly {TOP_N_SKILLS} codes, do not invent others.
4. Top {TOP_N_TRANS_SKILLS} Transversal skills from: {trans_skills_str}.
- IMPORTANT: Always return ONLY the exact skill CODE (e.g., "T2.2") in the "skill" field.
- For each selected skill, provide **text evidence** from the job description in the "explanation" field.
- Select exactly {TOP_N_TRANS_SKILLS} codes, do not invent others.
5. Determine the required education level. Choose from:
- MBO
- HBO
- WO (can also appear as master or academisch)
- If MBO or HBO is appropriate, return "MBO_HBO"
- If HBO or WO is appropriate, return "HBO_WO"
- If unclear, return "NOT_CLEAR"
- Also provide a confidence score between 0 and 1.
6. Is this job in the energy sector? Answer with "Yes" or "No".
7. Determine the seniority level:
- "Junior" if suitable for <5 years experience
- "Senior" if suitable for >5 years experience
- If unclear, return "NOT_CLEAR"

Campus Living Lab: An Underutilised Educational Tool?

Connor McGookin[a], Derek Gladwin[a] and Naoko Ellis[a]

[a] Systems Beings Lab, The University of British Columbia, Canada

Abstract

Campus as a living lab has emerged as a collaborative framework to advance sustainability challenges on university campuses. This paper provides a summary of the Campus Living Lab operated through the University of British Columbia's Sustainability Office. It documents two flagship projects and offers reflections on how they contribute to the university's objectives across operations, education, and research. It further demonstrates the impact such projects can have on key goals such as reducing the campus's carbon footprint. Although there are challenges associated with working in diverse teams that bring together partners from inside and outside the university, Campus Living Lab can offer low risk, high reward outcomes for research. We highlight it as an underutilised educational resource as there has been limited engagement with teaching and learning programmes. To this end, we outline a variety of ways that education could be enriched through more active involvement with the Campus Living Lab.

Keywords: campus living Lab; experiential learning; postgraduate training; project-based learning.

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1 Introduction

Over the past twenty years, Campus Living Labs (CLLs) have emerged as a powerful approach for bridging research, education, and campus operations (Cooper and Gorman, 2018; Stuckrath, Rosales-Carreón, and Worrell, 2025). Rooted in the idea of using the university itself as a testbed, living labs transform campuses into dynamic spaces where students, faculty, staff, and community partners can experiment with real-world solutions. Early initiatives in the mid-2000s were often tied to sustainability and energy efficiency, particularly within the realm of building operations often quite separate from research or educational aspects of the university, as institutions sought to reduce their own environmental footprint while enriching experiential learning. Today, CLLs are recognised not only as drivers of sustainability transitions, but also as models of collaborative governance that promote inter/trans-disciplinary problem-solving through community engagement (Galway et al., 2021; Mahmoud et al., 2021). They reflect a shift in higher education toward action-oriented research and hands-on learning, demonstrating how campuses can serve as exemplars for addressing some of society's most pressing challenges.

Historically, universities have been split into business units responsible for education, research, and operations. This division of responsibilities can hinder collaboration when pursuing complex challenges like reducing the campus's carbon footprint. Living labs provide an opportunity to increase collaboration within universities (Cooper & Gorman, 2018), while building relationships with outside partners (Evans et al., 2015).

Factors that contribute to universities being suitable places for exploring climate solutions include independent management of their utility networks, management of a multi-use built environment (including retail, catering, leisure, conferencing, offices, residential and laboratory facilities) and a significant and diverse community of staff and students who live and work within the university campus (Robinson et al., 2022). The campus thus represents a small town or quasi-municipality, providing a scaled-down version of society (Stuckrath, Rosales-Carreón et al., 2025).

Recent studies highlight the challenges associated with living labs and how success is measured. From a series of interviews with living lab projects at the University of Utrecht, Stuckrath et al. (2025) highlight three dimensions to perceived success in CLLs: sustainability outcomes, scaling pathways, and process outcomes. Although many of the participants report that their original targets were not fully met, they still perceived their efforts as successful because they were making progress towards vital sustainability goals. In their review of six living lab projects, Herth et al. (2025) note several challenges related to how living labs are set-up, issues with administration, coordination and governance, and the tensions between academic and operational processes. While Van Der Wee et al. (2024)

outline challenges associated with institutional norms, policies and practices, as well as the differing perspectives of those involved that must be navigated when teaching and learning in living labs.

Using the Campus Living Lab at the University of British Columbia as a case study, this paper explores the contribution of such initiatives to energy education across the campus's operations, teaching, and research. It provides insights on the impact of CLL projects as well as reflecting on opportunities for further expansion. There are two central research questions:

- How does CLL support energy education?
- How could it be better utilised within and outside the university?

2 Case Study: The University of British Columbia

2.1 Campus Living Lab at the University of British Columbia

The University of British Columbia (UBC), located on the traditional, ancestral, and unceded lands of the xʷməθkʷəy̓əm (Musqueam) peoples, offers a compelling example of a CLL as it meets all the factors of success outlined by (Robinson et al., 2022). Uniquely placed outside the City of Vancouver jurisdiction, as an unincorporated area, UBC Vancouver has a Board of Governors, who perform many of the functions of a municipal government with regards governance, land management, and public services. The UBC main campus and South Campus provide housing for around 30,000 residents (both students and staff as well as other residents), operate district heating and electricity networks within the main campus, and are responsible for their own land management planning.

UBC's CLL provides a collaborative framework for faculty, staff, students, and partners to address urgent global sustainability challenges, grounded in the local contexts and conditions of the university's campuses. The concept, which was initiated in the mid-2000s, originated from an understanding that as a public university, UBC has a dual responsibility to (UBC Sustainability Hub, 2024):

- Explore and advance the various dimensions of sustainability through interdisciplinary research, teaching, and learning;
- Exemplify sustainable innovation and best practices in its operations and related activities both on and off campus.

There are two different streams to CLL within UBC: large capital projects for housing and district energy; and support for research through the CLL Fund Competition. Since 2020, the UBC Vancouver CLL Fund Competition has supported sixteen projects across more than ten academic departments and fifteen operational units (Campus as a Living Lab UBC, 2025). The projects span a diverse set of topics that have included: bioenergy, disaster response, forest

fire detection, a community food hub, e-waste recycling, insect tracking, and wastewater treatment (Campus as a Living Lab UBC, 2024).

3 Campus Living Lab Energy Projects at UBC

Heating and operating buildings account for approximately 97% of UBC total campus operations emissions, and the vast majority of these come from burning natural gas (86%) (Campus and Community Planning UBC, 2021). The Academic District Energy System (ADES) is the main source of heat to campus buildings via a network of hot water pipes. Heat for the ADES is provided by biomass and natural gas. With the goal to reduce operational emissions by 85% by 2030 compared to 2007 levels, the UBC Climate Action Plan 2030 commits to using 100% low carbon fuels within the ADES by 2030 (Campus and Community Planning UBC, 2021).

3.1 Building the Bioenergy Research Demonstration Facility (BRDF)

A significant capital project undertaken through CLL at UBC was the decision to install a biomass gasifier that would reduce the amount of natural gas used for the campus district heating system. The switch from natural gas to biomass for heating was motivated by the provincial carbon tax (increasing annually since 2008) and university's commitment to reduce its operational GHG emissions (Campus and Community Planning UBC, 2021). A local gasifier provider, Nexterra Energy Systems, provided the biomass gasifier, acquired through substantial funding both from Federal and Provincial governments, and the university. A multidisciplinary research team including faculty, staff, student researchers, and volunteers was formed to deal with both technical aspects (e.g., efficiency of certain types of biomass in the gasifier, impurities in the produced gas, etc.) and social aspects (e.g., disruption from having two large trucks entering the campus to deliver biomass daily, local air quality concerns, etc.).

The original operation started in 2012 and involved a 6MW gasification system that converted wood waste into renewable syngas. After the addition of a grate-fired boiler in 2021, the facility now produces 20 MW of thermal energy from biomass (Campus as a Living Lab UBC, 2022). The expanded facility can meet 100% of the UBC campus's heating and hot water needs for 8-9 months of the year. It also houses an onsite research lab, the Biorefining Research and Innovation Centre, which examines bioenergy, biofuels, and bioproduct development.

Through the BRDF, UBC has shown leadership in the decarbonisation of energy systems, provided a valuable demonstration project for research on biomass systems, and facilitated cross-departmental collaboration across operations, education, and research.

3.2 An ongoing educational resource: Bioenergy from Commercial-Municipal Organic Waste

Stemming from the operation of the BRDF, this project aims to demonstrate that the organic waste from green bins can be used as a biomass energy source to heat the campus – a potential outcome that could significantly help UBC meet its emission reduction goals. UBC and the adjacent municipalities currently collect approximately 1,300 and 50,000 tonnes per year of organic waste, respectively (Campus as a Living Lab UBC, 2023). Much of UBC's and all of the City of Vancouver's organic waste is transported out of the municipality for disposal, leading to a significant transportation carbon footprint. Moreover, although the waste is composted and thus diverted from landfill initially, it is rarely utilised as such since synthetic fertiliser is preferred, and then most of it ends up buried in the ground either through landfill cover or soil remediation (McGookin et al., 2025). The BRDF currently requires up to 25,000tonnes of biomass each year and will need to find a reliable source of local biomass to continue to meet this demand (Campus as a Living Lab UBC, 2023).

A multi-disciplinary team of UBC researchers, BRDF operations, and a composting company was established to oversee the project. The waste treatment plant provides composted organic waste, which is tested by the UBC team to assess its energy potential. It is expected that composting organic waste will help to increase the calorific value of the fuel, and also reduce the concentration of nitrogen in the fuel, which would produce harmful emissions when burnt (McGookin et al., 2025). In addition to the lab testing, trial runs will also be done at the BRDF for hydraulic system testing, to understand how well the fuel burns, and what pollutants it produces.

This project again demonstrates leadership on a critical sustainability issue. Through CLL, UBC is highlighting new ways to source renewable biomass fuels while training postgraduate students in real-world sustainability challenges and addressing campus operation needs to close the loop on organic waste on campus and source biomass for heating.

4 Discussion

4.1 How has CLL supported energy literacy on campus?

Energy is vital to our modern way of life and tangled in almost everything we do. Widespread understanding of the impacts of our current energy system on the environment, and what can be done to mitigate them, is an essential enabling factor in the transformation of our energy system away from fossil fuels. However, despite the noted importance of energy literacy, it has not received as much attention as climate education or literacy (Ramachandran, Ellis, and Gladwin 2024). The energy literacy framework from Gladwin and Ellis (2023) provides three dimensions of energy literacy to consider: *knowing* (epistemology

– what energy is), *being or existing* (ontology – what energy is about), and *doing or applying* (application – what energy does).

Students living adjacent to the BRDF are exposed to the smell of the biomass, making them acutely aware of the energy source used to provide their heating. Other neighbourhood communities have also been engaged with the development of the biomass gasifier unit through air quality monitoring and other social aspects of the operation. This has led to the discussion of how the South Campus neighbourhood that operates its own district energy system could reduce greenhouse gas emissions from heating. Understanding the technology, seeing it operates, and connecting to how they feel when experiencing it, has allowed residents to engage in meaningful discussions around their future energy decisions. The BRDF has created an opportunity to connect lived experiences of *being* with technical and social knowledge and awareness of *knowing* and *doing,* highlighting holistic forms of energy education that engage people across a wide spectrum of experiences.

A primary motivator of these projects was to be a leader in the adoption of an innovative technology to reduce greenhouse gas emissions associated with campus operations. As documented (Pajouhesh, 2016), the campus has provided an opportunity to implement and test many innovative technologies at a local, neighbourhood scale, contributing to the notion of campus as a societal testbed, and fostering a culture of innovation and risk tolerance. Campus as a living lab projects can help to advance technology readiness levels and cultivate a spirit of experimentation and demonstration (Save, 2014), particularly through educating what energy is and what energy is about, not only its more apparent aim of what energy does.

4.2 Opportunities of CLL as an educational resource

It is reported that more than 1,000 people tour the biomass facility each year to learn about the technology, the building, and how this unique facility supports campus life (Campus as a Living Lab UBC, 2022). Considering that the student population of the campus is around 70,000 this represents only a small fraction of it. The facility could be better integrated into curriculums with lab projects or site visits forming part of coursework. Similarly, Herth et al. (2025) conclude that CLLs are not achieving their full potential, as none of the six cases they reviewed within their university were included in education and curricula. Educational opportunities extend beyond traditional forms on campus, moving into life-long learning opportunities for the public. These might include tours of the facility, along with QR code engagement on the external facade of the building. They could also involve UBC public relations teams highlighting the unique aspect of UBC CLL's in Strategic Plan documents and as a central achievement on websites and promotional literature.

There is also opportunity for further educational engagement with outside groups, as municipalities across the Lower Mainland become increasingly interested in district heating

as a replacement for natural gas heating within urban areas. UBC CLL projects could serve as models or pilot projects for others to take on and develop further. As the provincial carbon tax was first of its kind in North America when started in 2008, the driver for establishing the biomass gasifier was included as a success story among many courses covering GHG emissions reduction, carbon management, and policy. A strong case was made to support clean energy innovation on campus supported by the policy of the day as UBC walking the talk. The BRDF has been a signature project producing many reports and storyboards (UBC Sustainability 2018a, 2018c, 2018b, 2023).

Emancipatory pedagogies acknowledge the complexity, uncertainty and ambiguity of sustainability challenges and generate space for reflexivity and choice, empowering the student to take ownership of the project (Tassone et al., 2022; Van Der Wee et al., 2024). CLL as a place for experimentation can help to foster inter/trans-disciplinary practices (Fam et al., 2019; Popović, Bossert, and Bronner 2020). There have been 8 peer reviewed papers, 4 graduate theses, 8 undergraduate student projects and at least 16 reports concerning the BRDF as of 2019 (Johnson, 2019). Two PhD students and two master's students have conducted the majority of their dissertation research at the BRDF (Ibid). An interesting example of how further integration between student projects and CLL can be facilitated is the case of the Living Lab team in the University of Manchester, who regularly communicate with course leaders to understand the subject focus, research requirements, and deadlines of specific programmes. Acting as a liaison between different departments such as Estates and Procurement and prospective projects to identify current and mutually beneficial research opportunities (Evans et al., 2015).

5 Conclusion

The case study presented in this paper has demonstrated that CLL can have great impact on operational sustainability goals like climate action while also providing a valuable educational resource. There are, of course, always added complications when working with real-world problems and collaborating in diverse teams. CLL is not immune to failure and challenges such as tensions between the needs of students and operations or other partners, the desire for impact as well as non-academic outputs placing extra burden on students, uncertainty and risks associated with innovative, new technologies. However, it is this very fact that makes CLL such a valuable educational opportunity. Embracing failure is an important part of reflective practice, which will help students to grow. This is why they offer low risk, high reward engagements with large-scale projects that have the potential to vastly improve sustainable infrastructures. Navigating the challenges associated with working inter/trans-disciplinary and on real-world problems will provide important lessons for the students and better prepare them for the working environment.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Applying The Energy Literacy Framework In A Transdisciplinary Doctoral Programme

Connor McGookin[a], Derek Gladwin[a] and Naoko Ellis[a]

[a] Systems Beings Lab, The University of British Columbia, Canada

Abstract

Energy is vital to our modern way of life and tangled in almost everything we do. Despite the noted importance of energy, literacy about it has not received as much attention as climate or ecological literacy. This paper applied an energy literacy framework with a transdisciplinary PhD cohort. The students come from a diversity of technical and non-technical backgrounds, some with experience in the mining sector and others with very limited experience with energy topics. Through a workshop intervention the students were introduced to the energy literacy framework and then applied it through a series of exercises. The reflections on this process provide insights into the complexity and interconnectedness of energy issues, importance of language, and how our experiences shape the context within which we view the energy system.

Keywords: energy literacy; energy education; postgraduate training.

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1 Introduction

Energy literacy involves understanding energy supply and systems, as well as how they function within society and culture (McCaffrey, 2014). It also emphasizes developing knowledge that helps us think about energy in relation to society and our place within it (Szeman and Boyer, 2017). Because energy fundamentally shapes the world around us, energy literacy expands not only what we *know* but also how we *think* about energy, guiding us through an unpredictable energy transition (Smil, 2016).

This transition involves moving away from fossil fuels—oil, gas, and coal—and the injustices tied to them, toward renewable and equitable forms of energy that also envision reducing overall consumption. While technology and capability are important, moving toward fossil fuel free future is not limited as only a technical issue, but more of an educational opportunity to guide and sustain these transitions (Ramachandran, Ellis, and Gladwin, 2024; Sovacool, 2019).

In this study, we approach energy literacy through a holistic framework that integrates epistemology (knowing), ontology (being), and application (doing). Put simply: what energy is, what it means, and what it does. This framework makes it possible to translate diverse experiences and knowledges for learners, users, and actors, while also charting pathways toward sustainable energy futures (Gladwin and Ellis, 2023). As (Butler, Lerch, and Wuerthner, 2012), p. 4) remind us, "*there is no task more urgent than promoting widespread energy literacy*" to support a sustainable civilization for the future.

To explore these dimensions of energy literacy in practice, this study engages participants in a 2-hour workshop designed to connect conceptual learning with applied, collaborative activities. Following a short presentation on the energy literacy framework and an introduction to a model case study community based on a rural municipality in British Columbia (BC), Canada, participants took part in a series of guided activities. These included collaborative mapping of energy literacy concepts within a ternary diagram, and energy systems mapping exercises focused on coal and biomass. Participants then analysed a fictitious community case study, considering how different social, cultural, and institutional dynamics shape energy systems, before concluding with individual and group reflections on their learning.

Through this process, the study examines how participants engage holistically with epistemological (knowing), ontological (being), and applied (doing) dimensions of energy literacy, while generating insights into how educational approaches can better prepare learners to navigate energy transitions. Drawing on this study, we explore two research questions:

- How does the energy literacy framework facilitate participant's engagement with the epistemological, ontological, and applied dimensions of energy?
- In what ways can the energy literacy framework support learners in navigating the complexities of energy transitions toward more sustainable and equitable futures?

2 Background

2.1 Collaborative Transdisciplinary PhD Cohort in Energy Transition

Accelerating Community Energy Transformation (ACET) is a multi-partner research initiative focused on supporting small- and mid-sized communities in transitioning to clean-energy. The Collaborative Transdisciplinary PhD Cohort in Energy Transition, is funded through ACET and builds on the experience of Professors Naoko Ellis and Derek Gladwin, who previously ran the Transdisciplinary Collaborative PhD Pilot for Climate Emergency from 2021-2023. The project involves a cluster hire of four PhD students researching various aspects of energy transitions, spanning technical, socio-cultural, arts-based, economic, political, and scientific efforts to shift from fossil fuels. The students have their own individual research topics and interests related to energy but will undergo training in transdisciplinary research together as a cohort. Three out of four students come from the social sciences rather than technical backgrounds, and they have a spectrum of experience with energy from very familiar to limited experience.

2.2 Energy Literacy Framework

Energy is vital to our modern way of life and tangled in almost everything we do. However, despite the noted importance of energy literacy, it has not received as much attention as climate education or literacy (Ramachandran, Ellis, and Gladwin, 2024). The energy literacy framework from (Gladwin and Ellis, 2023) provides three dimensions of energy literacy to consider: *knowing* (epistemology – what energy is), *being or existing* (ontology – what energy is about), and *doing or applying* (application – what energy does).

When trying to understand fossil fuels, for example, we can consider how it is both material (i.e., a solid, liquid or gaseous fuel extracted from deep within the earth) and sociocultural (i.e., how we value and conceptualise it in our daily lives). Linking the *what energy is* to *what energy is about* fuses two integrated theories that both include and extend beyond the function of material energy and applications of what energy does in our lives. Oil is a resource that can be refined into petrol or diesel (*what energy is*), which are widely used transport fuels (*what energy does*), and because of its central role in our energy system, it is often at the heart of geopolitical tensions and conflicts (*what energy is about*).

3 Methods

The primary intervention that this paper reports on is a 2-hour workshop held with the four PhD students in their second week of term. The workshop was conducted online using Zoom and a Mural board was used to complete the exercises. The workshop schedule is outlined in Table 1 below. It began by introducing the energy literacy framework before moving onto several exercises to apply these learnings to energy system mapping.

Table 4 - Summary of the workshop schedule

Activity 1: Introducing the Energy Literacy Framework (20 min)	Profs. Ellis and Gladwin lead a short workshop on their energy literacy framework used in this study.
Activity 2: Mapping Energy Literacy (20 min)	Mapping of topics based on energy literacy framework. Students are asked to collaboratively work on entering topics into the ternary diagram.
Activity 3: Energy Systems Mapping (20 min)	Next, students are divided into two teams (2 students each) and asked to map out energy systems based on coal (one team) and on biomass (second team).
Activity 4: Case Study Dialogue (25 min)	Students are given one fictitious community energy case study based in BC to collaboratively analyse. Students are then given a worksheet to work on the following questions collectively. What are the primary sources of energy in the case study community? What services does energy provide? How might different beliefs or attitudes within the community shape views of the energy system?

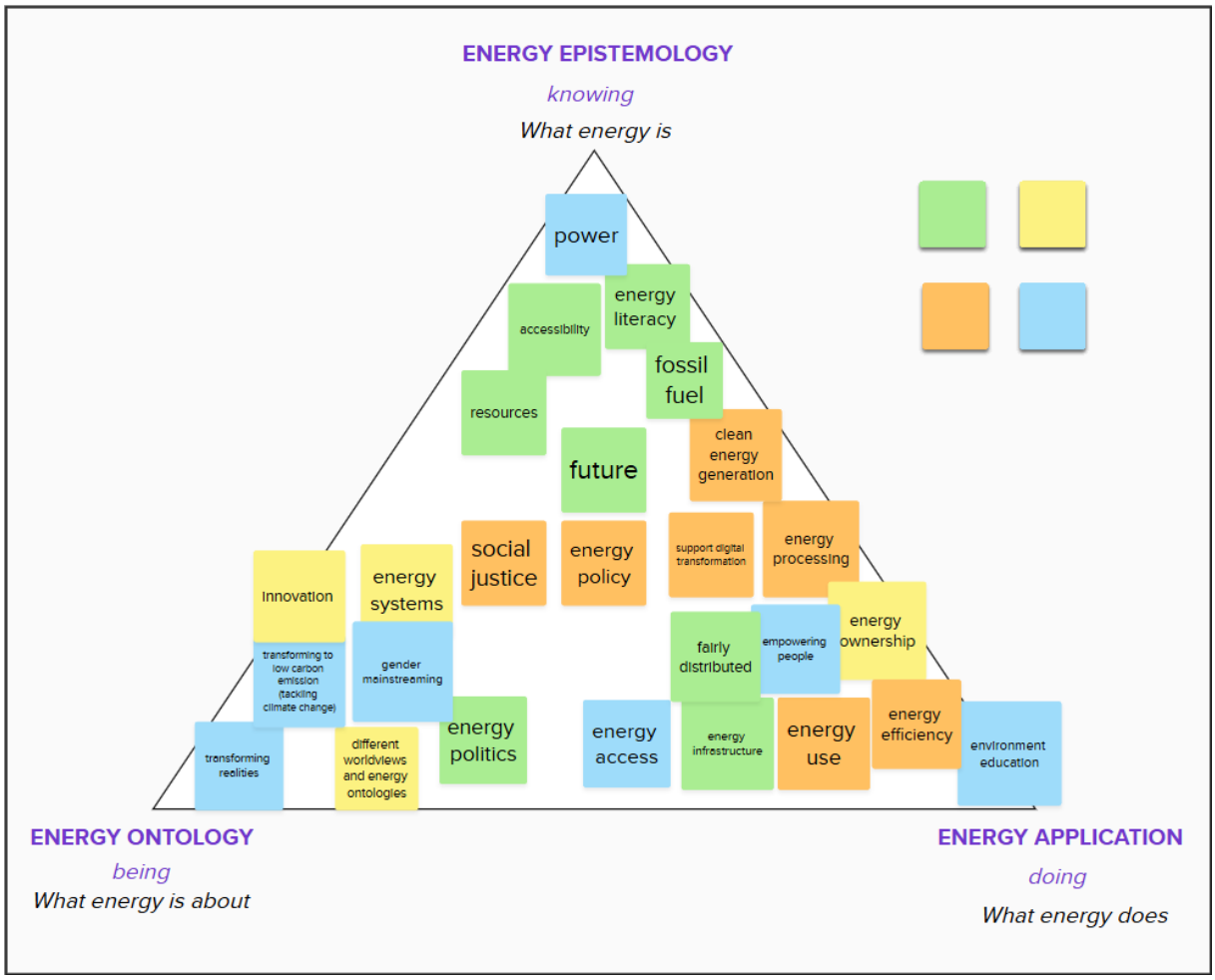
4 Results

4.1 Mapping Energy Literacy

The first exercise involved asking the students to place topics on the energy literacy triad (Figure 1). There were some elements that could be placed into one section such as power, accessibility and resources within 'What energy is', as well as many topics that sit between the different pillars. Students noted the interconnectedness of the three corners of the energy literacy framework. As we discussed topics, things would gravitate toward the middle as the conversation around where different topics should go highlighted how interconnected and overlapping the energy system is. For example, in the case of energy justice, the type of energy may determine who can access it (*what energy is*), which impacts the quality of their lives when this means going without services such as adequate heating, cooling or

refrigeration (*what energy does*), and these inequities are reinforced by our political and economic systems (*what energy is about*). There was also a comment on language, as one student noted that they would consider 'what is energy' to be ontology rather than epistemology as in the framework. We observed how this activity allowed students to engage with various topics around energy as they communicated where to place a topic in the diagram. Students wondered how this map may change if they were to repeat this exercise later in their doctoral programme.

Fig. 3 - Mapping Topics to the Energy Literacy Framework from (Gladwin and Ellis, 2023)

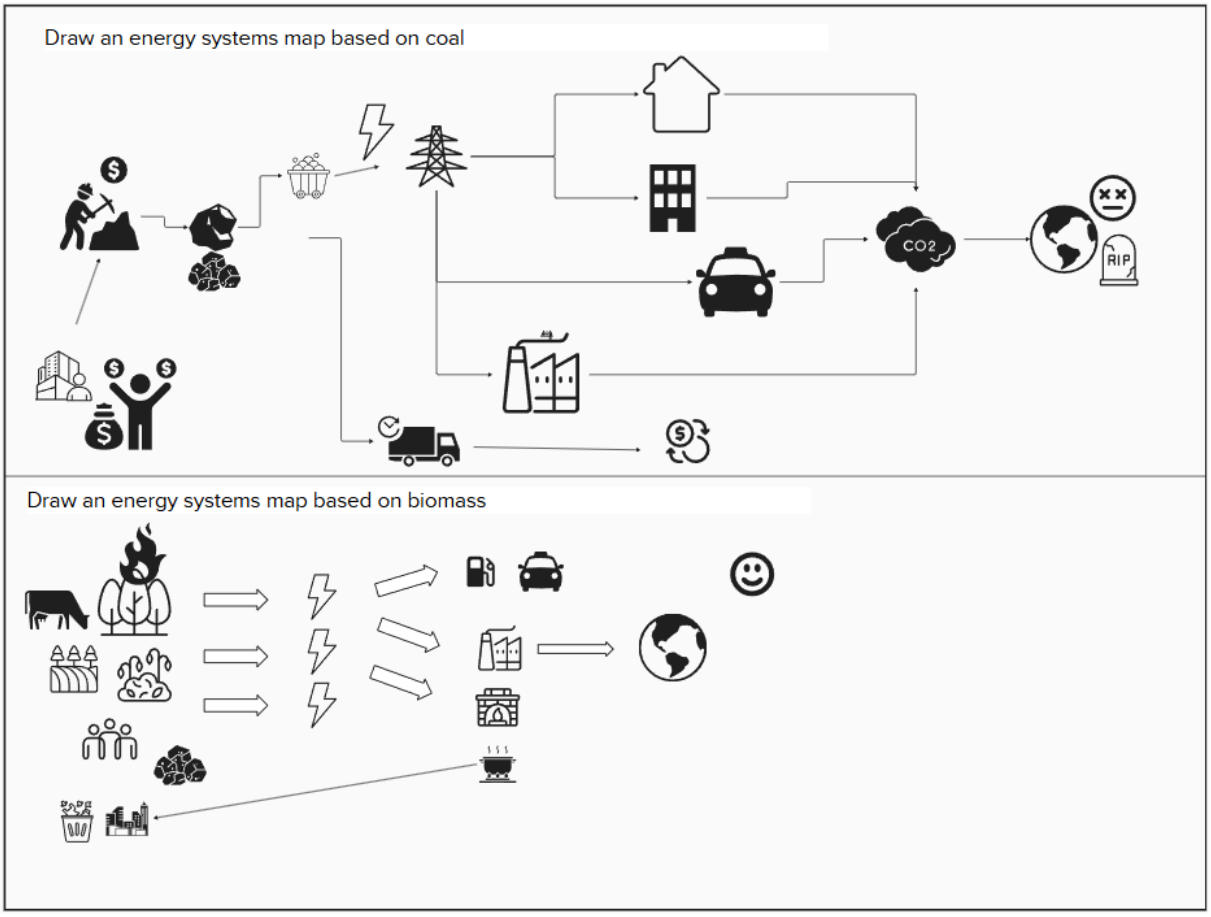


4.2 Energy System Mapping

In the second exercise the students were split into two breakout rooms and asked to draw an energy system map based on coal and biomass. This was a bit more challenging for the students than the previous exercise as it required a greater knowledge of how the energy system operates. It emerged that the students background, and in particular the context within which they had lived, shaped their ability to engage with the exercise. One student coming originally from a country in Southeast Asia was familiar with coal since electricity is

primarily generated from coal there, while another having grown up in BC was not familiar with how coal is mined and what it could be used for. The biomass group struggled to envision an energy system as none of the students had direct experience with biomass and lacked basic knowledge. Given more time, we would switch the groups to add layers to their initial systems map giving further opportunities for co-learning. The energy literacy framework can provide a structure for not only thinking around these layers, but also for observing the interconnections and layers that exist within these energy systems. Such a practice supports the development of deeper energy understanding.

Fig. 4 - An energy system map based on coal (top) and biomass (bottom)



4.3 Case Study Dialogue

Bringing together the learnings from the previous two exercises, in the third activity the students were given a summary of a rural BC community and then reflected on what energy is, what it does, and what energy is about within that case study. The municipality of Terrace was used as the case study. It is a rural community of ~13,000 people in north-west BC, known for its outdoor adventure activities and wilderness as well as being a hub for industries like forestry, mining, and LNG. The energy related CO_2 emissions in the community are 50%

higher than the provincial per capita emissions, reflecting the large amount of industrial activity in the region.

There was some confusion around the different sources of energy, and how they are used within the community, highlighting the lack of familiarity the students had with energy systems specific to the BC context. Much of the discussion revolved around understanding the graph presented and per capita emissions rather than addressing the questions posed. This perhaps reflects the difficulty of engaging with macro-energy system analysis. Once contextualised, however, the students did nonetheless develop a clearer picture of the barriers to transition present in the community. They noted the contribution of planning to car dependency and higher heating from dispersed detached housing, power of vested interests (in this case the mining sector within the community), and economic ties to the extractive industries.

5 Discussion

Reflecting on the research questions posed, there are three key insights to draw from the present paper: 1) how our experiences shape our understanding of the world around us; 2) the challenges associated with language when working in diverse teams; and 3) the need for a generative approach to energy education.

Something that was quite apparent during the discussions was the impact of previous experiences on students' perception of the energy system in BC. Coming from different countries (i.e., Italy, Canada, Brazil, and Indonesia), the students have had exposure to very different energy systems, and the cultures that power them, which shaped what they saw as primary sources of energy. Their understanding of what energy is, does, and is about was very much framed within the context of their home countries. Those from the Global South having a strong opinion on energy access, justice, and need to transition away from coal, while those from Global North were more focused on policy and implementation barriers. This speaks to the value of generative learning, encouraging students to actively generate information and make connections between new and existing knowledge.

Another area that emerged multiple times during the conversations was the importance of having a shared language and understanding. One of the students challenged the positioning of 'what energy is' as an ontology rather than how it was presented as an epistemology. There was also quite a bit of confusion around the use of gas in heating as it was purposefully referred to as simply 'gas' and not 'natural gas'. These reflections highlight the need to find common meaning as a starting point. Another aspect to note is how the energy literacy framework provides an effective way to engage with the different dimensions of the energy system, despite it being a complex subject matter. As demonstrated in the third exercise, although the students were not very familiar with technical terms/units like 'GWh' and

'tCO_{2eq}', they were still able to map a clear picture of the challenges facing the case study community.

An interesting part of the workshop was that three out of four of the students come from non-technical backgrounds and have limited experience with energy. Their backgrounds in the social and political sciences mean that they are quite familiar with topics within 'what energy is about', but less so with regards 'what energy is' and 'what energy does'. This was reflected in the discussions throughout the activities, with much of the conversation being around what different fuels are and how they support our everyday lives. Some of the students noted that the main benefit of the workshop was getting exposure to new topics and identifying gaps in current knowledge.

A potential limitation of the present study was that the workshop involved only four students. This is a rather small sample size to test the framework. However, as evidenced by the reflections here, it still provides some valuable insights on energy literacy. We find it to be an honest and intimate way to capture some of the aspects of energy literacy, which can inform a scaling up of the exercise after further refinements to the framework.

6 Conclusion

This paper provides a useful demonstration of how the energy literacy framework can support energy education. The reflections outlined around the need for a shared language and understanding one's own context in order to collaborate effectively in a group of different disciplinary backgrounds are issues that are well documented within inter/trans-disciplinary research. An important further consideration is the need for a generative approach to energy education. This perspective shifts education from a quest for definitive answers to a continuous journey of inquiry, where confronting what we don't know is as crucial as accumulating facts. Such an approach is essential for energy literacy given the complexity of the system, its ever-evolving nature, and the uncertainty around emergent technologies.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Identifying Future Needs And Skills By The Solar Sector In Greece

Paraskevi Kapetanopoulou[a], Stergios Maropoulos[a] and Stefanos Gerardis[a]

[a] Department of Mechanical Engineering, University of Western Macedonia, Greece

Abstract

In the first quarter of 2025, 42.5% of net electricity generated in the EU came from renewable energy sources. In June 2025, solar was the largest source of EU electricity for the first time, with multiple countries producing record amounts of solar power. At least 13 member states set new monthly solar records, with the Netherlands and Greece leading the way at 40.5% and 35.1%, respectively. Using a Markov Chain Grey Model the purpose of this study is to forecast the electricity mix in Greece until 2034. The analysis, which is based on the recent available yearly data covering the period 2015 - 2024, indicates a substantial transition in Greece's electricity production landscape, characterized by a gradual shift from coal towards more sustainable energy sources. The energy transition requires not only technological innovation but also a workforce that can support the transition and is capable of leading the change. Identifying educational needs in this rapidly evolving context is therefore a critical challenge.

Keywords: educational needs; Greece; electricity; Markov chain grey model.

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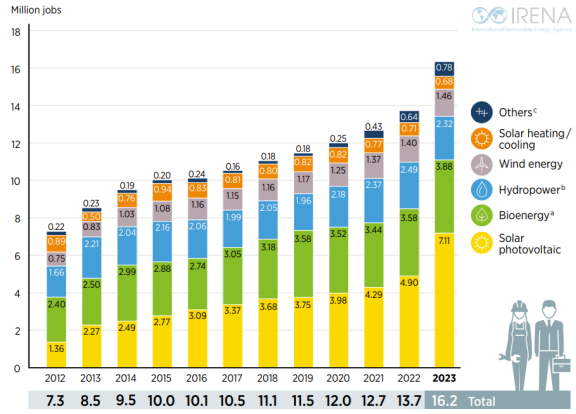
1 Introduction

In 2024, 46.9% of the electricity generated in the EU came from renewables and 22% of renewable electricity came from solar energy (Eurostat, 2025). June 2025 was the first month in history where solar energy was the main source of electricity generated in the EU at 22%. At least 13 member states set new monthly solar records, with the Netherlands and Greece leading the way at 40.5% and 35.1% respectively (Ember, 2025). For Greece, as part of the European Union (EU), forecasting the energy mix is crucial for aligning with the ambitious targets of the EU (Kapetanopoulou and Karagrigoriou,2025). The energy transition requires not only technological innovation but also a workforce that can support the transition and is capable of leading the change. Identifying educational needs in this rapidly evolving context is therefore a critical challenge (European Commission, 2024). The solar energy sector in Europe requires a diverse range of technical and digital skills, including installation, maintenance, and design (Solar Power Europe, 2022). Needs in solar energy sector have created both new opportunities and new challenges. Opportunities include new workforce potential and challenges include the skills gap in the deployment and operation of new technologies and the need for a qualified young workforce (European Commission, 2023). In its 11th edition of the 'Renewable Energy and Jobs' annual report, International Renewable Energy Agency (IRENA) highlighted that directly or indirectly, renewable energy employed (see fig.1) 16.2 million people in 2023, of which 7.1 million jobs were in the solar PV industry (International Renewable Energy Agency, 2024).

Fig. 1 - Evolution of global renewable energy employment by technology, 2012-2023



Source: International Renewable Energy Agency (2024)

Reskilling and upskilling workers are essential for the PV sector, as the needs for workers will continue to grow along with the planned manufacturing expansions as well as the planned installations in the next years (European Commission, 2025). The solar sector will need 1 million workers in Europe by 2027. To facilitate the energy transition it is urgent to mobilize the workforce with the right skills (Solar Power Europe, 2024). Especially photovoltaic technology is becoming more widely used worldwide. The workforce of the photovoltaic

sector grew by 27% to 826 000 by the end of 2023, up from 648 100 workers in 2022. This rapid growth means that Europe could see more than 1 million solar workers by 2027 (European Commission, 2024).

Although solar energy (SE) is one of the fastest-growing sectors, observations demonstrate that lack of awareness on the specific skills needed by the sector exist. Studies including Amalu et al. (2023) and Lucas et al. (2018) reported on mismatch between skills produced by the academia and the skills in-demand by the sector. Skills identification should be future-oriented as any investment in education without a clear roadmap would be rather unreliable. This research constitutes the first step in identifying future needs in electricity production, which will form the basis for organizing and identifying future needs for training programs by universities and businesses. We employ Grey Systems Theory (GST) which is intended for predictive purposes in cases with small samples and limited information (Deng, 1982; Julong, 1989). To increase forecast precision, the GM(1,1) is combined with a Markov Chain (MC). The combined Markov Chain Grey Model (MCGM (1,1)) merges the Grey forecasting approach of GM(1,1) with a Markov Chain mechanism to adjust / correct the residual errors produced by *GM*(1, 1) (He and Bao, 1992). The results of the research can be used to turn the uncertainty of future needs into a strategic advantage. The paper is organized as follows. In Section 2, the methodology section explains the Grey Model GM(1,1), including the integration of the Markov Chain to adjust residual errors. Subsequently, the results section discusses the outcomes highlighting gaps and needs for training programs. Finally in section 4 the conclusions are given.

2 Methodology

2.1 The Grey Model GM (1,1)

The GM(1,1) model is widely recognized for its ability to generate reliable short-term forecasts using a limited dataset of non-negative values. The modelling steps for GM(1,1) are as follows: First we set all actual data to the original sequence related to time, X represents the original data sequence (containing n observations) $X = (x_1, x_2, \ldots, x_n)$. Since the original sequence is generally not regular, perform a cumulative generation operation and let Y as X one cumulative sequence $Y = (y_1, y_2, \ldots, y_n)$ where:

$$y_k = \sum_{i=1}^{k} x_i \quad , k = 1,2, \ldots, n$$

Subsequently, let $Z = (z_2, z_3, \ldots, z_n)$ k=1,2,...,n the values computed as follows:

$$z_k = \frac{y_k + y_{k-1}}{2} \quad k = 1,2, \ldots, n$$

which means that z_k value is the arithmetic mean of the two neighboring data points. The exact equation of GM(1,1) is $x_k^{(0)} + \alpha z_k^{(1)} = b$ where α is the developing coefficient and b is the Grey effect. Treating the above as linear regression model the estimation of parameters $\hat{a}$ and $\hat{b}$ can be obtained by using the principles of Least Square Estimation (LSE). The cumulative values y_1 , y_2 , …, y_n can be approximated by the first-order Grey differential equation:

$$\frac{dY}{dt} + aY \quad = b$$

The solution of the above equation is called the time response function:

$$\hat{y}_k \ = \left(x_1 \ - \frac{\hat{b}}{\hat{a}}\right) e^{-\hat{a}(k-1)} + \frac{\hat{b}}{\hat{a}} \quad k = 1,2, \ldots$$

and the predicted values of X are:

$$\hat{x}_k \ = \ \hat{y}_k \ - \hat{y}_{k-1} = \left(1 - e^{\hat{a}}\right)\left(x_1 \ - \frac{\hat{b}}{\hat{a}}\right) e^{-\hat{a}(\kappa-1)} \quad k = 2, \ldots,$$

2.2 The Marcov Chain Grey Model – MCGM (1.1)

Markov Chain is a stochastic process based on the observed discrete state and empirical estimation of the transition probability. The state at the future time t_{k+1} is only associated with the state of the current time t_k, instead of with the state of the past time. The modelling steps for MCGM(1,1) are as follows: First we identify discrete states for the residual errors produced by GM(1,1). Let $\varepsilon_k = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n)$ be the series of relative errors, where:

$$\varepsilon_\kappa = \frac{\hat{x}_k \ - x_k}{x_k} \ x \ 100, \quad k = 1,2, \ldots, n$$

and ε_{min}, ε_{max} be the minimum and the maximum values of residuals, respectively. We split the range of residuals $[\varepsilon_{min}, \varepsilon_{max}]$ into q intervals of the same length. Each interval is assumed to be a state. Thus, state 1 corresponds to the interval R_1 with the lower bound equal to ε_{min} and state q corresponds to the interval Rq with the upper bound equal to ε_{max}. Each residual value is classified into the state to which it belongs and finally the sequence of residual values is converted into a sequence of states. The number of state divisions was not strictly defined, for more practical purposes three to five states are suitable (Jia et al., 2020). Then we calculate Markov probability transition matrices to understand the statistical behaviour of residuals. Assumed that $P_{ij}^{(m)}$ is an m-step transition probability qxq matrix, where i denotes the rows, j denotes the columns and m refers to the number of the steps. Each element $p_{ij}^{(m)}$

(i,j =1,2,…, q) represents the transition probability from state i to state j in m steps. For m=1 we have the one step transition probability matrix with $p_{ij}^{(1)}$ (i, j =1,2,…, q):

$$p_{ij}^{(1)} = \frac{number\ of\ transition\ from\ the\ i-th\ to\ the\ j-th\ state\ in\ m=1\ step}{occurrences\ of\ state\ i\ with\ the\ residual\ sequence}$$

Based on Markov chain transition probabilities and the error states the original residuals will be corrected. Let us assume that at the current time k the residual is in the state i, belongs to interval R_i. The adjusted residual is a value equal to a linear combination of all transition probabilities from state i to state j (including itself) and a set of representative values, say r_1, . . . , r_q, for all states involved, which are the center points of the corresponding intervals/states (Barbu et al., 2017). Then the corrected residual for m steps ahead point time k is given by:

$$\hat{\varepsilon}_k^{(m)} = p_{i1}^{(m)} r_1 + p_{i2}^{(m)} r_2 + \cdots + p_{iq}^{(m)} r_q$$

and the adjusted forecasts are:

$$\hat{\hat{x}}_{k+m} = \hat{x}_{k+m}(1 - \hat{\varepsilon}_k^{(m)}) \quad k = 1,2, \ldots, n.$$

3 Results and discussion

The data for our study were collected from the comprehensive database of "Our World in Data" (https://ourworldindata.org/), renowned for its extensive global energy statistics. "Our World in Data" dataset provided us with annual figures of electricity production across various sources in Greece, measured in terawatt-hours (TWh). Table 1 presents data on Greece's electricity production measured in terawatt-hours for the years 2015 through 2024.

Table 1 - Electricity production in terawatt-hours

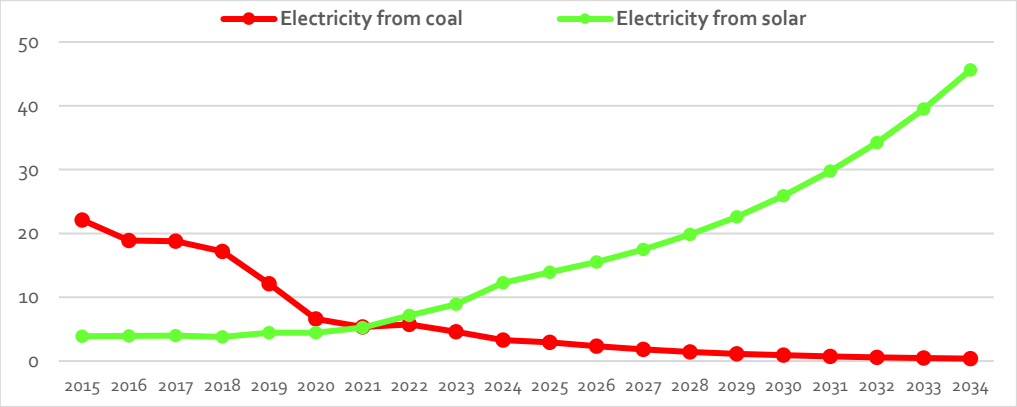
Year	Coal	Solar	Year	Coal	Solar
2015	22.11	3.9	2020	6.61	4.45
2016	18.88	3.93	2021	5.32	5.25
2017	18.76	3.99	2022	5.76	7.14
2018	17.19	3.79	2023	4.59	8.89
2019	12.12	4.43	2024	3.29	12.27

Starting from 2015, when Coal was predominant, there has been a noticeable diversification and increase in renewable energy sources (RES) over the years. Electricity production from solar started from nearly negligible amounts in 2015 but show significant growth. Table (2) and Figure (2) presents the MC*GM* (1, 1) predictions of Greece's electricity production from coal and solar in Terawatt-Hours (TWh) from 2025 to 2034.

Table 2 - Electricity production prediction in Greece (in TWh) from 2025 to 2034

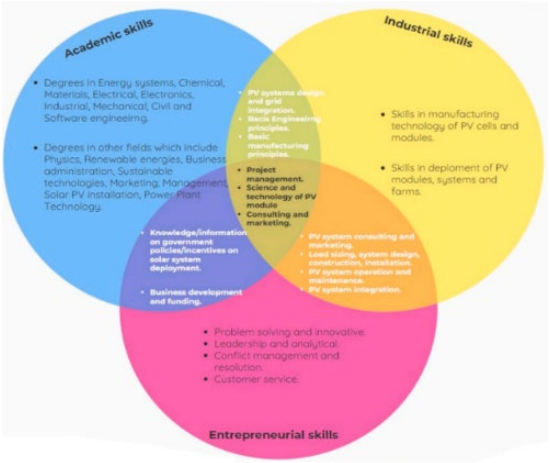
Year	Coal	Solar	Year	Coal	Solar
2025	2.94	13.91	2030	0.91	25.90
2026	2.33	15.54	2031	0.73	29.75
2027	1.82	17.49	2032	0.59	34.25
2028	1.43	19.84	2033	0.47	39.51
2029	1.14	22.62	2034	0.38	45.63

Fig. 2 - Greece's Electricity Production (in TWh) by Source



Electricity production from Solar is forecasted to grow significantly, solar is expected to more than triple (from 12.27 TWh in 2024 to 45.63 TWh in 2034). This rapid increase highlights the expanding role of solar power in Greece's energy portfolio and, as a result, the need for appropriate infrastructure (grid and storage) and specialized personnel is considered imperative. Recent studies (Cioccolanti et al., 2026; Lucas et al., 2018; Amalu et al., 2023; Middleton, 2018) identify critical skills, needs and gaps in the solar energy technology sector and result in strategies and recommendations that will improve and facilitate access to renewable energy education and training. Science and technology of photovoltaic, project management as well as marketing and consulting are common among the key skills of academic, industrial, and entrepreneurial skills. Amalu et al. (2023) list a number of institutions in four European countries with courses they offer in solar energy technology/engineering and depict the Venn diagram representation (see figure 3) of the three critical in-demand skills. Academic, industrial, and entrepreneurial skills are identified as critical solar energy systems needs.

Fig. 3 - Critical in-demand skills in the solar energy sector



Source: Amalu et al. (2023)

Universities are recognized as the key pillar of this transition and the vehicle that will be used to cover the skills gap in the solar technology sector. It is proposed to review and modernize curricula based on the needs arising from research in industry and the labour market. The knowledge and skills requirements for graduates in the energy sector strongly recommend that modernization should combine both technical/scientific and business/management knowledge to guarantee the quality of employment in a sector with an interdisciplinary nature. To this end, the modernization of undergraduate and postgraduate curricula needs to be oriented towards directions that include fields related to Science, Technology, Engineering and Mathematics (STEM), environmental engineering, financial management, renewable energy technologies, sustainable economic development and life cycle management assessment.

By Aligning educational content with the energy efficiency goals of the EU Green Deal and enriching educational programs with lectures from solar energy companies, educational visits, informative courses on relevant solar technology courses and a closer collaboration between graduates and professionals can directly contribute to reducing the skills gap in the fields of solar energy systems, and technology.

4 Conclusions

As solar energy in Greece is expected to more than triple (from 12.27 TWh in 2024 to 45.63 TWh in 2034) the need for appropriate infrastructure (grid and storage) and specialized personnel is considered imperative. Latest data shows that in the first five months of 2025 (between January 1 and June 1) 8.9% of total renewable energy generation was rejected (The Green Tank, 2025). This is more than the curtailments of the entire year of 2024. Curtailments, beyond simply wasting green energy, translate into direct economic losses for

renewable energy producers by depriving them of revenues that would otherwise be realized (Helleniq Energy Center for Sustainability and Energy, 2025).

Skills development is a key enabler of a transition, but this skills identification should be future-oriented as any investment in education without a clear roadmap would be rather unreliable. The results of this research can be used to turn the uncertainty of future needs into a strategic advantage. It follows that, we must enhance education and training for new labour market entrants and ensure that existing workers have opportunities for reskilling and upskilling.

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Gender Responsive Electric Vehicle Adoption In Pakistan: Overcoming Financial, Cultural, And Infrastructural Barriers

Roha Rehan[a], Kiran Siraj[b] and Naveed Arshad[b]

[a] Dept. of Electrical Engineering, Syed Babar Ali School of Sciences & Engineering, Lahore University of Management Sciences, Pakistan

[b] LUMS Energy Institute, Lahore University of Management Sciences, Pakistan

Abstract

Pakistan's New Energy Vehicle Policy (NEVP) envisions a cleaner mobility future, yet gender considerations remain peripheral to its implementation. This paper investigates the financial, cultural, and infrastructural barriers limiting women's participation in the country's EV ecosystem. Drawing on global literature (Spurlock et al., 2019; Mukherjee & Ryan, 2020) and a mixed-methods study conducted between January and April 2025, the research integrates survey data (n≈500) and semi-structured interviews with financial institutions, EV manufacturers, and logistics firms. Findings reveal that high interest rates, limited collateral, and low financial literacy restrict women's access to EV ownership and employment opportunities, while poor lighting, safety risks, and male-centric design discourage adoption. Comparative insights from India, Taiwan, the Nordic region, and emerging African EV initiatives demonstrate how gender-sensitive finance and design accelerate equitable transition. The study proposes a gender-inclusive framework linking finance, infrastructure, and workforce participation, arguing that inclusion is not only an ethical imperative but also a catalyst for sustainable market growth in Pakistan's clean-mobility transition.

Keywords: electric vehicles; gender equity; financial inclusion; infrastructure design; sustainable mobility.

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1 Introduction

Electric vehicles (EVs) are vital to Pakistan's clean mobility goals under the National Electric Vehicle Policy (NEVP), yet gender remains overlooked. Women face barriers in finance, safety, and vehicle ownership, echoing global trends, German women's low-tech access (Kawgan-Kagan, 2020), Nordic women's focus on safety (Sovacool et al., 2019), and EVs' feminine symbolism limiting adoption in masculine societies (Plananska et al., 2023). EV transitions are social as well as technical, neglecting gender risks exclusion. This paper explores financial access, design, and workforce participation to argue for a gender-responsive EV transition that advances both equity and adoption. Pakistan's New Energy Vehicle Policy (NEVP, 2025) outlines targets for two- and three- wheelers, charging standards, and fiscal incentives, yet omits gender considerations despite evidence of gendered mobility gaps.

2 Methodology

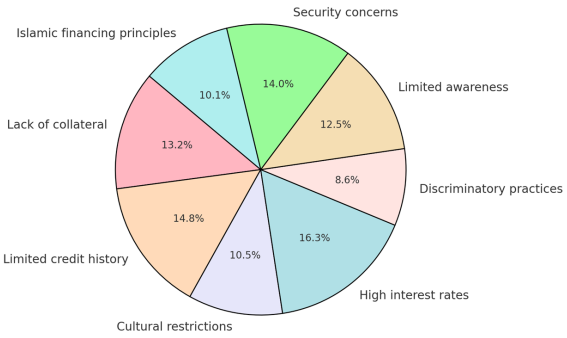
This study used a mixed-methods approach, surveys, interviews, and policy reviews, to examine gendered barriers in Pakistan's EV ecosystem across finance, infrastructure, employment, and logistics. All surveys and interviews were designed and conducted by the authors between January and April 2025, in collaborations with local EV showrooms and financial institutions. Five localized surveys ($n \approx 500$) targeted women EV users, engineers, logistics workers, employers, and financial representatives, using multiple-choice, Likert, and open-ended items adapted from Spurlock et al. (2019) and Yang et al. (2019). In parallel, fifteen semi-structured interviews with banks, microfinance institutions, logistics firms, and EV manufacturers explored institutional perspectives on risk, gender targeting, and design, following Mukherjee and Ryan (2020). Quantitative data were descriptively analyzed (Mansyur, 2024), while qualitative data were thematically coded around finance, safety, trust, and inclusivity within the Technology Acceptance Model (TAM) framework. As in Spurlock et al. (2019) and Yang et al. (2019), the urban, middle-income sample limits generalizability, though the findings offer rare insight into gendered mobility and strengthen calls for gender-responsive EV research in the Global South.

3 Gendered Pathways to Equitable EV Adoption in Pakistan

3.1 Financial Aspects of Women's EV Adoption

Financing remains the key obstacle to women's EV adoption in Pakistan. High interest rates, limited credit history, and collateral requirements mirror global findings (Yang et al., 2019; Pamidimukkala et al., 2023; Mukherjee & Ryan, 2020). Security and mobility concerns further restrict access (Mansyur, 2024). Though collateral-free loans and gender-sensitive banking could ease these gaps, structural bias persists (Pamidimukkala et al., 2023).

Fig. 1 – Percentage distribution of key financial barriers to women's EV ownership based on survey

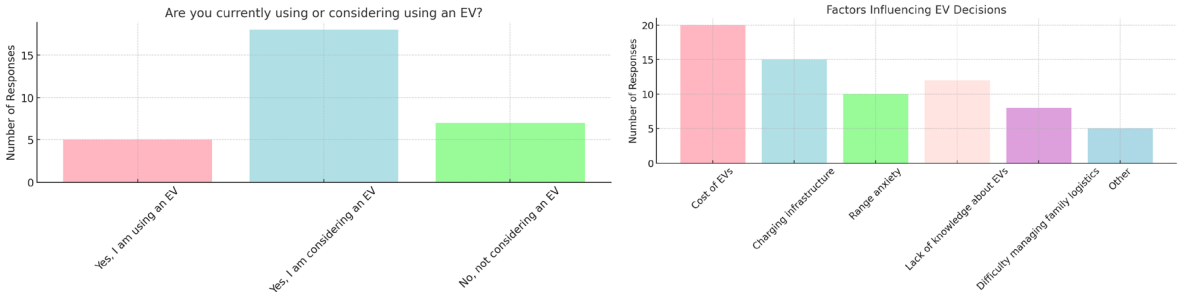


Despite progress in gender inclusion, Pakistan's financial institutions still underserve women pursuing EV ownership. Structural barriers, limited property rights, formal employment, and decision-making power, restrict access to finance (Ibtasam et al., 2018). Surveys and interviews identified rigid credit criteria, lack of tailored products, and weak outreach as major constraints. Collateral-based lending excludes most women, who rarely own assets despite strong repayment records (Ibtasam et al., 2018). Low awareness (85%) and cultural barriers (60%) reinforce dependence, though microfinance and instalment schemes remain preferred (Aparoopa & Parida, 2024). Bank interviews confirmed low financial literacy and outreach, with tools like behavioural scoring still at pilot stage. Successful local models, Kashf Foundation, Kamyab Jawan, UNDP, and Hope Uplift, show that coupling finance with training enhances confidence and repayment (Aparoopa & Parida, 2024). Similar global examples, SEWA Bank, M-Shwari, Grameen, and Crediamigo, demonstrate that literacy programs, alternative credit scoring, and Shariah-compliant products are key to making women central to Pakistan's clean-mobility transition.

3.2 Women in the EV Workforce: Interest, Barriers, and Pathways

Only 40% of Pakistani women pursuing EV careers realize their goals due to training gaps and limited outreach. Inclusive training, mentorship, and flexible workplaces can leverage women's sustainability focus to advance the EV transition (Plananska et al., 2023).

Fig. 2 – (a) Women's current and intended use of EVs in Pakistan. (b) Key factors influencing EV adoption



3.3 Gender-Sensitive EV and Charging Infrastructure Design

3.3.1 Why Gender-Sensitive Design Matters

Women's EV use in Pakistan is growing, but safety and access barriers persist, mirroring global caregiving challenges (Csillak & Kamenz, 2023). Addressing these can boost participation and adoption.

Table 1 – Survey Results: Challenges in the Current EV Ecosystem

Challenge	Key Findings
Design exclusion	Only 66.7% of manufacturers consider women's needs; male-centric design norms
Safety	66.7% of women feel unsafe at charging stations due to poor lighting and security
Ergonomics	Lack of adjustable features (seats, pedals, handlebars) reduces accessibility
Family facilities	73.3% want family-friendly amenities; 83.3% prefer restrooms/cafés

Table 2 – Key Lessons from Global Practices

Company	Country/Region	Key Practice
Gogoro	Taiwan	Lightweight scooters; secure battery-swap stations
Hero Electric	India	Affordable, manoeuvrable two-wheelers for women riders
Tesla	USA	Adjustable seating, intuitive interfaces, secure 24/7 charging
Ather Energy	India	Mobile apps with navigation and safety features
Yamaha	Japan	Lower-seat EV bikes; ergonomic controls from women's feedback
BMW	Europe	Secure charging hubs: branding remains male-oriented (Christensen et al., 2022)
BYD	China	Family-friendly features (child-safety systems); gender-inclusive partnerships

3.3.2 Insights from Surveys and Interviews

A survey of 30 women at EV showrooms showed high demand for inclusive design, family-friendly features, modular options, and safer charging (Bhatt et al., 2024). Half charged vehicles during errands, reflecting caregiving mobility (Pink, 2022). Most OEMs saw gender-sensitive design as market-shaping despite modest cost increases.

Fig. 3 – Feedback through surveys on inclusive EV design, subsidies and rental models rank highest

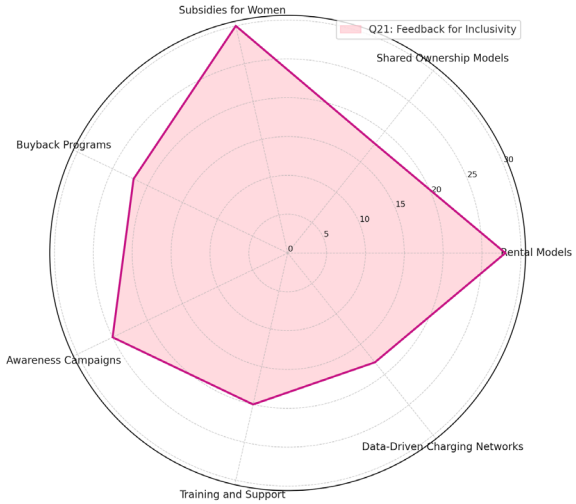


Table 3 – Recommendations for Gender Sensitive EV Design

Stakeholder	Key Actions
Manufacturers	Ergonomic features (adjustable seats/pedals/handlebars); modular dashboards & storage; safety tools like emergency alerts
Infrastructure Developers	Safe charging (CCTV, lighting, security) (Bhatt et al., 2024); family facilities (seating, play zones, storage); stations in schools, malls, and residential hubs
Policymakers	Gender-inclusive design standards (Csillak and Kamenz, 2023); subsidies for women buyers; awareness and training campaigns

3.3.3 Toward Inclusive Adoption

Integrating women's perspectives in EV design and infrastructure is both ethical and strategic, ensuring equitable adoption and reducing gendered inequalities (Csillak & Kamenz, 2023; Christensen et al., 2022; Pink, 2022; Bhatt et al., 2024).

3.4 Women in Logistics and Last-Mile Delivery

3.4.1 Why Women's Inclusion in Logistics Matters

Women's limited participation in Pakistan's EV logistics reflects safety, cultural, and financial barriers, yet their inclusion can strengthen equity and operational efficiency (Bates et al., 2018; Leduchowicz-Municio et al., 2023). The survey results reveal intersecting cultural, financial, and safety barriers that shape women's participation in logistics. Tables 4 & 5 highlight these patterns and show how employer attitudes often diverge from women's aspirations.

Table 4 – Survey Results: Challenges Faced by Women in Logistics

Barrier	Key Findings
Safety	90% cited unsafe routes, harassment risks, insecure delivery environments
Cultural norms	Stigma around women in public delivery roles
Harassment	Verbal and physical abuse; weak enforcement of laws
Infrastructure	Lack of women-friendly rest stops, washrooms, and secure charging
Financing	35 respondents struggled to access loans, leasing, or employer vehicles
Family duties	60% stressed need for flexible hours
Training	30 respondents cited lack of driving and technical training

As Bates et al. (2018) note, last-mile delivery depends not only on technology but also on human realities, parallels reflected in women's lived challenges in Pakistan.

Table 5 – Survey Results: Women's participation and safety perceptions in EV logistics

Theme	Women (n=65)	Employers (n=30)
Interest in logistics	54.5% expressed interest	Only 2 currently employ women
Financing preferences	Employer-provided vehicles (40); subsidies (30)	8 open to hiring with subsidies
Safety perceptions	15 "very safe," 40 "moderately safe," 25 unsafe	25 cited safety as hiring barrier
Preferred vehicles	EV two-wheelers (30); three-wheelers (25)	Concerns over cost of women-friendly vehicles (20)
Flexible work hours	60% said flexibility would aid participation	12 had women-friendly measures (flexibility, secure routes, training); 18 had none
Skill/training gap	30 cited lack of driving/technical training	22 cited lack of skills; 20 noted societal limits

These findings mirror Leduchowicz-Municio et al. (2023): without gender-sensitive design, electrification programs risk reinforcing exclusion rather than empowering women.

3.4.2 Best Practices for Promoting Women in Logistics

Global and local evidence show that inclusive, human-centered logistics enhance both efficiency and equity (Bates et al., 2018).

Table 6 – Global and local initiatives promoting women's participation and safety in EV logistics

Type	Organization(s)	Key Practice
Global	FedEx, UPS, CEVA	Diversity programs, GPS safety tracking, women's leadership initiatives
Global	Infosys, Sustainability Magazine cases	Diverse supply chains as drivers of innovation and resilience
Local (Pakistan)	Daraz	Female riders in delivery networks
Local (Pakistan)	Truck It In	Hired Pakistan's first female truck driver; inclusion of women & transgender individuals
Local (Pakistan)	Maersk Pakistan	Workforce diversity and equity under female leadership

Taken together, these findings show that women's participation in EV logistics require aligned interventions, safety assurance, financing, employer commitments, and community acceptance.

3.4.3 Recommendations for Boosting Women's Participation

Advancing women's role in EV logistics demands aligned policy, corporate, and community action. Subsidies and women-focused finance can shift household dynamics (Leduchowicz-Municio et al., 2023), while integrating social factors strengthens logistics alongside electrification (Bates et al., 2018).

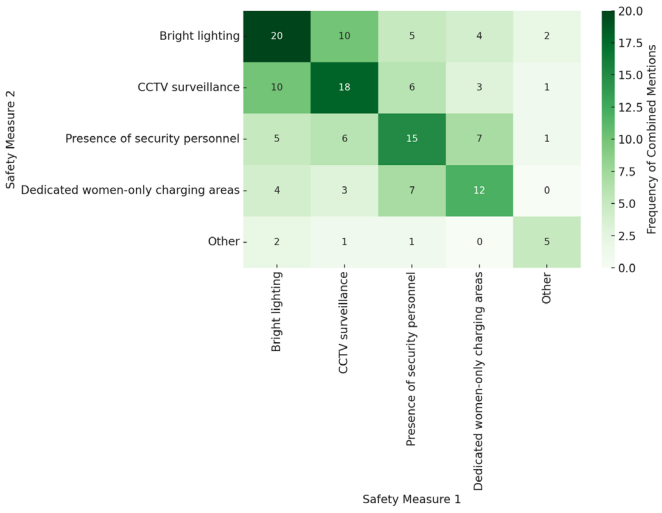
Table 7 – Policy, community, and industry measures supporting women's inclusion in Pakistan's EV logistics sector

Area	Key Actions
Policy & Programs	Subsidies/loans for women EV buyers; tax breaks for inclusive firms; government-backed leasing; amend EV Policy 2020 to mandate women's participation
Corporate Initiatives	Secure GPS-tracked delivery routes; EV training (driving & maintenance); women-friendly scooters/three-wheelers
Community & NGO Collaboration	Recruitment and awareness campaigns; women-friendly charging hubs with CCTV, lighting, panic buttons
Family-Oriented Models	Promote EVs as shared household assets to ease acceptance
Fleet Operator Incentives	Grants or awards for gender-diverse fleets; tailored insurance and safety packages for women riders

3.4.4 Toward a Gender-Inclusive EV Logistics Framework

Women's inclusion in EV logistics depends on safety, financing, and flexibility. Subsidies, employer vehicles, and safety measures can unlock their potential, making the sector inclusive and scalable. Sustainable logistics must unite efficiency, human insight, and social justice (Bates et al., 2018), as only gender-sensitive design ensures true inclusion (Leduchowicz-Municio et al., 2023).

Fig. 4 – Heatmap illustrating women's most valued safety features in EV logistics through surveys



4 Conclusion & Discussion

Women in Pakistan face financial, cultural, and safety barriers to EV adoption but show strong intent to engage. EV uptake is shaped by social factors, symbolism, safety, and

finance, amplified by inequities in property and credit. Gender-responsive measures such as Islamic finance, training, and safer infrastructure can expand participation, aligning inclusion with market growth and NEVP goals.

5 Future Work

Future research should include rural and informal sectors, assess pilots like collateral-free loans and women-only charging, and examine gender alongside class, geography, and age. Cultural studies, longitudinal tracking, and participatory co-design will be vital for an equitable EV transition in Pakistan.

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Educating Global Engineers for Sustainable Energy: Integrating Systems Thinking, Mobility and Applied Learning

Anna Kerstin Usbeck[a] and Fatou Ndiaye[b]

[a] Faculty of Sustainable Engineering Sciences, Hamburg University of Applied Sciences, Germany
[b] Electrical Department, Ecole Supérieure Polytechnique, Dakar, Senegal

Abstract

The integration of e-mobility into the energy mix plays a crucial role in reducing CO_2 emissions, as transportation remains one of the largest contributors to global greenhouse gas output. By addressing urban mobility challenges and optimizing electric vehicle systems, this teaching concept links technical competence with the broader goal of sustainable energy transition. At both universities, HAW Hamburg and Ecole Supérieure Polytechnique in Dakar, an electric vehicle serves as a learning platform in engineering science. These vehicles enable students to conduct electrotechnical investigations and perform simulations of energy consumption and usage patterns in urban traffic. The e-mobility topic arose in the course of a three-year cooperation between HAW Hamburg and ESP Dakar entitled 'Cooperation to Focus on Renewable Energy Education'. The approach aims to develop students' systemic understanding of energy flows and conversion processes. Learning activities are aligned with higher cognitive levels according to Bloom's taxonomy, supported by Biggs' constructive alignment of objectives, methods, and assessments. Students work in interdependently on physical subsystems and a digital twin to analyse energy consumption and optimization strategies. Assessment combines documentation, presentations, and reflection to address cognitive, affective, and psychomotor domain. The concept has recently been implemented at HAW Hamburg under supervision of a lecturer from the Ecole Supérieure Polytechnique in Dakar, Senegal. The comparison reveals challenges in transferring learned skills to different infrastructural and cultural contexts. The research question is: How can engineering students be educated to develop a systemic understanding of energy processes and acquire the ability to independently optimize technical solutions for sustainable mobility?

Keywords: renewable energy education; e-mobility; project-based learning; constructive alignment; competency development.

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1 Introduction

The purpose of this paper is to present and critically evaluate a project-based teaching concept that uses an electric vehicle as a hands-on learning platform to foster competencies in renewable energy education. It aims to explore how engineering students can develop a systemic understanding of energy processes and control strategies and acquire the ability to independently optimize technical solutions for sustainable urban mobility. The e-mobility topic arose in the course of a three-year cooperation between HAW Hamburg and ESP Dakar entitled 'Cooperation to Focus on Renewable Energy Education'. The paper examines the implementation of this concept at HAW Hamburg under the collaboration of a professor from Ecole Supérieure Polytechnique in Dakar. As an outlook challenges and opportunities of transferring such learning approaches to the Senegalese University are discussed.

At both universities, HAW Hamburg and Ecole Supérieure Polytechnique in Dakar, an electric vehicle serves as a learning platform in engineering science. The course is held in the third of engineering studies. It addresses higher taxonomy levels of learning in a complex systems context. Training these taxonomy levels is essential in order for students to understand not only how technology works, but also its effects and the possibilities for influencing it. The electric vehicle is empirically examined and modelled, and then virtually tested in a traffic context. This allows predictions to be made about energy consumption in urban traffic and potential for optimisation to be identified.

2 Theoretical framework

The teaching concept builds on Bloom's taxonomy, which distinguishes three domains of learning: cognitive, affective, and psychomotor. While traditional engineering education focuses on cognitive knowledge, this module integrates hands-on activities and teamwork to address all three domains. To ensure coherence between learning objectives, teaching methods, and assessment formats, the concept applies Biggs' constructive alignment. Students progress through higher cognitive levels such as application, analysis, and evaluation, supported by real-world tasks and interdependent collaboration between the teams and their (sub-) systems.

2.1 Bloom's Taxonomy model

Boom's taxonomy model has undergone numerous changes since 1956 (Anderson, 2001). The basic idea will be explained here using three different taxonomy levels based on the technical example of the e mobile.

- Descriptive Level: Students understand technical components such as electrical drive, controller, battery, transport profiles and energy consumption of the vehicle, ...

- Analytical Level (Analysis) Students analyse real measured data of the e-car, evaluate data of the Lithium battery, develop al GPS-module to track the speed of the car, …
- Reflective Level (Evaluation and Perspective-Taking): Students validate and verify the developed systems and measured data to predict the car's behaviour…

2.2 Constructive alignment

The constructive alignment approach ensures that learning objectives, teaching methods and assessment formats are coherently aligned. Basic engineering skills of *Knowledge* and *Comprehension* are mainly taught during the first and second year. After developing these first two taxonomies (Bloom), this third-year module requires higher taxonomy levels of *Application, Analysis, Creation and Evaluation.* Higher taxonomic levels in the cognitive and non-cognitive domains require different examination formats (than just written exams) in order to do justice to the constructive alignment. The progressive development of competence levels throughout the Mechatronics program has already been described by the author in an earlier contribution (Usbeck, 2015).

2.3 Assessment

The examination format combines technical documentation, interim presentations, and regular feedback rounds to ensure continuous reflection and progress monitoring. To address a broad range of competencies, students work in teams of three to five persons and are assigned specific subsystems: electrical components, mechanical powertrain, battery, simulation, controller, and measurement technology.

Fig. 1 – Sample agreement between student team and teaching staff

Group: Battery

Team members: Schulz, Marlene; Shahami, Ahmed; Zurkow, Maric

Project: RiksHAW25

Goals and tasks:

- Conversion to Li-ion batteries
- Understanding the functionality and wiring of Li-ion batteries
- Inventory: Data on batteries, motor, controller
- Mechanical integration: Mounting and fastening
- Creation of new electrical wiring

…

Evaluation criteria:

- Customer requirements met
- BMS, fuses and protective measures are correctly implemented
- Electrical and mechanical components are neatly and stably installed
- Circuit diagram and conversion process are clearly and correctly documented
- Time management and adherence to deadlines

Grade agreement:

- We would like a **group grade**

Signatures of team members

Source: Agreement of 'Mechatronic Design' course in summer 2025

Each group is responsible for developing and optimizing its subsystem so that, by the end of the semester, the electric vehicle operates in an improved state. This includes test drives to check the functionality of the electric drive and the battery. During the test drives, the quality of the measurement data collected must also be ensured. The simulation model is compared with the measurement data in order to create an optimised simulation model of the electric vehicle.
In order to address individual students equally, the overall goal is discussed together at the beginning of the semester, and the sub-goals are roughly defined. The student teams then draw up a contract listing the tasks and assessment criteria for achieving the individual goals. The lecturer and students agree at the beginning on what can be achieved during the semester (see Fig. 1).

3 E-mobility as an objective

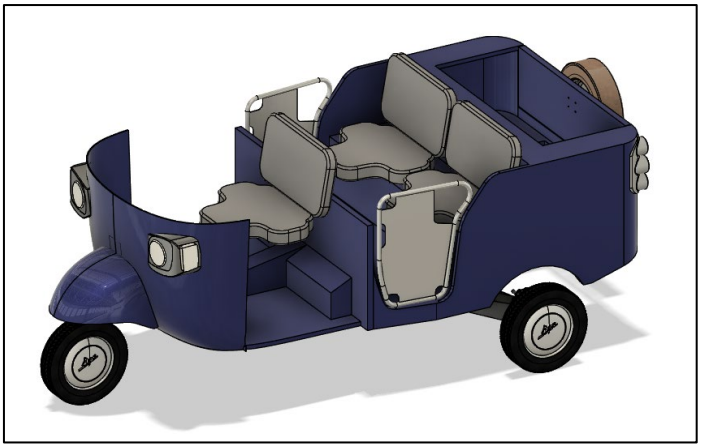
The e-mobility platform enables students to apply engineering methods learned in former semesters and collaborate across domains. By running the car under different operation conditions, time, load and control parameter-dependent system behaviour can be analysed. Modelling and simulation tools like MATLAB/Simulink and CAD support digital prototyping.

3.1 Implementation e-mobility as a hands-on learning-platform

An APE Calessino, a three-wheeled vehicle that has been converted from a combustion engine to electric drive in the university's workshop. It now serves as a teaching platform with open access to controller, electric, gear and battery. The small size and low power (5.5 kW, 48 V) allow students to work autonomously and safely on individual subsystems.

An image of this APE Calessino can be seen in Fig. 2. as a result of the 'Design and Development' group (groups will be described below). In addition to remodelling the original APE in 3D, also a design adjustment to two-wheel hub motors in CAD.

Fig. 2 – CAD model of the redesigned APE Calessino

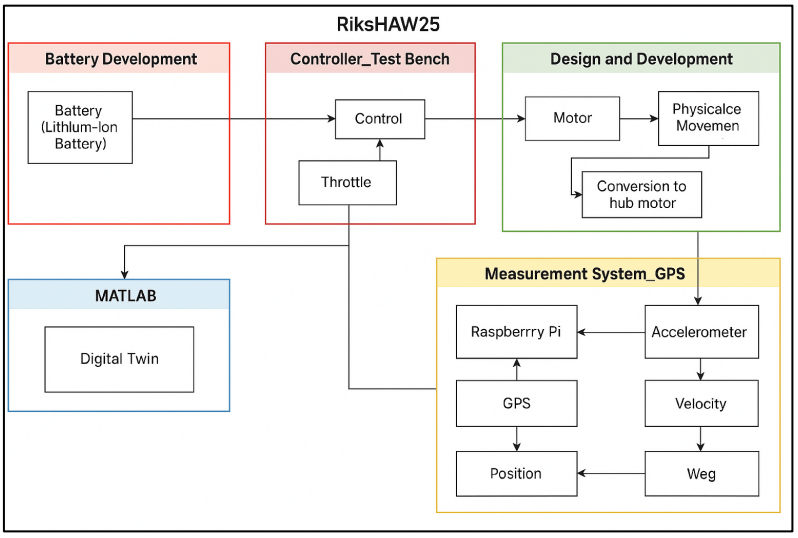


Source: Results of Group "Design and Development" (2025)

The open access makes it possible to make changes on different components in a practical manner. Different sub-systems such as the electrical motor, the mechanical power train, the controller, which runs the electrical motor, the battery and its charging characteristics, are analysed and developed further. An additional GPS system is developed to supplement the controller's measurement data with geographical data (e.g. elevation profiles).

Complementary to the groups working on physical systems with empirical data, there are other groups dealing with the virtual prototyping as well as the measuring systems. The main application of modelling and simulation tools (in particular MATLAB/Simulink and CAD) are used for a digital simulation of the power train and the CAD-model of the vehicle. Both tools are main part of the nowadays digital engineering. As shown in Figure 3, the five different student groups work interdependently (with interfaces) on sub-systems. The sixth student group will work in the role of project management.

Fig. 3 – System setup and interdependencies of the working groups



Source: Results of Group 'Project Management' (2025)

3.2 Student profile

The module targets third-year engineering students with prior knowledge in electrical, mechanical, and control engineering. It emphasizes higher cognitive skills such as analysis, synthesis, and evaluation, assessed through project outcomes and documentation. In addition to cognitive learning, teamwork and hands-on activities activate the affective and psychomotor domains. In table 1 the different tasks of the module are linked to the different domains of Bloom's taxonomy.

Table 1 – Three Dimensions of Learning

Domain	Content
Cognitive Domain	Understanding system architectures, modelling techniques, and development processes; applying engineering methods and evaluating system behaviour
Psychomotor Domain	Implementing, operating, measuring physical subsystems; using tools and lab equipment to realize functional prototypes
Affective Domain	Collaborating in teams, taking responsibility for tasks, reflecting on group outcomes, and committing to quality and ethical standards

Source: Author's own data, module 'Mechatronic Design', Summer 2025 according to Bloom's taxonomy

3.3 Design process

The students work on their subsystems in individual working groups. As in industry, they are therefore required to be aware of the interfaces with the other groups and to coordinate with each other. These coordination processes are described in VDI 2206 and can be applied to the student groups: "[A] suitable exchange of information must take place between product design and production system design. This is to be coordinated in three dimensions: time, content and intensity of the cooperation." (VDI 2206).

4 Recent tasks and outputs

4.1 Group activities outputs

All groups contribute to the optimization of the e-vehicle platform. The groups achieved the outputs listed in Table 2 within one semester in terms of time and content. In doing so, they are more or less dependent on the cooperation and specifications of the other groups.

As an example: The location for battery installation must be agreed with the 'Design group', the battery can only be operated with the correct controller settings, and the MATLAB simulation relies on measurements from the controller and GPS data acquisition. Table 2 is a summary of the student reports. In addition to the 'main task', which is defined in the agreement at the beginning of the semester, the 'output', describes the actual results at the end of the semester. Essential for the higher taxonomy level in teaching is the column of the 'Challenges', which represents the students' reflections on the extent to which the assumptions made at the beginning of the semester were correct and what difficulties arose.

Table 2 – Outputs of the individual groups

Group	Main Task	Key Outcomes	Challenges
Battery Development	Replace old lead-acid batteries with modern Li-Ion batteries	Improved system reliability and range; successful test	Existing batteries failed due to parallel connection.
Controller / Test Bench	Optimize motor controller parameters	Successfully limited motor current; improved driving behaviour; validated MATLAB scripts.	Initial lack of understanding of controller parameters; current limits required experimentation.
Design and Development	Design and model a new drive system using hub motors; create CAD models and assembly instructions.	Developed a complete concept with CAD models and cost analysis; prepared for future implementation.	Risk of incorrect measurements and incomplete documentation; emphasized need for better planning.
MATLAB Simulation	Create a digital twin of the electric drive system using MATLAB/Simulink; validate with real driving data.	Built a functional simulation model; validated with real data; used for energy consumption estimation.	Simplified model lacked battery and thermal effects; future improvements suggested for realism.
GPS	Develop a GPS-based data logger for vehicle tracking and acceleration measurement.	Built and installed a modular GPS system with Raspberry Pi; successfully tested during public event.	I2C multiplexer failed; limited sensor integration; required redesign of system architecture.
Project Management	Coordinate all project teams; documentation, and communication.	Structured project; ensured smooth collaboration; supported all teams effectively.	Verbal communication led to misunderstandings; emphasized need for written documentation.

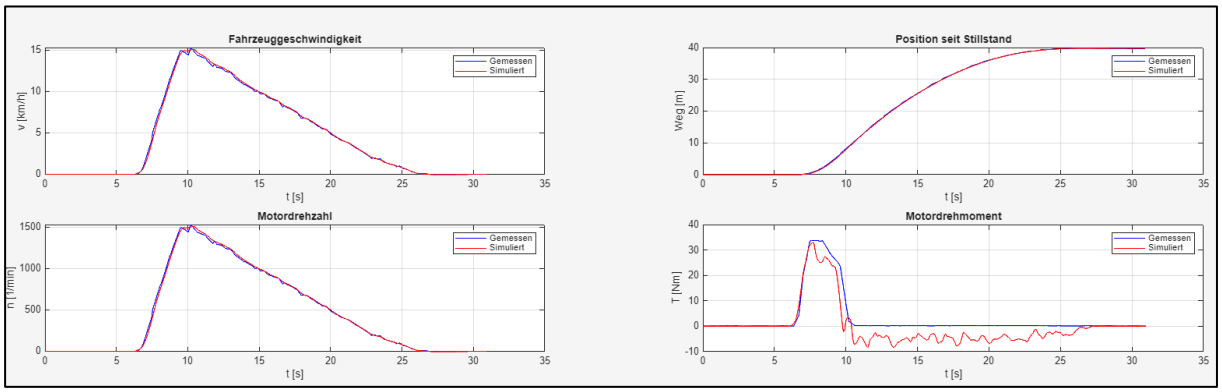
Source: Author's own data, module Mechatronic Design, Summer 2025

4.2 Interdisciplinary result of the optimized Rikscha APE Calessino

The overall result of the work is an optimized controller, which ensures that the battery current is limited to 100 A, a new working lithium battery, evaluable GPS and Controller Data and CAD model and a MATLAB digital twin. The digital twin maps the APE with its control parameters, allowing specified driving profiles to be used to forecast energy requirements and battery discharge. In figure 4 the measured data of one tracked journey in blue colour is

compared to the simulation of the digital model in red colour (speed (v), position (s), rotations of the motor (n) and motor torque (T)). In the long term, the data can be used to perform simulations in urban traffic and to design a charging infrastructure that is suitable for the electric vehicle fleet.

Fig. 4 – MATLAB simulation and real measurement – comparison



Source: Results of Group "MATLAB" and "Controller/Test Bench" (2025)

5 Evaluation and student perspectives

5.1 Evaluation from teaching perspective

An electromechanical system was systematically examined, modelled and improved by the individual groups over the course of a semester. The groups understood how to apply their knowledge of electrical, mechanical, electronic and programming technology. Through the complete analysis and description of an electric vehicle, the essential technical aspects of efficient energy conversion and storage were addressed at a high level.

5.2 Feedback from students

Feedback from students was not systematically collected but can be summarised as follows based on the comments in their documentation: The students demonstrated high motivation and active participation throughout. In addition to deepening their technical skills, teamwork and communication skills were strengthened, particularly with regard to coordination between interdisciplinary groups. The project proved to be an effective learning environment for technical creativity, systemic thinking and practice-oriented collaboration, preparing students for future organisational and technical challenges.

5.3 Feedback from Senegalese lecturer

German students are much more independent in their activities. While in Senegal, the lecturer is called in at every step and has to approve the work, students in Germany are given

tasks and are assessed on the results. The agreement that students must sign at the beginning of the semester is to be tried out as an activating feature at ESP Dakar in the future.

5.4 Challenges and learning impulses

Students initially struggled with open-ended tasks and interdisciplinary coordination, but these challenges fostered personal responsibility and collaborative problem-solving. Stress and tensions were part of the process but resolved through shared achievement. A key challenge in project-based learning lies in ensuring a clear understanding oft the problem and associated tasks from the outset, that student teams are intrinsically motivated, and the fixed deadline tied tot the project goal. Supporting students through these challenges and fostering resilience are essential to the development of competencies that extend beyond technical expertise.

6 Conclusion and outlook

The teaching concept presented for the APE Calessino shows how sustainable mobility can be taught in engineering studies not only in theory but also made practically tangible. The combination of real vehicle data, simulation-based analysis and reflective engagement with global mobility issues creates a multi-layered learning space that combines technical competence with social responsibility. The positive feedback and high level of self-motivation among students confirm the educational value of the concept.

There are plans to further develop the teaching concept and to work on the digital twin both Ecole Supérieure Polytechnique Dakar and HAW Hamburg. This offers potential for joint projects and intercultural exchange.

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Verein Deutscher Ingenieure VDI. VDI2206: Design methodology for mechatronic systems (Richtlinie VDI2206).

Chatbottutor For Higher Education – Experimental Design For Optimizing Technical Accuracy

Linda Becker[a], Michele Valerie Martin[a], Loredana Tiedke [a] and Semih Severengiz [a]

[a] Sustainable Technologies Laboratory, Bochum University of Applied Sciences, Germany

Abstract

While integrating Large Language Models (LLMs) can provide personalised, continuous feedback at scale in large courses, doing so responsibly requires technical accuracy and data privacy. In this study, we present an on-premises, privacy-preserving chatbot tutor for a university course that focuses on energy and sustainability related tasks. This tutor is built using Ollama and Docker, and is aligned to the curriculum via Retrieval-Augmented Generation (RAG). The first phase of a three-phase evaluation involves running a full-factorial experiment (three LLMs × three RAG datasets × six prompts x five repetitions; 270 runs) under an automated Puppeteer protocol. The outputs are rated on seven dimensions, including correctness, hallucinations, pedagogical value and repeatability, which reflect the failure modes observed in external audits. The result is a practical framework for optimising LLM/RAG configurations so that energy-domain learning tasks receive reliable feedback without sending student data off-campus.

Keywords: chatbot; education; feedback; generative AI; RAG.

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1 Introduction

The integration of Artificial Intelligence (AI) is transforming the landscape of higher education. Early AI systems primarily featured avatars or multimodal interfaces such as video and voice, and embodied agents — AI systems with a body (Jusoh & Kadir, 2025; Pataranutaporn et al., 2021). Large Language Models (LLMs), a leading type of generative AI, have catalysed a functional leap in these modalities, enabling open-ended, multi-turn reasoning and simulating even more realistic interactions (Jusoh & Kadir, 2025; Sarker, 2024). These AI advances provide substantial educational support through lesson planning and reflective learning, with reported gains in efficiency, motivation, and accessibility (Jusoh & Kadir, 2025; Neumann et al., 2024; Yigit & Bayraktar, 2025). However, resources on commercial platforms that are both education-specific and aligned with learning design remain scarce, highlighting a gap between the potential of LLMs and their practical deployment in real educational environments (Gonda & Chu, 2019).

This technological surge provides higher education institutions with an opportunity to overcome long-standing resource limitations, particularly in areas requiring frequent personalised interaction and feedback with students. This is especially relevant in energy and sustainability education, where students work on practical tasks such as efficiency trade-offs and life-cycle reasoning scenarios. In large-scale courses, practical exercises and prompt feedback are widely regarded as being helpful in terms of understanding the course content. However, providing intensive one-on-one tutoring and personalised feedback for large, lecture-based courses remains difficult with current staff resources in most universities and institutes for higher education. The Chatbot-Tutor addresses this issue by acting as a personal learning assistant that students can access at any time and from anywhere. As well as providing content support, the project explicitly teaches students about the theoretical and practical applications of generative AI, while also promoting the sustainable use of technology in higher education.

Translating these theoretical benefits and project goals into practice requires an evidence-based evaluation under real-world constraints. For instance, system performance is influenced by various factors, including hardware configurations, temperature and prompt engineering strategies (Kachris, 2025; Peeperkorn et al., 2024; Schulhoff et al., 2025). Local hosting provides a concrete case that allows assessing total cost of ownership, integration hurdles, governance/privacy requirements, and scalability, offering a pragmatic perspective on implementation in real institutional contexts.

To explore this potential, the Sustainable Technologies Laboratory at Bochum University of Applied Sciences launched a project to develop a subject-specific, locally hosted chatbot to provide feedback. This paper contributes to this effort by:

- Presenting an on-premises architecture (Ollama + Docker + WebUI).
- Introducing an experimental design for improving technical accuracy.
- Evaluating subject matter accuracy across LLM and RAG configurations.

2 System architecture

The Chatbot Tutor has been designed specifically to support students on the bachelor's degree course eco-design. Its primary functional objectives are to: (i) provide personalised feedback on exercise solutions, (ii) simulate tutor–student interaction to provide guidance and facilitate reflection, and (iii) offer clarification of concepts and terminology from the course materials on demand. This targeted implementation provides a testing environment for continual improvement and is anticipated to decrease the required supervision workload in the long-term following successful deployment.

Table 1 – System overview

General Function	Chatbot specific setup
Software	
- Container	Docker
- Framework	Ollama
Language Model	Discolm-mfto-7b-german-v.0.1
Retriever	Sentence-transoformers/all-MiniLM-L6-v2
User Interface	Open WebUI
Hardware	
- Server	Dell Precision 3680 Tower, Core i7 (33 MB Cache, 20 Cores, 28 Threads, 21, GHz up to 5,4 GHz, 65 W), 64GB Ram
- Graphics Card (GPU)	Gigabyte NVIDIA GeForce RTX 4060 Ti AERO OC Graphics Card – 16 GB

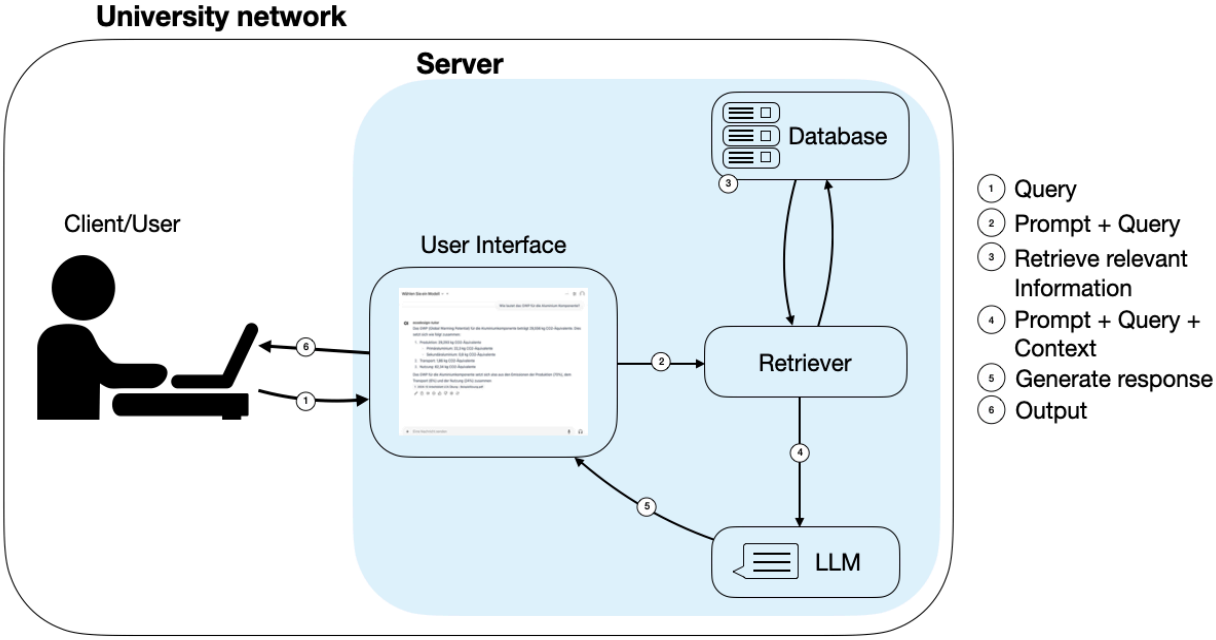
The initial system used the component stack summarized in Table 1. This setup provides a locally hosted chatbot tutoring system that is designed to help students with their exercises by offering personalised feedback and detailed explanations. Importantly, the technology components are limited to a single server-class machine, making it a practical deployment model for education departments unable to rely on expensive, complex cloud clusters. Preliminary observations from the original build piloted with students indicate only partial accuracy: the tutor consistently identified significant errors in student work but occasionally added incorrect content and produced unreliable results for mathematical operations. Measured latency ranged from ~5 seconds to several minutes, and the system does not currently support concurrent requests. However, data security is robust: all inputs remain

within the university network, are not shared with external providers and are accessible only to the system administrator.

2.1 System Setup and Performance Status

The Chatbot Tutor system is deployed on premises, which ensures that the institution has full control over its data and resources. This architecture uses Docker containers, which are standardized units of software, to package and manage application dependencies. Using consistent, isolated units enables reliable testing and deployment across different environments. Within this containerised environment, Ollama is used to run the Large Language Models on the server's dedicated hardware. This stack enables a self-hosted, privacy-preserving deployment — a critical requirement for educational tools. We selected DiscoLM German 7B due to its optimisation for German-language instruction, its support for RAG-friendly prompting to minimise hallucinations and its seamless integration with the Ollama/Docker ecosystem. Our deployment runs on a university server with a web interface. Access to the Chatbot Tutor requires the internal Virtual Private Network (VPN) of the Bochum University of Applied Sciences and a user account that is unlocked for students after registration. The system is in the early stages of development with noticeable latency, which is expected to improve with a planned GPU upgrade. For the subject-matter accuracy study, the system has been upgraded to utilise an NVIDIA RTX 6000 Ada Generation 48 GB graphics card.

Fig. 1 – Privacy preserving RAG pipeline



2.2 Retrieval-Augmented Generation (RAG) and Framework

Existing LLMs can be grounded via Retrieval-Augmented Generation (RAG) to incorporate up-to-date, subject-specific sources and improve factual accuracy or context relevance (Li et al., 2024). The choice of the Ollama framework is central to supporting this mechanism. Ollama is a framework that enables the local execution of LLMs on standard hardware, supporting privacy-preserving offline workflows (Marcondes et al., 2025). Its architecture also facilitates model customisation, including parameter-efficient fine-tuning and prompt templates. These features make the platform ideal for controllable, reproducible and self-hosted research deployments (Marcondes et al., 2025). In our RAG implementation, the model is grounded in retrieved sources rather than relying solely on its internal parameters by using exercises, lecture notes, and curated supplementary materials to inform its answers. For instance, when a student requests feedback on their life-cycle assessment of an e-scooter, the system locates the specific exercise sheet and lecture notes used in the classroom. This means that the feedback is based on the same definitions, formulas and assumptions that the instructor expects in the course, rather than generic information from the open web. At query time, a retriever selects the most relevant document snippets (see Figure 1); these are incorporated into the prompt, prompting the generator to produce a response that cites or reflects this context. This design offers the following benefits: (i) higher factuality and reduced hallucinations, (ii) curriculum alignment through domain-specific materials, (iii) up-to-date content without the need for costly model retraining, and (iv) greater transparency via source attribution (Singh, 2024). These benefits are particularly valuable for an educational chatbot. Compared with fine-tuning, which adapts model behaviour but requires curated training data, significant computing power and periodic retraining, RAG updates knowledge simply by adding or revising documents (Narayan & Agarwal, 2025). This makes it cheaper and faster to maintain and better aligns with privacy constraints in our educational setting.

3 Methodology

Our study will proceed in three phases: (1) system improvement through a comparative study of LLMs and RAG datasets on correctness, consistency, explainability/traceability, and hallucination rate; (2) a summative technical accuracy evaluation accompanied by a student survey; and (3) a performance evaluation. The following experimental setup and methodology details phase one.

3.1 Experimental Design

Drawing upon the BBC newsroom audit (Elliot, 2025) and the evaluation of Fobizz's AI grading tool in a school context, we derived our core methodology and evaluation focus. These studies motivate the selection of accuracy, hallucinations, source attribution,

context/impartiality, and consistency as primary dimensions, and they inform our design choices of deterministic decoding, five repeated runs, and human ratings. We implement a full-factorial experiment (3 LMs × 3 RAG datasets × 6 prompts) with five repetitions per configuration, yielding 270 test runs in total. This enables us to identify the most reliable and pedagogically effective combination of models and course materials before introducing the system to large groups of students. The three LLMs span different parameter scales (7B, 13B, 30B) and complementary strengths— general reasoning, logical/mathematical reasoning, and German-language/ persona interaction — allowing us to probe the impact of scale and specialization for educational assistance. To vary knowledge grounding, the RAG datasets increase in complexity from baseline exercise-plus-solution, to exercise-plus-solution with lecture notes, to a deep context set that further adds domain papers. Prompting is likewise diversified: three competence-oriented prompts target factual accuracy, reasoning, and pedagogical quality, while three diagnostic variants are designed to elicit distinct error types and test error detection, critical thinking, and robustness.

3.2 Evaluation

We conduct reproducible, end-to-end tests using a Puppeteer script, which is a browser automation framework that simulates human interaction with the interface by typing and clicking. This allows us to programmatically drive the chat interface under controlled conditions. Test inputs are parameterized and loaded from a version-controlled fixture that specifies the model, RAG setting, prompt variant, and repetition index. For each run, Puppeteer submits the input, waits for completion, and writes structured logs containing the raw model response, token/character length, latency, timestamp, run ID, and environment metadata. This enables deterministic replay of scenarios, batch execution across conditions, and auditable traceability from outputs back to inputs.

To control output variance, decoding and retrieval parameters are standardized. Generations are capped at 300 tokens (≈200 words) to keep response length comparable across conditions. The temperature is set to 0, removing sampling randomness; with deterministic backends, identical inputs produce effectively identical outputs while the retained five repetitions quantify any residual instability.

3.3 Analysis

We assess model outputs across seven dimensions that directly correspond to the requirements of classroom deployment. 'Correctness' verifies valid reasoning for accurate learning, while the 'hallucination rate' captures fabricated content that could mislead students. 'Source attribution/traceability' links answers to course materials, thereby supporting scholarly practice and auditability. 'Pedagogical value' judges whether the response effectively teaches by explaining steps and providing support, rather than simply

providing an answer. 'Improvement suggestions' evaluates the model's ability to guide productive next steps, sustaining formative feedback cycles. 'Relevance' ensures that the output remains on task and consistent with the prompt and resources. Finally, 'repeatability/consistency' measures stability across reruns, which is a prerequisite for instructors to have trust in the model in higher-stakes settings. Together, these dimensions reflect our working criteria for educational LLMs: reliability, safety, transparency, and instructional effectiveness. They also reflect known failure modes, such as the variability and misattribution reported in the BBC newsroom study (2025).

4 Discussion and Conclusion

This paper outlines a self-hosted chatbot tutor for an eco-design study course, oriented to energy and sustainability education, as well as an evaluation design focused on technical accuracy. The Ollama/Docker stack meets privacy and transparency requirements, and the planned experiment provides a reproducible basis for selecting a reliable deployment configuration. There are clear advantages to building in-house: data governance remains on campus, RAG aligns the tutor with the curriculum without the need for expensive fine-tuning or fees, and updates are simplified. End-to-end transparency, from prompt templates to Puppeteer logs, enables auditing and instructor oversight. While this is a concept paper, the methodology — deterministic decoding, controlled retrieval settings and ratings across seven education-relevant dimensions — targets the known failure modes of AI assistants and prioritises instructional quality. Limitations include pending student validation and performance effects, both of which will be addressed in the planned phases. Looking ahead, the experiment will identify the most reliable LLM × RAG configuration for domain correctness and consistency. Subsequent evaluations will address pedagogical validation and operational performance.

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Socioeconomic Realities Of The Just Transition: The Case Of Western Macedonia, Greece

Nikolaos Taousanidis[a] and Andreas Taousanidis[b]

[a] Mechanical Engineering, University of Western Macedonia, Greece
[b] University of Western Macedonia, Greece

Abstract

Responding to society's growing concerns for climate change, European Union (EU) launched European Green Deal (EGD) a plan to transform Europe into a sustainable community. Acknowledging the vulnerability of coal regions in this transition, EU offers support to these regions to reduce negative impacts and to assist the development of a new production model with the minimum negative impacts on local society. This paper examines the transition efforts in the most affected region—Western Macedonia. It analyses how national and local authorities assess the process, identifies key gaps, and suggests ways to address emerging injustices.

Keywords: climate change; just transition; lignite phase-out.

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1 Introduction

Coal-dependent EU regions face major challenges in meeting climate-neutrality targets because their economic structure has long relied on lignite-based activities. The rapid phase-out therefore generates significant socioeconomic disruption.

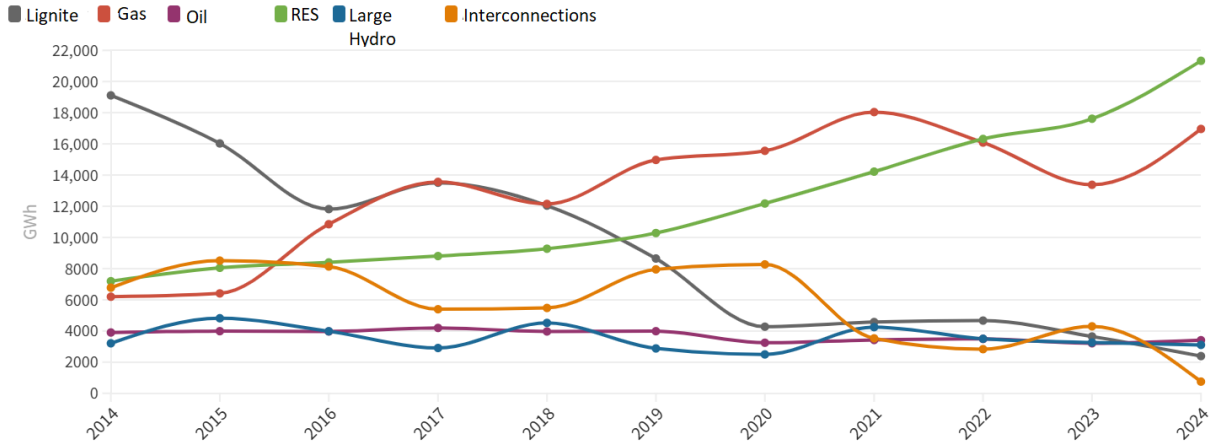
Frans Timmermans, Executive Vice-President of the European Commission, pointed out, that "solidarity with the most affected regions in Europe, such as coal mining regions and others" is apparent "to make sure the Green Deal gets everyone's full support and has a chance to become a reality" (Timmermans, 2020). To secure a fair transition EU adopted The Just Transition Mechanism (JTM) mobilizing around €55 billion over the period 2021-2027 in the most affected regions. However, throughout the years followed, it has been proven that JTM cannot alone change the scenery, but a lot of complementary actions, a clear strategy and a bottom-up assessment are necessary, although sometimes not enough, to implement the target of "no one is left behind".

Recent studies analyse the socioeconomic impacts of the coal phase-out, including emerging inequalities, local perceptions, and regional development risks. Within this body of work, Western Macedonia consistently appears as the most affected Greek region. This paper focuses on its overlooked structural characteristics and highlights areas where local needs diverge from central government priorities.

2 The case – Problem recognition

Western Macedonia has relied heavily on lignite mining and electricity production since 1960s. Due to decline in lignite and the subsequent electricity production (around 80%, see Figure 1) in the last twenty years, the region faced a rapid decrease in Gross Value Added-GVA (around 15%, see Table 1). It is worth mentioning that the decrease in production (around 75%, see Figure 3) in the last six years is one of the fastest in Europe as Europe is moving in the same direction, albeit more slowly (44% reduction).

Fig. 1 – Electricity production by fuel



Source: I.P.TO. (2025) (authors representation)

A result of this decline was the decrease in total population by 13,7% (the largest in Greece) and in economically active population (ages 16-64) by 7,9% (see Tables 2, 3). Obviously, this was not in conformity with the just transition targets. The urgency to abolish any electricity production from lignite (the only national energy source) by 2028 according to the National Energy and Climate Plan (NECP, 2025) does not create the best environment to apply any corrective measures or revise the whole procedure of the Territorial Just Transition Plan.

2.1 Systematic Assessment Framework

To structure the problem-recognition process and enable comparability with other regions in transition, we apply a four-pillar evaluation framework based on regional data and established transition-assessment methods:

(1) Structural Vulnerability Assessment: Evaluation of pre-transition conditions, including dependency ratios (share of lignite in GVA, employment concentration), productivity levels, innovation capacity, and demographic resilience. This provides a baseline of inherent weaknesses independent of the phase-out decision.

Table 1 – Gross Value Added for Western Macedonia region

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Western Macedonia	4.437	4.565	4.551	4.414	4.743	4.507	4.487	4.176	3.776	3.782	3.691	3.508	3.093	3.317	3.776
Grevena	347	330	330	302	286	272	270	276	269	266	267	275	277	290	317
Kozani	2.656	2.750	2.790	2.705	3.033	2.890	2.803	2.582	2.289	2.275	2.236	2.069	1.746	1.878	2.163
Kastoria	589	585	555	525	491	466	462	459	434	424	438	437	410	444	474
Florina	845	900	877	883	933	879	951	859	784	818	750	727	660	705	822

Source: Hellenic Statistical Authority (2025)

(2) Transition-Pressure Analysis: Measurement of the direct pressures created by the accelerated lignite phase-out. Indicators include pace of production decline, job displacement rates, migration flows, and the temporal gap between planned and actual implementation of transition instruments.

(3) Institutional and Implementation Capacity Review: Assessment of regional and national governance mechanisms: clarity of targets, investment-readiness, licensing times, administrative barriers, and responsiveness of support schemes. This identifies procedural bottlenecks affecting the Just Transition plan.

(4) Regional Absorptive Capacity and Future Potential: Analysis of the region's capability to attract new activities, considering spatial planning, infrastructure, human capital, business

climate, and alignment with endogenous strengths (agriculture, tourism, food production, niche manufacturing).

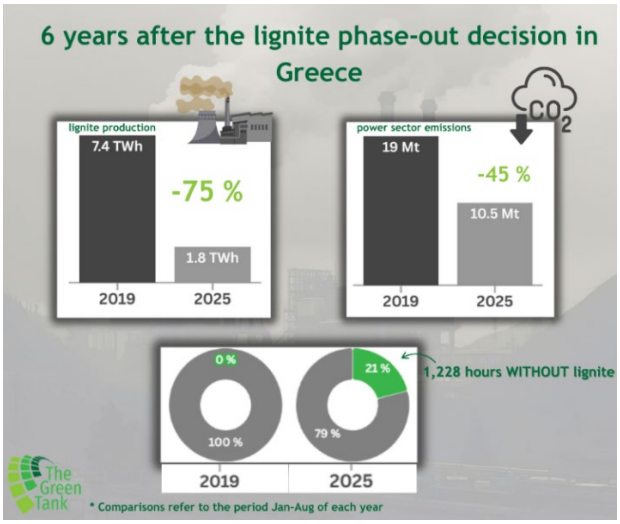
Applying this four-pillar structure clarifies which problems originate from long-term structural characteristics and which stem from the transition process itself. It also enables replication in other coal regions by offering a transparent, data-driven template for assessing readiness, gaps, and policy priorities.

Looking forward for a ten-year plan (which presumably will be the case, as developed economies as Germany will continue to use coal for electricity production until 2038 (IEA, 2025)) we will present a roadmap and a "learning by mistakes" view for policies and opportunities in the region of Western Macedonia

All initial assessments, either from official institutions (EU, 2025, Christiaensen and Ferré for World Bank, 2020), or scholars (Vrontisi et al., 2024, Peretto et al., 2025) concluded to the heavy dependence of Western Macedonia from lignite mines exploitation, however they were forecasting challenges for energy transition. In the contrary the recent studies (Vrontisi et al., 2024b) are characterized by anxiety or at least uncertainty for region's future.

The basic reasons are grounded on:

Fig. 2 – Electricity production by lignite in transition period



Source: The Green Tank (https://thegreentank.gr/2025/09/23/lignite-phaseout-6years-el/)

- Lack of ability to recognize structural problems existing before the lignite phase out period.
- Unclear and not quantitative targets, that is how much (funds), how many (jobs), what is the height of (income, GVA).
- Ignorance of the capabilities or possibilities to attract investments, considering the region's actual context.
- A-cut-throat schedule in confrontation with bureaucracy and the apathy of implementation mechanisms. The schedule and the step raised by the institutions to

create the conditions of structural problems removal, is at least disappointing, as further will be analysed.

- Western Macedonia has long exhibited structural weaknesses: persistent unemployment and low GVA (Christiaensen and Ferré, 2020), limited industrial diversification (Christiaensen and Ferré, 2020), weak innovation performance (EU-RIS, 2025), and minimal digital capacity. Despite opportunities created by EU accession, national development incentives, and the establishment of higher education structures, the region failed to cultivate alternative economic activities. The long-standing dominance of the Public Power Corporation (PPC) discouraged diversification and created barriers for sectors such as agriculture and tourism.

Table 2 – Estimated population evolution on the 1st of January for the years 2014-2024 in Western Macedonia (per regional unit). Source: Hellenic Statistical Authority (2025)

2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	
278.706	**276.423**	**273.843**	**271.488**	**269.222**	**267.008**	**264.670**	**262.052**	**253.875**	**250.279**	**247.270**	**W M**
31.200	31.052	30.817	30.628	30.622	30.588	30.629	30.292	26.494	26.148	25.914	GREVENA
49.293	48.798	48.244	47.723	47.163	46.668	46.071	45.517	45.796	45.115	44.482	KASTORIA
147.155	145.774	144.309	142.941	141.559	140.233	138.817	137.455	136.845	134.908	133.295	KOZANI
51.058	50.799	50.473	50.196	49.878	49.519	49.153	48.788	44.740	44.108	43.579	FLORINA

3 Limitations of existing plans and proposals

The Western Macedonia Master Plan for Transition focuses **on five main areas**: clean energy development, industrial manufacturing, smart agriculture, sustainable tourism, and research–innovation–education. These targets are consistent with EU priorities and the national Plan for Just Transition, but the question raised is if they are achievable as after 5 years, they drag their heels. More specifically just two targets have been met substantially, but it was clear that they couldn't create the desirable results: clean energy development (PV parks construction) and voluntary exit of PPC personnel (financially cushioned).

Table 3 – Economic population evolution in Western Macedonia

Employment status	**Total population aged 15+**	**Labour Force**			**Employed**		
Year		persons	activity rate	% aged 20-64	persons	employment rate	% aged 20-64
2024	231,3	112,6	48,7%	74,0%	98,5	42,6%	64,8%
2023	231,6	112,9	48,8%	75,0%	94,0	40,6%	62,3%
2022	231,7	108,1	46,7%	71,2%	89,0	38,4%	58,8%
2021	231,8	111,7	48,2%	72,7%	89,7	38,7%	58,2%
2020	231,9	108,5	46,8%	70,4%	87,1	37,6%	56,4%
2019	232,3	115,4	49,7%	74,3%	87,1	37,5%	56,0%
2018	233,0	118,2	50,7%	74,8%	86,2	37,0%	54,6%
2017	234,9	119,2	50,8%	74,8%	84,5	36,0%	52,7%
2016	236,9	118,0	49,8%	73,3%	81,1	34,2%	50,4%
2015	239,5	117,3	49,0%	71,6%	81,2	33,9%	49,4%
2014	240,3	113,9	47,4%	70,5%	82,5	34,3%	51,2%

Source: Hellenic Statistical Authority (2025)

The first serves the national (and international) target for sustainability, however, does not offer stable income and new jobs (excluding the construction phase), transfers profits outside the region and does not promote regional industry or innovation Vrontisi et al. (2024) underline that these interventions rely on a high share of imported technological equipment and have the lowest employment multiplier effect (Vrontisi et al., 2024). The second affects positively the limitation of lignite sector but again does not create jobs and is addressed to people over 50 years aged directly employed in the energy sector satisfying their status.

What could create jobs and is not implemented:

- Incentives for investment attraction. As such are infrastructure, spatial planning (industrial areas) economic incentives for the attraction of specialized personnel and fast treatment of strategic investment proposals. It is characteristic the case of very large Greek companies' investment proposals which have been directed to other EU regions (not in transition) due to the favourable investment climate and fast state response.
- Spatial planning and fast licensing procedure. There is no statutory procedure with specific and attractive measures for installation in such areas, not referring to the total lack of them, nor tax incentives.
- Coal mines rehabilitation. Recently was announced by the Greek government that funds for rehabilitation have been excluded, which practically means that the whole project will be delayed. This reflects to the efforts of agricultural and livestock enterprises to be developed in large and non-fragmented areas, in order to be more cost effective, the application of smart technologies.

- Time schedule. Just transition is not a technical issue but a socio-economic one. Consequently, it cannot be completed in a time horizon of eight years (2020 estimations). Western Macedonia cannot replace the economic value chain of lignite, which accounted for 42% of the GDP, with 5000 permanent and 15,000 non-standard jobs, and up to one billion Euros in wealth produced from lignite per year (Government Committee SDAM, 2020). It is characteristic that just transition in the largest coal dependent region of Rheinland (DE) started in the eighties (Arora and Schroeder, 2022) and considering also Lusatia region (Schuster et al., 2023), the lignite phase-out procedure in Germany has 2038 as a time horizon, underlining the importance of time for the rest of the regions in transition.

Disappointment is dispersed between the citizens for the future of the region and the nostalgy for the period of the period of economic prosperity to dominate and to feed the "with coal forever" attitude (Frantal et al., 2025) , but is also certain that European Union will not return in that period, even if – because of Ukraine-Russia war – does not push for the strict time schedule implementation. The unclear future of the region, completely different from the past, forces young people with qualifications to migrate, as they do not have the patience to wait and consequently leads to population ageing. It is a fact that must be accepted as a short-term and justifies how vital is to create the conditions for their return stalling this "bleeding". There are some ways to achieve that, and our proposal is summarised as follows:

- Investments in areas of youth interests, related to employment, everyday life and perspectives for them and their families.
- attract local capital, which right now moves to more attractive investments in other regions/countries or are in slumber.
- Creation of a brand-name for the region so it will be connected, for any possible reason, with life quality.

A historical background to non-energy activities in Western Macedonia (the region has around one century of life as independent territory) reveals agriculture, livestock breeding, fur processing and logging as thy main economic activities, apart trade. The geographical characteristics, such as extensive mountain ranges, lakes and rivers, and national trust lands, is an unchanged parameter which must be considered. Adding on that the favourable environmental conditions after the termination of lignite mines and coal electricity production, especially on the axis Kozani-Ptolemais-Florina, leads to certain challenges:

- A fully integrated agricultural sector with high quality products, exploiting the existing products of designated origin (PDOs) or products of geographical indication (PGIs) and creating new ones, an international promotion to all relevant fora, with complete quality control in all levels by regional scientific institutions (winery products is a good example). Also, special attention is necessary for livestock farming with an integrated circle of production (food, breeding, slaughtering, meat products, recycling).

- It is obvious that primary sector jobs are not attractive for young people, thus they must relate to high income, insurance of production against weather conditions, plant diseases, in situ scientific support, agricultural industries and high products' demand.
- Tourism development should build on the region's mountain, lake, and cultural assets, but must be differentiated to remain competitive with neighbouring areas. High-quality infrastructure, reliable transport, accommodation, and health services are essential, along with specialized offerings in outdoor, sports, and cultural tourism that reflect Western Macedonia's unique characteristics.
- Specially designed support (funding, taxation, fast track procedures) for investments in forementioned sectors can mobilise capital, entrepreneurship and the creation of a distinguished identity, which in turn will create new perspectives.

All these could attract young people, if also infrastructure as education, social housing, hospitals, nurseries, schools and of course local transportation will be enhanced and improved. As far as education is concerned, important are the schools which can offer certified skills, practically tested, with generous support from Just Transition Funds. Western Macedonia carries a disproportionate share of the burdens of the energy transition as the process is asymmetric (Vrontisi et al., 2024b) and compensating and supporting mechanisms should allocate funds accordingly.

However, no decision for all the above will have any result, without the participation of all stakeholders and especially those who are bearing all the consequences of the transition, that is local society with no exclusion (women and young people are mentioned as such groups (Schuster et al., 2023)), and those who potentially could invest in the region (public or private). In addition, decision is only the first step as fast implementation without bureaucratic obstacles should follow. Inaction is disastrous as not only delays the progress but also discourages and reveal anxieties, breaks up trust and expectations.

A feasible schedule for these actions could have a time horizon until 2035. More specifically, starting from year 2026, the strategic plan must be reviewed, redesigned with identification and quantification and exact (increased) funding allocation from EU. Data frailties should be avoided as incomplete or biased information could result to inefficient measures (Frantal et al., 2025). Next year decisions must be taken on a national and local level to guarantee the legal and financial framework of the actions and the large infrastructure projects must be launched. In 2028 the infrastructure must reach a final stage and financial support for specific private sector initiatives will be announced. In parallel all education mechanisms designated to enhance skills will be implemented. Also, community resilience has to be reinforced through information about the transition threats and opportunities to enhance their capability to adapt and to mobilize its resources, absorb shocks, and to develop new growth paths (Frantal et al., 2025). From 2030 until 2035, investments will be attracted, the regional identity will be established with the support of a continuous promotion and any infrastructure related to quality of life will reach a final implementation stage.

During all this period the 600MW modern thermoelectric power station Ptolemaida V will continue to operate, district heating will be supported as it improves quality of life and environment of the largest towns in the region. The reasons for the Ptolemaida V extended operation are more than regional (security of energy supply) and offers numerous direct and indirect jobs. Lignite phase-out does not mean ending abruptly whole industries but rather giving opportunities for far-reaching planning.

4 Conclusions

It is out of question that coal phase-out is necessary and is not debatable. However, understanding the existing regional economic paradigm and the economic history is of utmost importance not only for the just implementation of actions but also for the integration of the region dynamics, taking into consideration social and demographic forecasts. Space and time are significant factors (Heffron and McCauley, 2018) for economies in transition, especially when inequality problems are concerned, which result from a short-term timeframe and a top-down leadership model. Western Macedonia is characterised by stagnating economy, declining and ageing population, low skilled personnel, and the rhetoric of SWOT analysis (Ziouzios et al., 2021, Tranoulidis et al., 2022) cannot replace the disruption of socioeconomic fabric. The entire process should attempt to support rather than replace the social and cultural continuity of region. And as García-García et al. point out just energy transition is a "long-term technological and socio-economic process of structural change that affects the generation, distribution, storage and use of energy, [...] while also ensuring that the desired socioeconomic functions can be accomplished through decarbonized and renewable means of energy production and consumption, safeguarding social justice, equity and welfare" (García-García et al., 2020).

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PBL And IPD Methodologies In A Real-World BIM-Based Learning Scenario

Paula Gordo-Gregorio[a], Eloi Coloma Pico[b], Blanca Tejedor[a] and Joan-Marc Garces Sabaté[b]

[a] Department of Project and Construction Engineering, Group of Construction Research and Innovation (GRIC), Universitat Politècnica de Catalunya, Spain.
[b] Department of Architectural Technology, Group of Quality of Urban Life: Innovation, Sustainability and Social Engagement (QURBIS), Universitat Politècnica de Catalunya, Spain.

Abstract

This paper presents a multidisciplinary project designed to implement a Project-Based Learning (PBL) approach in construction education through the adoption of Integrated Project Delivery (IPD) methods within a real-world scenario using Building Information Modeling (BIM). The proposed methodology enables students to engage in collaborative, practice-oriented projects that simulate professional construction processes while addressing tangible challenges in construction management. The approach immerses students from conceptual planning to detailed implementation, emphasizing collaboration and coordination, and the use of digital construction technologies, including BIM. It supports comprehensive digitalization and management, integrating scheduling, cost estimation, and a sustainable approach. Considering the aforementioned aspects, this study examines the academic and pedagogical outcomes of students across four academic years (2021/2022–2024/2025) through a structured Likert-scale questionnaire. Results highlight that the integration of PBL and IPD notably increases student motivation, strengthens interdisciplinary coordination, and supports the development of practical BIM skills. At the same time, the methodology supports the development of competencies in areas such as cost and team management, client communication, and facility management within construction processes. However, aspects related to health and safety, sustainability and energy management require a more robust approach to fully benefit from its implementation.

Keywords: IPD; PBL; BIM; construction management; campus lab.

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1 Introduction

Compared to traditional classroom activities, projects tend to be more engaging and meaningful for students. In this context, the multidisciplinary project approach implemented in the Master's in BIM Management in a Spanish university, represents an innovative application of PBL, using a real-world scenario to enhance the educational experience. The aim of this paper is to assess the pedagogical outcomes of a PBL–IPD methodology in a BIM project. The paper highlights the implementation process over the past four years, involving engineering and architecture students working collaboratively on an onsite and online project. In addition, the study evaluates whether the integration of BIM tools enhances the effectiveness of PBL and identifies which areas of knowledge are most positively impacted.

1.1 Innovative Educational Strategies: PBL, BIM, and IPD in Campus Labs

PBL is an interactive, student-centered methodology in which learners engage in a subject by collaboratively addressing real-world problems. This process requires the development of multiple competencies, including self-directed learning and critical thinking (Kokotsaki et al., 2016).This project also introduces IPD, which is a collaborative approach to construction projects that unite all key stakeholders under a shared set of project goals (Viana et al., 2020). There is solid academic evidence supporting that implementing IPD in academic contexts fosters collaborative learning, teamwork, and prepares students for innovative methodologies that are shaping the construction industry (Pikas et al., 2025).

Additionally, BIM is an essential resource for training future construction managers, as it enables them to comprehend digital modelling across every stage of the project lifecycle (Klinc, 2016). Teaching BIM faces challenges like rigid curricula and steep learning curves for students while academic programs struggle to keep up with rapidly evolving industry practices (Taban et al., 2021). Along these lines, a Living Lab exemplifies innovation in real-world contexts involving active engagement, and when such a project uses a university facility as its primary setting —as is the case for this project— it is referred to as a Campus Lab (Vezzoli & Penin, 2006).

1.2 Existing experiences

Existing practices in construction education include the integration of IPD principles into PBL to prepare students for industry demands. In Peru, students work on real-world projects like construction schedules and 4D/5D BIM models (Gutierrez-Bucheli et al., 2016), fostering collaboration and innovation, while in Korea, the Constructivism Process uses PBL to enhance interdisciplinary BIM understanding across the lifecycle (Jin et al., 2020). Similarly, masters-programs integrating BIM-IPD have been developed to address gaps between university curricula and industry requirements (Patching et al., 2024). Additionally, this

project aligns with UPC initiatives like BIM4CLIMATE, reflecting a broader move toward BIM-based learning in a Campus Lab (Tejedor et al., 2024).

2 Methodology

2.1 Project implementation

The project is based on the hypothesis that the university has acquired a site in Barcelona to expand its facilities and would design a new "superblock" in the 22@BCN District 3. The project focuses on aligning stakeholder goals, enhancing decision-making, and promoting a multidisciplinary design process. Special focus is placed on sustainability and energy efficiency by encouraging strategies that reduce operational impact. To emphasize team management, the project incorporates "human factor" courses that aim to strengthen students' collaboration, communication, and coordination skills.

2.2 Questionnaire development

The questionnaire, divided into three parts, was deployed across students from the last four academic years. The first part collected socio-demographic information to contextualize the responses. The second part was focused on students' engagement and motivations in the PBL–IPD environment. The third part addressed perceived learning outcomes and open-ended questions were also included to gather feedback and suggestions. A previous pilot test with two students was conducted to validate content and functionality. Data analysis was performed using RStudio. After completing the descriptive analysis, Pearson's Chi-Square test was used to identify correlations among the variables (Sharpe, 2019).

3 Results and discussion

The tables show a stable demographic pattern, with engineers representing 31–32% less than architects and online students about 43–45% in the samples. The respondents' gender distribution fairly reflected the population, with women consistently representing a smaller percentage than men. The sample can be considered broadly representative, as the main deviation (5 percentage points) falls within the acceptable range for categorical variables and the distributions by field of study and modality remain consistent (Kotrlik & Higgins, 2001).

[3] The 22@ is an urban renewal area in Barcelona, created to transform industrial land into a hub for innovative activities.

Table 1 – Demographics of the respondents

Gender	Studies	Modality
Women: 38%	Engineering 31%	Online :45%
Men: 62%	Architecture 69%	In-Person: 55%

Source: Own elaboration

Table 2 – Demographics of the addressed population

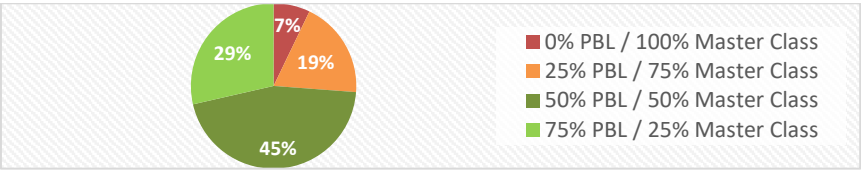
	2024	2023	2022	2021	Average
Men	58.82%	61.54%	51.92%	55.81%	57.02%
Women	41.18%	38.46%	48.08%	44.19%	42.98%
Online	45.10%	42.31%	44.23%	39.53%	42.79%
In-Person	54.90%	57.69%	55.77%	60.47%	57.21%
Architectur3e	64.71%	73.08%	71.15%	60.47%	67.35%
Engineering	35.29%	26.92%	28.85%	39.53%	32.65%

Source: Own elaboration

3.1 Learning Experience in PBL-IPD

Fig. 1 shows that around 74% of the students reported that at least 50% of the courses taken during their bachelor's degree were conducted through the PBL methodology, largely because architecture and engineering programs include a strong project-oriented component (MacLeod & van der Veen, 2020).

Fig. 5 - Distribution of Student Experience Between Project-Based Learning (PBL) and Traditional Courses



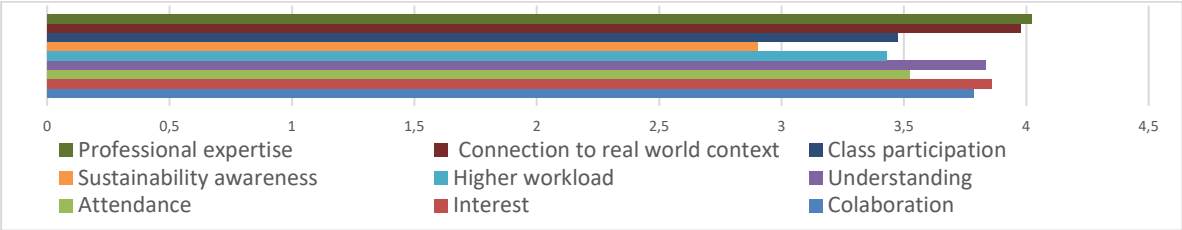
Source: Own elaboration

3.2 Perceived Impact and Benefits

Fig. 2 shows that students rated the acquisition of professional experience as the most positively impacted aspect of the PBL-IPD methodology using BIM (Rodrigues & Lindhard, 2021). In contrast, active class participation, and awareness of sustainability showed lower ratings. Overall, the results indicate that the methodology strongly supported students' professional development, interest, and collaborative learning, while having a moderate effect on participation and sustainability awareness. The approach was challenging, as

indicated by the reported increase in workload, a finding that aligns with previous analyses of PBL implementation (Herrero-de Lucas et al., 2022).

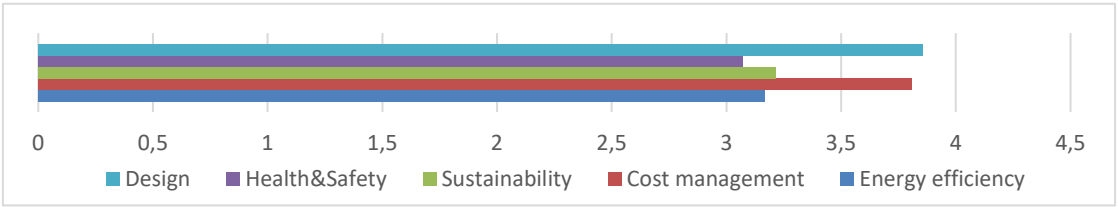
Fig. 6 - Students' assessment of the positive impact of the PBL-BIM methodology on different aspects



Source: Own elaboration

Furthermore, the analysis shows in Fig. 3 that students considered formal design and cost management as the areas where PBL most strongly enhanced value across disciplines. Cost management and design are often emphasized in BIM adoption for their immediate, tangible benefits (Raza et al., 2023). In contrast, sustainability or energy efficiency demand more detailed and precise BIM data to have a meaningful impact (Alvur et al., 2025). These aspects require more expertise, so early adoption focuses on "easier wins" like coordination and cost management, while sustainability or safety integrate more slowly (Pan et al., 2024; Waqar et al., 2024). Moreover, sustainability and energy analysis in BIM commonly relies on interoperability with separate assessment tools, which is still technically challenging (Meng et al., 2024). Due to these interoperability barriers, instructors also tend to treat them as conceptual add-ons rather than coupled BIM exercises, further diluting students' perception that BIM could be the main driver of this domain. This perception may arise from a gap between abstract, long-term sustainability competencies and the tangible BIM-PBL outputs (d'Escoffier et al., 2024). A viable solution entails incorporating sustainability-focused deliverables such as energy performance reports, or life-cycle analysis into BIM-PBL project requirements (Shen et al., 2012).

Fig. 7 - Perceived value of applying PBL-BIM to these disciplines

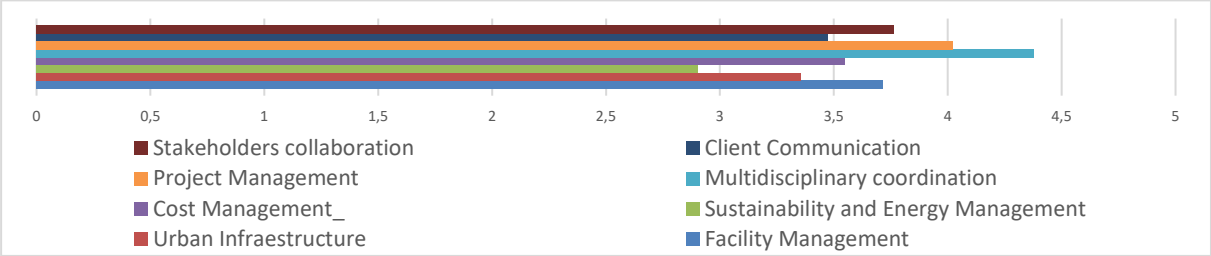


Source: Own elaboration

When focusing on understanding, in Fig. 4 students reported the greatest improvements in multidisciplinary coordination and project management—key components of the IPD methodology—whereas urban infrastructure and sustainability showed the lowest levels of perceived progress. Overall, the PBL-IPD-BIM methodology effectively enhances managerial

skills. Moreover, the results indicate improved understanding of facility management, likely strengthened by direct feedback from a facility manager during the courses, providing practical post-construction insights. By extension, this suggests that incorporating targeted feedback from sustainability experts could strengthen the integration of sustainability considerations within the PBL-BIM project (Nguyen & Adhikari, 2024).

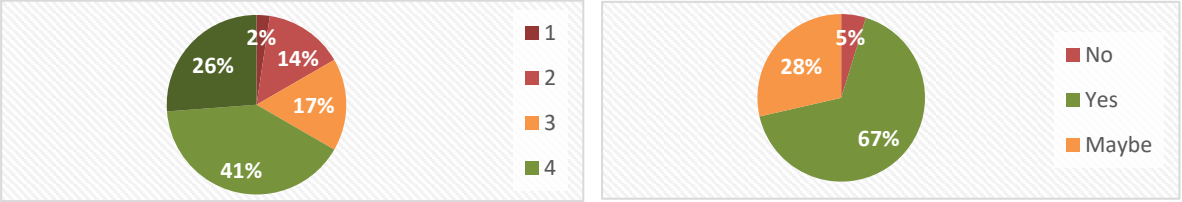
Fig. 8 - Areas of Enhanced Student Understanding Through the Course



Source: Own elaboration

Finally, Fig. 5 illustrates that 67% of students reported that collaborating within teams and analyzing members' skills during the course had a highly positive impact on their learning experience. In terms of the project's broader implications 67% believed it would have a significant positive impact on the city, while 28% were uncertain, and only 5% expressed scepticism about it. This suggests that most of students saw a real link between their project and the city, believing it could benefit the urban environment.

Fig. 9 – *a)* Perceived Impact of the Course's "Human Factor" *b* Students' Perceptions of the Project's Positive Impact on the City



Source: Own elaboration

3.3 Correlation analysis

Using the Chi-square test of independence, significant associations were found between gender and design ($\chi^2 = 10.23$, $p = 0.0059$). These results indicate that men tend to assign higher importance to design compared with women. In this context, women appear to assign similar importance to design as they do to other domains. Research studies support that men attribute more importance to design-related activities in project settings while women could have more ponderate interests (Patrick et al., 2021). Likewise, participants in the online modality showed greater interest in design ($\chi^2 = 7.27$, $p = 0.026$), which may suggest that, since the online modality attracts participants from diverse regions in some countries BIM

could still be more be closely associated with design than with data management areas such as health and safety or sustainability (Sanchís-Pedregosa et al., 2020). No statistically significant associations were observed for the other variables with gender and modality. The correlation analysis also revealed a significant association between field of study and professional expertise ($\chi^2 = 6.68$, $p = 0.035$), indicating that engineers tend to place greater importance on professional expertise than architects. A correlation was also observed between participants who rated the "human factor" courses highly and those who indicated that the PBL-IPD project fosters attendance ($\chi^2 = 20.41$, p-value = 0.00041), understanding ($\chi^2 = 15.53$, p-value = 0.0037), and class participation (χ^2 28.58, p-value = 9.499e-06). Students who value human factor courses are likely to appreciate the similar focus on collaborative learning found in PBL-IPD projects (Manzione et al., 2011). Furthermore, as the correlation analysis did not identify any other significant associations between the responses from online and in-person modalities, it implies that the project was perceived similarly regardless of the mode of instruction. This suggests that it has reached a point comparable to other post-pandemic studies in education, where efforts are made to achieve similar impact across online and on-site modalities (Mahmoud Saleh et al., 2023).

4 Limitations

Despite these positive outcomes, several limitations must be acknowledged. The analysis relied on self-reported data, which can introduce biases related to perception. Additionally, the study was conducted within a single institutional and cultural context, limiting the generalizability of the findings to other educational settings or regions. Future research could expand the sample size and explore diverse settings to enhance robustness and applicability.

5 Conclusions

This study demonstrates that integrating PBL and IPD methodologies into a BIM-based academic framework provides an effective pedagogical approach for construction education. It supported the acquisition of technical skills while reinforcing soft skills such as teamwork, communication or leadership. Students reported increased motivation, engagement, and perceived professional relevance, as the real-world scenario allowed them to connect theory with practice, even though online students had more limited access to the site. Students who valued "human factor" courses also appreciated the PBL-IPD project, highlighting how teamwork- and communication-focused curricula enhance engagement and collaboration.

The findings show that the IPD methodology improved learning outcomes, particularly in multidisciplinary coordination and project management, while gains in areas like sustainability or energy efficiency were more modest. This underscores the need for stronger curriculum integration, including explicit project deliverables targeting these areas. This could be also achieved by introducing sessions on these topics or by inviting field experts to

provide feedback on the projects. The analysis showed that men and online students rated design as more important than women, who valued design similarly to other domains. Students consistently noted a higher workload associated with the methodology. While this intensity contributed to deeper learning, it also underscores the importance of balancing academic rigor with workload management. Finally, the correlation analysis did not identify significant differences between online and face-to-face modalities, indicating that the project was perceived similarly regardless of the mode of instruction.

In conclusion, the PBL–IPD–BIM framework provides a valuable bridge between studies and professional practice, equipping students with digital, managerial, and collaborative skills demanded by the construction sector. To maximize its impact, future editions should strengthen the integration of sustainability and energy management.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Developing Boundary Crossing Skills By Participatory Tools From Systemic Co-Design To Accelerate The Energy Transition In Regional Experimentation Areas

Angelique Ruiter [a], Helleke Hendriks[b] and Sarah Elbert [c]

[a] Research Group CoDesign, Utrecht University of Applied Sciences, The Netherlands
[b] Research Group CoDesign, Utrecht University of Applied Sciences, The Netherlands
[c] Centre of Expertise Energy, Hanze University of Applied Sciences, The Netherlands

Abstract

The energy transition requires a workforce equipped with both hard and soft skills. However, current training often emphasizes technical competencies, resulting in skill mismatches, particularly among professionals transitioning from fossil fuel sectors. To support a just and inclusive transition, boundary spanning skills are essential for aligning diverse stakeholders and navigating complex systems. This study, conducted within the Sprong SURE consortium, explores how Mission Mapping and Systemic Constellations, two participatory systemic co-design tools, can contribute to the development of these competencies in regional energy transition experimentation areas. By engaging a diverse group of stakeholders, the tools facilitated the sharing of perspectives, the building of trust, and the development of systemic awareness. Thematic analysis and grounded theory revealed that these tools enhance communication, stakeholder alignment, and informal leadership across boundaries. Although these tools are currently used at the end of projects, the findings suggest that they could be even more effective if used earlier on to highlight system dynamics and blind spots. Future research should investigate the optimal timing and conditions for applying these tools to further empower professionals in the energy transition.

Keywords: boundary spanning; energy transition; soft skills; mission mapping; systemic constellations.

Ruiter, A., Hendriks, H., Elbert, S. (2026). Developing Boundary Crossing Skills By Participatory Tools From Systemic Co-Design To Accelerate The Energy Transition In Regional Experimentation Areas. In: Proceedings of the Second International Conference on Sustainable Energy Education (SEED 2026): Research Papers. Utrecht, the Netherlands, 24-25 March 2026. DOI: https://doi.org/10.48544/89b87ed9-ab41-4f06-ba29-78fd276db20c.

1 Introduction

Employees in the energy transition sector, now and in the future, require a combination of hard and soft skills. Key hard skills may include engineering, data analysis, programming, and knowledge of renewable energy systems (Lyu and Liu et al., 2021; IRENA, 2023). Soft skills, such as communication, adaptability and collaboration have proven essential skills for a successful energy transition (Costa et al., 2025), but do not always address the supply-and-demand of the market (Ramsarup et al., 2024). Skill mismatches are, therefore, common, particularly among workers transitioning from fossil fuel sectors with an emphasis on hard skills (Greenspon and Raimi, 2024). A just and inclusive transition, however, requires targeted training and workforce development strategies that align with regional needs, including stakeholder alignment, and evolving energy technologies (Briggs et al., 2022; IRENA, 2023). Knowing this, it seems crucial that the soft skills of employees working in the energy transition include the ability to work across the boundaries (or differences) of the different areas of expertise needed to accelerate the energy transition. These boundary spanning skills will enable employees to align stakeholders and processes, but they will need to be facilitated by the organizations in which the employees work and by the curricula of educators aiming to bring the next energy transition professionals to the market (Cash et al., 2003).

The Sprong SURE (SUstainable cities and REgions) consortium, comprising Utrecht University of Applied Sciences, Hanze University of Applied Sciences and many organisations and local municipalities in the Netherlands, aims to strengthen the connection between technical possibilities and the social domain by taking a neighbourhood-centred approach. The consortium works together with citizens, municipalities and other partners on the energy transition in regional experimentation areas. Using examples from regional experimentation areas within Sprong SURE, we have looked at how systemic co-design (or participatory design) tools strengthen participants' boundary spanning skills for working in the energy transition.

2 Theoretical Framework

Sustainability transitions, especially in the energy sector, are characterized by complex systems that require not only technical innovation but also institutional changes, and social acceptance (Geels, 2002; Markard et al., 2012; Ystrom, 2021). To navigate these complexities, boundary spanners, and boundary spanning skills, play a crucial role by linking actors across organizational, disciplinary, and cultural boundaries (Ystrom, 2021). As Warbroek et al. (2023) argue, boundary-spanning skills are not optional but necessary for the implementation and success of energy transitions, particularly in institutional environments where multiple actors must coordinate under conditions of uncertainty.

Boundary-spanning skills (e.g. De Groot et al., 2023; Keszey, 2018; Stephens et al., 2024; Merindol, 2024) encompass a range of competencies and roles, including:

(1) connecting stakeholders,

(2) facilitating communication,

(3) bridging knowledge gaps,

(4) stimulating innovation and

(5) promoting trust.

Shnaydar et al. (2021) state that to carry out the type of institutional and organizational change that an energy transition requires, more attention and resources should be dedicated to intra-organizational boundary spanning. Developing boundary-spanning skills is critical for driving successful energy transitions. These competencies enable professionals to bridge organizational silos, reconcile conflicting logics, and facilitate collaborative problem-solving (Carlile, 2004; Warbroek et al., 2023). Boundary spanners support the translation of sustainability goals into practical innovations by fostering experimentation, cross-functional collaboration, and organizational learning (Brown & Wyatt, 2010). Operating across system levels, they help mediate tensions, align stakeholders, and navigate complex power dynamics with political insight and legitimacy (Geels & Schot, 2007). Importantly, they also contribute to more inclusive transitions by engaging diverse actors in the process.

Professionals can develop boundary-spanning skills through structured yet flexible environments, such as living labs, that encourage reflection, experimentation, and openness to complexity (van Geenhuizen, 2018). These learning environments help individuals build relational and political competencies, such as empathy, trust-building, and strategic awareness, enabling them to navigate (inter-)organizational power dynamics and foster cross-boundary collaboration (Ystrom et al., 2023).

In the Sprong SURE experimentation areas we used Mission Mapping and Systemic Constellations, as tools for learning boundary spanning skills. Mission Mapping enables participants to construct a shared "mission landscape" that visually aggregates individual activities into common territories, fostering a shared language and enhancing collective sensemaking across multidisciplinary networks (Kuijper et al., 2024). Systemic constellations (Birkenkrahe, 2008; Burchardt, 2015; Levin-Keitel, 2016; Scholtens et al., 2021), on the other hand, function as shared representations that promote communication and understanding between different systems and stakeholders (Levin-Keitel, 2016; Scholtens et al., 2021). Both allow for anchoring learning in practice and equip (upcoming) professionals with cognitive and relational boundary spanning capabilities (Möller et al., 2022).

Below we will investigate how participatory tools from systemic co-design can contribute to (the development of) boundary spanning skills.

3 Research Method

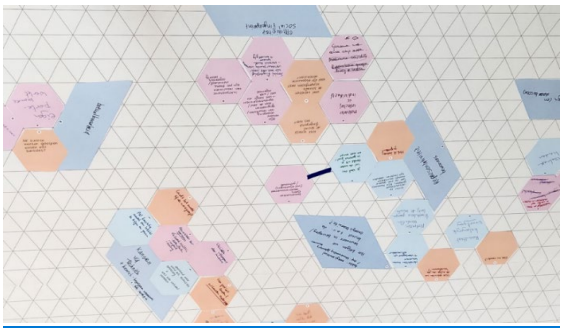
In the context of the SPRONG Sure program, we organized structured evaluation sessions across five regional experimentation areas in the Netherlands, each area differing in its characteristics, ranging from urban neighbourhoods facing metropolitan challenges to small rural villages in the north of The Netherlands.

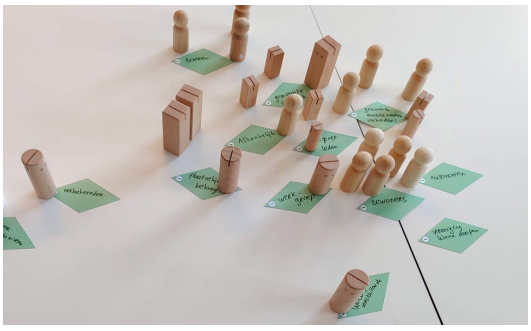
In these sessions, we engaged a diverse group of stakeholders, including i.e. local government officials, project managers, residents, and academic researchers. The sessions were designed to assess the outcomes of local energy transition projects using the two participatory tools from systemic co-design as described above: Mission Mapping and Systemic Constellations.

Mission mapping intends to provide participants with a larger sense of 'the whole' system', by mapping the variety of activities in an experimentation area, utilizing the analogy of map making. Using mission mapping the participants gathered everyone's learning moments, insights and questions by interviewing each other, which were then collectively clustered into thematic "islands" with appropriate titles, see figure 1. These clusters were visually mapped to show relationships, connections and interdependencies.

Systemic Constellations intend to provide insight into overt or hidden dynamics, relations and tensions within the stakeholder system of the experimental area. Participants defined all the (involved and desired) stakeholders and then positioned them in relation to each other. After visualizing the current situation, they then set up the desired configuration of stakeholders and identified the necessary actions to achieve it, see figure 1.

Fig. 1 – Example of a mission mapping landscape (left) and a systemic constellation (right)





To analyse the boundary-spanning skills, we applied an initial thematic analysis to identify recurring patterns in how professionals navigate organizational boundaries and collaborate across sectors. After applying an inductive approach themes emerged directly from the data.

We used grounded theory to develop a theoretical idea of how boundary-spanning competencies can be developed and enacted over time through the use of the tools.

4 Results

The organized sessions using these tools yielded the following results/insights, categorized according to the five boundary spanning skills and roles.

4.1 Connecting stakeholders

As part of the mission mapping process, participants interviewed each other in small groups of two or three (all from different stakeholder backgrounds). These conversations offered deeper insights into each other's perspectives and underlying interests. One participant from Oldeholtpade noted, "You only know what people think when you engage in conversation with them." For example, during one session, residents came to understand why certain governmental processes take much longer than expected. Initially, there was a clear mismatch in the perception of time: residents often expected visible results within six months, while the municipality was still in the decision-making phase. The session helped clarify that residents need short-term progress to stay engaged, whereas municipalities must navigate complex procedures, which—if rushed—can lead to project failure and declining trust.

The use of systemic constellations further helped participants visualise the range of stakeholders involved and the often-invisible web of relationships between them. This increased their awareness of systemic complexity and highlighted the importance of collaboration. In Soest, for instance, the session revealed the pivotal role of social brokers from welfare organisations and the indispensable involvement of housing associations. As one participant put it, "Oh it now becomes visible how big the role of the welfare organisation actually was, that really gives me an idea for the next neighbourhood." These tools facilitated a deeper level of interpersonal engagement and supported the exchange of diverse viewpoints, forming a foundation for bridging existing knowledge gaps and identifying opportunities for improved cooperation based on shared interests and mutual goals.

4.2 Facilitating communication

Facilitation of communication between stakeholders clearly became visible during the mission map on one of the experimentation areas where an independent project leader was hired. It was discussed how he was hired by the municipality, physically embedded himself in the neighbourhood, working from a garage unit and meeting residents in their own spaces. By addressing practical needs with small, visible actions (e.g., radiator foil, mail slot fixes), he built trust and opened informal spaces for dialogue. This hands-on, approachable presence effectively bridged institutional goals and community realities. systemic constellations

further highlighted, by placing the project leader in a central position, how crucial such a proactive, locally embedded figure was for building engagement and transferring leadership to residents.

The skill of facilitating communication was further highlighted in mission mapping exercises in the North of The Netherlands, which helped stakeholders develop a shared language. Clustering individual insights revealed common concerns beneath different expressions. As one participant noted, "You have this issue, I have that issue, but we actually mean the same thing." Through naming these clusters, such as the shared term "long lines" to describe the need for stable, long-term planning, participants achieved mutual understanding and clearer alignment. Systemic constellations further underscored how shared vocabulary strengthens dialogue and future collaboration, as the need to have the municipality closer to the citizens was collaboratively identified as a gap caused by unclear messaging from the municipality.

4.3 Knowledge gaps

One of the results of the sessions with the participatory tools was that various questions about a local experimentation area in the North of Netherlands were uncovered, which none of the stakeholders had previously considered. Further research is necessary to address these gaps in knowledge. For example, during the mission mapping session in Oldeholtpade, the following question arose: "To what extent are residents genuinely involved, and does the initiative accurately represent them?" Another question was: "What is needed for transferability to other municipalities?". The difficulty of answering was also apparent in Soest, where a participant referred to a failed initiative to share experiences with other municipalities during the session and stated that "municipalities don't seem to want to learn from each other at all". Another point that arose during the session in Oldeholtpade was the statement that: "knowledge of technical possibilities alone is not enough. Understanding why it is necessary is also important." During the session in Paddepoel, Groningen, one of the questions raised: "What could be the role of the young inhabitants?" They often appear to be less involved in sustainable development, partly because of their short stay in the neighbourhood.

The participatory tools extracted identifiable relevant topics from the complex material of the energy transition. By doing this with the various stakeholders present, it was possible to immediately discuss the most relevant issues for those involved. One of the participants in Soest expressed his appreciation for the tools: "Using the Mission Mapping and Constellations tools is like 'pulling apart a ball of spaghetti'".

4.4 Stimulating innovation

The Mission Mapping and systemic constellation session enabled the articulation of shared goals and strategic alignment among the diverse stakeholders, facilitating the identification

of synergies and gaps in the collective ambition. In an experimentation area in Amsterdam, for instance, residents and the municipality discovered that current government policy had provoked resistance among residents because its implementation was perceived as neo-colonial. There were outsiders, municipality employees who did not live in Amsterdam, who decided who should receive subsidies and how they should be spent. The importance of enabling residents to make their own decisions also became clear from an example in the province of Utrecht. One of the participants in the session stated: 'Don't involve citizens; make them feel involved. Make them feel like owners." Another example that highlighted the importance of giving residents a significant role came from the north of the Netherlands. They found that, while the local council is familiar with the maps and technical aspects of the neighbourhood, the residents know the physical and social environment best and can identify potential opportunities. Relying on information from residents has proved beneficial.

The tool encouraged stakeholders to move beyond siloed thinking and engage in co-created dialogue, which is vital for developing innovative solutions to systemic challenges. The method supports relational innovation: innovation that emerges through better understanding of each other's context, values, and goals, not just through technological advancement.

Another insight that could be important for future innovation emerged from one of the sessions in the north of the Netherlands: people often find it difficult to borrow money, even though this is frequently a prerequisite for financing the energy transition. Finding solutions to this issue could be a valuable contribution to innovations in the energy transition.

4.5 Promoting trust

In all experimental regions, the mission maps showed that trust (or the lack thereof) was an important factor in the energy transition, especially in neighbourhoods with urban issues. This refers not only to residents' lack of trust in the government, but also to governmental bodies' scepticism towards citizen-led initiatives. This was further highlighted by the distance shown between residents and municipality in the systemic constellations. Consider, for example, all the rules and regulations that residents and small businesses must adhere to receive subsidies. This issue was particularly evident in Amsterdam and Soest. In the latter, one participant noted: "We also need to give them a voice." Furthermore, concerns about trust extended to relationships with commercial companies and fellow residents. During the session in Soest, it became clear that the energy transition offers opportunities to rebuild trust: 'There is a golden opportunity to resolve two issues: the energy transition and rebuilding trust in institutions. Trust can be restored by implementing the energy transition process effectively.".

The Mission Mapping sessions revealed the extent of the existing mistrust and helped to articulate these underlying tensions. In Amsterdam in particular, major mutual challenges appeared to be present, partly shaped by the colonial past. While it was already known that residents had little trust in the government, the reasons for this and how residents perceived the government's documentation requirements for initiatives as a lack of trust were less well understood prior to the Mission Mapping sessions.

5 Discussion and Conclusion

This study shows that mission mapping and systemic constellations support learning boundary spanning skills in experimentation areas. These tools increase awareness of differing interests, foster a shared language, and help build trust and collaboration. Through direct experience of diverging perspectives, participants gain a better understanding of the value of making needs and assumptions explicit.

The tools are particularly effective in developing skills such as stakeholder connection and communication facilitation, while also influencing trust-building over time. As boundary-spanning roles often emerge informally through active engagement rather than formal appointment (Yström et al., 2023), such tools can accelerate learning in practice.

Currently, these tools are mainly used at the end of projects. We suggest that systemic constellations in particular hold potential when applied early on, as they make system dynamics, roles, and blind spots visible from the start.

For future research, it is key to explore when and how these tools are most effective. Further research could, for example, focus on applying the mission map and constellations building on existing knowledge e.g. through the social fingerprint of neighbourhoods (Elbert en Wiekens, 2024), a methodology that captures Individual attitudes, socio-historical factors (e.g., trust in the municipality), social environment (e.g., whether neighbours know each other), and participation willingness, so as to incorporate perspective making and taking from a historical viewpoint as well.

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Sprong - SIA

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Repositioning Attitudes In Engineering Education: Systemic Design For Professional Development And Pedagogical Innovation

Ivo Vrouwe[a] and Gijsbert Korevaar[b]

[a] Kenniscentrum Talentontwikkeling, Rotterdam University of Applied Sciences, the Netherlands
[b] Center of Expertise HR Tech, Rotterdam University of Applied Sciences, the Netherlands

Abstract

This paper explores how attitudes and values can be integrated as essential components of engineering education, where energy education is embedded within the curriculum. The study introduces a small-scale, design-based professional development track grounded in systemic design. Using the 3.2.1.SPRINT framework and the Attitude-Centered Educational Design toolkit, educators participated in collaborative design sessions aimed at aligning pedagogical choices with desired student attitudes and learning goals. The research was conducted at Rotterdam University of Applied Sciences and evaluated through structured focus groups. Findings highlight the importance of co-creation, modular experimentation, and context-sensitive tools in fostering pedagogical innovation. While the results suggest that systemic design and participatory methods can support sustainable educational change, they should be interpreted within the limitations of an exploratory and context-specific study.

Keywords: engineering education; systemic design; design-based research; professional development; participatory design.

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1 Introduction

Teaching in higher education today involves more than transmitting disciplinary content. As Biesta (2022) argues, education must address not only the curriculum but also the student as an active participant and the world in which learning is situated. This perspective calls for a shift from purely technical instruction toward approaches that integrate ethical reasoning, collaboration, and personal agency.

At Rotterdam University of Applied Sciences, energy education is not a separate program but an integral part of engineering education. This study responds to the challenge of embedding sustainability and energy transition within engineering curricula by focusing on attitudes and values as leading elements of educational design. These challenges are closely linked to societal transitions and the United Nations Sustainable Development Goals (UN, 2015), which call for education that prepares students to act responsibly and contribute to global sustainability.

The research adopts a design-based approach, implemented on a small scale and evaluated through structured focus groups. Rather than aiming for statistical generalization, the study seeks to generate insights into how systemic design principles can support pedagogical innovation. To guide this exploration, the study examines which design elements and collaborative processes enable educators to align pedagogical choices with desired student attitudes and learning goals.

Two theoretical frameworks underpin this work. Shulman's concept of Pedagogical Content Knowledge (1986) emphasizes the integration of disciplinary expertise with pedagogical insight, while the OECD's SKAV model (2019) extends this view by including skills, knowledge, attitudes, and values. Together, these frameworks inform the development of the 3.2.1.SPRINT track and the Attitude-Centered Educational Design toolkit, which are introduced later in this paper and aim to help educators align teaching practices with desired student attitudes and learning goals.

Despite growing recognition of the need for integrative approaches, engineering education has traditionally emphasized technical mastery and lecture-based teaching, as noted by Felder et al. (2000), Mills et al. (2003), and more recent reviews by Lavado-Anguera et al. (2024) and Sukackė et al. (2022). These studies highlight structural and cultural barriers that inhibit pedagogical innovation, reinforcing the urgency of exploring new strategies for sustainable educational change.

2 Systemic Design Framework as the Foundation for Change

Societal challenges such as sustainability and energy transition demand creative responses that acknowledge their inherent complexity. Systemic design offers a promising approach by

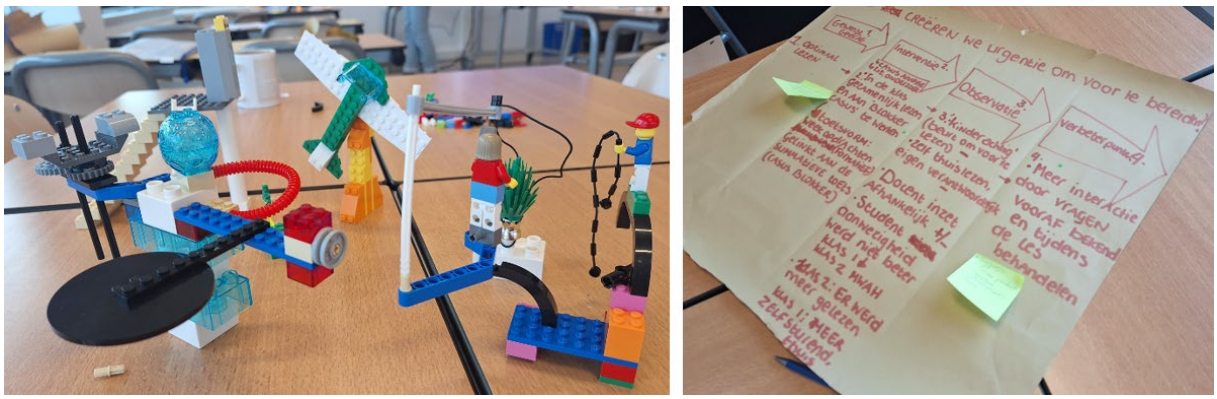
integrating systems thinking and design thinking to navigate such challenges through co-creation, participatory design, and iterative experimentation. Rather than attempting large-scale reform, systemic design emphasizes small, strategic interventions that generate insights and inform future steps in long-term transition processes (Kijima & Jones, 2018).

In this study, systemic design principles are applied to the development of a professional development track and a supporting toolkit aimed at fostering pedagogical innovation in engineering education. The effectiveness of both the track and the toolkit is evaluated using a structured focus group method, capturing participant reflections and identifying opportunities for sustainable educational change.

2.1 3.2.1.SPRINT

The 3.2.1.SPRINT professional development track was designed to foster sustainable pedagogical change by combining systemic design principles with collaborative experimentation. The track was implemented twice at Rotterdam University of Applied Sciences with groups of approximately 20 students and educators from engineering programs. Each track consisted of three in-class sessions and two practice-based intervals. The sessions were structured according to the Design Council's Systemic Design Framework (2021), which led to three stages: Orientation and Exploration (session 1), Design and Prototyping (session 2), and Catalysing Change (session 3). This structure provided a clear process for navigating complex educational challenges through iterative and participatory design.

Fig. 1 – Examples of artefacts as made during Orientation and Exploration (session 1)



Source: Vrouwe (2025)

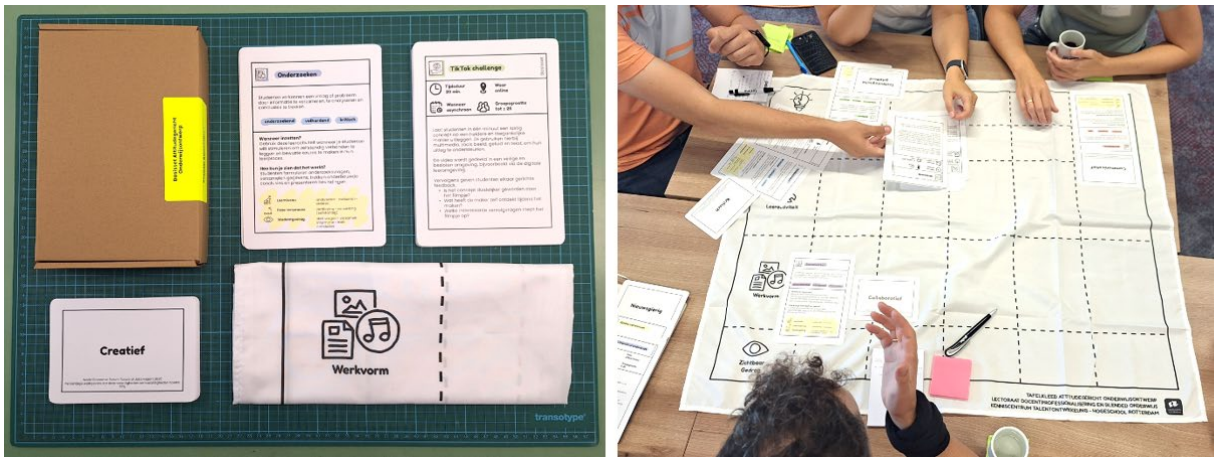
The first session focused on exploring perspectives and challenges using creative tools such as LEGO and flipcharts to stimulate dialogue and idea generation (Fig. 1). Educators were encouraged to frame opportunities in relation to societal challenges, including sustainability and energy transition. The second session introduced the Attitude-Centered Educational Design toolkit (Fig. 2), enabling participants to co-create lesson and course designs with

students, teachers, and advisors. The final session emphasized sustaining change and sharing outcomes. Between sessions, participants tested prototypes in their own teaching practice, using student feedback to refine their designs. This modular approach allowed educators to experiment with small-scale innovations while maintaining relevance to their existing teaching context.

2.2 Attitude-Centered Educational Design Toolkit

The Attitude-Centered Educational Design (ACED) toolkit was developed to help educators design lessons that begin with desired student attitudes and learning goals rather than focusing solely on content. Central to the toolkit is the ACED-BASE, a visual textile canvas used in collaborative design sessions to align pedagogical choices with intended behavioural and cognitive outcomes (Fig. 2). Participants worked with structured card sets to map learning activities, work forms, target attitudes, and observable student behaviours, fostering intentional alignment between design intentions and outcomes.

Fig. 2 – Attitude-Centered Educational Design Toolkit: Content and Use



Source: Vrouwe (2025)

The toolkit operationalizes two theoretical frameworks. Shulman's concept of Pedagogical Content Knowledge (1986) ensures integration of disciplinary expertise with pedagogical strategies, while the OECD's SKAV model (2019) extends this view by including skills, knowledge, attitudes, and values. By combining these frameworks, the toolkit supports educators in moving beyond technical instruction toward pedagogical practices that foster ethical awareness, agency, and transdisciplinary collaboration.

The design process took place in an informal 'Third Space' (Bhabha, 1994), encouraging co-creation between educators, students, and advisors and giving student voice a meaningful role in shaping learning environments.

2.3 Evaluation via Focus Group

The evaluation of the 3.2.1.SPRINT professionalization track was conducted using a structured focus group method, aligned with Morgan's (2009) emphasis on purposeful group interaction to generate rich qualitative insights. Participants engaged in facilitated discussions supported by visual tools such as flipcharts and canvases, creating a dynamic environment for shared reflection. Data were captured using a horizontal table format that documented raw observations (quotes, behaviours, notes), interpretations linked to core educational questions, and actionable suggestions for improvement. To prioritize follow-up, each action was ranked by perceived value and implementation effort. This approach reflects Morgan's criteria for effective focus group research (i.e. range, specificity, depth, and personal context) by enabling participants to explore diverse perspectives while grounding their input in concrete educational experiences.

3 From Reflection to Transformation in Teaching Practice

The 3.2.1.SPRINT track and the Attitude-Centered Educational Design toolkit were applied across multiple professional development activities within engineering education at Rotterdam University of Applied Sciences. This chapter presents insights from a structured focus group evaluation, highlighting how attitudes, both of educators and students, can be repositioned as central elements in educational design.

3.1 Repositioning Attitudes in Educational Design

The focus group revealed that attitudes, both of educators and students, play a central role in the effectiveness of educational design. Teachers who openly acknowledged trying something new were perceived by students as more approachable, which increased engagement and collaboration. This suggests that vulnerability and transparency can be strategic tools for building trust and fostering a culture of learning. However, some educators reported challenges in connecting with students due to generational or cultural gaps, highlighting the need for perspective-taking and relational learning.

These findings align with three conceptual clusters:

- **Pedagogical goals:** conceptual understanding, critical reflection, systems thinking
- **Attitudes & values:** ethical reasoning, responsibility, personal agency
- **Collaboration & process:** co-creation, participatory design, stakeholder engagement

Designing for these clusters can help educators move beyond content delivery toward future-oriented education that supports adaptability and co-agency.

3.2 Toolkit Use and Reflections

Participants responded positively to the Attitude-Centered Educational Design toolkit, particularly when its language was accessible and practice-oriented. Abstract terms such as 'student-centered' were perceived as barriers, while concrete phrases like 'expanding your repertoire' increased clarity and commitment. The toolkit was most effective when supporting small-scale experimentation, allowing educators to test individual work forms within existing lessons rather than redesigning entire courses.

Reflections emphasized the value of modular design and peer feedback. Teachers appreciated opportunities for observation and structured reflection, suggesting that the toolkit should be embedded in a broader culture of collaborative professional learning. These insights reinforce the importance of future-oriented clusters such as adaptability, societal contribution, and transdisciplinary thinking, which align with SDG-related educational goals.

3.3 Tension and Opportunities

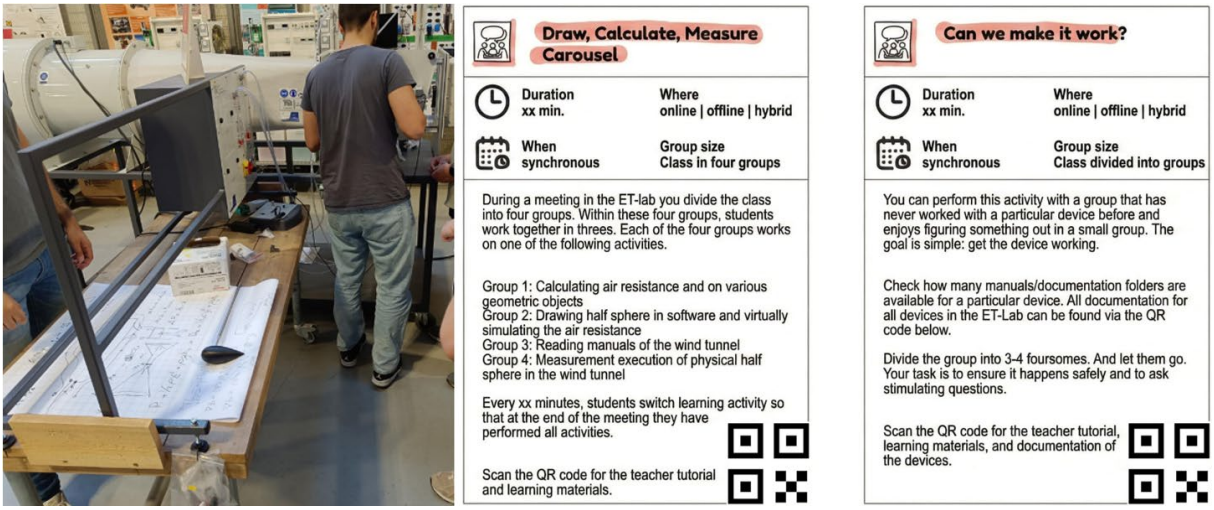
Several tensions emerged, particularly around the concept of professionalization, which some participants described as an 'itchy word.' Educators expressed a preference for autonomy and informal, practice-based development over formalized training. This indicates a need to reframe professional growth as a shared, embedded responsibility rather than an external mandate.

Despite these tensions, the focus group identified clear opportunities for transformation. There was strong support for designing education that prepares students not only for current industry needs but also for uncertain futures. Teachers recognized the importance of didactic flexibility and student agency in shaping sustainable, future-proof learning environments. These findings suggest that systemic design and attitude-centered approaches can help bridge the gap between institutional goals and societal challenges.

4 Discussion

The findings demonstrate that systemic design and attitude-centered approaches can help educators move beyond content delivery toward pedagogical practices that foster ethical awareness, agency, and collaboration. By focusing on attitudes and values, educators were able to design learning experiences that resonate with societal challenges such as sustainability and energy transition. This shift reflects a growing need for engineering education to prepare students not only for technical tasks but also for responsible participation in complex socio-technical systems.

Fig. 3 – NRG-PACK, a context-specific extension pack to the ACED Toolkit



Source: Vrouwe (2025)

An important insight from the focus group is that language and context matter. Educators responded positively when tools and materials were framed in discipline-sensitive terms and connected to their professional identity. The development of the NRG-PACK illustrates this principle (Fig. 3). As an extension of the Attitude-Centered Educational Design toolkit, the NRG-PACK provides work form cards tailored to energy-related contexts, such as wind tunnel and hydrogen experiments, physical modelling and testing. This adaptation shows how attitude-centered design can be contextualized to strengthen relevance for energy education without creating separate programs.

While these results are promising, they should be interpreted within the limitations of a small-scale, design-based study. The findings are context-specific and exploratory, which means they offer directions rather than definitive solutions. Future research should examine how these principles can be scaled across disciplines and institutions and explore how student perspectives can be more fully integrated into the design and evaluation of educational innovation.

5 Conclusions

This study demonstrates that repositioning attitudes and values in engineering education is both necessary and feasible when supported by structured, participatory design processes. The 3.2.1.SPRINT track and the Attitude-Centered Educational Design toolkit provided educators with practical tools to reflect on their teaching practices, co-create lesson designs, and experiment with contextually relevant strategies. By starting from attitudes and values rather than disciplinary content alone, educators were able to design learning experiences that align with societal challenges such as sustainability and energy transition.

The integration of attitude-based educational design and modular work forms enabled teachers to move beyond traditional content delivery and engage with relational, ethical, and future-oriented dimensions of learning. The development of the NRG-PACK illustrates how these principles can be adapted to strengthen relevance for energy education within engineering programs, without creating separate tracks. This contextualization reinforces the potential of systemic design to bridge institutional goals and disciplinary realities.

To scale this approach, Rotterdam University of Applied Sciences is developing a Center for Teaching and Learning that will embed these principles into institutional practice. The center will support learning communities, participatory design, and co-creation as core strategies to address transition challenges in education. By connecting bottom-up initiatives with institutional support, systemic design offers a promising pathway for sustainable, system-wide transformation in higher education. Future research should explore how this model can be adapted across disciplines and institutions and examine how student perspectives can be more fully integrated into the design and evaluation of educational innovation.

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Preliminary Evaluation Of Sustainability Living Lab Performance In The Utrecht Region

Chantal van der Zanden[a] **and Martijn Rietbergen**[a]

[a] Centre of Expertise Smart Sustainable Cities, Hogeschool Utrecht, The Netherlands

Abstract

This paper presents a preliminary evaluation of three living labs within the Healthy and Sustainable Living Environment Utrecht Knowledge Consortium (GeLUK): KTC Zegveld, Hoefkwartier, and Utrecht Science Park. These living labs play a central role in advancing energy transition and energy education within the Utrecht region. Using the Framework for Evaluating living labs (Bouwma et al., n.d.), the study assesses twelve qualities across seven key dimensions, including design and implementation, collaboration, and outcomes and impact. The findings indicate clear differences in structure and operation among the three living labs. KTC Zegveld demonstrates strong practice-oriented innovation and financial continuity; USP focuses on research-driven experimentation within an academic setting, while Hoefkwartier emphasizes student-led and community-based collaboration. Common strengths across the labs include effective stakeholder engagement, strong regional and educational networks, and the ability to inspire participation. However, all three face challenges in systematically measuring long-term effects, such as behavioural change and knowledge adoption among stakeholders. These insights underline the need for improved monitoring mechanisms and shared evaluation practices to enhance accountability and impact assessment. The results of this preliminary study provide valuable input for the further development and embedding of the living labs within the GeLUK consortium and contribute to the broader discussion on regional cooperation in sustainability transitions.

Keywords: living labs; energy transition, regional cooperation.

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1 Introduction

Living labs have evolved into an essential research method for exploring and addressing complex societal challenges, particularly in the areas of health and urban sustainability. Such living labs also play a pivotal role in the GeLUK project in the Utrecht Region. GeLUK stands for Healthy and Sustainable Living Environment Utrecht Knowledge Consortium. The project is gradually progressing, so is the development of the living labs. With the project running for two years, the aim of this paper is to carry out a preliminary evaluation of the performance of three (out of ten) living labs within the GeLUK project in which energy transition and energy education play an important part.

1.1 What are living labs?

Although, a commonly accepted definition of living lab does not exist in academic literature, there is consensus about several characteristics of living labs. Kris and van Bueren (2017) distinguish nine characteristics in four dimensions of living labs: 1. Aims, 2. Activities, 3. Participants, 4. Context. The nine characteristics are: living labs aim at innovation (1), are aimed at formal learning for replication (2) and are aimed at increasing urban sustainability, in case of urban living labs (3). Living labs focus on development of a product / service (4), that are developed via a cocreation process (5) and through several iterations (6). Participants include public actors, private actors, users and knowledge institutes (7) and all actors have decision making power (8). Finally, living lab activities take place in real life context (9). In short, a living lab can be defined as both a physical or geographically bounded environment and a collaborative methodology wherein diverse stakeholders co-create, experiment with, and test innovations in a real-life setting (Maas et al., 2017; Schliwa & McCormick, 2016, as cited in Maas et al., 2017).

1.2 Impacts of living labs

A substantial body of literature highlights the impact of such living labs. These labs create environments that enable new ways of working through learning, experimentation, and innovation (Fuglesang et al., 2021). Living labs are evolving from grassroots initiatives, typically situated at the periphery of higher education institutions, into more independent organizations (Tercanli & Jongbloed, 2022). They have been shown to drive innovation and experimentation in sustainability, translating into tangible solutions for economic, environmental, and social challenges (Lakatos et al., 2024). Living labs also frequently produce valuable learning outcomes, including stakeholder capacity building, network formation, knowledge diffusion, and reflective learning processes (Bhatta et al., 2025). Nevertheless, some studies highlight limitations, noting that the economic value generated

by living labs is rarely identifiable and seldom reported. Furthermore, Paskaleva and Cooper (2021) indicate that there is limited evidence that living labs consistently deliver innovations.

2 Living labs in the GeLUK project

2.1 Introducing the GeLUK project

The Healthy and Sustainable Living Environment Utrecht Knowledge Consortium (GeLUK) project is a multi-sectoral, multi-disciplinary, and multi-level collaboration within the Utrecht region. As part of an investment from the Dutch National Growth Fund, the project's primary objective is to accelerate the transition toward a healthy and sustainable living environment. The core of GeLUK consists of a consortium of six partners, comprising public-private partnerships (PPPs) linked to educational institutions, business representatives, and a secondary school (see www.wijzijngeluk.nl). The mission of the consortium is to provide companies in the Utrecht region, particularly Small and Medium-sized Enterprises (SMEs), with the necessary tools to address sustainability challenges. This is achieved by: 1. Facilitating Lifelong Learning for the current workforce; 2. Equipping new talent (students) with future-proof skills; 3. Accelerating the sustainable transition by engaging students in real-life challenges and 4. Stimulating the development and implementation of sustainability innovations, via living labs.

2.2 Living labs in the GeLUK project

The living labs are a central component of the GeLUK ecosystem. They are physical locations across the province of Utrecht where industry, education, and research converge to work on sustainability innovations and practice-based education in real-life settings. These labs function as 1) Testbeds for innovations related to sustainability and a healthy living environment; 2) Context-rich learning environments where students from secondary to higher education and professionals can learn and experiment and 3) Hubs for collaboration among businesses (especially SMEs), government bodies, knowledge institutions, and residents.

2.3 Living labs under investigation

This study evaluates three living labs which have been selected for this purpose because energy transition and energy education are an overarching theme**:** KTC Zegveld, Hoefkwartier and Utrecht Science Park. KTC Zegveld is an experimental farm that hosts two l*iving labs:* the High-Water Farm and the Extensive Peat Meadow Revenue Model. Additionally, KTC is setting up an energy park to investigate sustainable energy generation and storage in peat meadow areas and share the gained knowledge in their new demo location. Hoefkwartier is a newly developed district in the city of Amersfoort. The challenge

is to transform Hoefkwartier into a healthy and sustainable neighbourhood. The student-built *Celciushouse* acts as a community centre for the neighbourhood where residents can meet and learn about sustainable energy solutions and researchers and students test home management systems. At Utrecht Science Park, extensive efforts are being made to transform the Utrecht Science Park into a healthy and sustainable district. To achieve this, Utrecht University has established the Centre for Living Labs which currently manages eleven active living labs on campus on themes such as climate adaptation, carbon neutrality, circularity, and biodiversity. Research is conducted and concepts are tested in real-life situations to stimulate innovation. Two notable campus living labs with a focus on sustainable energy are the *biomeiler* which releases 100 megawatts of heat each year (to be used by the adjacent farm) and *lumifield*, where students investigate the conversion and storage of solar energy.

3 Method

The 'framework for evaluating living labs' by Bouwma et al. (n.d) presents a structured methodology for evaluating the performance of living labs (LLs), particularly those addressing complex societal transitions. The framework was used in this study to gain an informed perspective on the different living labs' functioning and to identify areas for improvement. The framework identifies seven key components, which are further broken down into twelve distinct "qualities." These qualities represent the crucial functional areas that collaborating parties jointly shape and that determine the overall effectiveness of the living lab. These seven key components and 12 qualities are described in the following table.

Table 5: Key components and qualities for evaluating living labs.

Design and implementation:

1. Being Relevant: Assesses whether the LL addresses significant transition challenges and provides relevant solutions for stakeholders.
2. Inventive: is it able to properly organize the resources (time, money, knowledge, network) needed to keep the living lab running?

Collaboration

3. Being connected: is the living lab in contact with other actors (outside the living lab) and other initiatives working on the same transition challenge?
4. Being collaborative: are mutual relationships good and is there shared ownership of ambitions, processes and results?

Action

5. Being practical: is it possible to undertake concrete steps and activities to keep the partners motivated and involved?
6. Being responsible for action: Do activities undertaken consider quality, potential side effects, long-term effects, and compromises between different stakeholder values?

Image and reputation

7. Begin known: Do activities and results communicate (appropriately) and thus reach relevant target groups with the right information?
8. Being recognized: Do strategic communication efforts be made, and is the living lab recognized as a relevant player in the discussion surrounding the transition challenge?

Products and services

9. Being productive: Evaluates whether the living lab succeeds in delivering concrete products and services that stakeholders can use.
10. Being inspiring: Does the living lab engage people in living lab activities and motivate target groups to try out and implement new tools and practices?

Outcomes and impact

11. Sorting effects: What are the intended and unintended social, economic, and ecological outcomes and effects of the living lab?
12. Being adaptive: Do insights from monitoring and evaluation translate into adaptive actions to adjust aspects of the living lab that could be improved?

The framework also provides a set of key evaluation questions for each of the twelve qualities (see Bouwma et al., n.d). These questions guided a semi-structured interview with the coordinators of the three living labs in which energy transition and energy education are an important theme for education and research. The interviews typically took 90 minutes and were transcribed with speech to text software for further analysis. The key components and qualities of the three living labs were compared, analyzed, and reported in section 4.

4 Results

1. Being Relevant KTC has a clearly defined and shared understanding of its transition challenge: to generate knowledge and create perspective for farmers in the peat meadow area, while considering climate and environmental objectives. To maintain relevance for agricultural stakeholders, research is intentionally kept close to practical. At USP, all projects are linked to sustainability or healthy living and answer research questions which concern both Utrecht University and broader society. The campus labs are especially created for those questions which are difficult to answer without a physical place to test ideas and hypotheses. In contrast to KTC, USP does not present itself as one living lab, but rather sees the campus as a place where research in living labs, or campus labs, takes place. The living lab in Hoefkwartier was initiated with a focus on energy transition because of the risk of net congestion in this new neighbourhood. A relevant topic in the Utrecht region, however, as there was no clear covenant or ownership from the start of the project, it was not possible to keep this as the main theme of the living lab. The living lab therefore switched its focus to more social issues and now focuses on healthy living and liveability in the neighbourhood. There are plans to repurpose the *Celciushouse* soon and use it as a testing ground for 72 hours

without energy. If a clear and focused understanding of the transition challenge is not agreed upon by the stakeholders at the start of the lab, this can cause issues further on in the project.

2. Being Inventive KTC was established with initial capital from various public and private entities. Its ongoing funding is secured through a combination of subsidized projects and commercial business operations, such as contract research and revenue from milk sales. This business-oriented approach enables KTC to generate the necessary resources for equipment and personnel, thus ensuring a sound financial basis for ongoing projects. This is in stark contrast to both USP and Hoefkwartier, where students and researchers work on subsidized or student projects of limited time and budget which provides challenges for the continuation. In the case of the latter two living labs, it helps to have a solid foundation as the Centre for Living Labs at USP to keep the living lab running.

3. Being Connected All three living labs mention that they are well included in various diverse networks consisting of business, local) government and education, who work on similar transition challenges or that can support and further their work. It is good to note that all three living labs have a strong connection to higher and vocational education institutions: KTC with Wageningen University, USP with Utrecht University and Hogeschool Utrecht and Hoefkwartier with Hogeschool Utrecht and ROC Midden Nederland. These connections are mostly formed by the physical location of the living labs, employer of the coordinators, and the origin of the living lab.

4. Being Collaborative A sense of shared ownership and motivated participants are crucial for a successful lab. At KTC, this is fostered through general members' meetings, where KTC's strategic direction is discussed, and input from practice is gathered to collectively determine the main strategic lines. The Centre for Living Labs assists the living labs at USP to collaborate with partners, come to a common understanding and resolve issues in case they arise. The coordinator of Hoefkwartier mentions that the lack of ownership makes it difficult to work from a common understanding and build on something bigger. To combat this, the student projects work with an estafette method in which every student group is asked at the end of their project to provide at least two questions for the next group of students to work on. This way, the projects can still be built on each other and work together despite limited budget and resources.

5. Being Practical Whereas KTC is distinctly practice-oriented and its activities are directly linked to real-world farming and therefore perceived as realistic and useful by visiting agriculturalists, the living labs at USP and Hoefkwartier work more closely with education. In the case of USP, this is mainly with academic researchers and students whereas projects in Hoefkwartier are often carried out with students from vocational and higher professional education. As a result, their output primarily consists of scholarly publications or advisory

reports rather than actual prototypes or physical output. This is not always in line with the requests of stakeholders, but what is expected from the educational programmes.

6. Being Responsible The long-term effects on the environment, society, and the economy form the core of KTC's mission. Long-term research and monitoring of measurement series are crucial for this purpose. The other two living labs take these effects into account but are aware that the nature of living labs means that it can be difficult to predict long-term outcomes and effects. Because of the dependency on subsidies, for the other two living labs, the focus shifts during different phases of the labs and projects therein. At USP, living labs can scale up once the experimental phase is successful, whereas Hoefkwartier focuses on the small hurdles which can be tackled short-term to lead to long-term outcomes and success.

7. Being Known All three living labs inform stakeholders through meetings, publications in professional journals, and media coverage from regional news outlets. KTC has a yearly meeting with their paying members to inform them of ongoing and future projects, as well as finances. For USP, it can sometimes be a challenge to keep parties who are not directly involved in the projects informed about the results and challenges. The plan is to organize guided tours or open days to communicate the results to a wider audience. For Hoefkwartier, it helps that the *Celciushouse* is a recognizable staple in the neighbourhood which welcomes the residents and brings the various stakeholders together.

8. Being Recognized The recognition of living labs differs greatly for the three labs in this case study. For KTC, recognition is exemplified by visits from high-profile individuals, such as a government minister or national TV outlets, which underscore the credibility and utility of the living lab. USP, on the other hand, is mostly recognized within Utrecht University and other companies and institutions on campus, which contributes an open culture to living labs as a fruitful way of research on campus. In Hoefkwartier, recognition is more visible on municipal level, where the living lab is an active participant and voice in urban planning in Amersfoort.

9. Being Productive KTC is highly productive in delivering validated data for applications like calculation models. Regarding knowledge dissemination and the actual adoption of practices by visitors, however, productivity is more difficult to quantify. Many groups visit the facilities, but there is no systematic measurement of the impact on the visitors' agricultural practices, which is identified as an area for improvement. At USP, the outputs differ greatly between each living lab, the output comes not only in the form of research reports but also in innovative designs (e.g. the biomeiler built on campus by students) or floating gardens at Heidelberglaan which are visible to the public and data gathered from citizen science. As Hoefkwartier mostly works with student projects, output comes mainly in the form of research or advice reports, which is often a required study outcome. Because budgets are limited to further developing outcomes and prototypes, the living lab has become more

selective in starting new student projects because many ideas and projects have already been shelved for the time being.

10. Being Inspiring According to the coordinators, their living labs are successful in motivating their participants and stakeholders to participate in research and activities and share inspiring and interesting results. Nevertheless, this is a subjective take, as the actual impact of the living labs on visitors and stakeholders is not objectively monitored. It is unclear what visitors or stakeholders incorporate in their own practices from the information and insights gathered via the living labs.

11. Sorting Effects At KTC, the effects fall very clearly in the threefold distinction. The research is always based on reducing emissions and enhancing biodiversity whilst maintaining the social identity of farmers and their family business and keeping these practices economically viable. At USP and Hoefkwartier, the effects differ per project and whereas there is often a clear projective from the start, the focus on the outcome can differ during the project. An example from Hoefkwartier is their project on *plandelen* (walking through the neighbourhood together and picking up trash), which started from an environmental standpoint but contributes to social cohesion between residents and even yields technical results, as the plan is now to collect data during the activities and contribute to a citizen science project to make the neighbourhood cleaner. It is possible that due to its cooperation with mainly vocational and professional student projects, Checkwriter has more flexibility to accustom their projects and assignments accordingly. In contrast to KTC and USP, which are more directly driven by academic research.

12. Being Adaptive The coordinators agree that being adaptive is one of the most crucial aspects of a successful living lab. Evaluation and monitoring are a primary part of every project, and the projects allow for adjustments based on lessons learned. The role of steering groups and other stakeholders plays a big part in this regard. All three living labs questioned have experience with shifting focus or even abandoning projects or plans when it turns out that they do not work.

5 Conclusions

This paper conducted a preliminary evaluation of the performance of three living labs within the GeLUK project: KTC Zegveld, Hoefkwartier, and Utrecht Science Park. The evaluation employed the 'Framework for evaluating living labs' and highlights significant structural differences between the evaluated living labs, particularly regarding financial inventiveness and operational focus. Despite operational and structural variances, the living labs exhibit shared strengths, particularly in collaboration and connectivity. All three labs are well integrated into relevant networks and maintain strong institutional connections with higher and vocational education which results in continuous projects and research which provide

energy education to the students and contribute to the energy transition in the Utrecht region. A shared challenge across all three living labs lies in the measurement of concrete impact and productivity regarding knowledge transfer and behavioural change, this is also in line with the literature of Paskaleva and Cooper, and an area of improvement for the final two years of the GeLUK project. This research paper therefore serves as a prelude to further the quantitative and qualitative evaluation of living labs withing the GeLUK project. Future research will include the other living labs and not only question coordinators but also participants and residents. This is done to prepare the living labs for sustainable embedding within the organisations of the consortium partners and contribute to broader discussion on regional cooperation in living labs.

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Developing Training And Educational Facility And Accelerating Innovation For Heat Transition Through Future Heat Heroes Project

Aulia Tirtamarina[a] and Carleen van Hengel[a]

[a] Entrance/System Integration, Hanze, Netherlands

Abstract

A key component of the energy transition in the Netherlands is the heat transition: heating homes and buildings using sustainable energy sources. The ambition in the Dutch climate agreement (Government of the Netherlands, 2019) is to make 1.5 million homes sustainable by 2030, whereby 80.000 home equivalents per year must be connected to district heating, from 2025 to 2030. For this, professionals need to be trained, along with building training and innovation infrastructure, creating education and training programs, and developing innovation and knowledge through learning communities and a knowledge center. In order to ensure a complete coverage of education, innovation and knowledge sharing, the consortium of Future Heat Heroes (FHH) project will consult with stakeholders on needs and demands of the field of district heating, as well as innovation requirements. Based on these findings educational products and physical testing infrastructure will be developed. Educational pilots will be tested, as well as learning communities developed around joint stakeholder and educational institutions projects. To ensure future exchange of knowledge and needs, as well as continuous updating of education an innovation ecosystem for the heat transition will be created. The preliminary conclusions indicate that concise educational products are needed to keep up with the developments of regulations and the technology surrounding district heating. Developing students' logical and critical thinking will be crucial, as these skills enable them to adapt to ongoing developments in the sector. Furthermore, the stakeholders identify 5th Generation District Heating (5GDH) as the future of district heating in the Netherlands. Nevertheless, the 3rd Generation District Heating (3GDH), characterized by high-temperature systems, will continue to play a role in areas with poor building insulation. Consequently, the educational product should encompass the full spectrum of district heating technologies, from 3rd through 5th generation systems, to adequately prepare students for diverse practical contexts.

Keywords: district heating; infrastructure; education; innovation.

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1 Introduction

To reduce greenhouse gas emissions in the Netherlands, the Dutch climate agreement targets a 49% reduction by 2030 compared to 1990 levels. Roughly 1.5 million homes must become more sustainable, with roughly 80,000 home equivalents per year connected to district heating between 2025 and 2030, resulting in a 40 PJ heating demand by 2030 (Government of the Netherlands, 2019).

However, rollout of district heating faces challenges. First, the shortage of technical personnel—since 2021, over 70,000 vacancies persist in the technical sector (UWV, 2025). Finding and training future professionals is essential for realizing the heat transition. Secondly, adoption of district heating depends on policy, technology, and socio-economic factors (Cowley et al., 2025). High upfront costs for district heating connectivity consistently emerge as major barriers to adoption (Nava-Guerrero et al., 2021). Policy interventions such as subsidies and low-cost financing can shape socio-economic behaviour. Technological improvements that enhance district heating efficiency also help mitigate these challenges. Understanding technological, economic, social, and institutional drivers is therefore crucial to accelerate district heating deployment (Cowley et al., 2025).

Climate change reduces heating demand per area while increasing cooling needs (Aebischer et al., 2007). District heating and cooling (DHC) is among the most sustainable urban solutions (Buffa et al., 2020). Fifth-generation DHC (5G DHC) concept, with consumers becoming prosumers, is widely discussed and researched but scarcely implemented.

Next-generation district heating (DH) networks require specialized skills. While traditional expertise in planning and infrastructure remains relevant, new technologies—bidirectional networks, low-temperature systems, renewable integration—demand updated competencies. Moreover, even existing competencies must be adapted and applied appropriately within the context of modern DH systems.

Comprehensive expertise is required across all phases of district heating: planning, development, construction, operational management. The knowledge and skills can be divided into three themes:

- Heat networks
- Building installations
- Connection and integration between heat networks and building installations

The themes are multidisciplinary and encompasses not only technical dimensions but also digital, legal, social, and economic aspects tailored specifically to district heating.

Legal expertise is required in relation to the Dutch Collective Heating Act, but also contractual frameworks, ownership models and governance structures for DH systems, as well as quality of service standards, and identification of legal bottlenecks are needed.

From a financial perspective, high upfront capital costs, long payback periods, and economic risks make district heating investments less attractive (Čižman and Staničić, 2024). Therefore, economic expertise must explore market models, business models, cost structures, pricing mechanisms, long-term affordability along with peer-to-peer (P2P) heat exchange, and cooperative ownership models.

From the social perspective, issues such as public mistrust, limited awareness, and concerns over costs and service appear to be barriers to adoption for DHC (Čižman and Staničić, 2024). Social dimensions involve the human and societal implications of DH deployment, emphasizing community participation, stakeholder engagement, trust-building, and transparency. This calls for cooperative models and social innovations (Caramizaru and Uihlein, 2020; Onencan and de Koning, 2024).

From a technical perspective, the focus is on system design—including temperature regimes, flow management, thermal storage, subnetwork configurations, and substations—as well as building and household-level installations such as heat interface units (HIUs). Additionally techniques for integrating renewable energy sources into DH systems are also critical. Given the importance of measurement, monitoring, and control in DH operations, the digital domain plays a pivotal role, encompassing system optimization, data security, and privacy.

To cultivate these competencies, targeted educational initiatives are essential. In addition to traditional educational pathways, retraining and reskilling of existing personnel is imperative, given the evolving nature of district heating expertise and the growing demand of skilled professionals. Education must be closely aligned with ongoing technological and sectoral developments, necessitating practical environments for education, training, innovation development. Collaboration across educational tiers is essential to ensure comprehensive coverage of workforce requirements and additionally stimulate interest in the DH systems field.

Awareness should be cultivated from an early age, including within primary and secondary education (PE and SE). Life Long Learning (LLL) initiatives can support retraining and upskilling efforts, while vocational education and training (VET) and higher professional education (HE) provide structured learning pathways. A coordinated effort between educational institutions and industry stakeholders is vital to ensure that curricula reflect technological advancements and labour market demands.

Future Heat Heroes (FHH) project was established to address these challenges. It aims to ensure complete coverage of educating competent future heat professionals, as well as allow

for innovation possibilities and insurance of continuation of knowledge and developments. FHH will develop educational modules and expand training capacity (including hands-on experience) for the (future) professionals, while also fostering continuous knowledge exchange between academic institutions and industry actors in the domain of modern DH networks.

2 Methodological approach

2.1 Needs assessment and demand analysis

Part of schooling competent heat professionals is knowing what skills and knowledge these need to have. In creating this project stakeholder groups were identified and partners were found to participate in FHH in most categories (see table 1).

Table 1 – Stakeholders Future Heat Heroes*

Stakeholder (type)	**Project partner**
Vocational and Higher professional education institutes (VET, HE)	Hanze, Alfa, Noorderpoort
Life Long Learning (LLL) enterprises	Alfa, HanzePRO, DNA Next
Public engagement organizations	Energiehub050, STO
DH operators	WarmteStad
Installation companies	Koninklijke Oosterhof Holman (KOH), deGroot, *Homij*
Consultancy firms	Witteveen+Bos (W+B)
Engineering and system design companies	W+B, KOH, deGroot
Human capital companies	Abiant, Technicum
Public sector entities (municipality / government)	None (WarmteStad is municipality owned)
Development companies	TBC

* Partners in cursive are support only

VET (MBO in Dutch), HE (HBO in Dutch) and LLL (LLO in Dutch) institutes will be responsible for education, innovation and reskilling and upskilling professionals. Public engagement companies for awareness and outreach. WarmteStad is a DH operator, which operates and plans the expansion of the DH in the city of Groningen. It is a municipality owned company. KOH is an infrastructure company, which also lays piping for DH, deGroot works on building installations for industrial companies, whilst W+B is a consultancy and design company. Abiant is an employment company, which also utilizes LLL education to train its agency

workers. TBC develops and installs Heat Interface Units (HIU) for consumers of district heating.

The domain of DH systems—from planning through installation and operational management—extends beyond technical and digital considerations and also encompass legal, economic, and social dimensions.

DH operators must navigate not only the technical and digital aspects of system design and operation, but also contractual frameworks, community acceptance, and viable business models. For consultancy and development firms, a comprehensive understanding of financial feasibility and legal constraints is essential. Even installation and innovation companies working on for instance HIUs must consider household-level comfort and acceptable temperature regimes, thereby engaging with social acceptance and behavioural aspects of households.

To identify the knowledge and skills needed, both currently and expected in the future, interviews with project partners have been conducted.

2.2 Requirements for innovation

Due to the changing setting of district heating (temperature regimes, prosumers, etc.) needs the possibilities for innovation and knowledge development for the heat transition are being inventoried in this project via interviews and brainstorm sessions. The sessions are first with the researchers form the different disciplines (technical, economical, juridical, social and digital) and then together with the partners and other related stakeholders to ensure as complete as possible coverage.

Around these questions learning communities will be developed. Lecturers, researchers, students, project partners and other interested stakeholders formulate joint practice-oriented innovation projects to develop innovation and knowledge that is necessary for the heat transition. Annually, 200 students will be involved in these innovation development projects, either through learning communities, graduation projects or a combination of these two. Lecturers, researchers and local partners will incorporate the knowledge, approaches, and learning experiences into their own practice, follow-up projects, and the development of educational programs.

2.3 Complimentary alignment different kinds of education and educational pilots

Based on the needs assessment and demand analysis, educational products are being developed across the three themes (district heating networks, building-related installations, and connection and integration between DH networks and building-related installations) and five disciplines (engineering, legal, social, economy and digitalization). VET, HE and LLL

institutes will do this in close cooperation with one another. Inventory of existing educational products (and their topicality and quality) is being taken. Skills mapping will be executed to analyse gaps between the required skills and current skills among professionals. This will lead to a development plan of educational products.

The developed educational products will be implemented via a total of 10 modules, 2 online courses, 4 pilots courses at the HE, 6 pilots courses at the VET, 4 pilots courses at the SE and 6 pilots courses at the LLL. These will be evaluated and improved over the course of the project, together with integrating the products into curricula and application/adoption by trainers in knowledge platforms and learning communities.

2.4 Human capital

Project partner Abiant will conduct a recruitment campaign. For this the results of the needs assessment and demand analysis will be used. Since Abiant also trains its agency workers to fit the requirements of the employer the developed LLO education will be used here.

2.5 Test facilities

To facilitate physical training and innovation development infrastructure is being developed within FHH. The infrastructure will be used as a flexible testing ground for heat, where new knowledge is not only developed at the component level, but also field simulation at DH system level are possible. A digital twin (digital copy) of all heat infrastructure at Entrance, the center of expertise energy from Hanze university of applied sciences, is also being developed in this project, enabling not only physical but also digital (applied) examination in the form of simulations. Researchers, lecturers, students and companies will use the infrastructure at Entrance to accelerate innovations within the themes of heat transition.

The digital and physical infrastructure consists of:

- A Prosumer Heat Hub. The district heating infrastructure of Entrance will both consume and produce energy.
- A bidirectional connection between the district heating network at Entrance and the district heating network of WarmteStad. With bidirectional connections Entrance can both consume from and feed heat energy into the district heating network.
- An expansion and upgrade of the test facility for building related heat installations at Entrance (HeatHouse).
- Connections between all heat infrastructure of Entrance (heat productions, HeatHouse, heat buffers, the office buildings of Entrance as heat consumers).
- An overarching system data infrastructure.

2.6 Anticipated challenges

One of the biggest anticipated challenges within FHH is maintaining stakeholder involvement. For the educational institutes, time is allocated to development of education and pilot testing. However for the industry partners core operational priorities might logically take precedence over engagement with this project and future engagement as well. Furthermore, developments in district heating are uncertain and fluid, therefore the need remains to be alert and flexible in both innovation and education.

2.7 Continuation of knowledge and education

To tackle future developments in district heating and stakeholder engagement FHH will establish and expand the organizational capacity of the innovation ecosystem for the heat transition. Other ecosystems (such as those surrounding Energiehub050, DNA Next, Alfa, etc.) and organizations that all successfully play a role in training the workforce and the business community will be actively connected.

The main activities for development of the knowledge center are:

- Organizational development for a knowledge center for heat transition
- Organizing knowledge exchange with market parties through panel discussions
- Recruitment campaign to gain interest in the heating sector
- Professional learning for educators

3 Preliminary Findings

Started in May 2025, the Future Heat Heroes project is still in its early stages. Several interviews with project partners and other stakeholders were conducted to identify current training needs of companies, and the knowledge and skills required for future developments. Additionally, an inventory of existing educational products was made.

According to the stakeholders one of the important challenges of this project is attracting new students to train for district heating projects. On the one hand, students are looking for job security, while the growth of district heating is unstable. In 2023 there were 22.000 new home equivalents connected to district heating. This number has dropped to 12.000 new connections in 2024 (RVO, 2025). This is much lower than the ambition to connect 80.000 home equivalents to district heating per year, as was set in the climate agreement (2019). On the other hand, the new Dutch Collective Heat Act (Kamerstukken, 2024) gives a better framework for developing heat grids to achieve this ambition, and therefore educating professionals now is necessary. A recruitment campaign is therefore a crucial activity in FHH.

The stakeholders also expect that regulations and the technology surrounding district heating will continue to develop rapidly in the near future. This poses another challenge for

this project. Training students to think logical and critical will be crucial so that the future heat professional can adapt to these developments. In addition, stakeholders stated the need for short educational product to keep up with the developments.

Furthermore, stakeholders identify 5th Generation District Heating (5GDH) as the future of district heating in the Netherlands. There are three main drivers behind its development. First, limited availability of heat source in the Netherlands. High-temperature (above 70˚ C) heat sources are scarce in the Netherlands. Low- and very-low-temperature district heating align better with the availability of heat sources. In addition, operating at lower distribution temperatures will lead to lower heat loss. Second, shortage of skilled technical workers. Traditional high- and medium-temperature rely on steel pipes, which require highly specialized skills and lengthy training. In contrast, low- and very-low-temperature networks use PVC pipes. A few days of training is sufficient to learn how to work with PVC. The deployment of district heating with PVC pipe networks is faster and less dependent on scarce expertise. Third, 5GDH systems allow customers to act as prosumers, customers who can also sometimes produce heat. This flexibility has the potential to increase public acceptance and engagement with district heating. However, the traditional high temperature district heating will remain needed in areas with poor building insulation.

In addition, the stakeholders identify several innovation and knowledge needs for district heating projects. The next step is to conduct gap analyses between existing educational products and the training, knowledge and skills needs. Once this analysis is complete (expected in February 2026) educational products can be developed and incorporated into curricula.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Is Separate Data On The Energy Consumption Of The Individual Departments Accessible? A Living Lab Approach To Energy Awareness At Universities

Bettina Minder[a] and Ute Klotz[a]

[a] Lucerne University of Applied Sciences and Arts / School of Computer Science and Information Technology, Switzerland

Abstract

The question is, can separate university units provide data on their energy consumption to raise energy awareness and foster energy efficiency with students and employees? Campus cafeterias often demonstrate this approach by displaying the carbon emissions of daily menu options. However, individual university units face challenges because data on energy use, recycling, waste, and similar metrics is typically held by the central university administration rather than by the departments themselves. We report on the journey of finding energy data for the Lucerne School of Computer Science & Information Technology (CS&IT), which aims to create an energy-efficient campus but struggles to access and display detailed energy information. Thus this paper addresses question: What are suitable strategies that help effectively overcoming common challenges, recurring issues, and tensions in obtaining quality energy data to promote internal energy efficiently? Our analysis is based on a research journey conducted within our own department. The paper draws on empirical data of the department we are employed as lecturers and researchers.

Keywords: case study; open data; smart building; campus; living lab; engagement; transparency.

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1 Introduction

The high energy efficiency standard of the wooden skyscrapers demonstrates the department's commitment to becoming fully CO_2-neutral by 2030. We are less confident when it comes to reducing energy consumption in everyday university life. But becoming carbon neutral requires exactly that: Reducing consumption. Research has shown that smart displays providing real-time consumption can help raise awareness for energy consumption, promote energy-saving behaviour and increase energy efficiency. In the age of data-driven decision-making, data transparency can act as a powerful motivator. However, data in bigger organisations such as universities are usually not readily available and may be of poor quality– e.g. not organised in meaningful categories and with faulty information. And as a public institution, we typically face barriers related to data management, privacy and lack of resources. It may also be the case that due to lack of resources and past experiences, projects encounter certain unwillingness or inertia. Often, projects are over before they have even begun. This paper therefore asks: 'What are suitable strategies that help effectively overcoming common challenges, recurring issues, and tensions in obtaining quality energy data to promote internal energy efficiency?' Our analysis is based on a research journey conducted within our own department.

1.1 Behavioural Change and Universities

Behavioural research suggests that awareness of energy use is a precondition for sustainable action (Cotton et al. 2016). König and Evans recommend seeing a shift in awareness and values as perquisite for lifestyle choices (König & Evans, 2013). Feedback mechanisms — such as smart meters and indoor displays have shown to reduce consumption in some cases – but only when accompanied by appropriate social measures (Schultz et al. 2015). Smart meters in private homes for example do not lead to energy savings per se. What matters is the rigor with which people engage in energy-saving behaviour (Henn et al. 2019). The authors highlight the importance of effectively check consumption and install saving energy measures: not only must people make appropriate behavioural choices, but they must also rigorously implement these choices. Often this requires a change in behaviour, which demanding especially when 'they are time-consuming or inconvenient, receive no social support, cost money, or require physical efforts (ibid:75). And these 'costs' are more likely to be overcome when a person embodies a high level of environmental attitude. Despite the mentioned reservations, displays are therefore acknowledged as a first step and requirement for an increased awareness and energy efficiency. This understanding of 'displays as a first step' can also be used as a blueprint leading to increased energy efficiency at universities. Providing energy consumption data in an accessible way can promote behaviour reflection among users.

When it comes to sustainable development and transformation of social behaviour, universities have been assigned a decisive role: As early as 2011 the European Union outlined a vision for the role of universities in transforming cities. The report highlights that universities public bodies and private sectors most operate together in a new creative mood (Committee of Regions, 2011). In this context universities are seen as living labs where energy use awareness can be trained, and social learning processes can contribute to sustainable development (Evans et al., 2015).

1.2 Smart monitoring and energy efficiency

Today smart building technology and sensors enable real-time monitoring – e.g. for private homes and businesses. However, research shows a need for a certain level of motivation in a person's environmental attitude for smart displays to become effective (Göltz, 2017). Also, smart-meter-based feedback do not work equally well for everyone because they require continuous engagement – e.g. registering to receive feedback; consulting the feedback device; switching off appliances; and potentially using some of them less frequently (e.g., dishwashers).' (Henn et al., 2019:74). To achieve some impact, smart displays need to be accurately implemented.

For university application a major challenge consists in accessing data in good quality and finding meaningful ways to display energy consumption data (Henn et al., 2019). Despite technological feasibility challenges therefore remain also on a technical and institutional level. This may potentially include disapproval and disengagement from stakeholders with different priorities – such as those responsible for operational excellence, strategic planning, or budgeting. We have little knowledge of how to meaningfully overcome these challenges. However, to implement the decisive role that the EU assigned to universities as early as 2011, we need a clearer understanding of suitable strategies. This understanding is essential for overcoming the common challenges and tensions in securing high-quality energy data. The paper draws on empirical data of the CS&IT where energy efficient building operation allows nearly 100% carbon dioxin free operation. But where more detailed data on wider energy consumption of the individual department is difficult to attain.

2 Methodology

As finding suitable ways to overcome challenges when trying to obtain quality energy data to promote internal energy efficiency is poorly researched phenomena a case-based study appeared best suited for this purpose as it allows investigation of "(…) a contemporary phenomenon within its real-life context, when the boundaries between the phenomenon and the context are not evident" (Yin, 2003). Our objective was to select a case providing in-depth insights into successful development processes in a single case study approach (Voss et al., 2002). We draw on data from the CS&IT. Despite appearing to follow the principle of

convenience, as it is the authors' current workplace (Langrish, 1993), it serves as an exemplary energy aware and innovative campus.

Our focus lies on identifying rich data contributing to a more comprehensive understanding of how we can better access quality energy consumption data. And how we can influence data management decisions in favour of quality data for separate university units.

2.1 Data collection

Data collection relies firstly on field notes from direct interventions in the department's context. This is combined with interviews, a survey, and a review of materials such as email correspondence. Both field notes and interviews will be central to the study, as they provide rich material around motives for prevailing challenges in attaining quality energy data and dominant protocols concerning data management decision making. Table 1 provides an overview over the information gained through different data collection method.

Table 1 - Overview over the information gained through different data collection method

Method	Assumptions as to how the methods contributes to answering the RQ
Field notes (on situative interventions)	Insights into common challenges, recurring issues, and tensions in acquiring quality energy data, along with examples of successful moments
Material (Mails)	Recurring patterns, challenges and strategies in the communication around the use of smart displays to raise energy awareness and around available data
1 Survey	Background information about students' awareness of an energy efficient campus; their preferred way interacting or seeing energy data; potential influence of smart displays
3 Interviews	Past experiences with similar projects in general and with smart displays in particular, and identification of main challenges and ways to sideline them

One of the authors is directly involved in the interventions and will report with field notes on the process of accessing quality energy consumption data: The realisation that typically data was not being collected for this purpose and there was little intention of doing so, formed the starting point for the interventions: We became curious how we might change existing approaches. The selection of people we contacted for information was based on expertise of the people but also on the network of the two researchers. Three interviews will be led with experts for sustainability and campus infrastructure. Their status as experts was based on job profile and experience gained from years of practical and/or academic experience. (Weiss, 1995:17). For the direct interventions, we did not disclose our research intentions, as our aim was to observe authentic university practices without influencing participants' behaviour. All statements will be kept anonymous and will be expressed in objective terms to minimise

potential harm to those involved. Direct citation is only used, were necessary or particularly compelling for the case.

2.2 Data analysis

The authors' background in innovation management and future studies (speculative fiction) will enable them to understand process dynamics and screen for meaningful narrative elements from qualitative data. When analysing the date, we will take the subjective perception due to the role we assumed (researcher and interventionist), into account by reflecting interpretation in relation to our role and own experiences we have with the institution. Table 2 provides an overview of data base used for the case study.

We are aware that the dual role as researcher and intervenor will shape what we notice and what we prioritise in the research. During analysis, we will account for the subjectivity inherent in the roles we assumed by critically reflecting on how our interpretations may be shaped by our position and prior experiences with the institution. Table 2 provides an overview of the data sources used for the case study. Field notes will help track decisions we make in the field and unintended consequences of our involvement.

Table 2 - Overview of data base

Data Type	Background	Association with University
Mails	Sustainability manager, infrastructure manager	Employee of the University
Intervention field notes	Sustainability manager, infrastructure manager	Employee of the University
Survey	SciFi and Speculative Fiction course dealing with sustainable futures.	Digital-Design Students
Interview 1	Sustainability manager	Employee University
Interview 2	Sustainability expert	External expert
Interview 3	Infrastructure expert	University or School CS&IT

The mails, survey, interviews and field notes will be analysed using an analogue procedure. Predefined categories related to process challenges and meaningful displays will be used to analyse the survey interviews and note – while remaining open for new categories (Miles et al. 2010). To enhance validity, material will be analysed by two researchers. Themes and subthemes will be discussed between the two.

3 Results

Most universities already collect data on energy consumption for infrastructure management. Providing more detailed data on the energy consumption of individual departments is technically feasible – but can prove to be institutionally challenging. The paper specifically accounts for the journey of accessing quality data for an individual department from the wider organisation. The paper identifies framing strategies that enabled the project to advance. Helpful approaches, useful attitude and effective tactics are highlighted through narrative descriptions. We will also report on preferred ways of displaying recurrent energy consumption data and meaningfulness interactions. Thus, we aim to answer the question of how university departments can access data on their energy to raise energy use awareness among students and employees. This should also enable us to discuss preconditions for universities as Living Labs that act platform for behavioural change.

4 Discussion

The paper adds to a growing amount of research literature that discusses new demands on universities when acting as platforms to engage with energy consumption and sustainable development in general. The study complements existing literature by providing a more picture of the journey of obtaining quality data from a wider institution for displays in smaller units – such as faculties or departments. Through the study's narrative description of suitable ways for accessing quality data and outlining display requirements. The study adds to our understanding of how universities can implement smart building technologies in ways that support the awareness and value shifts needed for changed lifestyle choices (König & Evans, 2013).

Successfully designing these strategies will be pivotal for universities. More studies are needed to make the results transferable to other contexts. And future research can look into how real live monitoring can be combined with social learning activities to promote not only energy use awareness but provoke behaviour change with students and staff.

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Environmental Impact Of Conceptual Green Hydrogen Storage Into A Solar Charging Station For Light Electric Vehicles

Noman Hanifa[a], Naren Matesh[a], Nora Schelte[a] and Semih Severengiz[a]

[a] Sustainable Technologies Laboratory, Bochum University of Applied Sciences, Germany

Abstract

To achieve the climate goals by 2030, Germany has introduced measures such as the expanding of renewable energy infrastructure and implementing policies that promote electric vehicles. These measures are intended to reduce the environmental footprint of the energy and mobility sectors. Light electrical vehicles (LEVs) can be substitute to the cars to reduce the emission and lower the traffic. However, sustainable charging solutions for LEVs remain limited, and the existing infrastructure has certain limitations, such as reduced reliability during periods of low insolation (e.g. cloudy days and winter). This study focuses on potential solutions by examining the use case of an off-grid solar charging station for an e-moped based on empirical data from a living lab. This paper assesses the environmental impact of a conceptual hydrogen-battery solar station (HydSCS) and compares with an extended battery solar charging station (BatSCS). Our analysis revealed that HydSCS has about 9% lower global warming potential (GWP) than BatSCS at the 50% utilisation. These preliminary findings suggest that hydrogen storage can be an environmentally favourable storage option for off-grid solar charging station.

Keywords: Green hydrogen; LEVs; Sustainability; Solar charging station; Integrated energy system.

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1 Introduction

In 2024, the energy sector was the biggest contributor to the GHG emissions, followed by the industrial and mobility sectors within Germany. Compared to other sectors, the mobility sector is lagging in achieving climate goals. According to the German Federal Environment Agency, the implemented measures such as promotion of Electric Vehicles (EVs) isn't sufficient to reduce GHG emissions (Ghosh, 2020). Light Electric Vehicles (LEVs) such as e-mopeds and e-bikes are a subcategory of EVs, which weight under 350 kg and are limited to 45km/h (Alexandre Santacreu, 2020). LEVs can be good substitute to the cars which can lower emission and traffic as well. The deployment of LEVs for short-distance urban travel is expanding, particularly in the context of shared mobility (*Moped-Sharing - Worldwide | Statista Market Forecast*, n.d.). At present the shared mobility operator utilise milk-run method to charge their LEVs. In this method the batteries of the LEVs are swapped using diesel powered vans leading to high emission (Schelte et al., 2022). Switching from conventional milk run method to solar power for charging leads to an approximate 85% reduction in charging-related Global Warming Potential (GWP), decreasing from 15.34 to 2.26 g CO_2-eq./km for a shared e-moped (Schelte et al., 2021). The main drawback of such systems is the reduced energy generation in winter or low radiation days and limited capacity of storage battery. Extending the battery storage or using other energy storage methods such as hydrogen is a solution. It is consistent with the growing use of Hydrogen Energy Storage Systems (HydESS) to sustainably meet grid demand (Arsad et al., 2022).

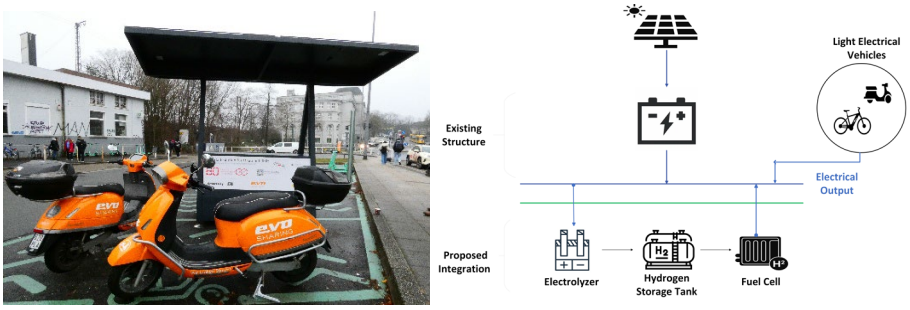
Several studies have focused on development of a conceptual system combining the HydESS with solar charging station (Alzahrani et al., 2022) (Song et al., 2022). However, research on the environmental impact of hybridized energy storage systems remains limited. To address this gap, this study proposes an integrated solar-hydrogen charging station and estimates its GWP. The study builds upon a living lab case study of an off-grid solar charging station for shared e-mopeds that revealed the system's limitations during cloudy or rainy days (Hanifa et al., 2025). The conceptual solar-hydrogen charging station tackles this problem. Using empirical data on surplus solar energy, the potential for green hydrogen production is estimated and conceptual system is designed. The GWP of the concept is subsequently evaluated based on data from literature which provides insights into the environmental performance of such systems, offering valuable guidance for their future design and optimization.

2 Existing living lab and conceptualized integrated hydrogen system

The living lab consists of off-grid solar charging stations in the city of Essen and Oberhausen, used by EVO (Energieversorgung Oberhausen AG) shared-mobility customers to charge e-mopeds. The station has a PV capacity of 1.6 kW, while the battery storage capacity is

3.6kWh. It is equipped with a 400 W charger, with BMS data transmitted over Wi-Fi. Figure 1 depicts a picture of the solar station placed at the Essen West Railway station as well it outlines conceptual hydrogen Integration. Surplus energy from PV powers an electrolyzer. The hydrogen is stored, and when storage battery is depleted, a fuel cell converts the stored hydrogen to electricity and charges the battery.

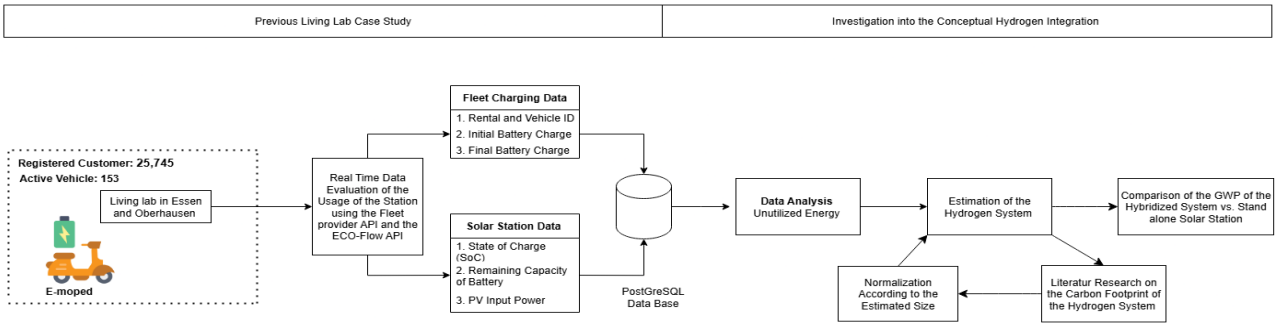
Fig. 1 –Solar charging station in Essen City & Simplified sketch of conceptualized hydrogen system



3 Methodology

Fig. 2 depicts the overall methodology of this study. The data gathered from the station are first analysed to identify the usage patterns, followed by the calculation of unutilised energy, conceptualisation of the hydrogen system and determination of the GWP of the hydrogen storage system. Finally, the overall GWP of the HydSCS is estimated.

Fig. 2 – Flowchart depicting the overall steps for this study



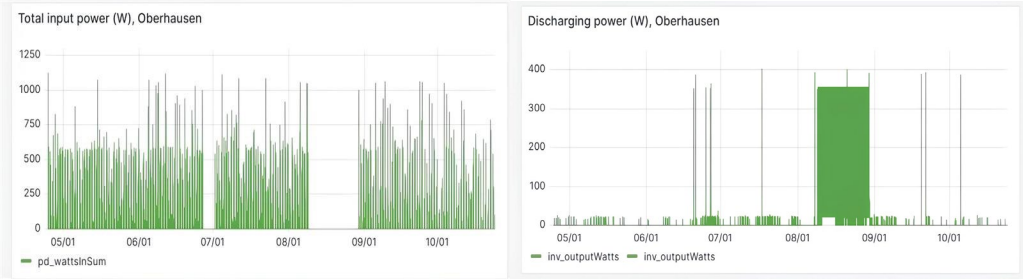
Source: Author's own work

4 Data collection and analysis

The data for the living lab was collected from within the period of April to October 2024, it includes vehicle and solar station data. The vehicles data were gathered using the Wunder API (provided by the sharing company). All vehicles detected within a 50 m radius of the charging station are flagged as potential charging candidates. Information such as the vehicles ID, current state of charge (SoC), distance to charging station and the timestamp are stored in the database. When the current SoC increases by at least 1%, then the charging sessions are stored in a separate database of successful charging which additionally stores final SoC (Hanifa et al., 2025). The solar station data such as SoC of the station's storage,

discharging power, PV input power etc. were fetched using the API of the Eco-flow i.e. the battery manufacturer inside the station. The following figure 3 depicts power generation and discharge from the station. The data frequency is at every 10 minutes and the average data from both stations were considered for further analysis.

Fig. 3 – Real time data from the solar station



Source: Extracted via the API of the ECO-Flow Energy Storage inside the charging station

Data analysis revealed 20 consecutive days without generation and the station's storage battery often reaches its maximum SoC condition due to under-utilisation of the station. Our previous analysis established that at best 50% utilisation is achievable (Hanifa et al., 2025). This means that, 50% of generated energy remains unused every day.

4.1 Size Estimation of the HydESS

The hydrogen system, including the fuel cell, electrolyser and storage tank, will be collectively referred to as 'HydESS'. The proton exchange membrane fuel cell (PEMFC) and PEM water electrolyzer (PEMWE) were chosen due to their quick startup time, rapid load response and low operating temperatures compared to other types of fuel cells and electrolyzers (*Wasserstoff im Klimaschutz*, 2021). It is assumed that the PEMWE would operate for one hour and the efficiency (η) is assumed to be 56% (Ceylan & Devrim, 2023). The peak power of the electrolyzer was determined as 1.18kW using the formula below.

$$PEMWE\ Power\ [kW] = \frac{Weekly\ Demand\ [kWh]}{Operation\ Time\ [h]}$$

To achieve 50% utilisation, at least four e-mopeds must be charged by 30% each week. Each moped has a total battery capacity of 4.2 kWh. The average-daily energy consumption is calculated using the formula shown below. Based on this value, the demand for twenty days can be calculated.

$$Demand\ \left[\frac{kWh}{day}\right] = \frac{Number\ of\ E-mopeds \cdot Battery\ Capacity\ [kWh] \cdot \Delta SoC}{Number\ of\ days}$$

The efficiency of the fuel cell is assumed to be 55% and the hydrogen would be stored at 150 bar (Ceylan & Devrim, 2023). At this pressure and 20 °C, the hydrogen has a density of 11.156 $kg \cdot m^{-3}$. The energy consumption of the compressor is assumed to be 4.5 kWh (Abdin et al.,

2021), and it is combined with demand for 20 days to derive the net energy demand. The hydrogen mass necessary to satisfy the net energy demand is then calculated using the lower heating value (LHV) of hydrogen, which is 33.3 kWh·kg^{-1}. The losses due to hydrogen compressed was omitted. Based on the supplied hydrogen and the density of hydrogen, the volume of the storage tank is determined to be 92.5l.

$$Tank\ Volume[m^3] = \frac{\frac{Demand\ [kWh]}{\eta \cdot LHV[kWh/kg]}}{Density\ [kg/m^3]}$$

The PEMFC needs to be operated only when the storage battery reaches minimum SoC conditions. The weekly demand is calculated to be 5.04 kWh, and 2 hours of operation for the fuel cell is selected as a balance between system compactness and charging duration. Using the formula below, the PEMFC's power was determined to be 4.58 kW.

$$PEMFC\ Power\ [kW] = \frac{Weekly\ Demand\ [kWh]}{Operation\ Time\ [h] \cdot \eta}$$

4.2 GWP of the HydESS & BESS

From the existing literature, GWP values for manufacturing the PEMFC and PEMWE was obtained, and it includes emissions due to raw material extraction and manufacturing processes only. The GWP is then normalised based on the rated power of PEMFC and PEMWE. A system with BoP is considered as base case for the study. The table below summarizes the PEMFC and PEMWE's GWP. Using the normalised GWP/kW values, the GWP for the conceptual hydrogen system can be determined.

Table 2 – GWP of fuel cells and electrolyzer

Component	Average GWP/kW [kg CO_2 eq./kW]	Source
Electrolyser stack without BoP	129.29	(Wei et al., 2024) (Koj et al., 2024)
Electrolyser with BoP	350.783	(Lotrič et al., 2021) (Gerhardt-Mörsdorf et al., 2024)
PEMFC stack without BoP	48.36	(Mori et al., 2023) (Stropnik et al., 2019)
PEMFC with BoP	112	(Stropnik et al., 2019)

A similar approach is applied to the hydrogen storage tank, normalising the GWP using the tank's volume (Beber et al., 2025). Glass fibre-reinforced polymer is chosen as the tank material instead of steel due to its lower GWP. Emissions due to water supply were omitted from this study. Instead of using hydrogen storage, a simpler alternative is to extend the battery capacity itself. To validate the viability of HydESS, a comparison with an extended

battery energy storage system (BESS) is necessary. The previous study calculated the GWP of 7.2kWh LiFePO4 to be 806.7 kg CO2 eq. for raw materials and manufacturing (Schelte et al., 2021). The GWP of the BESS, which has the same capacity as the HydESS, is calculated by normalizing the GWP from the previous study.

4.3 GWP of the HydSCS & BatSCS

In this study, the integrated system that combines the existing solar charging station with the HydESS is referred to as the HydSCS, while the system that combines the BESS with the station is referred to as BatSCS. A previous study conducted an LCA on a prototype solar charging station with a service life of 20 years for the modules and 10 years for the electronic components and battery. The results revealed the lifetime emission to be 5,689 kg CO_2 eq. per solar charging station and GWP per kWh varied according to the utilisation factor (Schelte et al., 2021). In this study, utilisation factors were considered, ranging from 10% to 100%, with 10% increments. Extrapolating the data of unutilised energy, the excess energy over the operational lifetime of the solar charging station (20 years) is determined. To calculate this use-phase related GWP, the formula shown below is used for each utilisation factor interval.

$$Emissions_{use-phase}[kg\ CO_2\ eq] = Unutilised\ Energy_{20y} \cdot GWP\ [kg\ CO_2\ eq.per\ kWh]_{solar\ station}$$

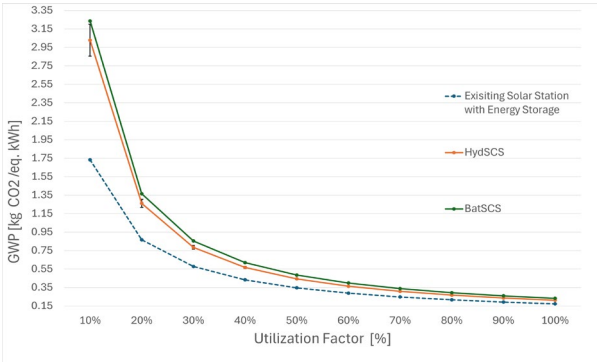
Combining the use-phase and lifetime GWP of the solar charging station along with the GWP due to manufacturing of the HydESS components results in total GWP of the HydSCS system.

$$Total\ GWP_{HydSCS} = GWP_{use-phase} + GWP_{station\ lifetime} + GWP_{HydSCS\ manufacturing}$$

The GWP per kWh for the combined system is derived from the ratio of the GWP of HydSCS to the lifetime energy generation of the solar charging station and utilisation factor. A similar approach is followed for the calculation of the GWP per kWh of the BatSCS. The GWP of hydrogen system components is replaced with the GWP of battery production.

5 Results

Fig. 4 – Results comparing the GWP of conceptual system



System	Capacity	GWP [kg CO2 eq/kWh] (at 50% Utilization)
Exisiting Solar Station with battery storage	PV-1.6kW, Battery-3.6kWh	0.34
Solar station with hydrogen storage (HydSCS)	PV-1.6kW, Electroyzer-1.1 kW, Fuel Cell-4.5kW, Storage Tank-92.5 lt.	0.44
Solar station with extended battery stoarge (BatSCS)	PV-1.6 kW, Extended Battery-3.6+7.2 kWh	0.49

The above figure 4 compares the GWP of HydSCS and BatSCS energy storage systems. Clearly, the BatSCS results in a higher GWP than the HydSCS. During the manufacturing phase, the GWP of the BESS is approximately 1.7 times higher than that of the HydESS. Under 50% utilisation, the BatSCS has a GWP that is 9.4% higher than HydSCS. Hence, choosing hydrogen as an energy storage medium from environmental perspective could be better alternative than extending the battery capacity however cost analysis remains subject to further analysis. The conceptual HydSCS has a GWP of 3 kg CO_2.eq/kWh at 10% utilisation which is approximately twice as high than the existing solar station however at 50% utilisation factor, the GWP is just 28% higher than the solar station. The GWP decreases with higher utilisation, reaching 0.21 kg CO_2eq/kWh at 100% utilisation, reflecting the improved distribution of fixed manufacturing impacts over higher energy output. This emphasises the importance of maximising system usage to mitigate the system's overall environmental impact. While HydSCS introduces additional GWP, strategic operational management and increased utilisation can offset this impact to a significant degree.

6 Discussion and Conclusion

An integrated hydrogen storage system was conceptualized using the available data from the solar charging station. An estimation of the GWP of the integrated system was done and it was compared to an extended battery storage option. Although this study excludes economic aspects, however from an environmental perspective, integrating hydrogen storage was proven to be a better option. If such systems were to be implemented and the usage profile remains high, the increased utilisation could substantially offset the impact of hybridisation. In this study only the GWP up to manufacturing were considered, hence future research could explore methods to assess the environmental impact over the complete lifecycle of the hydrogen and compare the results with that of BESS. Furthermoe, a validation with other use cases for the integrated system needs to be carried out. Nonetheless, the study could serve as a basic framework for estimating and comparing the footprint of hybrid storage systems.

Acknowledgements

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Investigating The Contribution Of A Circularity-Focused Problem-Based Learning Environment To Sustainable Energy Education

Erik Alexander Recklies[a], Santiago Eduardo[a] and Semih Severengiz[a]

[a] Sustainable Technologies Laboratory, Bochum University of Applied Sciences, Germany

Abstract

Anthropogenic climate change demands innovative educational approaches that effectively bridge sustainability concepts with practical learning. Particularly this applies to the broad context of sustainable energy education. The CIRCLE project (Creative Impulses for Recycling, Crafting and Learning) conducted by the Sustainable Technologies Laboratory at Bochum University of Applied Sciences offers a novel, problem-based learning environment which is initially designed to integrate analytical and practical applications of circular design principles into higher education sustainability courses. This paper illustrates how CIRCLE can furthermore successfully contribute to sustainable energy education. Referring to the example of a proton exchange membrane fuel cell it is shown in detail to what extent participating students not only assess and enhance product circularity but dealing with energy-related products simultaneously acquire theoretical knowledge of key facts, central concepts and relevant energy-related technologies as well as practical competencies. Future work will empirically assess CIRCLE's educational outcomes and explore scalable curriculum integration, contributing to innovation in sustainability teaching and learning.

Keywords: circularity; circular design; higher education; teaching; proton exchange membrane fuel cell.

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1 Introduction

Anthropogenic climate change represents a multidimensional and escalating global crisis: Human behaviour is not only increasingly transgressing planetary boundaries (Rockström et al., 2023) but also causes economic and social problems worldwide (Intergovernmental Panel On Climate Change, 2023). In response to these challenges, sustainability discourse has emphasised three interrelated strategic approaches: sufficiency, efficiency, and consistency (Behrendt et al., 2018; Huber, 2000; Rudolf & Schmidt, 2025). While sufficiency focuses on adjusting overall consumption to adequate levels, efficiency aims at optimising resource use through technological innovation, thereby reducing environmental impacts per unit of output (Rudolf & Schmidt, 2025). Consistency, in turn, refers to the systemic integration of human activities with natural cycles, for example through the use of renewable resources and sustainable energy or a shift towards circularity (Rudolf & Schmidt, 2025). While the environmental relief potential of the first two strategies is generally considered to be rather low (10–40%), consistency, in contrast, appears to be significantly more promising, with an environmental relief potential of 50–80% (Behrendt et al., 2018). Against this background and as the crucial role of education for a global sustainable development is well known (Tafese & Kopp, 2025), the need for successful educational programmes addressing both the topics of sustainable energy and circularity can be highlighted.

This paper extends the preceding discourse by examining the potential of circularity-focused educational approaches in addressing challenges in sustainable energy education. To this end, it analyses a problem-based research project at Bochum University of Applied Sciences centring on circularity. Based on the assessed project study, the successful integration of sustainable energy education through circularity approaches is evaluated. By doing so we focus on the following general research question: How can circularity-focused educational projects contribute to sustainable energy education?

2 Central terms and concepts

This section defines the central terms and concepts that will be referenced throughout the subsequent discussion.

2.1 Circularity and Circular Design

As there is a wide variety of understandings concepts such as circularity, circular economy, or circular design (e.g., Kirchherr et al., 2023), it seems unavoidable to find definitions in the context of this paper. We refer to the term circularity as a general feature that can be attributed to product-service systems in which products, components, materials, resources, and other flows are kept in use for as long as possible (Potting et al., 2017). Circularity plays a crucial role in the well-known concept of a circular economy as established in scientific

discourses and political, societal, and economic contexts: In general, the circular economy aims at the integration of so-called r-strategies (e.g. reduce, reuse, repair, repurpose, recycle) to minimise waste, virgin resource extraction, and therefore cost and emissions (Ellen MacArthur Foundation, 2015). For example, specific studies in the field of light electric vehicles have shown the substantial potential of integrating r-strategies in the end-of-life treatment of electric moped scooters in terms of ecological (Eduardo, Recklies, et al., 2025) and financial savings (Eduardo, Schmitz, et al., 2025).

The framework of circular design can be understood as a systemic approach emphasising the relevance of circular supply, resource conservation, multiple cycles, long life use of products, and system change at the stage of product development and design (Moreno et al., 2016). Particularly, circular design may be characterised as a facilitator of the transformation from a linear economy towards a circular economy. To be more precise, circular design offers the technical foundation for operationalising the otherwise mainly conceptual notion of the circular economy, by drawing on engineering and product design approaches to integrate the r-strategies outlined above.

2.2 Sustainable energy education

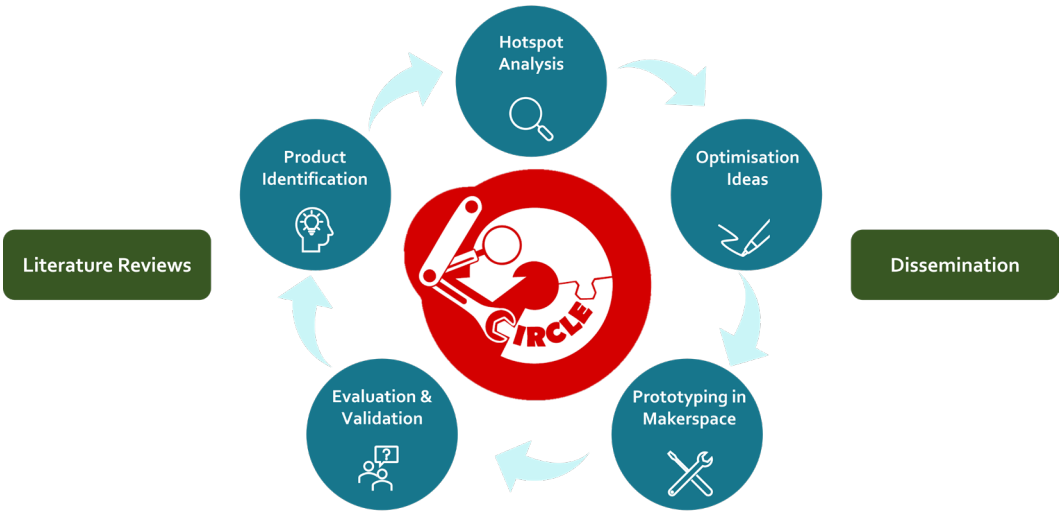
In the course of this paper we understand sustainable energy education as a general concept encompassing educational initiatives, projects, and courses on sustainable energy. In accordance with established definitions of sustainable development (World Commission on Environment and Development, 1987) sustainable energy can be defined as energy generation, storage, and supply meeting the needs of the present without compromising future generations' needs. Consequently, sustainable energy education provides theoretical knowledge of key facts, central concepts and relevant technologies as well as practical competencies in the context of these technologies. Following Kandpal & Broman (2014) sustainable energy education includes at least the three modes of information, investigation, and imagination.

3 The project CIRCLE

The acronym CIRCLE stands for Creative Impulses for Recycling, Crafting and Learning. The project is funded by the *Stiftung Innovation in der Hochschullehre* and is conducted by the Sustainable Technologies Laboratory at Bochum University of Applied Sciences (project duration: 01.04.2025 – 31.03.2025). The main goal of CIRCLE is to provide an innovative learning environment for students in higher education sustainability science courses combining the concepts of circular economy and makerspace (an open workshop for innovative development and prototyping). For this purpose, a problem-based learning project-study (Barrows, 1996; Hmelo-Silver, 2004) was developed, centring on the analysis of the circularity of a product's life cycle across the production, use, and end-of-life phases.

The project aims to use a sustainability assessment lens to identify the main contributors to greenhouse gas emissions, to ideate circular design concepts that minimise the environmental impact of these hotspots, and to prototypically implement these solutions within a makerspace to validate their functionality. Students will acquire and apply scientific methods and frameworks from the domains of life cycle assessment (LCA) and circular product design. The project study is guided and supervised by researchers from the Sustainable Technologies Laboratory. Figure 1 shows the overall structure of CIRCLE, visualising the interplay between the work steps product identification, hotspot analysis, development of optimisation ideas, prototyping in a makerspace, and evaluation & validation as well as overarching tasks like literature reviews and dissemination.

Fig. 1 – Structure and work steps of CIRCLE



4 CIRCLE's contribution to sustainable energy education

At first glance it seems counterintuitive that a project study focussing on evaluating the circularity of products and optimising them in terms of circular design contributes to sustainable energy education as defined in section 2.2. This apparent contradiction can be resolved as follows: Participating students in CIRCLE have the possibility to focus on products related to sustainable energy generation, storage, and supply. Accordingly, these students are expected not only to acquire competencies in the areas of circularity and circular design. Rather, they are also likely to develop substantial expertise in the detailed understanding of the structure, functionality, and application areas of the respective energy-related products. This abstract relationship can be illustrated using a concrete example and referring to the steps of CIRCLE depicted in section 3:

1. Product identification: As the first step within CIRCLE, students are expected to identify a product to be analysed and optimised in terms of circularity. For our example a proton

exchange membrane (PEM) fuel cell is assumed to be selected by students within the product identification step. This type of fuel cell is assumed to have its application within a decentralised energy system to reconvert hydrogen, which has been generated using electricity from renewable sources and stored, into electricity during periods of demand. In the context of this decision it is expected that the students will learn about central concepts and relevant technologies by understanding the general functionality of a PEM fuel cell and its application possibilities and by comparing this technology to other technologies of sustainable and unsustainable energy generation, storage, and supply (e.g. wind energy, photovoltaic, nuclear power, battery storage).

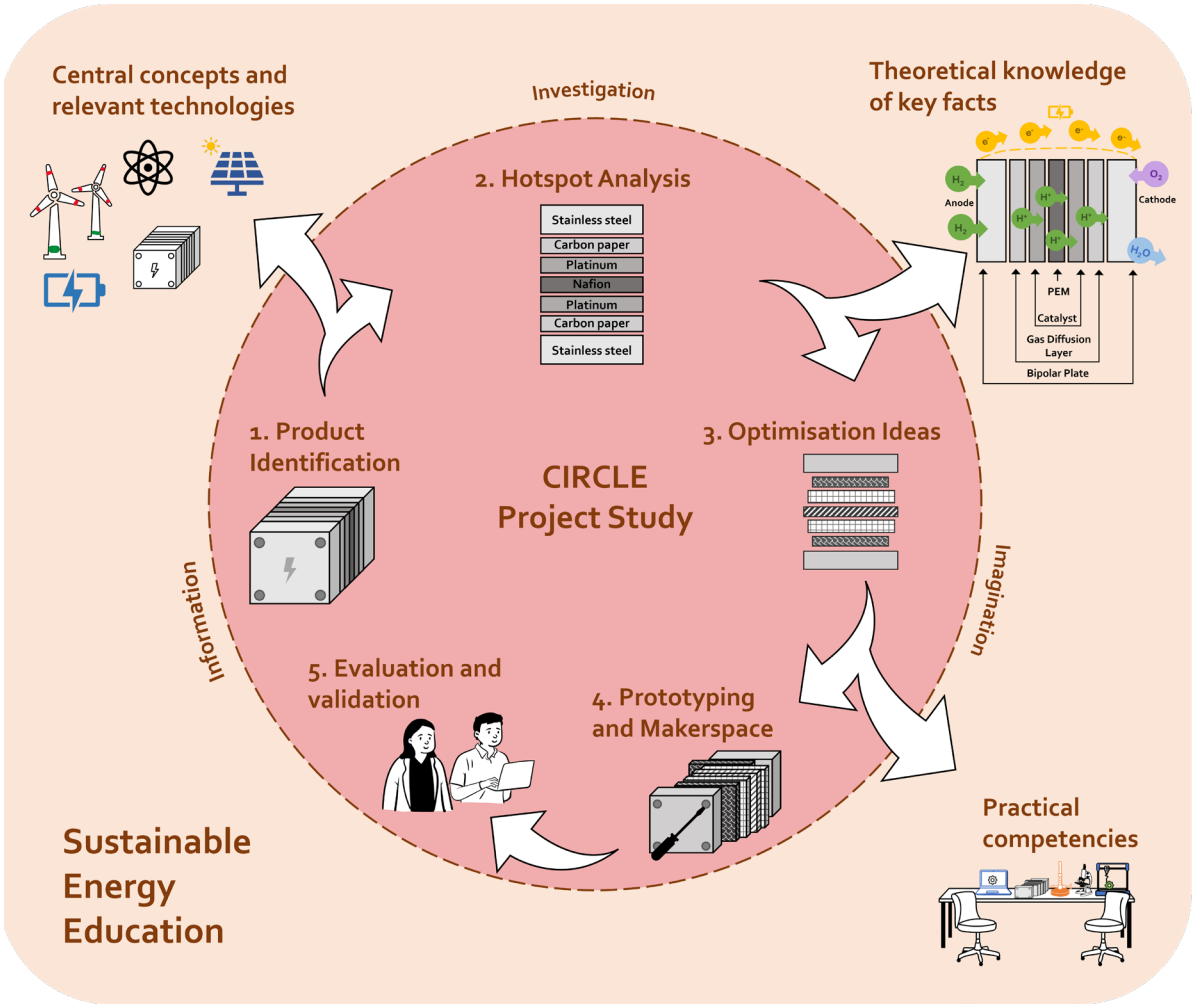
2. Hotspot analysis: The following step involves students conducting a screening LCA of a PEM fuel cell to gain an overview of its environmental impacts and to identify so-called hotspots (components or materials with particularly high environmental impact). To accomplish this analytical task, it is essential that students work with a bill of materials – or, if necessary, develop – a detailed overview of the components, materials, and resources used in the production of the PEM fuel cell. In this context, a number of questions naturally arise concerning the materials and components used. From the students' perspective, these questions might be imagined as follows: How is a PEM fuel cell constructed in the first place? Which components are made of which materials? More specifically: What materials are used in the individual components of the membrane electrode assembly (MEA)? Why is platinum required? What exactly is nafion, and how is it produced? By answering these and other questions the students will acquire theoretical knowledge of key facts concerning the structure of a PEM fuel cell. This is likely to surpass the initial general overview gained in step 1.
3. Development of optimisation ideas: The analytical step depicted above is followed by practical considerations regarding the weak points of the fuel cell in terms of circularity, and how these could be improved in the sense of circular design. For this practical step, it is essential that students are able to thoroughly understand both the overall functioning of a fuel cell and the specific roles of its individual components and materials. After all, circularity improvements should ideally not come at the cost of the fuel cell's functionality. At this stage, students must engage in a detailed investigation of the functionality of a fuel cell and how its components interact with each other. Within the ideation phase the following questions could be addressed by the students: How does the electrochemical reaction within the MEA take place? Where and how are hydrogen and oxygen introduced? What processes occur at the cathode and anode? What roles do catalysts play? Why are bipolar plates and gas diffusion layers necessary? What is meant by proton exchange, and what role does the membrane play in this process? Where does the electrical current actually flow? And finally: How are the various components and materials within the PEM fuel cell connected, and in what ways do different design

strategies affect both its performance and overall product architecture? As a result of the critical examination of these and further questions the students gain in-depth knowledge regarding the functionality of the PEM fuel cell. In addition to step 2 this can also be described as acquisition of theoretical knowledge of key facts.

4. Prototyping and Makerspace: By translating the ideas developed in step 3 into action in a makerspace setting, the learning focus shifts to a practice-oriented approach. In this step, students will complement and strengthen their conceptual understanding of core principles and technologies (step 1) and their theoretical knowledge of key facts (steps 2–3) with hands-on practical competencies. These include activities such as disassembling and documenting PEM fuel cell components, testing and characterising functional elements (e.g., membrane-electrode assembly, flow fields, and gas diffusion layers), and analysing performance data to identify possible optimisation opportunities. Through these tasks, students gain applied skills in experimental design, instrumentation, electrochemical testing, and data interpretation, bridging theory with real-world engineering practice.
5. Evaluation and Validation: The goal of this step in CIRCLE is to communicate the optimisation ideas developed and tested in the steps before to partners in the industry or field experts and to jointly evaluate and validate their overall viability and technical feasibility. For the example of the PEM fuel cell this could be done with fuel cell producers or recyclers having detailed insights into hydrogen technologies. From the perspective of sustainable energy education one can expect students to consolidate and strengthen their knowledge and competencies acquired throughout the previous steps 1-4.

Figure 2 illustrates the integration of circularity-related learning content with sustainable energy education referring to the example of a PEM fuel cell. It sums up our depiction that CIRCLE, while its primary focus lies in promoting competencies related to circularity and circular design, simultaneously can foster energy related expertise in an interdisciplinary and practice driven way – not through separate instruction, but through meaningful, application-oriented analysis of real-world technologies. While the inner red circle visualises the five consecutive steps within CIRCLE, the orange area represents the broader context of sustainable energy education. The arrows emerging from the red circle and pointing into the orange area represent the contributions to sustainable energy education made by the project. Referring to our understanding of sustainable energy education (2.2) these contributions encompass the provision of theoretical knowledge of key facts, central concepts and relevant energy related technologies as well as practical competencies in the context of these technologies addressing all three modes of information, investigation, and imagination.

Fig. 2 – Integration of circularity-related learning content with sustainable energy education, illustrated by the example of a PEM fuel cell



5 Conclusion and Outlook

Although CIRCLE is still in an early implementation phase, the planning and conceptual framework presented in this paper already point to the considerable potential of this innovation-driven learning environment. The approach outlined in this paper – exemplified through the case of a PEM fuel cell – is, of course, transferable to a wide range of products and technologies in the fields of sustainable energy generation, storage, and supply (e.g., electrolysers, photovoltaic cells, lithium-ion batteries, and flow batteries).

Our considerations demonstrate how students, through both analytical and application-oriented engagement with the circularity of energy-related products, not only develop competencies in areas such as life cycle assessment and circular design. Crucially, they also acquire in-depth knowledge, practical skills, and interdisciplinary competencies in the broader domain of sustainable energy systems. As such, CIRCLE, while originally conceived

as a project centred on circular design, also makes a substantive contribution to sustainable energy education – particularly when energy technologies are placed at the core of the learning process.

Future research accompanying CIRCLE will aim to empirically validate the conceptual considerations proposed in this paper. Qualitative methodologies, including individual and group interviews, as well as complementary quantitative data collection methods, may serve to evaluate the effectiveness and educational outcomes of the CIRCLE approach. Building on such findings, further inquiry will be required to assess the extent to which CIRCLE may be integrated into existing curricula as a permanent offering – or whether the development of CIRCLE-inspired educational formats may represent a viable and impactful contribution to the broader agenda of sustainable energy education.

Acknowledgements

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper

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BEST: An Innovative Engineering Program For A Sustainable Future

Richenel Bulbaai[a]

[a] Faculty of Engineering, University of Curaçao, Curaçao

Abstract

The Faculty of Engineering at the University of Curaçao (UoC) faced significant challenges in student enrolment and retention. Furthermore, the Caribbean SIDS faces a shortage of engineers specialized in sustainability, which will hinder the development of sustainability within the SIDS. The Bachelor of Engineering and Sustainable Technology (BEST) program was established to address these challenges. This innovative program integrates sustainability principles into applied engineering education. Designed in close collaboration with local partners, this innovative program focuses on project-based learning, multidisciplinary integration, and alignment with regional needs. Student enrolment has increased considerably compared to previous programs. Over the past three years, the enrolment has risen from an average of 5-15 students on a yearly basis per program to over 50 students within the BEST program. Furthermore, the retention rate has also increased from less than 50% to between 85% and 90%. The student evaluation by the students themselves shows a positive assessment of both the quality of education and the course content. The current results of the of the NVAO-positively assessed BEST program confirm that it offers a best-practice framework for sustainable engineering education in the SIDS, and specifically in Curaçao.

Keywords: engineering; sustainable technology; multidisciplinary; project-based.

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1 Introduction and Background

Curaçao is an island in the Caribbean, about 65 km north of the Venezuelan coast. Curaçao has a population of just over 150,000 in an area of 444 km² (Bulbaai & Halman, 2023). Curaçao, like many countries in the Caribbean region, is facing a significant shortage of engineers (Wilson Harris Nadine, 2017). This shortage impedes Curaçao's economic development, sustainability goals, and technological innovation. In the past, the Faculty of Engineering had provided bachelor's programs in ICT, Architecture, Civil Engineering, Industrial Technology, and Electrical Engineering. A master's program in Technology Management has also been offered by the faculty of engineering. All these programs have been positive assessed by the Accreditation Organization of the Netherlands and Flanders (NVAO). Although the positive assessment by the NVAO, the number of students enrolled in these programs remained too low to guarantee their continuity and financial viability.

Enrolment data show a sustained decrease over the years in these programs (Rendementsgegevens FdTW, 2025). Except for the ICT program which attracted more than 10 students annually, while the other programs got fewer than 10, and some even had fewer than five. For this reason, some programs could not be initiated. Another problem was the very low retention rate after the first year. This meant that only a small number of students advanced to the second year. These trends not only affect the sustainability of the faculty, but also the island's capability to educate and retain engineers who are immediately needed in the labour market. According to University of Wageningen & Research, the shortage of engineers is jeopardizing the achievement of global sustainability (*Shortage of Engineers Is a Threat to a Sustainable World*, 2023).

Previous studies have shown that sustainability specialist is among the fastest-growing occupations in the region, with the number of positions projected to rise by 29% by 2030 (*The Future of Jobs in Latin America and the Caribbean: Digital Skills Gap Must Close Quickly to Satisfy Evolving Employer Demands*, 2025). Furthermore, this expanding professional domain highlights the need for engineering education programs that integrate sustainability as a core component.

As a result, the Faculty of Engineering undertook a comprehensive redesign of its programs. The main objective was to develop a new program that would increase student enrolment and improve retention rates. The program aims to educate students to become highly qualified graduates with strong engineering competencies. It is designed to meet the needs of the labour market and to adhere to international standards (*Domeinbeschrijving*, 2022.). Moreover, students will be prepared to address urgent global and local sustainability requirements. The initial concept was presented at a field conference with approximately 40 industry and societal stakeholders to ensure its relevance and legitimacy. Following this field

conference, a dedicated committee consisting of academic and industry representatives was formed. Its mission was to develop a cost-effective, future-oriented curriculum tailored to the local context, based on the findings of the field conference.

This effort resulted in the development of the innovative program entitled Bachelor in Engineering and Sustainable Technology (BEST). This program is the first of its kind in Curaçao and the wider region, offering an innovative model for engineering education within small islands development states (SIDS).

The aim of this paper is to present the educational philosophy, program design, implementation challenges, and retention strategies of the BEST program.

To provide analytical structure, this paper examines the following research questions:

RQ1: How does the BEST program integrate multidisciplinary, project-based, and sustainability-oriented approaches in engineering education?

RQ2: Which challenges were identified by the faculty of engineering at the UoC when designing the BEST program within the resource-constrained context of SIDS?

RQ3: To what extent can an innovative sustainability-focused engineering program enhance student enrolment and retention in the context of SIDS?

The rest of this paper is structured as follows. The following section presents the methodology, followed by an overview of the educational philosophy and a pedagogical approach. The subsequent section describes the design of the BEST program, followed by a discussion of its implementation and institutional challenges encountered. Next, the paper highlights the impact of early results and provides a future outlook. Finally, the paper concludes with a summary of key findings, limitations, and future research.

2 Methodology

This study applies an exploratory case study approach to analyse the design, implementation and early outcomes of the BEST program at the UoC. The analysis is based on quantitative institutional data, which comprise student evaluations, enrolment numbers, and retention rates from both former engineering programs of the faculty and the new BEST program. Quality data were obtained from curriculum development reports, Quality Assurance documents, stakeholder feedback from a field conference, input from professional sector during the advisory committee sessions, and minutes of faculty meetings. Historical program performance was compared with recent outcomes of the BEST program to determine changes in enrolment and retention, as part of this process thematic review of qualitative materials emphasized design principles and implementation challenges.

3 Educational Philosophy and Pedagogical Approach

Students in the BEST program are educated in accordance with the modern T-shaped profile of an HBO bachelor professional in engineering and sustainable technologies (Alabadan et al., 2020; Ninan et al., 2022; Saviano et al., 2016). The horizontal dimension of the T-profile encompasses the general HBO competences and generic engineering competences, while the vertical dimension represents the specialized knowledge, skills, and attitude within the discipline of their choice (*Domeinbeschrijving*, 2022.)

The didactic concept of the BEST program is based on four pillars: First, it is activating, as students are regularly engaged in real-world problem solving through a project-based learning approach. Project-based learning is proposed in many studies as the most suitable way to achieve effective education based on technical competencies and that integrates knowledge, skills, and values (De et al., 2015). Second, it is collaborative, with students working in multidisciplinary teams on projects that address sustainability challenges. Third, it is investigative, focusing on inquiry, literature review, data analysis, presentation of findings, problem solving, and the formulation of recommendations. Finally, it employs simulations as well as fictitious and real-life cases to enhance students' understanding, retention, and the ability to apply knowledge in their future careers.

The professionalism learning path encompasses the soft skills that the future engineers need, for instance communication skills, writing and presentation skills in both Dutch and English. Coaching during their study period and self-reflection are also part of this learning path.

The practical skills and research from state-of-the-art labs are used. Practical skills are important for a future engineer. In the BEST program, emphasis is also on practical skills during the program. There are several other options, such as company visit, guest lecture, internship, minor and final thesis.

Furthermore, the program's research is primarily based on two research areas: Sustainable Living and Smart Industry. Within Sustainable Living, research focuses primarily on the interdisciplinary study of living, working, and life in SIDS. Smart Industry is applied in various sectors, such as healthcare, logistics, manufacturing, energy, and agriculture. It encompasses the integration of advanced digital technologies and information systems within the industrial sector. The United Nations Sustainable Development Goals (SDGs) serve as a key guideline and are reflected in the research areas. The following SDGs are considered the most relevant: SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 17 (Partnerships for the Goals). However, the research areas may also intersect with other SDGs not explicitly mentioned (Onderzoeksagenda BEST 2023-2027, 2022).

4 Program Design

The full-time program lasts four years and has a study load of 240 ECTS. A year (60 ECTS) is divided into four quarters of 15 ECTS. The program consists of a propaedeutic phase (one year) and a main phase (three years). Table 1 gives an overview of the structure of the BEST program.

Table 1 - Structure of the BEST bachelor program

Year	Phase	Focus	Educational components
1	Propaedeutic	General and core disciplinary foundations	Theory, practical, and project work
2	Bachelor	Development of professional skills within chosen major and minor disciplines	Theory, practical, and project work
3	Bachelor	Professional skills in chosen major and minor disciplines; Professional practice through internship or minor program	Theory, practical, project work, and Minor program or Internship,
4	Bachelor	Professional practice through internship or minor program and graduation in chosen major discipline	Minor program or Internship and final graduation project

The first year of study (propaedeutic phase) is broadly structured. During the propaedeutic phase, students acquire general foundations and basic knowledge of the five main specializations. A course such as Computer Science covers knowledge important for analysing products and information flows and designing ICT systems. The course The Method, Techniques and Research covers the basic aspects of research that will be used directly in the project in the first year. In the Engineering course, students learn basic knowledge and skills in engineering, such as building physics, digital twin, artificial intelligence, 3D printing, computer science, and electrical networks. The course of Mathematics is a supporting course, where students acquire the underlying mathematical knowledge and skills essential for a final qualification. The Professional Development course covers soft skills such as writing, presenting, professional development, and study guidance.

In the first-year project, the Smart Sustainable Seat project, students are challenged with a realistic problem for which they must devise a solution. This project offers a broad approach and covers various learning objectives. At the end of the first year, students choose one of five main majors.

The main phase is divided into the in-depth phase, the internship, and graduation phase. In the main phase, students specialize in their chosen major but maintain contact with the other major specializations through multidisciplinary projects and minor discipline.

This program also has a minor. The minor, Creating Sustainability for a Resilient Society, provides an integrated approach for developing solutions that integrate technical, ecological, economic, and social responsibility.

The program offers students the flexibility to undertake an internship or minor during either their third or fourth year of study. Students prepare for the internship through projects, practical, and excursions.

Finally, the graduation period takes place in the second half of the fourth year. Graduation takes place primarily in a business setting, where students work independently, research, and solution-oriented on a company assignment. The focus of the graduation project is on independently analysing, designing, and implementing an assignment to arrive at a solution (*Informatiedossier Toets Nieuwe Opleiding voor de Bachelor in Engineering & Sustainable Technology, 2023; Raphaela, 2023)*.

5 Implementation and Institutional Challenges

The biggest challenge we faced was convincing various colleagues that this was the path we should take. Resistance to change is common in every organization (Yılmaz & Kılıçoğlu, 2013), and it becomes even more difficult when the changes are accompanied by an innovative plan. This new program doesn't exist anywhere, and that makes people more sceptical. The UoC management was enthusiastic about the new plan to establish a new program within the Faculty of Engineering. This prompted the dean of the faculty to implement the faculty's new plan. Transparency and making agreements ensure that colleagues understand what is changing and the reasons for it. These are important factors in overcoming resistance to change (Gonçalves & Gonçalves, 2012). A development team was assembled with people from various disciplines within the faculty. Within this team, many meetings and brainstorming sessions were organized to develop this new program. In addition to these sessions, regular meetings were held to inform and involve the rest of the faculty in the processes. Gradually, the colleagues are starting to get used to the new idea. The major concern of the colleagues was that this program would not be accredited by the NVAO. After receiving positive feedback on the pilot accreditation visit for the BEST program, most colleagues helped us to seriously develop this new program. This program was designed according to UoC guidelines, with limited financial and human resources. These guidelines were provided by the Quality Assurance department, which plays a key role in the overall design of this new program.

6 Impact and Early Results

Enrolment in the program has increased markedly in recent years. Whereas the average enrolment in the former programs within the Faculty of Engineering at the University of Curaçao typically ranged between 5 and 15 students, the new BEST program has attracted more than 50 students annually over the past three academic years. The retention rate, which had previously been below 50% in the former programs, has now improved to between 85% and 90% (Inschrijvingen FdTW, 2025). Student evaluations and feedback indicate a consistently positive perception of both the courses and the quality of instruction. The program has received a formal positive assessment from the NVAO (Advies Rapport NVAO , 2025).

7 Future Directions and Collaborative Initiatives

Collaboration in higher education provides many benefits, from expanding academic opportunities to promoting innovation and global partnerships. In the BEST program, collaboration with both international and local institutions must be significantly strengthened in the coming years. Formal partnerships have already been established between universities in several countries, for instance Belgium, the Netherlands, Colombia, and Suriname. A learning community program is already being implemented in cooperation with Delft University of Technology and The Hague University of Applied Sciences. In addition, faculty exchanges are being conducted with the HAN University of Applied Sciences in Arnhem and Nijmegen. A minor program has already been developed in partnership with Thomas More University of Applied Sciences in Belgium, and another minor program is currently under development with Ghent University. Further collaboration efforts are underway with several other international universities and institutions, like the University of Applied Sciences in Utrecht and Amsterdam, to expand and consolidate these partnerships.

In addition to teaching, the faculty aims to further expand its research activities. To this end, it is establishing a Lectorate, practice-oriented research unit focused on sustainability research.

Furthermore, the possibility of introducing the BEST program on another island within the Kingdom of the Netherlands will be explored.

8 Conclusion, Limitations, and Future Research

8.1 Conclusion

The BEST program is an innovative, future-oriented program that focuses on project-based learning and multidisciplinary integration within a regional context. By integrating sustainability principles into the BEST program, it bridges the gap between engineering

expertise and the needs of sustainable development. Its multidisciplinary design not only prepares graduates to tackle real-world challenges but also contributes to improved student recruitment and retention within the UoC Faculty of Engineering. Initial results demonstrate that the program has significant potential to serve as a model for sustainable engineering education in the SIDS and beyond.

8.2 Limitations

Notwithstanding that this study presents useful findings on the development and preliminary results of the BEST program, several limitations should be considered. First, the analysis is based on institutional data from a single program, which may limit the extent to which the findings can be generalized. Second, the program is still in its initial phases, meaning that the long-term effects on student achievement and workforce outcomes cannot yet be conclusively assessed.

8.3 Future studies

Future studies may examine these limitations through longitudinal studies by integrating comparative analyses of comparable programs in other SIDS and acquiring perspectives from graduates and industry stakeholders.

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Enhancing Sustainable Energy Education: Use Of Scenario Studies

Mansi Mehta[a], Loredana Tiedke[a] and Semih Severengiz[a]

[a] Sustainable Technologies Laboratory, Bochum University of Applied Sciences, Germany

Abstract

The accelerating transition toward renewable energy is reshaping labour markets and placing unprecedented demands on education systems. While existing didactical approaches in energy education, such as project-based or simulation-based learning, strengthen technical skills, they often fall short in preparing learners to navigate the complexity and uncertainty of socio-technical transformation. This paper presents a scenario study based on the Ruhr region of Germany, exploring how renewable energy expansion and structural change may influence the regional education landscape by 2040. Using the Scenario-Manager™ framework, key socio-political, economic and technological drivers were identified, future projections were developed, and four plausible scenarios ranging from "Failed Transformation" to "Sustainable Transformation" were constructed. Across all scenarios, education emerged as both a driver and an enabler of sustainable transition, underlining the importance of long-term investment in green skills and inclusive access to emerging learning pathways. Beyond its empirical insights, the study demonstrates the value of scenario methodology as a didactic tool in sustainability and energy education. By engaging learners in systems thinking, foresight and collaborative decision-making, scenario-based learning equips future professionals to respond to and actively shape change in the energy sector.

Keywords: scenario study; scenario-based learning; energy education; skills for energy transition

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1 Introduction

A new global labour market is rapidly emerging around sustainable energy, from solar, wind and hydrogen to nuclear energy, demanding rapid changes in the current status quo of work skills, innovation and energy education. More specifically, innovations such as large-scale renewable energy generation, advanced storage systems, smart grids, and digital twins are reshaping how energy is produced, distributed, and consumed (Kolokotsa, et al., 2019; Heluany & Gkioulos, 2023; Adeyinka et al., 2024). The energy transition goals carry major uncertainties in terms of the scale, complexity, and the interdependencies that exist across different sectors of society (Svobodova et al., 2020). In such a case, the market increasingly demands professionals who can combine technical expertise with systems thinking and strategic foresight, as well as the ability to navigate emerging policy and technological changes (International Energy Agency, 2023). Here, educators are responsible for continuously upgrading curricula, teaching content and didactic methods to overcome the risk of leaving students underprepared for upcoming dynamic challenges in the energy sector (Beecroft & Schmidt, 2014).

In recent years, a wide range of didactical methods have been used to strengthen learning in energy education, to enhance engagement and connect theoretical insights with real-world energy problems. These include methods such as project-based learning (Serevina et al., 2024), simulation based learning (Wen, 2018), experiential learning (Maynard, 2021) and problem-based learning (Kolmos et al., 2021; Severengiz, 2024). While these approaches effectively promote active learning and critical thinking, they often emphasize specific problem-solving contexts or technical skills without sufficiently addressing the complexity and uncertainty which is often involved in the socio-technical energy transition. Students should be capable of synthesizing knowledge and perspectives from diverse subject areas as well as having system-based thinking to generate innovative and original solutions (Davis, et al., 2023; National Academy of Engineering, 2004). In such cases, methods-based learning approaches such as scenario studies provide students with the opportunity to explore multiple plausible futures and evaluate the strategic implications of their decisions under uncertain situations (van der Heijden, 2005).

Scenario studies act as a tool for improving decision-making, especially when working in settings that comprise many uncertainties (Varum & Melo, 2010). In the world of business development, scenario plannings have been popular for their ability to create future projections, thereby providing insights into potential challenges and to design optimized strategies focused on solving problems or company growth (Schoemaker, 1995; Cordova-Pozo & Rouwette, 2023). Similarly, in context of energy education, scenario studies hold the potential to foster creativity and prepare learners for decision-making while accounting for factors across various dimensions such as social, technological, political, and economic.

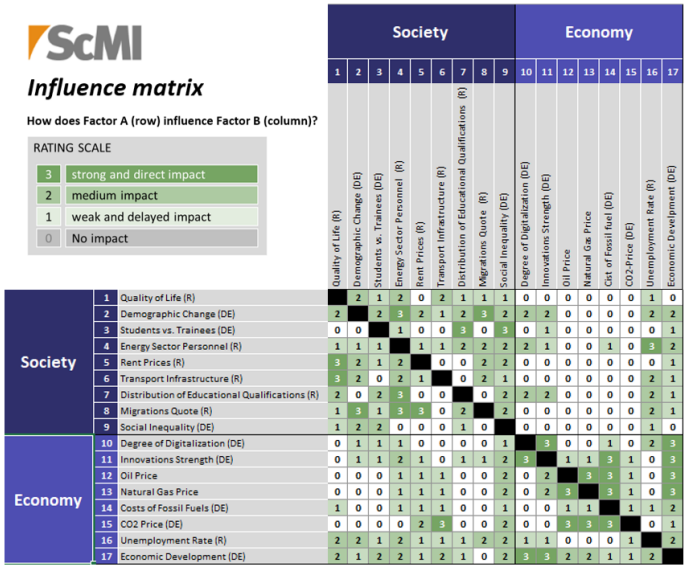
In the current article, we outline the methodological bases and the outcomes of a scenario study which explored the future possibilities of the energy education sector in a region based in Germany. We then discuss the results and describe how such learning methods equip the students to be better at envisioning the dynamic energy market and enhance their decision-making skills as future workers in this field.

2 Methodology

A scenario study was conducted exploring how energy transitions and structural changes in the Ruhr region (North-Rhine Westphalia, Germany) could influence the educational landscape by the year 2040. This study was conducted by students in a seminar held by the Sustainable Technologies Laboratory at Bochum University of Applied Sciences using Scenario-Manager™ framework (ScMI AG, n.d.). In the seminar, students were first introduced to the theoretical foundations of scenario studies and received a practical demonstration of each methodological step. The course design included group-based application of the method, culminating in a written term paper, a final presentation, and an oral examination to assess learning outcomes. The study was originally conducted in German, and all figures are translated to English for the purpose of this article.

The study first examined five major areas to anticipate the challenges and opportunities in the energy education sector: social, political, economic, education, and structural changes. Specific key factors such as teacher shortages, renewable energy expansion targets, and social inequality (measured by the Gini coefficient) were selected as key variables in these areas. Typically, around twenty key factors are selected to represent the most significant variables affecting the topic and used for further analysis (ScMI AG, n.d).

Fig. 1 – Snippet from cross-impact analysis of the influencing factors

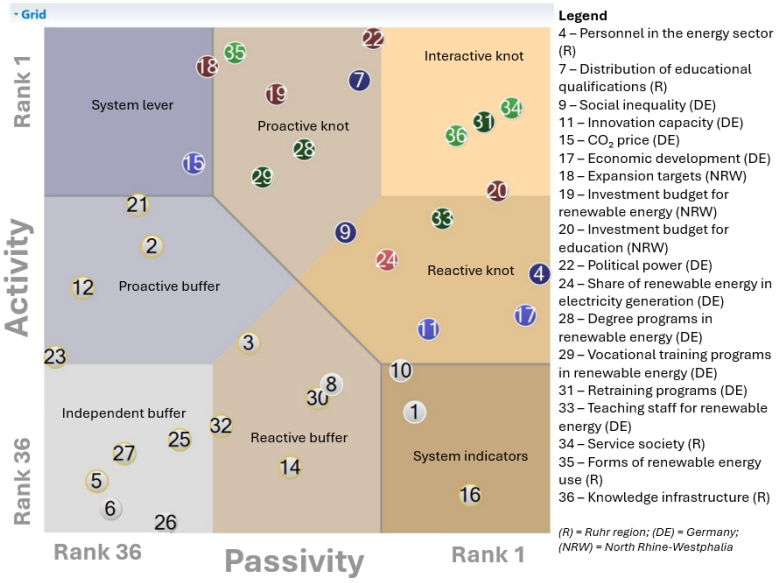


Source: Scenario study report by university students using Scenario Manager™ (2025)

The relative activity and influence of each factor was quantified through pairwise ranking, supported through specialized software like the Scenario Manager™. This step resulted in a cross-impact matrix (see figure 1), that categorizes factors as active, passive or independent nodes, depending on their level of interaction with other variables and their impact on the analysed system.

Changes in active factors are likely to cause changes in other factors, indicating high leverage within the system. Passive factors, however, are the ones that get influenced by other factors and have no strong influence on the system themselves. As such, they are seen as early indicators for changes within the system. This classification forms the foundation for prioritizing which factors to focus on in the scenario study, where factors with high value of activity and passivity are prioritized over independent ones. In the study at hand, as indicated by figure 2, the factor Retraining programs (number 31), for instance, was one of the factors high on activity as well as passivity which lies in the interactive knot of the grid.

Fig. 2 – Influencing factor matrix: Activity-Passivity grid



Source: Scenario study report by university students using Scenario Manager™ (2025)

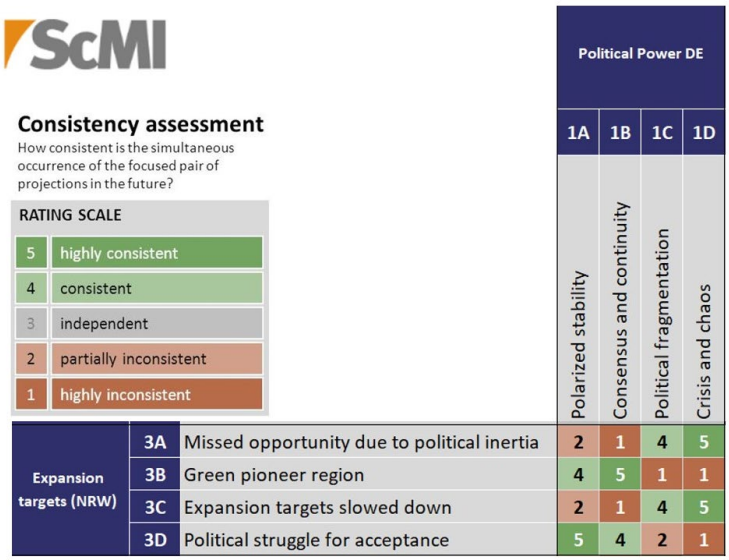
In the next step, questions were formulated for each key factor, such as "How will structural change affect the demand for skilled workers?" or "What role will state investment in renewable energy play in shaping educational pathways?". These guided the inclusion of both quantitative (e.g., GDP growth, renewable energy share) and qualitative (e.g., political will, social equity) dimensions.

Following this, two main dimensions were defined, such as "inclusive vs. non-inclusive educational access" and "high vs. low political commitment to renewable energy" for each of the key factors. These dimensions allowed the researchers to visualize different development paths within a scenario funnel. For instance, slow renewable energy advancement leads to

limited education opportunities (worst case) in comparison to rapid developments opening more doors to energy education advancement (best case).

Finally, a consistency analysis tested the logical coherence of scenario combinations. Cross-impact evaluations filtered projections to produce internally consistent and plausible scenarios. Figure 3 illustrates a section of the consistency matrix, where scenarios were rated from "5" (highly consistent, e.g., 3D and 1A) to "1" (highly inconsistent, e.g., 3D and 1D).

Fig. 3 – Snippet from the consistency analysis



ScMI

Consistency assessment

How consistent is the simultaneous occurrence of the focused pair of projections in the future?

RATING SCALE

5	highly consistent
4	consistent
3	independent
2	partially inconsistent
1	highly inconsistent

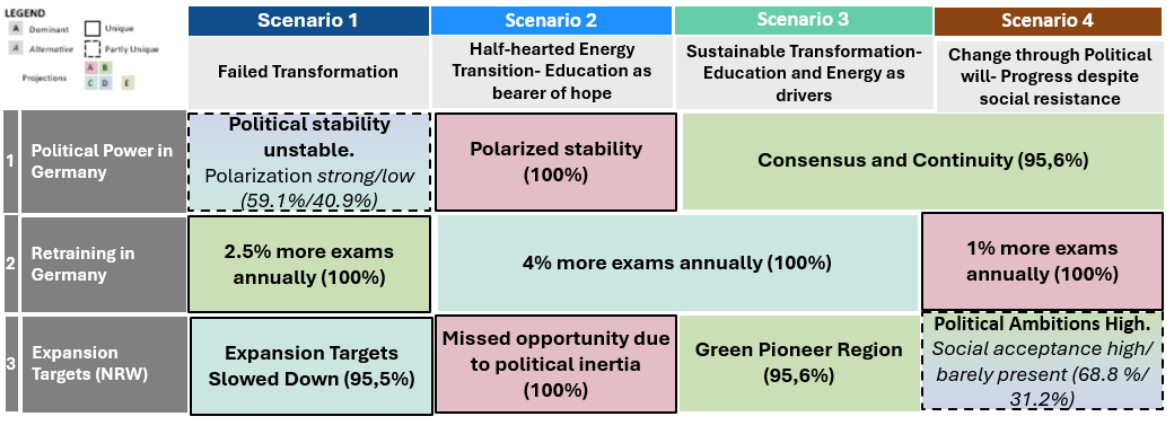
			Political Power DE			
			1A	1B	1C	1D
			Polarized stability	Consensus and continuity	Political fragmentation	Crisis and chaos
Expansion targets (NRW)	3A	Missed opportunity due to political inertia	2	1	4	5
	3B	Green pioneer region	4	5	1	1
	3C	Expansion targets slowed down	2	1	4	5
	3D	Political struggle for acceptance	5	4	2	1

Source: Scenario study report by university students using Scenario Manager™ (2025)

3 Results

The scenario analysis produced four plausible futures for the Ruhr region's education system under the influence of renewable energy expansion and structural transformation. A snippet of the results generated by the software is depicted in Figure 4.

Fig. 4 – Snippet from the four scenarios generated



LEGEND

A Dominant Unique
A Alternative Partly Unique
Projections A B C D E

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
		Failed Transformation	Half-hearted Energy Transition- Education as bearer of hope	Sustainable Transformation- Education and Energy as drivers	Change through Political will- Progress despite social resistance
1	Political Power in Germany	Political stability unstable. Polarization *strong/low (59.1%/40.9%)*	Polarized stability (100%)	Consensus and Continuity (95,6%)	
2	Retraining in Germany	2.5% more exams annually (100%)	4% more exams annually (100%)		1% more exams annually (100%)
3	Expansion Targets (NRW)	Expansion Targets Slowed Down (95,5%)	Missed opportunity due to political inertia (100%)	Green Pioneer Region (95,6%)	Political Ambitions High. *Social acceptance high/ barely present (68.8 %/ 31.2%)*

Source: Scenario study report by university students using Scenario Manager™ (2025)

- Scenario 1- Failed Transformation (Worst Case): Persistent political instability and weak economic growth lead to declining investments in education and renewable energy. Inequality widens, vocational training opportunities shrink, and the energy transition stagnates. The Ruhr's workforce becomes polarized, with limited access to upskilling opportunities and rising social disparities.
- Scenario 2 - Half-hearted Energy Transition: While renewable energy expands moderately, bureaucratic and financial barriers constrain progress. Education remains a "beacon of hope," with steady public investment and new training programs in sustainable technologies. Yet, industrial transformation lags, limiting innovation potential and job creation.
- Scenario 3 - Sustainable Transformation (Best Case): Stable political support and strong cooperation between science, education, and industry drive rapid innovation. By 2040, renewable energy accounts for over 80% of the energy mix. Vocational and higher education programs align with green industry needs, creating new employment pathways and social equity.
- Scenario 4 - Change through Political Will: Decisive government intervention accelerates renewable energy investment and reorients education policy. New teacher training and retraining programs support a skilled workforce for the green economy. However, overreliance on state direction risks reducing local flexibility.

4 Discussion and Conclusion

The scenario study produced four plausible development pathways illustrating how renewable energy expansion and structural transformation may reshape the Ruhr region's educational landscape by 2040. Across all scenarios, education emerged consistently not only as a passive respondent to transition processes but as an active enabler of sustainable transformation. Based on the results, several measures can be outlined to strengthen the role of education in energy transitions. For instance, providing continuous training programs for teachers on renewable energy topics with some incentives to further motivate the learning practice. At the same time, the results underline the necessity of designing long-term policy frameworks that secure investment in vocational and higher education programmes focused on renewable energy, digitalisation, accessibility of learning contents for all and interdisciplinary competencies. Such policies should promote retraining initiatives and integrate sustainability skills across curricula to ensure social inclusion and equal access to emerging job opportunities. In regions undergoing industrial transition, like the Ruhr area, adaptive and future-oriented education strategies are crucial to maintain innovation capacity and social stability during the energy transition.

These key insights of the energy market, projected 15 years into the future, were brought forward using a scenario study. Students who aim to work in such dynamic fields benefit from

the system-orientated framework which is needed to understand the inter-dependencies between economic, social, political, and technological dimensions, used by this methodology. Unlike traditional problem-based or simulation-based learning approaches, scenario studies emphasize uncertainty, long-term thinking, plurality of outcomes and the necessity to assess trade-offs across multiple competing futures. This fosters not only strategic foresight, systems thinking and value-based reflection, but students also gain in-depth knowledge of the social, political, and economic contexts shaping a given topic. Moreover, the collaborative and interdisciplinary nature of scenario studies also trains teamwork and communication skills in cross-disciplinary setting. By the end of the seminar, students acquire the methodological competencies to independently conduct a scenario study and learn to analyse and propose policy measures and interventions needed to guide development toward a preferred plausible future. Such competencies are increasingly demanded in the energy sector (Jankelova et al., 2024).

Beyond energy education, scenario studies offer a versatile framework for addressing broader sustainability challenges such as climate adaptation, energy justice, grid transformation, or resource scarcity (Ulrich et al., 2022; Oriol et al., 2024). By linking qualitative foresight with quantitative data, they enable students and practitioners to anticipate structural shifts, assess risks, and develop adaptive policy responses.

Thus, scenario methodology should not be seen merely as an analytical forecasting instrument but as a transformative pedagogical strategy. It bridges the gap between technical expertise and strategic future-oriented decision-making, empowering the next generation of professionals to navigate and shape the energy transition.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Overcoming Challenges In Green Hydrogen Education: Lessons Learned From A Training Of Trainers In Ghana

Lasse Frederik Maddey[a], Sima Wagner[a], Jonas Pluschke[a], Emmanuel Effah[a] and Semih Severengiz[a]

[a] Sustainable Technologies Laboratory, Bochum University of Applied Sciences, Germany

Abstract

Many sub-Saharan countries currently lack reliable electricity infrastructure, particularly in rural areas. Solar mini-grids can help remedy this situation. However, they require effective storage solutions, for which green hydrogen (GH_2) offers a possibility. Establishing green hydrogen as a storage solution for mini-grids in sub-Saharan Africa (SSA) requires expertise and a trained local workforce. Education in the field of green hydrogen in the region is therefore key, but has so far not been a focus in curricula. This case study examines a Training of Trainers (ToT) by the Green Hydrogen for decentralized Energy Systems in sub-Saharan Africa (GH2GH) Project that was conducted on the first green hydrogen system in Ghana. The experiences gained during the ToT in designing the curriculum and conducting the training, as well as surveys among participants, are assessed to identify challenges for conducting ToTs in the field of GH_2 in the region. Subsequently, solution approaches for establishing ToTs are developed. The challenges identified are mainly the lack of opportunities for trainees to gain more practical experience, involving the participants actively in the training, and the lack of further theoretical training opportunities and materials. Possible solutions discussed include the introduction of mock projects, adjusted practical training, digital materials or remote online courses, a GH_2 training system kit, and a GH_2 system simulation.

Keywords: green hydrogen; sustainable energy education; training of trainers; sub-Saharan Africa; hydrogen education

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1 Introduction and Theoretical Background

1.1 The need for energy storage in Ghana

A household is considered electrified if it has access to electricity for at least four hours per day, including a minimum of two hours in the evening, and if a peak power of at least 1 W is available (World Bank, 2013). In Ghana, 89.5% of households had access to electricity as of 2023 (World Bank, 2025a). In rural areas, the share is notably lower at 77.8% (World Bank, 2025b), as infrastructure for connection to the national power grid is often insufficient (Abubakari, 2025). Consequently, electricity in these areas is frequently supplied by diesel generators (Pelizan et. al., 2019). A more climate-friendly alternative to diesel are decentralized solar mini-grids, in which self-sufficient locations are supplied with solar energy. Daily fluctuations in electricity production and rainy seasons raise the question of long-term electricity storage. In addition to batteries, GH_2 is a possible solution. Despite the lower initial investment costs associated with batteries, GH_2 offers a more suitable long-term storage option, which becomes particularly important during the rainy season.

Framing GH_2 training within the UN Sustainable Development Goals highlights its dual relevance: It supports SDG 7 (access to affordable, reliable and modern energy) and SDG 13 (Climate Action) by enabling lower-carbon storage options that reduce reliance on diesel generation. Further educating local trainers also advances SDG 4 (Quality Education) by building local instructional capacity and promoting education for sustainable development.

Despite being a widely recognized solution for the electrification problem in SSA, there are many known cases in which mini-grids had to be shut down due to a lack of trained personnel for maintaining them. For example, the government of Malawi previously operated six mini-grids, all of which ceased operation due to a lack of funds for maintenance (Abubakari, 2025). To prevent GH_2 systems from suffering a similar fate, it is important to provide staff with training in this area. Therefore, renewable energy education is important for a successful energy transition (Daoudi, 2024). Lucas et al. (2018) compared the demand for skilled workers in the RE sector worldwide with the educational opportunities available and concluded that there is a shortage of educational opportunities, particularly in countries in the global south. This hinders the development of global energy transition. As there is also still a shortage of practically trained instructors in this field (UNIDO,2014), the first step of establishing a GH_2 education system is to qualify the instructors, for which ToTs are a suitable format. In this case study, the first ToT on GH_2 systems in Ghana is evaluated in order to find opportunities for improvement for conducting future ToTs in Ghana.

1.2 Education on Green Hydrogen in Ghana and Sub-Saharan Africa

The goal of ToTs on GH_2 is to enable lecturers to incorporate that topic into their teaching (Daoudi, 2024). Trainer qualification on the topic of GH_2 is still rare in SSA. ToTs regarding

other renewable energies, especially solar PV, are more common (UNIDO,2014; GIZ,2023; GBE& GIZ, 2022). Particularly noteworthy are the UNIDO (2014) and the GIZ (2023) ToTs. The UNIDO ToT mostly consisted of presentations, accompanied by one day of site-visits and one practical training session on solar PV. During the practical training, participants worked in groups to carry out tasks such as installing circuits. The GIZ (2023) project implemented solar training kits and software for designing solar systems in their educational centers, which was reported to have led to a more efficient learning environment. The 10-days ToT of GBE and GIZ (2022) on Solar PV was combined with several months of online training and a mentoring phase for the participants while they were incorporating the learned material into their teaching.

Concerning GH_2 education in SSA, UNESCO has set up a mobile GH_2 teaching unit equipped with a GH_2 System, teaching materials and a trainer (Cattelaens & Fromme, 2014). GH_2 systems, which are rare in SSA, can thus be transported to trainings in locations where they are most needed - places with a lack of energy infrastructure. In Ghana, there was only a single annual one-week training course on project development for GH_2, but this is no longer held (GIZ, n.d.).

The ToT examined in this case study by the GH2GH (Green hydrogen technology for decentralized energy systems in Sub-Saharan Africa) Project is currently the only format for qualifying teachers on the subject of GH_2. The GH2GH project is part of the Environmental Protection Export Initiative (Exportinitiative Umweltschutz) of the German Federal Ministry for the Environment, Climate Protection, Nature Conservation and Nuclear Safety and is coordinated by Zukunft – Umwelt – Gesellschaft (ZUG) GmbH with the assistance of NOW GmbH. In addition to the lead partner, Bochum University of Applied Sciences, the German consortium partners include a fuel cell manufacturer and an energy management software provider. The local project partner is Don Bosco Solar. Since 2014, the Don Bosco Solar Center in Tema has been offering various courses in the field of electrical engineering for instructors, electricians, students and others who are interested in the field of solar PV. The aim of the GH2GH project is to enable the sustainable development of structures for the implementation of green hydrogen technology for decentralised energy systems in sub-Saharan Africa (SSA). As part of the project, a hydrogen plant was installed and commissioned on the campus of the Don Bosco Solar Center in October 2024.

The Don Bosco Solar Center is in the process of developing into a centre of excellence for vocational training in the field of GH_2 (H2VE, 2025) and will be intensifying its activities in this

area accordingly. In Ghana, there is a particular need for practical training for both technical trainers and university lecturers. This observation is supported by GBE & GIZ (2014), who noted that teachers in the renewable energy sector in SSA lack practical experience themselves and are therefore unable to pass it on. However, since the GH_2 system by the GH2GH Project is the only system used for electricity purposes in Ghana, further hands-on training possibilities are lacking.

2 Methods

This case study adopts a mixed-methods approach to examine challenges and potential solutions arising from the ToT on GH_2 conducted in Ghana. The empirical basis consists of (1) the direct observations of the authors, who were present during the training (one author as instructor, one author as observer) and were also involved in the course conception and subsequent evaluation, and (2) a mixed-methods pre- and post-training survey completed by participants. The combined sources were used to identify operational, pedagogical, and contextual challenges and to explore pragmatic responses to them.

Data from the observations derive from systematic, reflective discussion after each training day and from notes taken during and immediately after sessions. Although no formal observation protocol or field diary was applied, these iterative reflections - conducted collaboratively by the teaching and organizing team - were used to identify recurring difficulties and to document emergent solution ideas.

All 25 course participants completed mixed-method surveys immediately before and after the ToT. The pre-training survey captured background, expectations and perceived learning needs; the post-training questionnaire captured perceived learning outcomes, experienced challenges, satisfaction with the teaching methods and the scope of knowledge conveyed, and suggestions for improvement. Open-ended responses provided participant perspectives that complemented the authors' observations. The data from observations and survey responses were analyzed through thematic categorization. Recurring patterns, challenges, and reported or proposed solutions were identified and grouped into themes.

The methodological decisions reflect the pragmatic limitations of a short case study. The absence of formal observation tools and the dual insider role of the authors are acknowledged. To minimize bias, interpretations were cross-checked between team members. Findings were triangulated with participant survey data. It is not yet possible to make generalizing statements - after all, there has only been one pilot ToT so far, which means there is not enough data to make quantitatively sound statements. The aim is to provide a transparent, practice-oriented overview of challenges and feasible solutions.

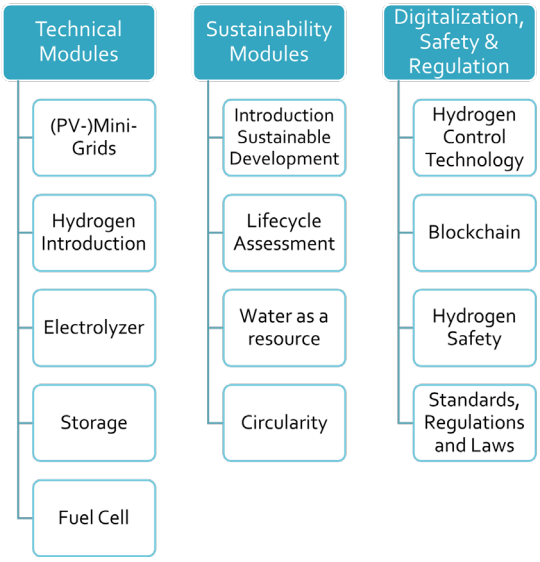
3 Training Procedure

Building on the existing structures at the Don Bosco Solar Center, the ToT was designed to further develop expertise in the field of hydrogen. The ToT addressed hydrogen as an energy storage medium in the context of mini-grids, including digital control technologies and sustainability aspects. In addition, the hydrogen plant already in operation on campus was used during the ToT to combine theoretical and practical training elements on a daily basis in order to promote the training participants' understanding of this complex energy system – an opportunity that is unique in the context of hydrogen as an energy storage in West Africa. This was intended to ensure the best possible transfer of knowledge about the technology introduced and to guarantee sustainable and appropriate use of the system.

The training participants were 23 Ghanaians, including 19 students from RE and Engineering departments, 17 of whom already had at least one university degree, and 7 already had a master's or PhD. Almost all of these participants had already given seminars on renewable energies themselves. The remaining participants were teachers from the Don Bosco Solar Center. The instructors were four representatives from German industry, a professor from a German university and a Ghanaian lecturer from the Don Bosco Solar Center.

The ToT was designed to give participants as comprehensive an insight as possible into the technical aspects, sustainability aspects and digital control of small-scale hydrogen systems for energy storage. The instructors from the partner organizations of the GH2GH project consortium trained the participants in the areas corresponding to their respective fields of expertise. The content areas covered in the ToT are visualized in Fig. 1.

Fig. 1 – Blocks and Modules of the ToT



The ToT took place over nine days. Most days, the instructors provided theoretical input until the lunch break. In the afternoons, participants mostly received practical training at the

hydrogen plant or, in some cases, at other parts of the mini-grid. On the last day of the training, participants were awarded a certificate of attendance.

4 Results

4.1 Observations during the 2025 ToT

While the dates for the ToT and the instructors had been determined well in advance, the final list of participants was not available until a few days before the training began. This resulted in difficulties in preparing the training materials and the curriculum, as the trainers and organizers were not aware of the exact background of the participants and their level of knowledge until very late, and the training content could not be perfectly adapted to this. During the theoretical sessions, the diversity of backgrounds proved beneficial, as those with more advanced knowledge supported others and contributed to peer learning. Clear instruction, interactive methods, and practical demonstrations enabled effective delivery of complex content and sustained engagement. However, several challenges emerged. The high classroom temperatures caused fatigue among participants and trainers. Extended lecture segments led to information overload and reduced interactivity, while inconsistent coordination between trainers occasionally resulted in overlapping content. Differences in accent comprehension and culturally influenced speech hierarchies - particularly participants' tendency to lower their voices when addressing instructors - sometimes impeded communication. Moreover, opportunities for participants to learn how to teach hydrogen-related content or to deepen their theoretical understanding beyond the course were limited due to the lack of follow-up materials or institutional programs.

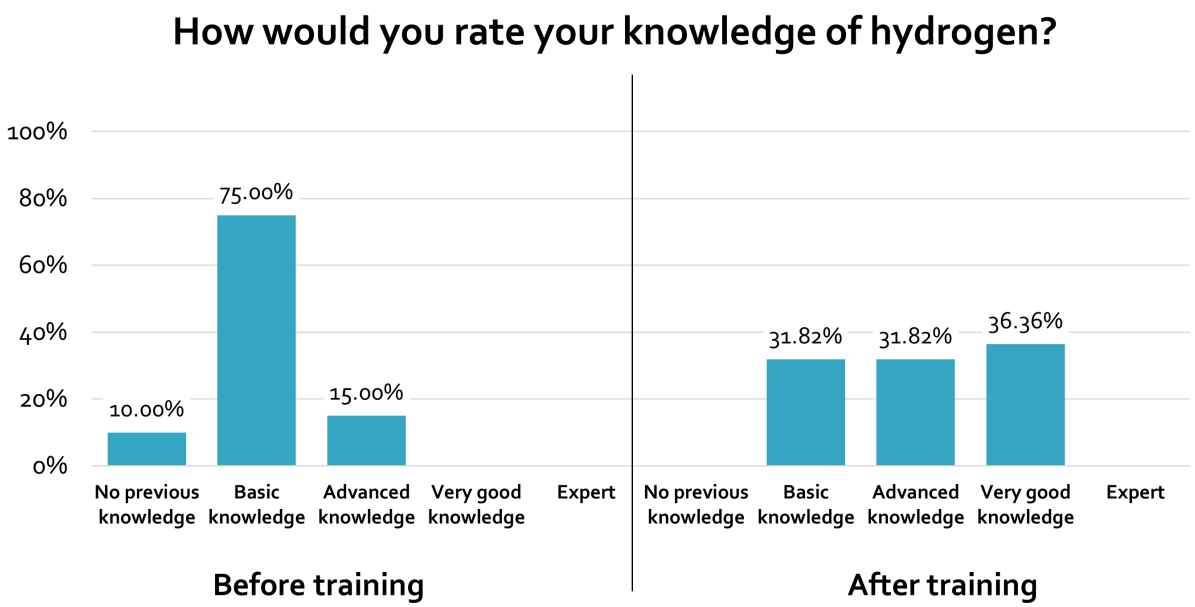
In the practical sessions at the H_2 System House, participants showed strong motivation, connecting theoretical input with operational systems they could observe directly. Questions and discussions deepened conceptual understanding. Yet, practical engagement remained largely observational: limited space and system noise restricted visibility and audibility, and since the system was already fully assembled and operating, participants had no opportunity to disassemble, maintain, or reinstall its components. Consequently, sustained access to hydrogen systems for continued practical experience remains a key challenge for future training iterations.

4.2 Feedback Survey of Participants

In the survey, the self-assessment revealed that most participants (85%) considered their GH_2 knowledge to be basic. This assessment changed over the course (Fig. 2): After the ToT, 68% stated that they had advanced or very good knowledge. The participants therefore had a sense of achievement. Concerning their learning experience, all participants stated that they find practical training particularly helpful. Presentations were rated as helpful by 85%, group

work by 55%, and self-study by 30%. Online teaching formats came in last with 5%. When asked what they expected to be obstacles to further learning after the ToT, the most frequent responses were a lack of teaching materials (33%) and the lack of opportunities in Ghana for practical work with GH_2 systems (25%). The lack of financing opportunities, the lack of infrastructure, and the time lag between training and practical application opportunities are perceived as obstacles to applying the knowledge learned in training into practice. The biggest concern regarding the ToT itself, however, is safety when working with hydrogen systems in practice.

Fig. 2 – GH_2-Related knowledge before and after the ToT



The survey conducted at the end of the training showed that all participants were highly satisfied with the ToT. Suggestions for improvement included a longer ToT, more practical components, the provision of more learning materials (including for independent further learning), a simulation of the H2 system, and consideration of the different backgrounds of the participants.

5 Discussion and Outlook

A compact, pragmatic set of measures is proposed for ToTs on green hydrogen in Sub-Saharan Africa to address the observed challenges. First, a timely pre-assessment of participants' backgrounds - conducted sufficiently in advance to allow tailoring of content - should be implemented to align curricular depth with learners' prior knowledge. This should be complemented by closer coordination among trainers prior to delivery to avoid overlap and unnecessary repetition. Alternatively, a responsive curriculum could be introduced, in which content can be adapted based on participants' prior knowledge and feedback. During

delivery, there should be a focus on learning conditions and pedagogy: Where feasible, theoretical sessions should be held in climate-controlled rooms, and dense theoretical blocks should be interrupted regularly with practical exercises to reduce cognitive overload. To involve participants more actively in the theoretical training, one approach could be to combine presentations with problem-based learning in groups, which was considered helpful in the survey. In group projects, participants could design mock mini-grids or come up with their own use cases for GH_2. Active formats that also train teaching skills should be emphasized (e.g., group work with presentations, think-pair-share, role-plays, reflection sheets, simulations or gamified tasks). If already existent, local trainers should be involved and paired with visiting instructors to mitigate language and cultural barriers and to foster sustainable capacity building.

To address the lack of practical training possibilities, future ToTs should concentrate on practical training - especially at the Don Bosco Solar Center Campus, as it offers the only GH_2 system so far. To offer participants an opportunity to practice beyond just observing, GH_2 training kits similar to the PV training kit provided during the UNIDO ToT could be implemented. Furthermore, a GH_2 system simulation for training purposes similar to the solar system simulation offered by GIZ (2023) could offer trainees the opportunity to experiment with different parameters and analyse energy systems. Immersive technologies (AR/VR) can further extend practical experience. Where such hardware is unavailable, structured video demonstrations offer a substitute. After the course, participants should receive follow-up materials and clear pathways for continued learning - e.g., repositories of teaching resources or links to partner institutions. To ensure sustained professional development beyond the initial training, future ToTs should actively contribute to establishing a *Community of Practice* (Wenger, 1998) in which trainers can collectively exchange experiences, co-develop materials, and support each other in navigating emerging GH_2 technologies. The options mentioned in the section above could be part of an online course as an additional offering for ToT participants or others. This would have the advantage of being freely accessible and thus help to close the gap in GH_2 education. Collectively, these measures aim to strengthen participant engagement during ToTs, enhance the teaching quality, and support sustainable knowledge development in the region.

The proposed solutions can help to ensure that ToTs are tailored to the circumstances in SSA, thereby improving their quality. GH_2 needs to become part of longer-term curricula, training programs and apprenticeships. Additionally, further R&D is needed to support post-ToT learning among trainers. Promising research topics include simulation tools and immersive environments such as H_2 system simulations and AR/VR applications, which can support ToTs in producing sustainable impact.

6 Acknowledgements

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Learning With A Real Microgrid: Designing And Evaluating An Authentic Problem Context Concept For PBL

Lukas Sturm[a,b], Semih Severengiz[b], Michele Velenderić[c] and Giovanni Cinti[d]

[a,c] Green Power Brains GmbH, Germany
[b] Sustainable Technologies Laboratory, Bochum University of Applied Sciences, Germany
[d] Department of Engineering, Università degli Studi di Perugia, Italy

Abstract

The energy transition requires engineers who can reason about complex renewable energy systems, diagnose faults, and work collaboratively in dynamic environments. Problem-Based Learning (PBL) is widely recognized for supporting such competencies, yet many engineering courses lack authentic contexts that reflect real professional challenges. This paper presents a problem context concept for renewable energy system education and evaluates its implementation in a PBL course built around a real solar microgrid. The concept integrates four elements: a real solar microgrid as the learning environment, a student-generated multi-layered system model, an expert-informed case library, and authentic engineering tools. A pilot course with six interdisciplinary students was conducted at Bochum University of Applied Sciences. Mixed-method evaluation - including self-assessments, pre/post-tests, and focus group interviews - was used to assess learning outcomes. Results demonstrate substantial gains in system understanding, problem-solving skills, teamwork, and motivation, with more modest improvements in theoretical knowledge and self-directed learning. The findings show that authentic problem contexts can significantly enhance PBL effectiveness in engineering education. The presented concept provides a replicable approach for educators seeking to integrate real-world systems into renewable energy teaching.

Keywords: problem-based learning; renewable energy education; problem context; educational innovation; solar microgrids.

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1 Introduction

The global transition toward renewable energy systems is reshaping both industry and education. Engineers are expected to master not only technical expertise but also interdisciplinary, digital, and collaborative skills to design, operate, and manage complex energy systems. However, traditional lecture-based teaching methods in engineering education often fail to address these evolving demands (Hadgraft and Kolmos, 2020).

PBL offers a pedagogical alternative that aligns with these needs. PBL engages students in solving authentic, interdisciplinary problems, enabling them to develop applied knowledge and transferable competencies (Barrows, 1986; Hmelo-Silver, 2004). Within renewable energy contexts, PBL can help bridge the gap between theory and practice by situating learning in real-world systems such as photovoltaic installations and smart microgrids (Huijben et al., 2022; Zekaria and Chitchyan, 2019). Despite its potential, existing PBL approaches often lack structured concepts for application in engineering contexts (Boelt et al., 2022; Olewnik et al., 2023).

This study addresses this issue by developing and evaluating a concept for an authentic problem context designed specifically for renewable energy PBL. The concept is grounded in Jonassen's troubleshooting model (2010) and operationalized through a real solar microgrid at Bochum University of Applied Sciences. The goal is to understand how such a learning environment influences student outcomes.

2 Research Aim and Questions

This study aims to develop a concept for designing authentic problem contexts in PBL courses and to test its effectiveness through a pilot implementation in renewable energy education.

Research question: Does the developed problem context concept effectively support learning in a renewable energy system PBL course?

3 Methodology

3.1 Research Design

A single-case study design (Yin, 2003) was applied through a pilot teaching project at Bochum University of Applied Sciences. Six interdisciplinary students from engineering and sustainability study courses participated in a PBL class focused on analysing and troubleshooting a solar microgrid system. The research employed a mixed-method evaluation, combining:

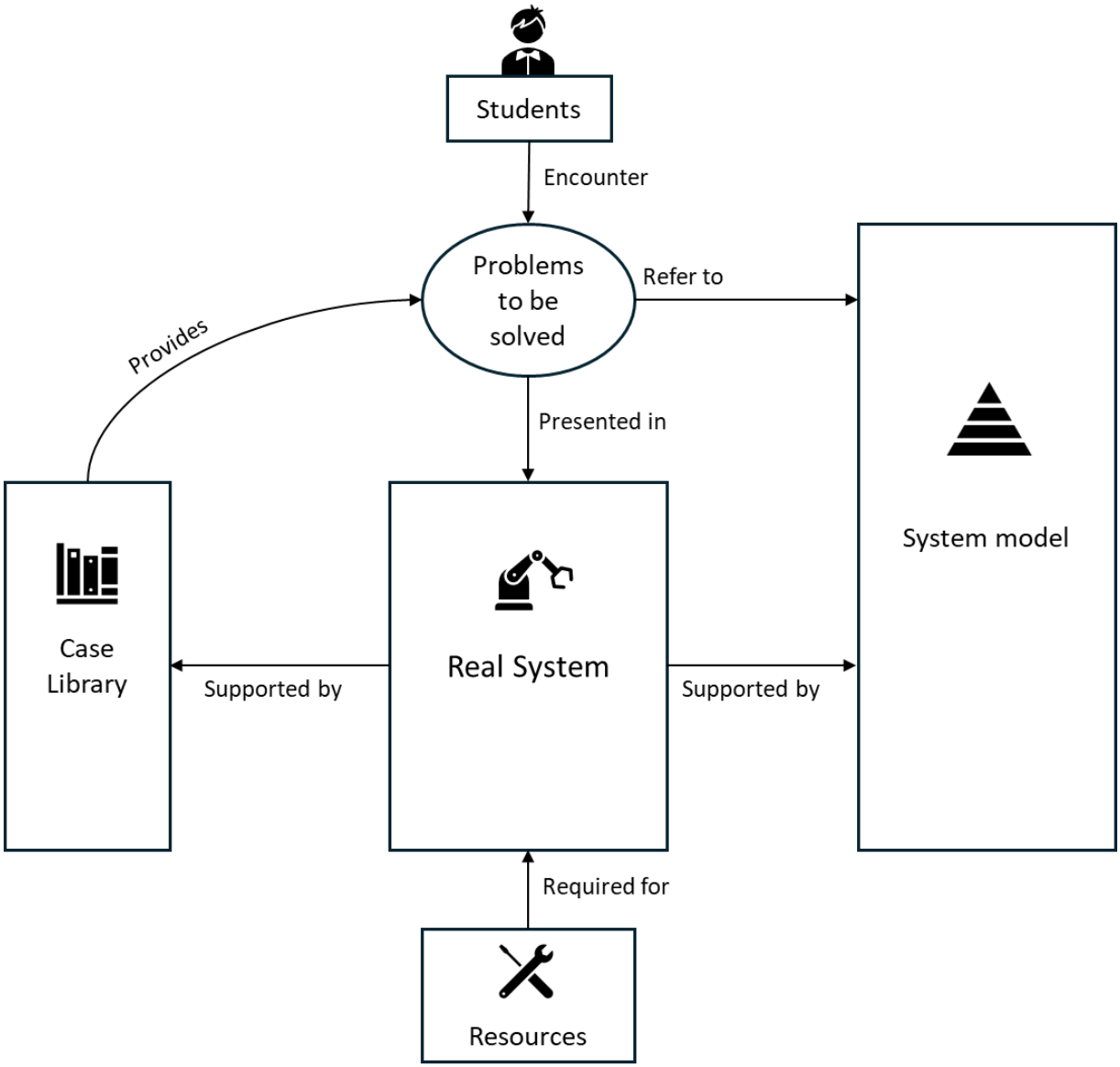
- Quantitative data from self-assessment forms and pre-/post-tests
- Qualitative data from focus group interviews

This design allowed for triangulation of findings across learning outcomes, perceptions, and observed performance.

3.2 Development of the Problem Context Concept

The problem context concept was inspired by Jonassen's (2010) troubleshooting model and adapted for renewable energy system education. It consists of four mutually reinforcing components that together create an authentic environment for engineering problem solving. Figure 1 provides an overview of these components and their interrelations.

Fig. 10 - The developed problem context concept used in the teaching project



Real System

A fully operational solar microgrid served as an immersive environment. Students interacted with photovoltaic components, charge controllers, battery systems, relays, and data communication equipment (see Figure 2).

Fig. 2 – Solar microgrid on the campus of the Bochum University of Applied Sciences

System Model

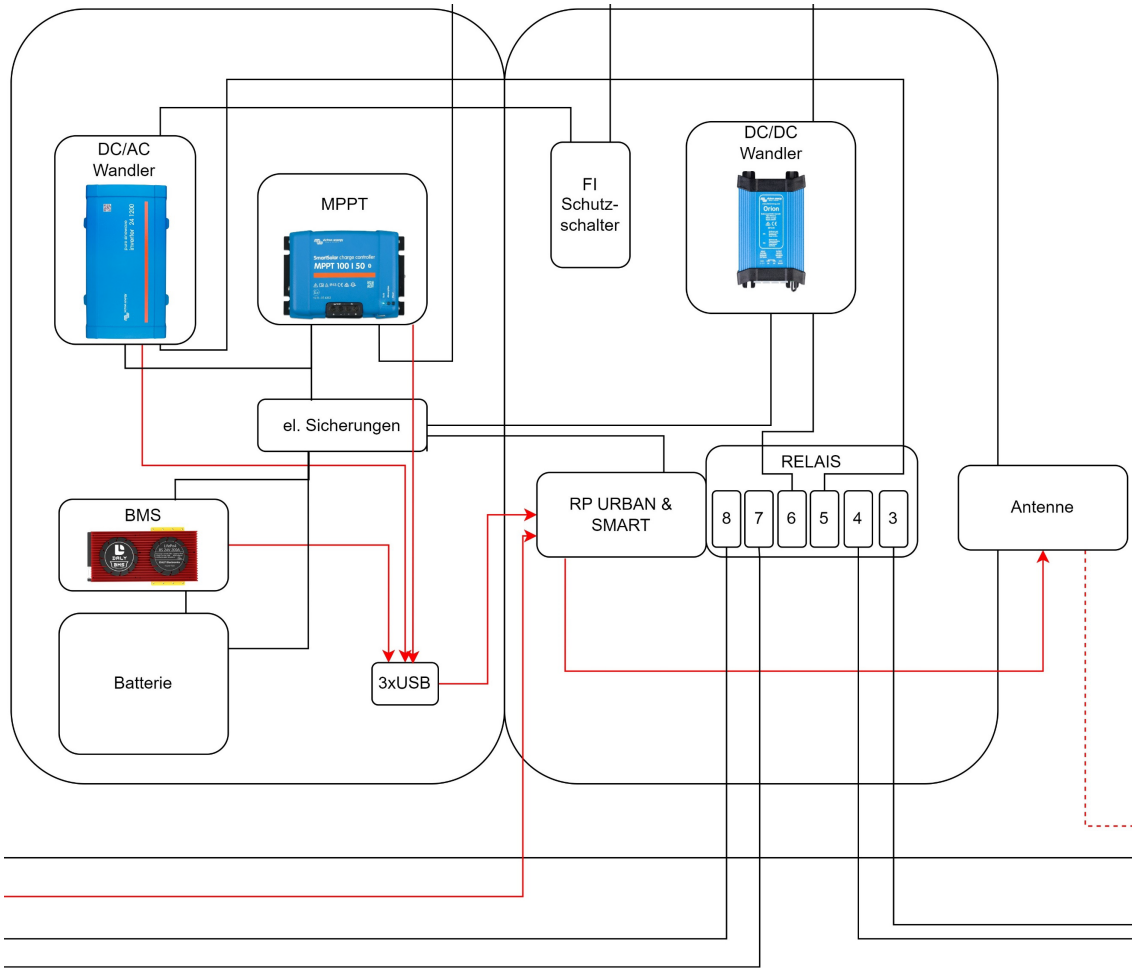
Students collaboratively constructed a system model with six representational layers:

- visual representation

- topographical structure
- state representations
- functional relations
- troubleshooting strategies
- procedural testing methods

Building the model during troubleshooting promoted integration of conceptual, procedural, and strategic knowledge. Figure 3 provides an overview of the visual and topographical layers of the microgrid's central control cabinet:

Fig. 3 - Topographical (top) and visual (bottom) representation of the microgrid's central control cabinet



Expert-Based Case Library

Five microgrid technicians were interviewed to gather real troubleshooting cases. These cases exposed students to authentic failure modes and reasoning strategies, serving as a resource for hypothesis generation and comparison.

Tools and Digital Resources

Students used industry-relevant tools including multimeters, wiring equipment, BMS adapters, SSH terminals (Termius), Grafana dashboards, and an InfluxDB database. Together, these components created a rich and authentic problem context that fostered realistic diagnostic reasoning and problem-solving.

3.3 Implementation in the Teaching Project

The problem context concept was applied in a multi-session PBL course. Students tackled engineering problems such as:

- Analyzing performance fluctuations in photovoltaic generation data
- Investigating state-of-charge imbalances and interpreting battery monitoring results
- Diagnosing communication and data transfer issues between Raspberry Pi controllers and the monitoring platform

Each problem was linked to learning goals such as theoretical knowledge, system knowledge or self-directed lifelong learning. Digital tools including MIRO boards, Grafana dashboards,

and SSH-based remote access supported online collaboration and data visualization. Students alternated between hands-on troubleshooting, system modelling, and analysis of case library examples.

3.4 Evaluation Methods

To assess learning outcomes, three instruments were used:

Table 1 – Evaluation Methods

Instrument	Purpose	Data Type
Self-Assessment Forms (SEF)	Student reflection on competence gains	Quantitative
Pre-/Post-Tests (PP)	Knowledge acquisition in system understanding	Quantitative
Focus Group Interviews (FGI)	Learning experiences, motivation, teamwork	Qualitative

The assessment covered the following learning dimensions:

- Theoretical knowledge (TK)
- System knowledge (SK)
- Problem-solving skills (PSS)
- Self-directed lifelong learning (SLL)
- Teamwork (TEM)
- Motivation (MOT)

4 Results

4.1 Quantitative Results

Self-assessment averages (0–10 scale):

- TK: 5.6 (moderately promoted understanding; noticeable but limited improvement)
- SK: 6.2 (above-average promotion; more than moderate improvement)
- PSS: 6.4 (above-average promotion; more than moderate improvement)
- SLL: 7.0 (well-promoted understanding; clear improvement)
- TEM: 7.0 (well-promoted understanding; clear improvement)
- MOT: 7.3 (strongly promoted understanding; substantial improvement)

Pre-/post-test analysis showed:

- +36% improvement in TK - indicating a small improvement in theoretical understanding

- +73% improvement in SK - indicating a strong improvement in understanding system structure and functionality

4.2 Qualitative Results

Focus group discussions confirmed:

- High engagement through real-world context and autonomy.
- Strong development of analytical reasoning and collaborative skills.
- Students reported a strong sense of motivation and satisfaction when their actions produced visible system responses or tangible learning outcomes.
- Challenges in self-directed lifelong learning, indicating the need for improved facilitation.

5 Discussion

The results suggest that an authentic problem context can substantially enhance key aspects of student learning in renewable energy PBL. The combination of a real microgrid environment, student-generated system modelling, and expert-informed cases appears to have supported system understanding, procedural reasoning, teamwork, and motivation. These outcomes are consistent with the theoretical assumption that authentic contexts promote engagement and deeper cognitive processing.

In contrast, theoretical knowledge gains were more modest, and students reported challenges in self-directed learning. While this study cannot establish causal relationships, these patterns may indicate that certain learning outcomes depend more strongly on the quality of facilitation than on the problem context itself. For instance, limited instructor input may have constrained theoretical development, and insufficient scaffolding may have hindered students' ability to regulate their own learning processes. Likewise, the strong performance in teamwork and motivation could also be influenced by group dynamics or individual student characteristics rather than solely by the problem context.

Future implementations should therefore consider integrating short, targeted mini-lectures to strengthen theoretical foundations and providing more structured guidance for self-directed learning.

6 Conclusion

This study demonstrates that an authentic problem context - built around a real solar microgrid - can meaningfully support learning in renewable energy PBL courses. The findings indicate strong gains in system understanding, teamwork, and motivation, which may be related to the realism and richness of the problem context. More moderate improvements in theoretical knowledge and self-directed learning suggest that these outcomes may depend more heavily on facilitation strategies than on context design alone.

While the study does not establish causal relationships, it provides initial evidence that problem context plays an important role in shaping learning experiences in engineering PBL environments. The presented concept offers a replicable starting point for educators seeking to integrate real-world energy systems into teaching. Future research should further investigate how different design elements - problem context, facilitation, and assessment - interact to influence student learning.

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Bridging Energy And Cybersecurity: Advancing Education For Sustainable Development

Nida Jafri[a]

[a] New Energy Research Centre, Turku University of Applied Sciences, Finland

Abstract

As the world transitions toward sustainable energy systems, the integration of digital technologies in energy infrastructure has introduced new cybersecurity challenges. Smart grids, renewable energy networks, and data-driven management systems depend on secure digital communication to ensure stability and efficiency. This paper reviews relevant literature and Finnish initiatives, identifies education and competence gaps, and proposes an academic curriculum integration model. The target audience includes educators, industry trainers, and university programme directors. Emphasis is placed on operational technology (OT) skills, hands-on labs/testbeds, cross-disciplinary learning outcomes, and compliance with NIS2 and national regulations. We conclude with measurable learning outcomes, arguing that embedding cybersecurity into sustainable energy curricula is essential for resilient, secure, and decarbonized energy systems.

Keywords: energy; cybersecurity; sustainable education; sustainable energy curricula; cybersecurity education.

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1 Introduction

The global energy transition toward renewable energy sources has accelerated over the past decade, driven by the imperatives of climate change and technological advances. However, as energy systems become more interconnected and digitally controlled, they are increasingly exposed to cyber threats. Recent cyberattacks on energy grids and oil pipelines illustrate the fragility of digital infrastructures that underpin sustainable energy systems (Diaba et al., 2024). Cybersecurity is recognized by the European Union as a vital strategic digital capability, emphasizing the importance of safeguarding information technology (IT) and operational technology (OT) environments to protect critical infrastructure, data integrity, and national security (Jelo and Helebrandt 2022).

Cybersecurity plays a crucial role in safeguarding a nation's digital infrastructure against sophisticated threats, including state-sponsored attacks targeting critical sectors like healthcare, energy, and defence. These threats often involve highly coordinated cyber espionage and sabotage efforts aimed at disrupting decision-making, stealing sensitive information, or damaging essential services. Additionally, cybercrime groups are increasingly involved in ransomware operations and other malicious activities, often acting as proxies for state actors to obscure their involvement and evade attribution. This evolving threat landscape underscores the importance of robust cybersecurity measures, international cooperation, and continuous monitoring to protect national security interests in an interconnected digital world.

Finland's Cyber Security Strategy has been revised to address the evolving operating environment, aligning with the priorities of Prime Minister Petteri Orpo's Government to strengthen national cybersecurity resilience and ensure the protection of critical infrastructure and digital services. Cybersecurity plays a crucial role in maintaining Finland's comprehensive security framework, particularly in its highly digitalized society, where trust in digital services is fundamental. To ensure ongoing reliability, Finland must invest in robust cybersecurity infrastructure, promote continuous innovation, and foster collaboration between the government, private sector, and academia. Implementing advanced threat detection, regular security audits, and user education will help safeguard digital assets and maintain public confidence in digital services, supporting the nation's goal of a secure, trustworthy digital environment (Publications of the Prime Minister's Office, 2024).

At the same time, education for sustainable development emphasizes interdisciplinary learning that promotes systems thinking, resilience, and responsible innovation. Integrating cybersecurity awareness into energy and sustainability education is, therefore, critical to ensuring both environmental progress and societal security (ENISA).

2 Methodology

To effectively teach cybersecurity, educators should employ a combination of methods such as interactive simulations, hands-on labs, case studies, and online modules. Utilizing tools like virtual labs and cybersecurity simulation platforms potentially helps to ensure practical, engaging, and accessible learning experiences. Incorporating adaptive learning technologies can personalize education to meet diverse needs, while assessments like quizzes and project work can evaluate understanding and progress, making activities measurable and adaptable. Moreover, leveraging open-source tools and cloud-based resources can enhance resource efficiency and scalability, ensuring that educational activities remain relevant and practical in preparing participants to address real-world cybersecurity challenges in energy systems. This review synthesises peer-reviewed literature, Finnish university projects, and sector reports. Key sources were found through desktop searches and include ENISA guidance on energy, Finnish university projects on smart-grid cybersecurity, and university research programs. The review focuses on educational design (learning outcomes, pedagogies), technical competencies, governance/compliance, and practical training mechanisms. Finnish contexts and projects are highlighted to base recommendations.

3 Literature Review

3.1 Cyber-physical threats and the energy domain

Energy infrastructure components, including SCADA systems, programmable logic controllers (PLCs), remote terminal units (RTUs), protection relays, distributed energy resources (DERs), and smart meters, are critical for maintaining power flow and ensuring safety. Still, they face unique cybersecurity challenges because they operate in OT environments that differ significantly from traditional information technologies (ITs). The differences highlighted emphasize the importance of ensuring high availability and deterministic timing in systems, the challenge posed by legacy devices that have limited patching capabilities, and the complexities involved in conducting forensic investigations within such environments. Studies and organizations like ENISA highlight the importance of domain-specific threat models and the need for defenders who are well-versed in the unique aspects of energy sector cybersecurity to effectively protect these vital assets (ENISA).

3.2 Education and curricula for smart-grid cybersecurity

International curriculum projects like the "Cybersecurity Curricula Recommendations for Smart Grids" led by the University of Vaasa, Finland, emphasize modular learning outcomes and a blended pedagogy. This integrates theory with practical experience through labs, living labs, and internships, catering to multiple educational levels—undergraduate, master's, and executive courses—focusing on awareness, technical depth, and governance. Finland has

been actively involved in these initiatives, contributing local guidance and developing testbed projects to support the implementation and adaptation of these curricula within its educational and industry frameworks (University of Vaasa, Finland).

3.3 Regulatory drivers and competence requirements (NIS2)

Network and Information Security Directive 2 (NIS2) broadens cybersecurity obligations for energy sector entities, emphasizing risk management, incident reporting, and supply-chain security, prompting Finland to incorporate these into national law via the Cybersecurity Act with clear deadlines and supervision frameworks. Ensuring compliance involves establishing robust governance processes and developing a skilled workforce capable of managing OT incident response and reporting. This, in turn, drives the integration of cybersecurity training and continuous professional development within energy education to meet regulatory demands effectively (Traficom).

3.4 Hands-on learning, testbeds, and competency measurement

Empirical studies and pilot projects highlight the critical role of physical and high-fidelity simulated labs in developing OT competencies such as PLC programming, network segmentation, and attack/defence exercises. University testbeds like CR-DES at the University of Vaasa and regional initiatives showcase how these labs facilitate accelerated learning and provide measurable competency assessments. Curricula recommendations emphasize a "Body of Knowledge" approach tailored specifically to smart grids, ensuring that training aligns with industry needs and technological advancements (University of Vaasa, Finland).

3.5 Workforce shortages and the need for cross-disciplinary professionals

To address the shortage of professionals skilled in both power system engineering and cybersecurity, it is essential to develop integrated educational programs such as co-taught modules, industry internships, and micro-credentials recognized by employers, fostering collaboration between academia and industry. Finnish universities and institutes are pioneering this approach by implementing multidisciplinary research funding and executive education initiatives, which help bridge the skills gap and prepare a workforce capable of safeguarding critical energy infrastructure (Aalto University, Finland).

4 Findings: gaps in current Finnish education & competence models

- Insufficient integration of cybersecurity into core sustainable-energy programmes. The integration of cybersecurity into core sustainable-energy programs is currently inadequate, with cybersecurity often treated as an elective rather than a fundamental component. To address this, it is essential to embed security learning outcomes directly

into core modules such as power system protection, control, and renewables integration, ensuring that future energy professionals develop comprehensive security competencies as an integral part of their technical education (University of Vaasa, Finland).

- Limited access to high-fidelity Operational Technology (OT) labs/testbeds for students and small utilities. Regional testbeds are emerging as vital hubs for innovation and research, offering unique opportunities for experimentation. However, their full potential is hindered by limited capacity and a lack of structured educational pathways to develop skilled personnel capable of leveraging these platforms effectively. Addressing these challenges requires expanding infrastructure and establishing formal training programs, such as specialized courses and curricula, to prepare individuals to utilize testbeds efficiently and foster sustained technological advancement, as emphasized by the University of Vaasa in Finland.
- Lack of standardised learning outcomes and assessment metrics for energy-cyber competencies. Bodies like the Cybersecurity Curricula Recommendation for Smart Grids (CC-RSG) offer valuable guidance and standards. But their adoption varies depending on factors such as industry, organizational size, and regional regulations, leading to inconsistent implementation across different sectors (University of Vaasa, Finland).
- Insufficient continuous professional development (CPD) pathways for in-service engineers and operators. While short courses are available, the broader adoption of continuous re-skilling and formal micro-credentials remains limited, highlighting a gap in ongoing professional development opportunities across various industries (Aalto University, Finland).
- Limited research-to-practice pipelines linking university projects and industry needs. Finland's robust research projects and funding are promising, but to enhance industry adoption, especially among small utilities, mechanisms such as targeted incentives, streamlined regulatory processes, tailored pilot programs, and increased industry-academia collaboration should be strengthened. These strategies can facilitate the transition from research to practical implementation, ensuring that small utilities can effectively leverage innovative solutions and contribute to the country's energy sustainability goals. The gaps in energy transition and regulatory scope are not unique to Finland but are intensified by the rapid pace of change and expanding regulations like NIS2. This necessitates comprehensive solutions such as curricular redesign, increased investment in laboratories, enhanced national coordination, and the development of certification frameworks to effectively address the challenges (Aalto University, Finland).

5 Integrating cybersecurity into sustainable energy curricula: proposed model

The curriculum integration model described is specifically designed to enhance the educational framework within Finnish higher education institutions, including universities of technology, polytechnics, and graduate schools, as well as professional education settings, by fostering cohesive and interdisciplinary learning experiences that align with institutional and national educational objectives.

5.1 Design principles

- Domain specificity: To effectively address domain specificity, courses should focus on the unique cybersecurity challenges faced by energy systems such as SCADA, DERs, and protection relays. These could emphasize real-world case studies, threat models, and security protocols, thereby equipping learners with targeted knowledge and practical skills to protect vital energy infrastructure.
- Crossdisciplinarity: A joint teaching program involving electrical engineers, cybersecurity experts, and legal/regulatory scholars would offer a comprehensive curriculum. This could well cover technical expertise with legal and regulatory insights, preparing students to address complex challenges in developing and securing electrical systems within the boundaries of legal frameworks.
- Competency-based learning: Clear learning outcomes aligned with industry roles are specific statements that define what learners should be able to do after completing a course or training, directly linked to relevant job functions and industry standards.
- Hands-on practice: Labs, simulations (digital twins), and field internships.
- Stackable micro-credentials: Badges for specific skills (ICS forensics, secure procurement) that can be accumulated to earn diplomas.
- Regulatory alignment: Map learning outcomes to NIS2 obligations (incident reporting, supply-chain security).
- Accessibility: Offer flexible formats (for example, blended learning) to upskill in-service engineers and procurement staff.

5.2 Curriculum structure (recommended for a Master's minor or specialization)

Core modules (compulsory):

- Foundations of Energy Systems and Control — power system fundamentals, protection, SCADA architecture, and physical constraints. (Learning outcome: Map grid control functions and identify critical assets)

- Cybersecurity Principles for Cyber-Physical Systems (CPS) — threat models, cryptography basics, secure architectures, availability/real-time constraints. (Learning outcome: Apply threat modelling to OT systems)
- Industrial Control System (ICS) /SCADA Security Lab — hands-on modules with PLCs, human machine interface (HMIs), protocol analysis (Modbus/DNP3/IEC-61850), segmentation, and incident simulation. (Learning outcome: Execute safe attack/defence exercises and document incident response)
- Risk & Compliance in Energy Systems — NIS2, national regulation, governance, and incident reporting. (Learning outcome: Preparing incident reports)
- Secure Integration of Renewables & DERs — security implications of inverters, microgrids, electric vehicle (EV) charging, smart meters. (Learning outcome: Assess potential vulnerabilities and security of DER integration scenarios)

Electives (examples):

- Industrial control system (ICS) Forensics & Threat Hunting
- Machine Learning for operational technology (OT) Anomaly Detection
- Secure Procurement & software bill of materials (SBOM) for Energy Vendors
- Crisis Communication & Governance for Energy Incidents

Capstone / Industry Thesis:

- Project with industry partner (utility, vendor, regulator) using real testbed or anonymized datasets.

5.3 Learning outcomes and assessment

- Cognitive: Students will develop the ability to model cyber-physical interactions within energy systems, enabling them to analyse how digital and physical components interact and influence each other. They will also learn to evaluate trade-offs between security measures and real-time safety requirements, understanding how enhancing cybersecurity can impact system responsiveness and safety protocols, ultimately fostering a balanced approach to designing resilient and secure energy systems.
- Practical: Demonstrate secure configuration of a simulated substation, detect simulated intrusions, and execute containment/forensics procedures.
- Professional: Produce compliant incident reports and procurement security checklists; perform vendor assessments. Assessment should combine written exams, lab practicals, and industry project evaluations.

6 Discussion

Implementing the proposed cybersecurity integration into sustainable energy curricula in Finland faces several challenges, including bridging the gap between active research projects

like CR-DES (University of Vaasa, Finland) and national curriculum recommendations such as CC-RSG with mainstream educational practices. The challenge also arises from ensuring faculty expertise and resources are sufficient to incorporate emerging cybersecurity topics, aligning academic programs with industry needs and regulatory standards, and overcoming institutional inertia or resistance to curriculum reform. Additionally, fostering collaboration among research institutions, government bodies, and industry stakeholders to translate research outputs into practical classroom content remains a complex process that requires strategic planning and sustained effort. These could be dealt with through:

- Faculty capacity and cross-disciplinary teaching — Universities should promote joint appointments and co-teaching across departments to foster interdisciplinary collaboration and innovation.
- Industry engagement and internships — To ensure effective collaboration, utilities and vendors should be open to hosting students and accommodating operational constraints, fostering a mutually beneficial relationship. Establishing formal memoranda of understanding (MOUs) can clarify expectations and responsibilities, while small stipends for internships can encourage participation and engagement from both parties.
- Regulatory alignment and rapid change — NIS2 obligations are continuously evolving within national practices, making it essential for curricula to be regularly updated. This could help ensure they remain relevant and effective in addressing current cybersecurity requirements and compliance standards.
- Resource constraints for labs/testbeds — Public-private partnerships (PPPs) are an effective strategy for procuring PLCs, digital twins, and secure test environments. These help reduce costs and leverage combined expertise, thereby broadening access and reducing the financial and operational burden on individual entities.

7 Conclusions

Embedding cybersecurity into sustainable energy education in Finland is crucial for developing a resilient, future-proof energy sector. Given that energy systems are cyber-physical, it's vital to cultivate domain-aware cybersecurity skills through interdisciplinary, competency-driven curricula that emphasize hands-on learning, aligned with regulations like NIS2. Utilizing testbeds and living labs can offer practical experiences that significantly enhance learners' skills and readiness. To effectively scale these educational reforms, robust national coordination among universities, utilities, government bodies, and regulators is essential for a sustainable energy future.

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Universities As System Orchestrators: Mediating Academia–Industry Co-Creation In Regional Innovation

Egena Ode[a], Kadja Manninen[a], Christopher Taylor[a] and Jennie Shorley[a]

[a] Centre for Enterprise, Manchester Metropolitan University, United Kingdom

Abstract

This paper explores how universities orchestrate academic-industry co-creation within mission-oriented regional innovation ecosystems. The empirical case analyses the Greater Manchester Electrochemical Hydrogen Cluster (GMEHC) through a structured collaboration between Centre for Enterprise, Manchester Metropolitan University, Bosch and regional SMEs designed to advance hydrogen innovation and supply chain development. The paper draws on qualitative case study and policy analysis to identify three structural gaps; innovation capacity, translation and coordination gaps that constrain regional participation in low carbon transitions. The findings demonstrate that universities act as multi-modal orchestrators deploying tri-domain legitimacy, multi-competence capabilities, and relational infrastructure to enable what the paper describes as "multi-stakeholder mission-aligned co-creation". This form of value co-creation differs from conventional models through asymmetric but collectively reinforcing value propositions, intermediated interaction, mission coordination logic and ecosystem catalytic temporality. The research contributes to the understanding of university orchestration while offering practical lessons for designing regional innovation policy in net zero transitions.

Keywords: hydrogen economy; innovation ecosystems; university orchestrators; low-carbon transitions; regional policy.

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1 Introduction

As governments accelerate the transition to net zero, hydrogen has emerged as a cornerstone of global decarbonisation strategies. Electrochemical systems such as fuel cells and electrolysers are central to reducing emissions across transport, manufacturing, and energy infrastructures. Yet the diffusion of these technologies depends not only on technological progress but also on the capacity of institutions to coordinate across fragmented actors and policy frameworks. Mission-oriented innovation policies seek to address this by mobilising research, investment, and collaboration around societal challenges such as climate change (Mazzucato, 2018), but their implementation requires active orchestration between global technology leaders, small and medium-sized enterprises (SMEs), and public agencies operating within specific regional contexts.

Within this landscape, universities are emerging as key orchestrators in regional innovation ecosystems. Beyond research and teaching, they convene diverse actors, mediate between scientific and industrial agendas, and provide infrastructures that translate knowledge into impact (Research England, 2020). Cooke et al. (1997) describe regional innovation systems as networks of firms, research institutions, and policymakers whose collective learning drives innovation. Universities are uniquely positioned to anchor these systems because of their legitimacy across sectors and strong local embeddedness.

The Greater Manchester Electrochemical Hydrogen Cluster (GMEHC), funded through the UK Government's Innovation Accelerator Pilot (2023–2026), exemplifies this orchestrating function. This paper examines how universities facilitate academia–industry co-creation within mission-oriented innovation systems, addressing three research questions: 1) How do universities act as orchestrators? 2) What forms of co-creation enable alignment between global firms, SMEs, and policy agendas? and 3) What lessons does this case offer for regional innovation policy in low carbon transitions?

1.1 Innovation Ecosystems and the Role of Universities

The promotion of innovation clusters has long been recognised as a core policy objective within regional innovation systems (Cooke et al., 1997), emphasising collaboration between firms, research institutions, and government agencies. The Triple Helix model (Etzkowitz and Leydesdorff, 2000) similarly identifies universities, industry, and government as key actors whose interaction aligns knowledge creation, application, and regulation. Complementing this, Isenberg's (2011) Six Domains model highlights the mutual dependence of policy, finance, culture, support, human capital, and markets, suggesting that effective ecosystems evolve through the dynamic interplay of these domains rather than through linear coordination.

Building on these perspectives, more recent work introduces the notion of orchestration: the active shaping and management of ecosystem development (Dhanaraj and Parkhe, 2006). Whilst large firms often take this role, universities have increasingly been recognised as capable orchestrators (Harkavy and Zuckerman, 1999; Benneworth and Charles, 2005; Youtie and Shapira, 2008; Goddard et al., 2014). As "anchor institutions," they are deeply rooted in their localities and possess the convening power to broker partnerships, coordinate networks, and facilitate knowledge exchange. Empirical studies show that universities act as regional orchestrators through incubation, outreach, policy collaboration, and network coordination (Benneworth and Charles, 2005; Youtie and Shapira, 2008; Uyarra, 2010).

Despite their influence, these frameworks have important limitations. Much of the literature remains conceptually rich but empirically thin (Gomes et al., 2018). While models such as the Triple Helix and Six Domains recognise the need for multi-actor collaboration, they pay limited attention to how coordination and leadership actually occur in practice. Universities, often positioned as both anchors and orchestrators, translate policy aims into collaboration and knowledge flow, but their effectiveness is contingent on stability and continuity in the policy environment. As Youtie and Shapira (2008) observe, policy-led ecosystems can be fragile and prone to disruption when priorities or funding streams shift.

1.2 Co-creating Innovation: The Orchestration role of universities in policy-driven ecosystems

The importance of inter-organisational collaboration and innovation networks is widely recognised (Hurmelinna-Laukkanen and Nätti, 2018; Thomas et al., 2021). Innovation has evolved beyond organisations' boundaries toward a more network-based approach relying on co-creation with diverse stakeholders (Etzkowitz and Leydesdorff, 2000; Kazadi et al., 2016). Co-creation emphasises a shift from the linear model of knowledge production to a more socially distributed and application-oriented model focused on joint value creation between diverse actors (Prahalad and Ramaswamy, 2004).

Innovation co-creation has evolved from a firm-centric, user-driven ideation to a systemic initiative that involves several stakeholders in the pursuit of shared objectives and value creation (Loureiro et al., 2020; Wong, et al., 2016; Zheng et al., 2025). Co-creation is essential to this transition, as it converts external stakeholders, particularly customers, from passive recipients into active partners in the innovation and value creation process (Kazadi et al., 2016; Nambisan and Baron, 2009. This strategic realignment is founded on the Service Dominant (S-D) Logic proposed by Vargo and Lusch (2004), which asserts that value is not an inherent attribute of products but is perpetually co-created by several stakeholders, including the customer, within a particular context of use (Galvagno and Dalli, 2014; Ranjan and Read, 2016; Prahalad and Ramaswamy, 2004).

Despite the benefits of co-creation, previous studies argue that innovation co-creation can occur within pre-existing power structures, where large industrial partners may exert disproportionate influence over the research agenda, a concept described as "corporate capture" (Slaughter and Rhoades, 2004). This has the capacity to steer university research towards incremental, commercially safe innovations at the expense of radical, long-term scientific inquiry that is the core of academic discovery (Thomas et al., 2021; Mignoni, et al., 2023).

Universities act as neutral, trusted intermediaries that weave networks, govern collaboration, and mobilise resources for collective good (Markkula and Kune, 2015). This role is particularly important in nascent, policy-driven innovation such as hydrogen, where the central actor is needed to overcome coordination failures. As orchestrators, universities link national policy goals with local initiatives, provide shared facilities that reduce entry costs, and bridge the gap between early-stage R&D and large-scale adoption (Hurmelinna-Laukkanen and Nätti, 2018). From this view, universities have increasingly been identified as fundamental orchestrators within regional and national ecosystems.

2 Methodology

This study adopts a qualitative case study approach to examine how co-creation unfolds between universities and industry within a policy-driven innovation context. A case study design is appropriate when the boundaries between a phenomenon and its context are intertwined and the aim is to develop a situated understanding of underlying processes (Yin, 2018). The selected case is the GMEHC, led by the Centre for Enterprise at Manchester Metropolitan University, which represents a regional, policy-aligned initiative supporting the UK's hydrogen strategy.

Data for this study were drawn from two complementary sources. First, a case study of the GMEHC activities was developed through institutional documentation and reflective accounts from academics. Second, relevant policy documents and strategic publications were analysed to identify how the GMEHC operates within the wider innovation ecosystem. These materials were examined through qualitative thematic coding (Gibbs, 2007) to trace how policy frameworks shape university–industry collaboration and to explore the university's role as an orchestrator within a mission-oriented innovation system.

3 Case Study: Greater Manchester Electrochemical Hydrogen Cluster

The GMEHC has flowed from the success of the European Regional Development Fund (ERDF) funded Manchester Fuel Cell Innovation Centre (MFCIC, 2016-20). Itself borne from the recognition that the university is a key orchestration actor in development of a new technology sector, the MFCIC was a collaboration between technical leads in hydrogen fuel cell technology in the Faculty of Science and Engineering and SME engagement leads in the

Centre for Enterprise, based in the Business School. The funding allowed a joint approach of scientific development and SME exploration of the technology, whilst also providing a place-based "centre", to which corporate firms and policy could be invited to promote development of this new sector. With targets around new research and also SME engagement, the MFCIC kickstarted the engagement of policy with the hydrogen sector, directly contributing to Greater Manchester being the only city region in the UK with a hydrogen strategy (2025).

The GMEHC includes two strands: an R&D strand delivered collaboratively by Manchester Metropolitan University (MMU), the University of Manchester, the Henry Royce Institute, and the National Physical Laboratory; and an innovation capacity-building strand. In November 2024, MMU entered a formal collaboration with Bosch to reconfigure the second strand of the GMEHC. Originally focused on strengthening hydrogen innovation capabilities in SMEs, evaluation showed that many regional firms viewed hydrogen as a future rather than immediate market opportunity. To address this, MMU and Bosch formed a strategic partnership to reshape the strand around co-creation, industry leadership, and ecosystem orchestration. This collaboration embedded Bosch's technological expertise and industrial perspective within GMEHC, transforming Strand 2 into a practical demonstration of how a university can orchestrate cross-sector partnerships linking global technology leaders with regional SMEs.

Within the restructured programme, the university's role was multifaceted and collaborative across its internal expertise. Bosch contributed industrial insight and strategic direction by presenting its hydrogen projects and plans to establish PEM electrolyser stack production and develop an associated UK supply chain. In parallel, the Centre for Enterprise led innovation and business development training to help SMEs translate emerging hydrogen opportunities into viable strategies, while the MFCIC provided technical and policy context, offering accessible overviews of hydrogen and fuel cell technologies and an in-depth analysis of regional strategy. Together, Bosch's industrial leadership and the university's academic coordination ensured that the masterclasses combined technical insight, policy awareness, and entrepreneurial capability building, enabling SMEs to participate in informed co-creation processes that linked technological potential with regional economic priorities.

The success and engagement generated through the Hydrogen Innovation Masterclasses extended beyond the formal scope of GMEHC, strengthening regional collaboration around hydrogen innovation and providing a foundation for subsequent initiatives led by the Greater Manchester Business Growth Hub. In this way, the MMU–Bosch partnership demonstrated how universities can orchestrate ecosystem collaboration, foster learning, and build capacity for mission-oriented innovation across regional value chains.

4 Findings

Analysis of the hydrogen transition landscape shows it is driven by an unprecedented wave of global and national policy commitment, which creates both opportunities and coordination challenges at the regional level. Globally, the Hydrogen Council projects a six-fold increase in hydrogen investment by 2025 and sixteen-fold by 2030, with around 20 percent directed to R&D. Nationally, the UK Hydrogen Strategy (2021) aims to establish a domestic supply chain for electrochemical technologies, scale up fuel cells across transport and industry, and commercialise new electrolysers for green hydrogen production. Complementary frameworks such as the Net Zero Strategy (2021), British Energy Security Strategy (2022), Energy Security Plan (2023), Clean Power 2030 Action Plan, and Industrial Decarbonisation Strategy (2021) reinforce hydrogen's role in the national decarbonisation and industrial competitiveness agenda. These policies are supported by mission-oriented funding streams, including the Hydrogen Business Model, the Net Zero Hydrogen Fund, and regional innovation cluster support.

The GMEHC operates within a nested policy architecture spanning local, regional, and national levels. Policy analysis identified three critical gaps that justify the orchestration role universities play. First, the *innovation capacity gap*: over half of SMEs in Greater Manchester are not innovating, and only one-third have a formal innovation strategy. Low technology adoption, weak cashflow, and economic uncertainty further limit R&D investment. Second, the *translation gap*: while national strategies outline ambitions, they lack clear mechanisms for connecting geographically embedded SMEs to global technology leaders and national R&D infrastructures. This disconnect illustrates the distance between policy aspiration and practical implementation. Third, the *coordination gap*: governance remains fragmented across spatial and sectoral levels, with no single actor possessing the convening power, technical legitimacy, and cross-sector trust to align disparate agendas.

These gaps position universities as key orchestrators of mission-oriented innovation ecosystems. The GMEHC reflects this role through two strands: advancing national hydrogen R&D and building regional SME capacity to adopt technologies and engage in emerging supply chains.

5 Discussion

This study examined how universities orchestrate academia–industry co-creation within mission-oriented regional innovation ecosystems, using the GMEHC as an empirical case. The findings reveal a layered orchestration architecture in which universities perform multiple mediating roles that bridge systemic gaps in policy-driven innovation systems. The GMEHC demonstrates that university orchestration operates across three interdependent dimensions: structural positioning, functional roles, and relational mechanisms.

Structurally, universities occupy a distinctive position in regional ecosystems as neutral intermediaries. Unlike firms or government agencies, they are neither market competitors nor regulators, yet they combine technical expertise, research infrastructure, and legitimacy across policy, industry, and civil society (Etzkowitz and Leydesdorff, 2000). This tri-domain legitimacy enables them to convene heterogeneous actors who might otherwise lack trust or a shared language. Within GMEHC, such neutrality created what Hurmelinna-Laukkanen and Nätti (2018) describe as a "safe space" for exploratory collaboration, allowing participants to exchange knowledge and assess opportunities without immediate commercial pressure.

Functionally, the university acted as a knowledge translator, capability builder, network architect, and policy–practice mediator, aligning with Rajahonka et al.'s (2015) concept of "multi-competence orchestrators." These functions were evident in the design of the Hydrogen Innovation Masterclasses, which integrated Bosch's industrial expertise with MMU's innovation and policy facilitation. Relationally, orchestration was enacted through staged engagement processes that fostered dialogue, trust, and shared understanding. The masterclasses were structured as interactive sessions illustrating Prahalad and Ramaswamy's (2004) argument that dialogue is central to co-creation.

Through these mechanisms, MMU facilitated what Vargo and Lusch (2004) term "resource integration": creating infrastructure that enabled diverse actors to combine capabilities for shared value creation. The case positions universities as multimodal orchestrators: institutions capable of simultaneously performing structural, functional, and relational coordination across fragmented policy landscapes. This extends orchestration theory by specifying the unique coordination capabilities universities contribute to mission-oriented ecosystems (Hurmelinna-Laukkanen and Nätti, 2018).

Overall, the GMEHC case illustrates that effective co-creation in policy-led innovation depends on moving beyond dyadic firm–customer models (Prahalad and Ramaswamy, 2004) toward multi-stakeholder, mission-oriented collaboration characterised by asymmetric value creation and ecosystem-level rather than transactional outcomes.

6 Conclusions

This paper examined how universities orchestrate academia–industry co-creation within mission-oriented regional innovation ecosystems, using the Greater Manchester Electrochemical Hydrogen Cluster (GMEHC) as an empirical case. It responds to calls for more evidence on how innovation ecosystems operate in practice and addresses the gap between theoretical models of university–industry–government collaboration and their implementation in policy-led contexts. The study makes three key contributions. First, it positions universities as multimodal orchestrators, extending beyond the triple helix (Etzkowitz and Leydesdorff, 2000) and anchor institution (Goddard et al., 2014) frameworks

to highlight their coordination capabilities in mission-oriented ecosystems. Second, it advances co-creation theory by moving beyond dyadic firm–customer models (Prahalad and Ramaswamy, 2004) to identify multi-stakeholder, mission-aligned co-creation. Third, it identifies three systemic constraints—innovation capacity, translation, and coordination gaps—that limit regional engagement in low-carbon transitions. Finally, the GMEHC case contributes to mission-oriented innovation literature (Mazzucato, 2018) by showing how universities act as gap-bridging institutions that translate national policy ambitions into regional practice through orchestration and co-creation.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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From Sustainable Energy Engineers To Sustainable Energy Ambassadors: An Empathy-Based Learning Framework For Sustainable Energy Education

ASM Mominul Hasan[a] and Bernd Möller[a]

[a] Sustainable Energy and Development (SEDev), Europa-Universität Flensburg, Germany

Abstract

The transition to sustainable energy is a complex socio-technical challenge that demands professionals capable of navigating its profound human dimensions. Moving beyond technical proficiency, this paper asks how we can train sustainable energy engineers to become more empathic, reflexive practitioners to solve the trilemma of energy transition. To answer this, we propose a modified version of Problem-based Learning (PBL) that integrates the empathy components from the Empathy-Based Learning (EBL). Adapted from healthcare, this framework introduces a structured three-stage Empathic Reflection Model (i.e., Recognition, Parallel Experience, and New Understanding) into the sustainable energy curriculum. This modified pedagogic approach aims to guide students to first comprehend the "lived experience" of energy systems from a personal stance ("me and us") before engaging with broader stakeholders ("you and them"). It also develops a course development framework integrating EBL into PBL and an evaluation method to assess the effectiveness of the modified framework. The modified PBL is designed to transform sustainable energy engineers into sustainable energy ambassadors. However, the framework can be applied to various other disciplines confronting sustainable development challenges.

Keywords: empathy-based learning; problem-based learning; community-engaged learning; empathic reflection.

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1 Introduction

The escalating climate crisis, marked by unprecedented temperature rises and intensifying natural disasters, presents a "wicked" problem that is as much socio-behavioural as technological (IPCC, 2021). This is equally true in the energy sector, where the transition to sustainable systems is a recognised socio-technical challenge (Miller et al., 2015). While technological innovation and policy are crucial, the human dimension, including social acceptance, behavioural change, and equitable distribution, often presents the critical bottleneck. Education is therefore fundamental to preparing a generation capable of navigating these challenges. While traditional Sustainable Energy Education (SEED) has predominantly emphasised an interdisciplinary approach, including technical, social, and policy-oriented competencies, it potentially overlooks the affective and relational skills required to manage profound societal shifts (Sovacool & Blyth, 2015).

To address this, academic institutions offering interdisciplinary SEED, adopted pedagogical frameworks like Problem-Based Learning (PBL) (Kolmos et al., 2004) and Community-Engaged Learning (CEL) to bridge theory and practice (Hasan et al., 2025). Rather than relying on lectures and seminars, a significant share of the students' workload is based on supervised project work, often in cooperation with real stakeholders and communities. For example, the M.Eng. Sustainable Energy and Development (SEDev) programme, formerly known as Energy and Environmental Management (EEM, 2009-2025) and Sustainable Energy Systems and Management (SESAM, 1999-2009), has been offering several courses using PBL and CEL for over 20 years to train sustainable energy professionals (Hasan et al., 2025). At SEDev, we observe that while these approaches develop technical problem-solving and community interaction, a critical dimension remains underdeveloped, which is the empathic understanding and critical self-reflection on sustainability issues. Without this perspective, students risk viewing stakeholders or targeted communities as laboratories and participating people as abstract figures, perpetuating the very top-down approaches that undermine the concept of sustainability and justice.

This gap often reinforces a central paradox in sustainability: the notion that it is a prescription for "others", particularly those in developing nations, rather than a shared responsibility rooted in collective and individual practice (Shove, 2010). This perception contradicts the phenomenon of sustainable and sustainability leadership (Boeske, 2023). Following the review of leadership towards sustainability by Boeske (2023), we identify that there is a lack of emphasis on promoting the concept of shared responsibility and being socially and environmentally responsible in current SEED pedagogies to train future sustainable energy practitioners and leaders. When future engineers and policymakers are not guided to confront their own energy behaviours, biases, and the emotional complexities of change, they may design PBL solutions that are technically elegant yet socially inert, and CEL projects

that, despite good intentions, fail to grasp the lived reality of the communities they aim to serve. To address this gap, this paper has two primary objectives. First, to modify the existing PBL and CEL model to develop a novel pedagogical framework for sustainable energy education by reviewing and adapting established models of Empathy-Based Learning (EBL). Second, to propose an administration and evaluation framework for EBL-integrated PBL and CEL.

2 Literature review

The growing recognition of these socio-technical challenges illustrated above has raised calls to reform the training of sustainable energy professionals, specifically to cultivate not only cognitive skills but also empathic understanding and critical self-reflection. This has catalysed interest in EBL, a pedagogical approach with foundations in philosophy, psychology, and adult learning theory (Batson, 2009; Jack & Levett-Jones, 2022; Kolb, 1984). EBL manifests in various forms across disciplines, such as the user-centred design thinking model in engineering, which employs empathy as a research tool for innovation and product development (Brown, 2008). EBL also appears in narrative engagement models in the humanities that foster moral imagination through stories (Keen, 2006). Perhaps the most robust framework for fostering a deep, reflexive praxis form of EBL is the clinical empathy model, popular in the healthcare discipline for a very long period (Bearman et al., 2015). Within this domain, the Empathic Reflection Model (ERM) proposed by (Jack & Levett-Jones, 2022) which draws on the phenomenological philosophy of Edith Stein (1891-1942), offers a uniquely structured and transferable methodology. Stein's seminal work conceptualises empathy not as a singular emotion but as a structured, three-stage process of intentionality: (1) the emergence of the other's experience to the self, (2) the "fulfilling explication" where one draws upon a "parallel" personal experience to comprehend the other's state while maintaining the critical "as if" self-other distinction, and (3) the return to a clarified comprehension of both the other and the self (Stein, 1964). This philosophical foundation provides a rigorous structure for reflection that avoids emotional fusion and preserves professional objectivity. The ERM, as operationalised in nursing education by Jack and Levett-Jones (2022), translates this philosophy into a cyclical pedagogical tool, guiding learners through stages of recognition, relational connection, and new understanding via structured prompt questions.

This model finds strong theoretical synergy with Kolb's (1984) experiential learning theory, as Stein's framework provides a specific protocol for reflective observation. Furthermore, its aim, a fundamental re-evaluation of one's assumptions, aligns directly with transformative learning theory (Mezirow, 1991). By integrating Stein's structure with experiential learning, the ERM offers a disciplined method to help students first understand the "lived experience" of energy systems from a personal stance before engaging with broader stakeholders.

Furthermore, we identify that the synergy with healthcare education is striking: just as a nurse must understand a patient's lived experience to provide effective care, an energy practitioner must understand the lived reality of citizens and stakeholders to design viable and just energy transitions. In the energy sector, the complexities of data collection, policy implementation barriers, and technological adoption are not merely abstract problems but human experiences coupled with emotion, habit, and socio-economic constraints. An EBL model has the potential to address these complexities by ensuring students:

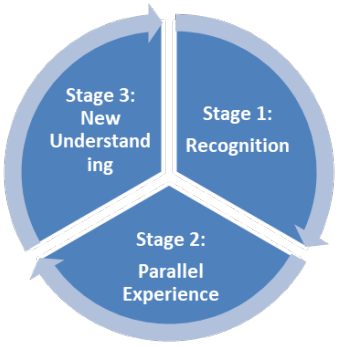
- Internalise energy realities: Move from abstract data to a felt understanding of energy consumption and its impacts.
- Grasp socio-technical complexity: Appreciate the real-world, human hurdles towards sustainable energy transitions.
- Cultivate inclusivity: Develop empathy for diverse communities, economic backgrounds, and cultural values to advance a just transition.

3 The proposed model

3.1 Empathic reflection model for sustainable energy education

Inspired by the "empathic reflection model" by Jack & Levett-Jones (2022) from nursing education, we propose a similar cyclical, three-stage learning process for sustainable energy students, as shown in Figure 1. The model is developed to enrich PBL with empathic reflection. PBL typically begins with a complex, real-world problem. The empathic reflection model ensures that the "problem" is never viewed as purely technical. The three stages are:

Fig. 11 – The empathic reflection model



Source: Jack & Levett-Jones (2022)

Stage 1: Recognition

- Standard PBL: Students are given an ill-structured and complex problem (e.g., Design an energy efficiency improvement plan through retrofit in households suffering from energy poverty.). They might immediately jump to technical audits, simulation, and cost-benefit analyses.

- EBL-Enhanced PBL: Before any technical solutioning, students must first complete Stage 1 of the empathic reflection model on themselves. They conduct their own energy audit and reflect on their privileges, habits, and the infrastructures they rely on. This self-diagnosis creates a foundational humility and awareness that their own experience is not universal. With the problem example, the following prompt questions can be used:
  - What does my personal energy data reveal about my lifestyle and its impact?
  - What are the physical, social, and economic infrastructures that make my current energy use possible?
  - What sustainability measures can I take to improve my energy usage?
- Expected outcome: When they approach the PBL problem, they do so with an immediate understanding that the "problem" involves deeply embedded human behaviours, economic constraints, and cultural norms, not just inefficient buildings.

Stage 2: Parallel experience

- Standard PBL: Students might interview stakeholders as a data collection step.
- EBL-Enhanced PBL: Student interactions with community members (as part of the PBL research or part of CEL) become the source for Stage 2 reflection. The parallel experience is no longer abstract; it is the direct comparison between their own challenges in changing behaviour (from their personal plan) and the reported challenges of the residents in the households. As a result, the PBL/CEL task of "understanding stakeholder barriers" becomes a deep, empathetic exercise guided by the Stage 2 prompts, such as:
  - What parallel challenges did I face in implementing my own plan (e.g., cost, convenience, social pressure)?
  - How did these challenges mirror those encountered by my peer/community members?
  - Based on my experience, what feelings, such as resistance, anxiety, or empowerment, might different stakeholders (homeowners, policymakers, industry leaders) experience during a sustainability transition?
- Expected outcome: The design solutions generated in the PBL activity are more nuanced. Instead of just proposing technical solutions like insulation and LED bulbs, students might also design community ambassador programs, flexible financing models, or educational materials that explicitly address the anxieties and practical hurdles they have empathically identified.

Stage 3: New understanding

- Standard PBL: The final output is a technical report or design proposal.
- EBL-Enhanced PBL: The final PBL deliverable must be accompanied by a Stage 3 reflection. Students must articulate how their technical solution was directly shaped by

their empathetic insights. They answer prompts about which of their initial engineering biases were challenged and how they would manage stakeholder engagement in the implementation phase.

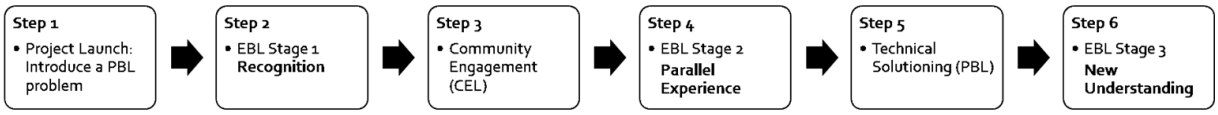
- What did I learn about the complexities from this empathetic exercise?
- What previously held beliefs or biases about "irrational" public behaviour were challenged?
- How will this understanding change my approach as a future energy engineer or policymaker? What self-care strategies will I employ to avoid burnout and compassion fatigue in this challenging field?

- Expected outcome: The learning outcome shifts from can design a technical solution to can design a technically sound solution that is socially intelligent and contextually appropriate.

3.2 Course administration

EBL can be implemented in various forms in SEED programs. However, to adopt the above-mentioned model, the curriculum must support PBL and CEL through formats like community fieldwork and incorporate flexibility in administration, assessment, and evaluation. Corresponding faculty resources must be reallocated from classroom lectures to supervision and mentoring. The following steps in Figure 2 demonstrate how a single project can coherently integrate EBL, PBL, and CEL.

Fig. 12 – Integration of EBL with PBL and CEL



Source: Authors, inspired by Jack & Levett-Jones (2022)

3.3 Methodologies for measuring empathic learning outcomes

Upon applying the above-mentioned EBL embedded PBL or CEL model, SEED institutions can apply various mixed-methods approaches to evaluate the development of both technical competence and empathic aspects through reflexive practice. To measure the EBL effectiveness, group evaluation can be performed using questionnaires and reviewing the report and presentations, as well as stakeholder opinions. At the same time, organisations can also promote self-evaluation for the students to reflect on their learning experience. The following strategy employs key tools at critical points in the empathic learning journey.

Evaluation Methods:

- Quantitative data collection and analysis (at Step 1: Baseline and post Step 6: evaluation):
  - Adapted Jefferson Scale of Empathy (JSE): Measures shifts in empathic concern (Hojat et al., 2002).
  - Systems Thinking & Reflexivity Scales: Gauge growth in understanding complexity and self-awareness (Mezirow, 1991; Sweeney & Sterman, 2007).
- Qualitative data collection and analysis (Step 2 to post Step 6: evaluation):
  - Thematic Analysis of Reflective Journals: Students maintain journals using the three-stage model prompt questions. Analysis identifies themes like challenged assumptions, navigated complexity, and emotional engagement.
  - Semi-Structured Interviews/Focus Groups: Capture rich narrative data on personal transformation and the integration of EBL, PBL, and CEL.
- Project assessment with rubrics (post implementation):
  - A dual-focused rubric assesses final PBL deliverables on both Technical Rigour and Socio-Technical Integration (e.g., equity, justice, stakeholder inclusion).
- Multi-stakeholder feedback (post implementation):
  - Community partner surveys: Provide external validation of students' collaborative skills and the project's real-world appropriateness.

4 Discussion

It becomes increasingly apparent that technical solutions alone do not lead to higher acceptance levels of technologies required for the energy transition. Addressing sensitive social issues in renewable energy project development, such as NIMBYism, requires a deep understanding of public perspectives. This understanding may constitute an important skillset for future decision makers; hence, it certainly belongs to the catalogue of competences in interdisciplinary engineering degree programmes directed towards the transformation of energy systems. The applicability of the proposed empathy-embedded PBL and CEL model extends beyond the specific context of sustainable energy education. The core principles of this empathy-based approach are transferable to other disciplines confronting sustainable development challenges, such as water resource management, sustainable urban planning, and circular economy initiatives, where technical solutions are equally dependent on social acceptance and behavioural change.

However, the implementation in study programmes increasingly subjected to budget constraints, governmental regulation, and bureaucracy, is difficult. Lecturers may be unwilling to reconsider their roles as conveyors of knowledge, and students may also avoid unnecessary complexity in educational formats while asking for fair means of assessment and

evaluation. Only through radical re-thinking of university-level education, a further complication of educational practices is feasible. EBL, because of the required interaction with communities and people and the higher complexity of assessment, is more resource-intensive compared to classical lectures and seminars. Its outcome is less predictable, because it highly depends on the availability and cooperativeness of communities; there is even a risk that EBL projects fail. This also might be true for the evaluation of EBL learning, because a greater part of learning happens outside the lecture room, becoming more dependent on exogenous conditions.

At Europa-Universität Flensburg, as part of the M.Eng. programme Sustainable Energy and Development, EBL is currently being considered as an add-on to the established module "International Community Energy Project", which has practised PBL and CEL for more than 20 years, and may offer the required framework conditions for including empathy as part of the qualifications for future sustainable energy engineers to become sustainable energy ambassadors.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Crossing Boundaries In Sustainable Energy Education: Insights Into Regional And Transnational Collaboration And Learning

Evelien Ketelaar[a], Lenny van Onselen[b] and Esther Wijma[a,c]

[a] Research group Vocational Education, HU University of Applied Sciences, The Netherlands
[b] Research group Co-design, HU University of Applied Sciences, The Netherlands
[c] Amsterdam VET College, The Netherlands

Abstract

The aim of the regional and transnational collaboration within the CoVE SEED project is to develop regional Centres of Vocational Excellence (CoVEs) for sustainable energy education. Continuous boundary crossing occurs throughout this collaborative process. However, limited insight existed into what happens during boundary crossing, what the enablers and barriers to learning across boundaries are, and how this relates to regional and transnational collaboration and learning. This article presents findings from a descriptive case study that explored the flow of knowledge between regional and transnational collaboration and learning. Drawing on project minutes, documented meaningful moments of collaboration, and field observations, the study examined the process of boundary crossing as well as the enablers and barriers involved. The results show that CoVE SEED project partners initially focused on building the community and developing activities aimed at achieving tangible outcomes. Over time, transnational collaboration increasingly served as an enabler for regional learning and development. Brokers played a key role in this process by bridging organisations, countries, and disciplines.

Keywords: regional learning; transnational learning; collaboration; boundary crossing.

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1 Introduction

For successful sustainable energy education, a regional approach is needed, with education and industry closely working together on innovation, research and educating future and current professionals. This can be organised in a so called Centre of Vocational Excellence (CoVE). CoVEs are formed by a consortium of vocational and higher education, companies, and other public organisations. As a CoVE is usually set up around a topic that is globally challenging, transnational collaboration between regions is seen as a way to accelerate regional learning and development. Although transnational collaboration between regions seems promising and multiple examples of such projects can be found within Europe, research on the benefits of transnational collaboration for learning and development within participating regions is lacking. This paper reports on a study within the CoVE SEED project, focussing on enablers and barriers to regional and transnational collaboration and learning, and the interplay between these two, taking a boundary crossing perspective.

1.1 Context: CoVE SEED project

CoVE SEED is an international collaboration of five regions in Europe: Western Macedonia (Greece), Valencia (Spain), Bochum (Germany), Turku (Finland) and Utrecht (the Netherlands). These five regions are collaborating in the four-year Erasmus+ programme to develop sustainable energy education through regional CoVEs. They regularly hold regional meetings to work on project tasks. Furthermore, twice a year, a broader network of regional stakeholders are consulted and involved. The five CoVEs regularly hold transnational meetings, where work package leaders and region leaders represent their regions.

1.2 From two-way exchange to systemic boundary crossing

A first explorative study (authors, 2024) concluded that in the first 1,5 years transnational learning in the CoVE SEED project was a two-way street between transnational meetings and regional meetings. By sharing expertise and knowledge, this two-way street focussed on learning about collaboration and teaching practices to strengthen CoVEs. The study showed that the transnational project meetings sparked ongoing regional learning, paying attention to both immediate actions and long-term strategic goals. Individual and collective presence and commitment were found to be essential enablers of learning within regions and across borders. Summarised, during the first 1,5 years within the CoVE SEED project there was a constant knowledge flow between the regional level and the transnational level. However, only limited data sources were used in this first explorative study and deeper insights into the knowledge flow was missing. Also, the project continued and it developed over time, for example through expanding activities and closer ties within and between the participating CoVEs.

As a follow-up on this study, the present study further explored the enablers and barriers of the knowledge flow. Moreover, during the CoVE SEED project period it came to the fore that it is not just a two-way street between transnational meetings and regional meetings in which participants move around, but a network of systems where participants move within and between. In other words, participants move across boundaries both within and between CoVEs. They cross borders of organisations, countries, and disciplines. Therefore, the central research question leading this study is:

What are the enablers and barriers of learning across organisational, national, and disciplinary boundaries in the CoVE SEED project?

2 Literature review

A literature review explored regional learning, transnational learning and the interactions between these two in contexts similar to those of the CoVE SEED project (authors, 2024). However, research is limited in the specific context of regional and transnational learning in CoVEs and/or public-private partnerships, particularly regarding the interaction between the two (e.g., Mierlo, 2020). Although learning plays a key role in transitions, underlying theories of learning and learning processes are often underexplored (Scholz, 2020).

Research has identified several enablers of learning in comparable contexts, including the role of knowledge brokers (Haupt, 2019), early investment in interregional relationships (Keay et al., 2017), participation in face-to-face meetings and site visits (Haupt, 2019), and alignment between project activities and broader policy agendas (Vinke-de Kruijf et al., 2020). Barriers of regional and transnational learning include systemic differences between contexts (Keay et al., 2017), the time-intensive nature of learning processes (Stead & Pojani, 2018; Haupt, 2019), and challenges in fostering mutual engagement among partners from diverse contexts (Keay et al., 2017).

Boundary crossing theory (Akkerman & Bakker, 2011) offers valuable insights into how learning occurs between stakeholders from different contexts. When stakeholders from regional and international settings engage in learning and actively seek out and cross boundaries, new insights can emerge. Within the framework of boundary crossing, four distinct learning mechanisms can be identified when crossing boundaries: (1) *identification* is a process of becoming aware of one's own beliefs and identity and how they might differ from the way others see the world; (2) *coordination* seeks ways to collaborate constructively; (3) *reflection* aims to see reality, and one's own practice, through someone else's perspective; (4) *transformation* changes a way of working or action by bringing together (elements of) the different perspectives so that it becomes a new practice.

Supportive in boundary crossing are so-called *boundary objects*—artifacts that help bridge the gap between practices—and *brokers*—persons acting as a bridge between two contexts, by fulfilling a role in both contexts (Akkerman & Bakker, 2011).

Taken together, these insights provide a conceptual foundation for examining how learning unfolds within and across regional and transnational settings in the CoVE SEED project. By drawing on boundary crossing theory and existing knowledge about enablers and barriers, the present study aims to deepen our understanding of the mechanisms that facilitate or hinder learning across organisational, national, and disciplinary boundaries.

3 Case study approach

To investigate the enablers and barriers to learning across organisational, national, and disciplinary boundaries in the CoVE SEED project, a case study approach was followed, using existing project data, purposefully collected data, and field observations.

3.1 Project data

Minutes from CoVE SEED meetings (Oct 2022–May 2025) were analysed, including 48 regional meetings (392 coded quotes), six online transnational meetings (70 quotes), and six face-to-face transnational meetings (34 quotes). Using insights from the literature review, a deductive codebook was developed around boundary crossing mechanisms, enablers to learning, and barriers to learning. Two researchers iteratively applied and refined the codes, until a final codebook was agreed upon.

3.2 Meaningful moments

A two-hour session using the *critical incident timeline* method (cf. Soini, 2012) invited participants to share 'groan' and 'grow' moments in regional and transnational collaboration. Fourteen participants contributed 30 cards describing their meaningful moments. Thematic analysis identified learning levels (regional, transnational, and transfer), boundary crossing mechanisms, and boundary objects.

3.3 Overall observations

Findings from the project data and the meaningful moments were compared to identify the enablers and barriers of learning across organisational, national, and disciplinary boundaries. The researchers were also participants in the CoVE SEED project themselves and used their field observations to indicate and contextualise the insights gained from the data.

4 Enablers and barriers to regional and transnational collaboration and learning

From the project data, meaningful moments, and overall observations several enablers and barriers to learning across organisational, national, and disciplinary boundaries in the CoVE SEED project were identified. These related to the establishment and positioning of the CoVE within the region, the role of transnational collaboration and learning for the development of the CoVEs, and the role of boundary crossing learning mechanisms.

4.1 Establishing and positioning the CoVE within the region

Notably, most fragments from the regional and transnational meetings relate to the establishment and positioning of the CoVE within the region. This was perceived both as an enabler and a barrier to learning. Particularly during the initial phase of collaboration within a CoVE, this theme appeared to be significant. As an enabler, becoming familiar with the project, its structure, and its objectives emerged as important. The results indicate that working towards a concrete outcome enhances intrinsic motivation and positively influences the collaborative process within the CoVEs. During the initial phase of development, CoVEs reported a search for a shared goal between the CoVEs and greater clarity regarding the specific objectives to be pursued. This lack of initial alignment led to friction among the stakeholders involved.

> *"The lack of tangible output outlined in the project made it difficult to stay involved."*

One of the main barriers for the CoVEs was engaging industry partners and/or a committed group of stakeholders from relevant companies and align wider agenda's.

> *"When collaborating with businesses, we need to think about whether the labour market needs are aligned, especially regarding the quality of work. How things are done versus how they should be done. What kind of skills do companies need in their workforce?"*

In addition to these barriers, several actions were reported that aimed to create enablers to learning, such as investing in the development of the CoVE community and finding ways to position the CoVE within existing regional initiatives.

> *"This moment was important because it changed how people in our region worked together. Before, education providers, companies and the regional governance were doing things separately. When we all came together, we started to understand each other's needs and goals. It helped everyone see that we're stronger when we work as a team. Since then, it's been easier to build on activities that really match what our region needs."*

4.2 Transnational collaboration and learning as enabler for regional learning and development

As the main goal of the CoVE SEED project is regional learning and development for sustainable energy education, it is evident that this also forms the primary focus of the transnational collaboration and learning. It took place during online and face-to-face transnational meetings, in the preparation for these meetings (e.g., delegates from multiple CoVEs jointly preparing and hosting a workshop), through joint work on project tasks (e.g., two CoVEs sharing responsibility for a task), and via the exchange of good practices.

Face-to-face transnational meetings, in particular, appeared to be strong enablers of both collaboration and learning within and between the five CoVEs —provided they were well organized. Over time, a development was observed in the data: while the consortium initially searched for the right balance in meeting duration and structure, this was later reported as having improved and contributed positively to the collaboration and learning between the five CoVEs.

> *"The meeting gave the participants a clear understanding of where the project is headed to. Goals were clearly communicated and actions outlined. Starting the meeting with a timeline and ending the meeting with a project management meeting (rounding up all actions) helps."*

In line with this, the effective use of opportunities created by face-to-face meetings was mentioned repeatedly. In general, the activities invested in the CoVE SEED project were often a topic of discussion during transnational meetings.

Transnational meetings can be regarded as important catalysts for learning within the CoVEs. Partners from each CoVE who participated in these meetings learned both individually and collectively, and were then responsible for transferring this knowledge back to their respective CoVEs. The results indicate that these knowledge brokers play a crucial role in facilitating the flow of knowledge from transnational meetings to regional CoVEs.

> *"Presenters clearly articulated not only what worked in their own regions, but also the conditions that enabled success and the potential challenges of implementation elsewhere. This transparency and contextualization where key to understanding which elements might be transferable in our region."*

Furthermore, the results show that several boundary objects facilitated the transfer of transnational learning to regional CoVEs. Examples include good practices introduced by individual CoVEs, which other regions and CoVEs attempted to adopt and adapt within their own settings. Another example is the concept of codesign, which was introduced during a workshop and subsequently applied in various ways throughout the project.

> *"A key grow moment was when we sat down with stakeholders to co-design the good practices activities and they began to clearly see how these efforts could directly benefit their students. It was the turning point where the abstract idea of a CoVE became something concrete and valuable in their eyes."*

The results indicate that the main barriers to transferring transnational learning to regional contexts are systemic differences between the regions. While transnational meetings and the exchange of knowledge and good practices were found to be inspiring for many partners, contextual differences often limited the direct implementation of these practices in their own CoVEs.

> *"A 'groan' moment for us was the initial difficulty in translating the CoVE model into something that truly fit our regional context. While the transnational examples were inspiring, we struggled to apply them directly due to different local structures, resources and priorities. It felt overwhelming at times, and there was a risk of losing motivation among partners. However, this challenge also pushed us to adapt the model creatively and focus on what would realistically work in our region"*

Although systemic differences pose a challenge, the act of sharing knowledge and inspiring one another is also considered an enabler for learning. It encourages CoVEs to think creatively and explore alternative opportunities within their own regional systems.

4.3 Boundary crossing learning mechanisms supporting transnational collaboration and learning and regional adaptation

In the first six months of the CoVE SEED project, partners encountered barriers to initiating smooth regional and transnational collaboration and learning. Despite enthusiasm, unclear roles and goals hindered progress. The authors provided training in boundary crossing and codesign practices. This section reflects on how boundary-crossing learning mechanisms supported transnational learning and collaboration and consequently adaptation within the CoVEs.

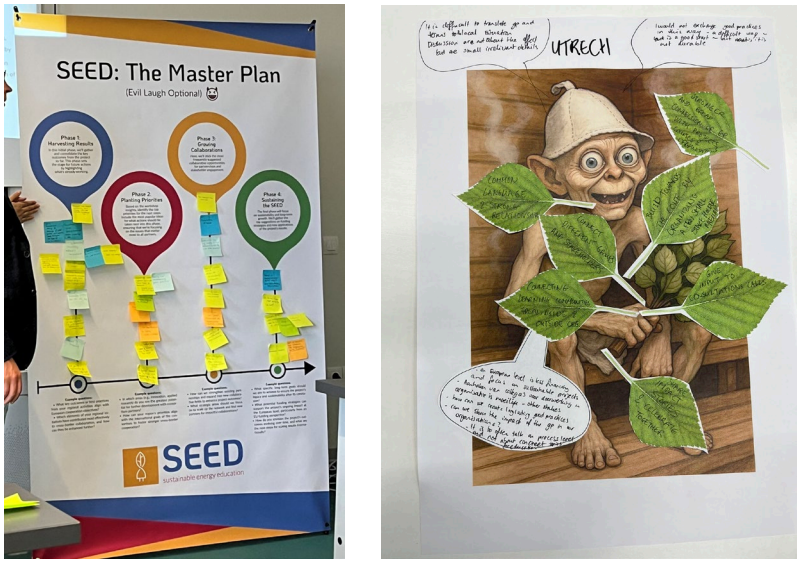
Identifying differences helped partners reflect on their beliefs and roles. For example, participants were asked whether they saw themselves as 'thinkers' or 'doers' and how they experienced the collaboration. Thinkers struggled with unclear tasks, while doers were frustrated by extensive discussions and limited action. These insights led to the creation of a symbolic tree, representing values (roots), guidelines (stem), and goals (branches), which helped brokers navigate boundaries and foster productive collaboration—marking the start of the coordination process.

Transnational workshops brought brokers together to reflect on differing perspectives. In the final year, signs of transformation emerged: partners more readily adopted new ways of

working and initiated activities that evolved into new practices. Codesign techniques and templates were used in workshops to support joint learning and brainstorming (Fig. 1).

In contrast, new partners who joined later relied on traditional ways for exchanging knowledge (e.g., presentations and Q&A rounds). Codesign methods and boundary crossing transformed collaboration and knowledge exchange. While not all knowledge and practices were adopted within the CoVEs, brokers introduced new goals, creativity, and learning approaches. They became more aware of others' beliefs and adapted new methods to fit regional contexts.

Fig. 1 – Codesign ways of working adopted by partners



Left: a workshop poster made by a Greek and Dutch partner; right: a workshop template created by a Finnish partner

In sum, enabling transnational learning and removing barriers lays the groundwork for lasting change in learning and collaboration within regional settings.

5 Conclusion

The CoVE SEED project demonstrated how transnational collaboration and learning can spark mutual learning and innovation in sustainable energy education. By exchanging knowledge and best practices across vocational education, higher education, and industry partners, new goals for learning were developed, which would not have been possible through regional efforts alone. A transnational learning strategy, three summer schools, and codesign methods such as Mission Mapping, fishbowls, and co-design workshops enhanced learning and collaboration within the CoVEs. Further research could explore how brokers' boundary crossing influenced regional learning and contributed to educational transformation within regions. In conclusion, transnational collaboration and learning adds

value by inspiring partners to co-create innovative educational ecosystems that prepare professionals for societal challenges.

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Integrating Sustainable Development Goals Into Transdisciplinary Project Based Learning For Environmental Design

Indu Ramachandran Nair Santha Kumari Amma[a], Abhilash Suryan Resikendran[a], Manju Gopalakrishnan Nair[a], Deepa Rani Rangaswamy[a] and Jisha Velayudhan Rajamma[a]

[a] College of Engineering Trivandrum, Thiruvananthapuram , India

Abstract

Sustainable development has become the driving force for research and higher learning. Integration of the sustainable development goals into the academic curriculum demands a transdisciplinary approach involving different disciplines and the stakeholders. This study combined quantitative and qualitative approaches to assess the impact of interdisciplinary learning for the Masters program in Environmental Design. The study has followed up on the success of previous experiments in the institution involving undergraduate students. The results of the study established the effectiveness of the transdisciplinary project based approach and provided valuable insights towards improving the current methodology.

Keywords: sustainable development goals; interdisciplinary; transdisciplinary; environmental design; project based learning.

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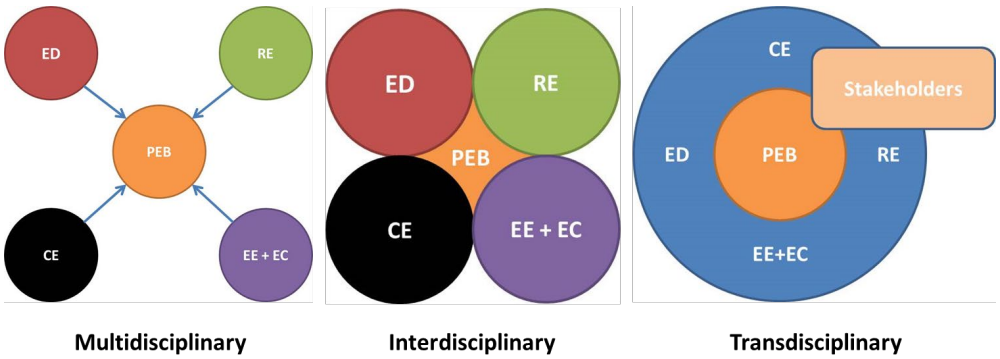
1 Introduction

The Sustainable Development Goals (SDGs) adopted by the United Nations in 2015 (United Nations, 2015) provide a roadmap for achieving a better and sustainable future for the planet. Education, across various academic disciplines, is fundamental in advancing social, economic, and environmental sustainability (Didham et al., 2024). Higher education institutions worldwide have been integrating sustainability into their academic programs (Albareda-Tiana et al., 2018). Academic research in institutions of higher learning has started realigning the research focus along the objectives of sustainable development goals (Tafese M B and Kopp E, 2025). Educating academicians for sustainable development itself has become a major research topic in recent times (Fischer et al., 2022). India, with one-sixth of the world's population, has a critical role for the success of the SDGs (United Nations, India, 2015). India is one of the best-represented nations globally in the 2024 edition of the Times Higher Education Impact Rankings. Many of India's universities stood out when scrutinized against the demanding SDGs, particularly in areas vital to India's wider social and economic goals (Baty, 2024). The National Institutional Ranking Framework (NIRF) 2025 has, for the first time, introduced a category dedicated to Sustainable Development Goals (SDGs), reflecting India's push toward aligning higher education with global sustainability targets. As many as 791 institutions have participated in the debut edition of NIRF 2025 SDG category (NIRF, 2025).

The process for solving complex or comprehensive problems for sustainable development demands an interdisciplinary approach (Annan-Diab and Molinari, 2017). Interdisciplinary collaboration among different fields of expertise can enhance sustainable development as well as accelerate the process (Vaverková et al., 2025). Many institutions have developed interdisciplinary curricula that equip students with the knowledge and skills necessary to address problems of sustainable development (Avelar et al., 2023). Taking the process one step further, the transdisciplinary approach, in addition to dissolving the boundaries between the disciplines, incorporates an active engagement with the non-academic stakeholders (Keestra et al., 2016).

Fig. 1 – Multidisciplinary, Interdisciplinary and Transdisciplinary concepts



1.1 Positive Energy Buildings

Buildings are responsible for a significant share of global energy consumption and account for a major chunk of the greenhouse gas emissions (Zhan et al., 2018). Total household energy consumption as well as emissions can be reduced through retrofitting existing buildings (Ibrahim et al., 2024). Use of renewable energy sources such as solar (Shirinbakhsh and Harvey, 2024), wind energy (Lu et al., 2024) is central to the design of sustainable and energy efficient buildings. At present, efficient technologies, selection of smart equipment and the integration of renewable energy systems have allowed improvement over the Net-Zero (or Nearly Zero) Energy Buildings, NZEB to the so-called Positive (or Plus) Energy Buildings, PEB (Hawila et al., 2022). This has been achieved by incorporating high-performance insulation (Zhou et al. 2025), energy-efficient windows (Priya and Shaik, 2024), advanced HVAC systems (Aljashaami et al., 2024), smart building technologies (Ferdaus et al., 2024), automated lighting and climate control systems (Qiang et al., 2023) and the optimization of energy use (Shivanaganna, 2024). Water conservation is another equally critical aspect taken into account for environmental design (Flores and Ghisi, 2022). For the design of a positive energy public building, interaction with the stakeholders at different stages, a transdisciplinary approach, is desirable. There has been previous exercises involving under graduate students in the institution (Nair and Suryan, 2020, Induja et al.,2025).

Environmentally responsible design practices respecting the natural landscape and leveraging local climate conditions are of paramount importance for the students. The present study proposes a transdisciplinary project based learning approach in Environmental Design for the graduate students. The objective is to bring the students of the graduate programs in Environmental Design, Renewable Energy, Automation, Instrumentation, Hydraulics and Geotechnical Engineering under one platform and mentor them towards the successful design of a real life Positive Energy, Disaster-resilient, Sustainable building. The impact of the exercise is assessed through review of the design by external experts and stakeholders as well as the self-assessment by the students. Thus the study attempts to establish the effectiveness of transdisciplinary project based learning.

2 Methodology

The present study is based on 25 students who successfully completed the Master's program in Environmental Design under the Department of Architecture and Planning. The participants worked in collaboration with their peers from different disciplines. Faculty mentors from all specializations partaking in the exercise are briefed about the project well in advance. They are requested to nominate a graduate student each from their specialization to join the team. At the inception stage, the student teams are formed as described in Table 1. The entire team attends the design studio together. The teams are then introduced to the

sustainable development goals through the discussion of case studies. The task identified in advance is then introduced to the teams clearly stating the objectives. Project-based learning help develop the students' critical thinking, creativity, communication, collaboration, and the understanding of content knowledge. The project activities and milestones are planned. The mentors provide guidance and feedback to students as they work on their tasks and product. The project outcomes are evaluated using rubrics or other tools to assess student performance and learning.

Table 1 – Student teams

Department (Major)	No. of students	No. of faculty mentors
Architecture & Planning	6	1
Renewable Energy (ME)	1	1
Automation & Sensors (EE & EC)	1	2
GeoTech (CE)	1	1
Hydraulics (CE)	1	1

2.1 Research Design

The study adopted a mixed-method exploratory design combining quantitative and qualitative approaches to assess the impact of interdisciplinary learning within the M. Arch Environmental Design program. Data were collected through a structured questionnaire and open-ended feedback from students, focusing on the integration of technical and design-based knowledge domains.

2.2 Data Collection

A comprehensive questionnaire was administered, structured into five sections (A–E):

- Section A: Respondent profile and interdisciplinary exposure
- Section B: Perceived Knowledge and Conceptual Integration
- Section C: Application, Collaboration and Skill Development in design and research projects
- Section D: Attitude and Perception toward interdisciplinary learning
- Section E: Evaluation of Learning Outcomes across five key domains —Coexistence with Surrounding Environment, Contemporary & Smart Building Technologies, Sustainability & Future Adaptability, Safety, and Energy Efficiency.

Open-ended questions were also included to capture qualitative insights on influential subjects, practical challenges, and curriculum enhancement suggestions.

2.3 Data Analysis

Responses to the Likert-scale questions (Sections B–D) were analysed using Microsoft Excel. Three composite indexes were computed to evaluate learning effectiveness:

- Knowledge Integration Index (KII): Mean of Section B scores
- Application and Skill Index (ASI): Mean of Section C scores
- Attitude Index (AI): Mean of Section D scores

An additional Interdisciplinary Exposure Index (IEI) was derived from the average of responses representing exposure to the six disciplines. A Correlation Matrix was then developed to determine the strength of relationships between interdisciplinary exposure and perceived learning outcomes in the five domains. Open-ended responses were subjected to thematic coding to identify recurring concepts, challenges, and recommendations. The coded data were then mapped against the five learning outcomes to assess qualitative alignment and depth of interdisciplinary influence. Frequency counts of themes were used to develop interpretive charts, while representative quotations were incorporated for contextual support.

3 Results and Discussion

The analysis of survey data and qualitative feedback reveals a strong consensus among students that interdisciplinary subjects significantly enhance their design capability, environmental sensitivity, and technical proficiency. The integration of engineering, energy, and spatial disciplines contributes to holistic learning outcomes in sustainability, comfort, safety, and innovation within the M. Arch. (Environmental Design) program.

3.1 Quantitative Analysis of Learning Indexes

3.1.1 Knowledge Integration Index (KII)

The mean Knowledge Integration Index across respondents indicated a high level of understanding regarding the interconnections between design and technical disciplines. Students demonstrated awareness of how building systems, renewable energy concepts, and environmental parameters influence architectural decisions.

3.1.2 Application and Skill Index (ASI)

The Application and Skill Index revealed that students could apply interdisciplinary knowledge effectively in design studios and dissertations. The integration of simulation tools, energy modelling, and GIS-based site analysis were particularly noted for enhancing analytical depth and environmental performance evaluation.

3.1.3 Attitude Index (AI)

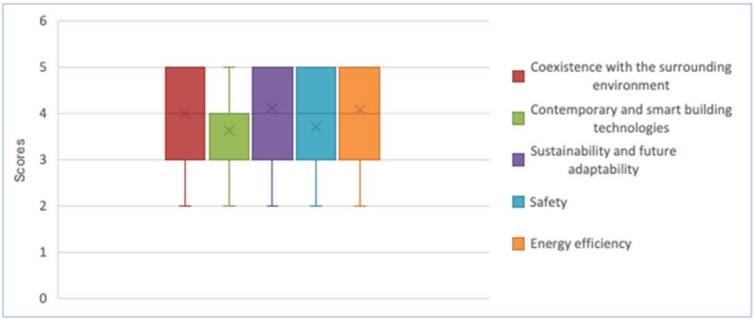
The Attitude Index showed strong positive orientation toward interdisciplinary learning. Students valued the relevance of technical knowledge in addressing sustainability and efficiency goals and recognized the need for collaboration across disciplines.

3.1.4 Correlation Analysis

This step explored how interdisciplinary exposure (average of all disciplinary inputs) correlates with each of the outcome domains:

- Coexistence with Surrounding Environment
- Contemporary and Smart Building Technologies
- Sustainability and Future Adaptability
- Safety
- Energy Efficiency

Fig. 2 - Box Plot of scores given by students on each of the learning outcomes



Interdisciplinary Exposure Index (IEI) was first computed as given below:

IEIi=AVERAGE(Scores for Architecture, Civil, Mech, Elec, Renewable, GeoInfo)

Then the Outcome Correlation Matrix was formulated computing the correlations between IEI and each outcome domain.

Table 2 - Outcome Correlation Matrix

Outcome Domain	Correlation with IEI (r)
Coexistence with the surrounding environment	0.41
Contemporary and smart building technologies	0.65
Sustainability and future adaptability	0.44
Safety	0.39
Energy efficiency	0.73

Correlation results demonstrated a clear positive relationship between Interdisciplinary Exposure (IEI) and perceived achievement across the five key learning outcomes as shown in

Table-1. It is found that Outcome domains Contemporary and Smart Building technologies and Energy Efficiency has more correlations with the interdisciplinary Exposure. These correlations confirm that greater exposure to interdisciplinary subjects yields higher perceived competence in Building Technologies and sustainable and energy-efficient design practices.

3.2 Qualitative Thematic Insights

3.2.1 Influential Subjects

Building Physics and Renewable Energy were consistently identified as the most influential subjects shaping students' understanding of sustainable design and energy optimization. Intelligent Building Systems and Environmental Engineering complemented this learning by improving awareness of performance-based design decisions.

3.2.2 Integration of Engineering Concepts

Students acknowledged that concepts from Civil, Mechanical, and Electrical disciplines improved their understanding of structural safety, HVAC design, and comfort control. However, they reported difficulties in directly translating this technical knowledge into design practice due to limited hands-on exposure.

3.2.3 Interdisciplinary Application in Studios

Several projects including Campus Design, Urban Design Studios, Thesis Project, and Solar Decathlon India Design Competition showcased successful integration of GIS, renewable energy, and smart technologies. These experiences enhanced contextual design quality, environmental responsiveness, and data-driven decision-making.

3.2.4 Challenges in Technical Learning

The most recurring challenges involved insufficient practical exposure, limited software access, and the lack of interdisciplinary mentoring. Students also cited difficulty linking engineering concepts to architectural intent, often relying on self-learning through online tutorials.

3.2.5 Recommendations for Curriculum Enhancement

Participants emphasized the need for subjects on Climate Informatics, Environmental Economics, Green Certification, and Social Sustainability, alongside mandatory hands-on workshops and project-based integration of theory and design. They advocated linking all interdisciplinary subjects to studio assignments for better synthesis of knowledge and application.

The findings collectively demonstrate that interdisciplinary learning directly enhances the cognitive, analytical, and practical capacities of Environmental Design students. Building Physics and Renewable Energy foster sustainable decision-making, while GIS and Smart Systems promote climate and data responsiveness. However, a recurring gap remains in translating technical knowledge into design performance due to limited practice-oriented exposure. To address this, an experiential pedagogy that combines interdisciplinary studios, software training, and live collaborations with engineering experts is recommended.

The study also highlights emerging opportunities for integrating AI, data analytics, and environmental finance into the curriculum which is essential for preparing architects capable of addressing future urban and climate challenges.

4 Conclusion

The synthesis of responses from 25 M. Arch. Environmental Design students reveals that interdisciplinary exposure significantly enhances holistic design thinking. Building Physics and Renewable Energy were the most influential in shaping sustainable and energy-efficient design attitudes, while transdisciplinary interactions with the stakeholders strengthened contextual coexistence. Participation of the students from Mechanical and Electrical Engineering disciplines improved understanding of safety and comfort and contributed to the design decision-making. The analysis emphasizes the importance for interdisciplinary studio integration, data-driven environmental analysis, and system-level collaboration to align architectural education with future-ready sustainable development goals.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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The Rotterdam Energy Transition Program: An Integrated And Multidisciplinary Approach To Sustainable Energy Education

Gijsbert Korevaar[a], Johan Antonissen [a], Robbert Hoogendijk [a] and Koen Muilwijk [a]

[a] Centre of Expertise HRTech, University of Applied Sciences Rotterdam, Rotterdam, The Netherlands

Abstract

The global energy transition demands a new generation of engineers equipped with not only deep technical knowledge but also a broad, systemic understanding of complex, interconnected challenges. This paper presents the "Rotterdam Energy Transition" program, an innovative educational framework developed by the Rotterdam University of Applied Sciences. The program is part of the unique industrial, maritime, and urban landscape of Rotterdam, which also acts as a living laboratory for sustainable energy education. We detail the competency-based learning pathway (Kolmos & De Graaff, 2020) for third and fourth-year students, culminating in a unique, integrated minor program. This minor unites four distinct engineering tracks—Offshore & Construction (Mechanical Engineering), Process Technology & Energy Transition (Mechanical Engineering), Power Electronics (Electrical Engineering), and Maritime & Shipbuilding (Naval Architecture)—under a single collaborative umbrella. A key focus of this paper is to demonstrate how this integrated structure fosters multidisciplinary problem-solving while creating significant educational efficiencies and cost reductions. By centralizing the planning of excursions, masterclasses, and facility usage, the program delivers a richer student experience more sustainably than four siloed programs could achieve. This model represents a transferable "good practice" in competency-based learning, industry-academia partnership, and innovative curriculum design, directly addressing the core themes of sustainable education.

Keywords: education; energy transition, system Integration.

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1 Introduction

The transition from a fossil-fuel-based economy to a sustainable energy system is one of the most significant and complex challenges of our time. It necessitates a paradigm shift in technology, policy, and societal behaviour. For higher education institutions, this translates into a critical responsibility: to educate engineers who can navigate and lead this transition. These future professionals must be "T-shaped," (Kunrath & Ramanujan, 2021) possessing deep expertise in their chosen discipline (the vertical bar of the T) while also having the broad skills to collaborate across different fields and understand the entire energy system (the horizontal bar).

The city of Rotterdam, with its world-class port, extensive industrial complex, and ambitious climate goals, provides a unique ecosystem (Fenner et al., 2020) for educating these future engineers. It is a crucible where the challenges and opportunities of the energy transition—from offshore wind development in the North Sea to industrial electrification and urban heating solutions—converge. The Rotterdam University of Applied Sciences has developed its Energy Transition program to capitalize on this dynamic environment, creating a learning pathway that is deeply integrated with industry and grounded in real-world challenges.

This paper outlines the structure of this program, with a specific focus on the advanced curriculum of the third and fourth years. We will provide a detailed analysis of the program's capstone: the "Rotterdam Energy Transition" minor. This section will explore how the minor program synergizes four specialized tracks to create a vibrant, multidisciplinary learning community. Finally, we will demonstrate how this collaborative model is not only pedagogically effective but also economically efficient, reducing operational costs through shared resources and centralized planning. This program serves as a powerful case study in designing and implementing effective, sustainable energy education for the engineers of tomorrow.

2 The Energy Transition Learning Pathway: Years 3 & 4

The educational philosophy underpinning the Rotterdam Energy Transition program is built on a progressive, competency-based learning pathway (Kolmos & De Graaff, 2020). Students develop foundational knowledge in their first two years, and the third and fourth years are dedicated to deepening their expertise and applying it to complex, integrated problems. This structure ensures that students are well-prepared for the final specialization phase of their education and their subsequent careers.

The third year of study marks a significant shift towards professional practice and specialization. The cornerstone of this year is the Semester 6 Project (15 EC). In this extensive project, students work in teams on real-world assignments sourced directly from industry

partners. These projects are carefully selected to align with the core challenges of the energy transition and require students to apply theoretical knowledge to solve practical problems.

This experience serves several crucial educational purposes:

- It moves students beyond the classroom, immersing them in the professional environment and technical standards of the energy sector.
- Students must integrate knowledge from various courses to deliver a comprehensive solution, fostering a holistic engineering mindset.
- It builds essential skills in project management, teamwork, client communication, and technical reporting.

By the end of the third year, students have not only advanced their technical knowledge but have also gained invaluable experience that prepares them for the high level of autonomy and specialization required in their final year.

The fourth and final year is the culmination of the students' undergraduate education, designed to showcase their mastery of the subject. It is composed of two major components, each worth 30 ECs:

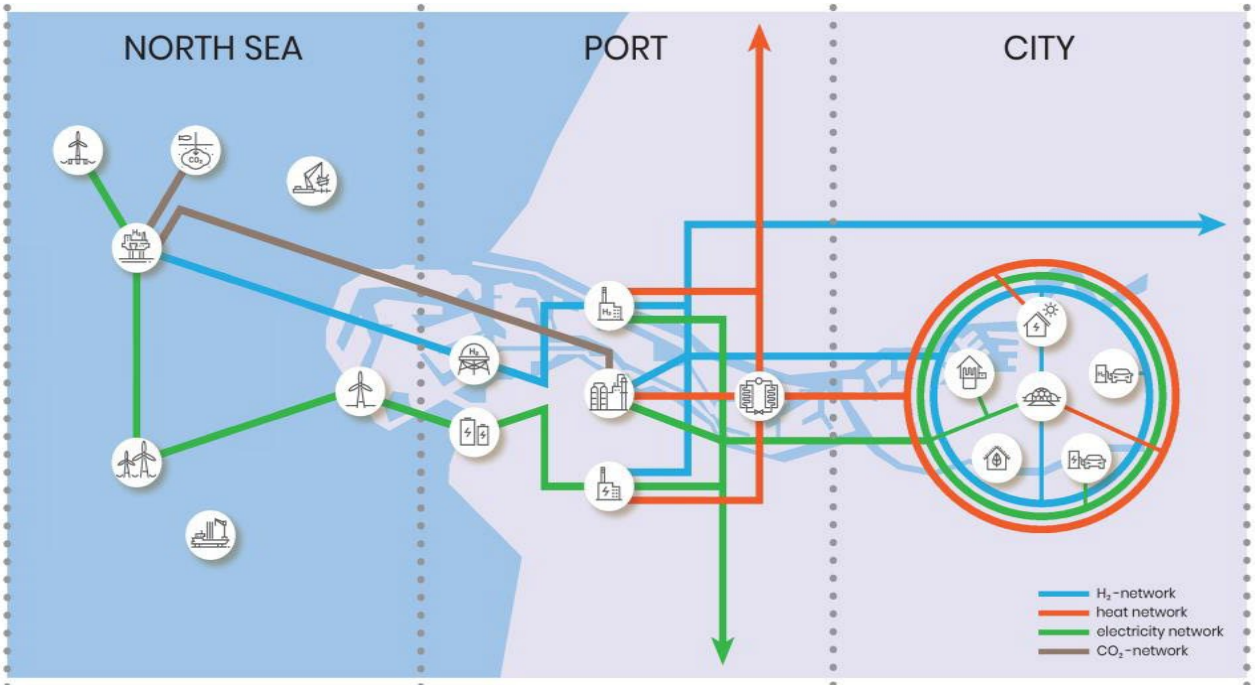
- The Minor Program: A full semester dedicated to specialized, multidisciplinary learning within the "Rotterdam Energy Transition" framework. This is the central focus of our paper and is detailed in the following section.
- The Graduation Project: The final capstone project where students independently undertake a research or design challenge, often in collaboration with a company or research institution. This project demonstrates their ability to function as starting professional engineers.

Together, these two components ensure that graduates are not only specialized in a key area of the energy transition but also possess the integrated, systemic perspective necessary to be effective agents of change.

3 The Integrated Minor: A Hub for Multidisciplinary Collaboration

The fourth-year minor program, "Rotterdam Energy Transition," is the most innovative feature of the curriculum. Instead of offering several separate, specialized minors, the university has created a single, overarching structure that houses four distinct tracks. This model is designed to break down the traditional silos (Garcés et al., 2025) between engineering disciplines and foster a collaborative environment that mirrors the integrated nature of the modern energy industry of the Rotterdam delta (Figure 1).

Fig. 1 - Energy transition of the Rotterdam delta



The minor is built upon a standardized template, ensuring a consistent and high-quality experience for all participants. The 30 ECs are allocated as follows:

- Core Program (6 EC): Disciplinary deepening within a chosen specialization track.
- Elective Program (6 EC): Two elective modules that allow students to either further specialize or broaden their knowledge by choosing modules from other tracks.
- Talent Innovation Pool (TIP) (3 EC): A shared professionalization program for all students in the minor.
- Practical Industry Project (15 EC): A large, multidisciplinary group project that serves as the minor's centre piece.

Upon entering the minor, students choose a primary specialization track. While there are four official minor registrations, they function as three core technical tracks under one umbrella, providing both a clear identity for students and administrative flexibility.

The minor consists in the following tracks:

- Track: Offshore & Construction: Focuses on the engineering of offshore energy systems. The core module, Design of Offshore Equipment, involves the complete design cycle of a knuckle-boom crane, including stress analysis, 3D CAD modelling, and adherence to industry standards like Lloyd's Register.
- Track: Process Technology & Energy Transition: Concentrates on optimizing energy use in industrial processes. The core module, Energy Systems in Process Industry, covers key

concepts such as process efficiency maximization, heat reuse and upgrading, and the application of climate-neutral fuels using pinch and exergy analysis.

- Track: Power Electronics: Dives into the Rotterdam's system integration of power electronics by looking at concepts like net congestion, peak shaving, load balancing using power to X.
- Track: Maritime & Shipbuilding: Deals with the specific challenges of energy systems at sea. The core module, Floating Wind Experiments, has students design, build, and test a scale model of a floating foundation for a wind turbine, integrating principles of hydrostatics, wave dynamics, and scaling.

The Rotterdam Energy Transition serves as the administrative entry point and umbrella for the program, allowing students to select one of the three technical tracks after an initial kickoff. This structure ensures that students receive a rigorous education in their chosen field, providing the deep disciplinary knowledge required for professional excellence.

The true power of the integrated minor lies in its Elective Program. Each track offers two specialized elective modules. For instance, the Offshore track offers 'Offshore Windfarm Design' and 'Heavy Lifting and Transport', while the Process Technology track offers 'Smart Electrification' and 'Hydrogen and Fuel Cells'.

A student can choose the two electives from within their own track. An Offshore & Construction student, for example, could take both Offshore Windfarm Design and Heavy Lifting, graduating with profound expertise in that specific domain. This forms the strong vertical bar of their "T-shaped" profile.

Alternatively, a student can choose one or both of their electives from the offerings of the other tracks. A Maritime student focused on floating wind platforms might find immense value in taking the Hydrogen and Fuel Cells elective from the Process Technology track, understanding how to integrate hydrogen production into their offshore designs. This cross-pollination of knowledge builds the horizontal bar of the "T," creating versatile engineers who can communicate and innovate across disciplinary boundaries.

This flexible, student-centered approach (Silva et al., 2025) is fundamental to developing the adaptable, system-thinking engineers the energy transition requires. It allows each student to tailor a curriculum that aligns with their personal career aspirations while ensuring a baseline of interdisciplinary exposure.

4 Synergies in Collaboration: Educational Efficiency and Cost Reduction

A primary driver for integrating the four minor programs was the recognition that collaboration could unlock significant efficiencies, reduce costs and administrative burden while simultaneously enhance the educational experience. By treating the entire cohort of

minor students—regardless of their track—as a single group for planning purposes, we have streamlined operations and optimized resource allocation (Alhassani et al., 2025).

The most significant savings are realized through the shared components of the minor, particularly the Talent Innovation Pool (TIP). This 3 EC module is a professional development program that includes masterclasses from industry leaders, fair visits, symposia, and multi-day excursions.

The annual study trip to Berlin is a prime example. Organizing logistics for a single large group is exponentially more efficient than it would be for four separate ones, making such a high-impact experience financially and logistically feasible.

The collaborative model extends beyond event planning to the daily use of educational resources. All students in the minor have access to the HRTech Energietransitielab on the RDM Campus. This dedicated project space is a central hub for collaboration. It is equipped with whiteboards, presentation screens, and even relaxation areas to foster community and informal knowledge sharing. This avoids the cost and inefficiency of maintaining four separate, underutilized project rooms.

5 A Model for Sustainable Education

The Rotterdam Energy Transition program's design and execution align closely with the key themes of sustainable energy education, offering a robust model for sustainable education in practice.

Competency-Based Learning & Skill Assessment: The program is fundamentally project-driven. Assessment is based on the application of knowledge in design reports, technical analyses, and project defences, rather than traditional examinations alone. This directly measures the competencies required of a professional engineer.

Innovative Materials & New Tools for Teaching: The Energietransitielab serves as an innovative teaching tool (Hadgraft & Kolmos, 2020)—a physical space designed to promote project-based work, teamwork, and the cross-pollination of ideas. The integration of industry-standard software (FEM, CAD) and design codes (Lloyd's Register) ensures students are learning with the tools used in the professional world.

Teaching and Learning Experiences: The curriculum is a dynamic blend of theoretical lectures, hands-on experiments (e.g., building a floating wind foundation), masterclasses from industry experts, and direct engagement with real-world energy projects. The informal, community-fostering environment of the project space, complete with a foosball table and gaming console, is a deliberate pedagogical choice derived from modern tech workplaces to stimulate creativity and collaboration.

Experiences Outside the Classroom: The program institutionalizes learning beyond the university walls. The industry projects, study trips (Berlin), and site visits (Groningen, Maasvlakte) are not optional add-ons but core, credit-bearing components of the curriculum.

New Teaching/Learning Theories and Models: The integrated minor is itself a new educational model that dismantles disciplinary silos. It is an applied example of fostering "T-shaped" professionals and explicitly incorporates principles of system thinking to address transition science.

Learning for Employment: The constant and deep collaboration with industry (Shields & Theis, 2020)—through guest lectures, projects, and excursions—ensures the curriculum remains relevant and that students develop a professional network long before graduation. This direct link between education and industry is key to ensuring high employability for graduates in the sustainable energy sector.

6 Conclusion

The Rotterdam Energy Transition program, particularly its integrated fourth-year minor, stands as a testament to the power of collaborative, multidisciplinary education. By breaking down the walls between traditional engineering disciplines, the program successfully cultivates the T-shaped engineers who are essential for tackling the multifaceted challenges of the global energy transition. Students gain deep technical expertise in their chosen field while simultaneously developing the broad, systemic perspective needed to innovate and collaborate effectively.

Furthermore, this paper has demonstrated that this pedagogically rich model is also a highly efficient and sustainable one. The synergies created by centralizing the planning of shared academic and professional activities lead to significant cost reductions and a reduced administrative burden. This allows for the reinvestment of resources into high-impact learning experiences, such as international study trips and industry-led masterclasses, which might otherwise be unfeasible.

The program's structure offers a scalable and transferable framework (Sánchez-Carracedo & López, 2020) for other institutions of higher learning. It is a proven "good practice" that effectively blends competency-based learning, deep industry collaboration, and innovative curriculum design. By preparing engineers who are not just technically proficient but also collaborative, adaptable, and system-aware, we are making a direct and lasting contribution to a sustainable energy future.

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Bachelor Program Energy And Sustainable Development (EDO): An Integrated, Mission-Driven Approach To The Energy Transition

Robert van Breukelen[a] and Wilko Planje[a]

[a] Institute for Design and Engineering & Research group Applied Urban Energy Transition, University of Applied Sciences Utrecht (HU), The Netherlands

Abstract

The transition to a sustainable and climate-neutral society requires professionals with integrated technical, economic, legal, ethical and societal competencies. The University of Applied Sciences Utrecht (HU) introduces the full-time bachelor's program Energy and Sustainable Development ("Energie en Duurzame Ontwikkeling", EDO) (NLQF/EQF level 6), planned to start in September 2026. Developed through extensive consultation with 75 stakeholders from 60 organizations, the program aligns with HU's mission-driven profile and integrates education, research and practice via authentic projects, learning teams and field labs. EDO prepares graduates for roles as system designer, advisor and project manager by cultivating six core competencies: analysing, designing, advising, managing, researching and professional development. The Body of Knowledge and Skills (BoKS) is organized in four learning tracks: Energy Technology in Transition (ETT), Built Environment in Transition (GOT), Ethics, Economics and Law (EER), and Energy and Sustainable Development in Society (EMA). Admission is open to NLQF/EQF level 4–5 diplomas, with structured technical support in the first term for students lacking prior science background. The curriculum spans four years, progressively increasing complexity, and culminates in an individual graduation project demonstrating competencies at final level. EDO responds to urgent societal needs by training connecting professionals capable of accelerating the energy transition in urban environments.

Keywords: energy transition; interdisciplinary education; sustainable development; built environment; applied sciences.

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1 Introduction

The transition to a sustainable, climate-neutral society is among the most pressing global challenges and demands an integrated approach. Professionals require comprehensive energy expertise and the ability to develop innovative products, services, and processes, while embedding sustainability and business-economic considerations (Di Battista et al., 2023; Employee Insurance Agency of the Netherlands, 2022; NIDAP Research, 2022; Selhorst-Koekkoek et al., 2024; Social and Economic Council of the Netherlands, 2018). Based on a systematic analysis of the current Dutch higher education landscape, it was established that no existing bachelor's program in the Netherlands explicitly integrates these domains into a single, coherent educational pathway.

The University of Applied Sciences Utrecht (HU) will introduce the full-time bachelor's program (NLQF/EQF level 6) Energy and Sustainable Development (EDO) in September 2026 at Utrecht Science Park as part of the Institute for Design & Engineering (IDE).

The EDO program aims to educate professionals with a technically substantive and cross-disciplinary knowledge base to address urban sustainability and energy transition. Students collaborate in learning teams on authentic real-world projects, creating a practice-oriented learning environment aligned with HU principles (University of Applied Sciences Utrecht, 2022).The program reflects professional field requirements and HU's mission-driven profile, emphasizing societal themes such as sustainability and digitalization. This paper outlines the origin, development, and structure of this new bachelor's program.

2 Intended final qualifications

2.1 Feedback and involvement from vocational field

The EDO program addresses the growing demand for professionals who can accelerate the energy transition in the built environment through a practice oriented, integrated, and future proof curriculum that responds to societal and technological challenges in urban contexts while maintaining strong links with industry.

Program development started in June 2024 through consultations with 75 stakeholders from 60 organizations. These consultations demonstrated the need for professionals who connect technology, economics, society, and the built environment, and who can develop robust business cases and innovative technical solutions, like in installation technology in buildings and its interaction with adjacent energy systems in urban areas.

Stakeholders including grid operators, consultants, municipalities, and housing corporations supported an educational profile focused on healthy buildings and urban areas. The program therefore integrates social and organizational aspects such as stakeholder engagement, user

behaviour, and collaboration, alongside legal frameworks, financial models, and technical disciplines including installation technology, engineering, ICT, and systems design.

Insights from these consultations informed key choices in the program's educational design and content. To ensure continued alignment with the professional field, a Professional Advisory Committee (PAC) was established, supported by HU research groups. Its input guided the definition of the professional profile, competencies, learning outcomes, and the structure of the Body of Knowledge and Skills and learning tracks, as detailed in the following sections.

2.2 Professional Profile

The professional profile was developed in collaboration with the professional field. The roles of system designer, advisor and project manager are intended to address complex energy challenges through an interdisciplinary approach. This requires combining advanced knowledge, skills and competencies from business administration, urban planning, construction, energy technology and socio-economic domains.

The program focuses on integrated projects that tackle sustainable energy issues within a business context in the built environment. Graduates should be able to guide, design and advise on energy-related challenges for various urban areas such as residential, office, commercial and industrial zones, and at different levels including buildings, neighbourhoods, districts and entire cities. In all cases, they must ensure that sustainability aspects are incorporated.

Relevant factors include compliance with regulations and legal requirements, technical feasibility, financial viability and sound business cases. Social dimensions such as resident participation and stakeholder communication are essential, as well as ethical considerations related to societal, political and economic trade-offs.

2.3 Competencies and Learning outcomes

The EDO program aims to train students as junior professionals who can contribute to the energy transition in urban environments. The curriculum is structured around six competencies with corresponding learning outcomes:

Analysing: The professional conducts a thorough analysis of complex energy issues, integrating societal, technical and economic aspects. Information is gathered from reliable sources, stakeholder analysis is performed, and a program of requirements is developed and refined.

Designing: The professional defines design frameworks and translates them into specifications for systems, processes or methods. Solutions are sustainable and feasible,

applying systematic design methods and evaluating impacts on sustainability, health and environment.

Advising: The professional develops advisory approaches based on energy ecosystem analysis. Challenges are broken down into steps, and solutions are substantiated. Stakeholder interests are considered, communication is effective and choices are well balanced.

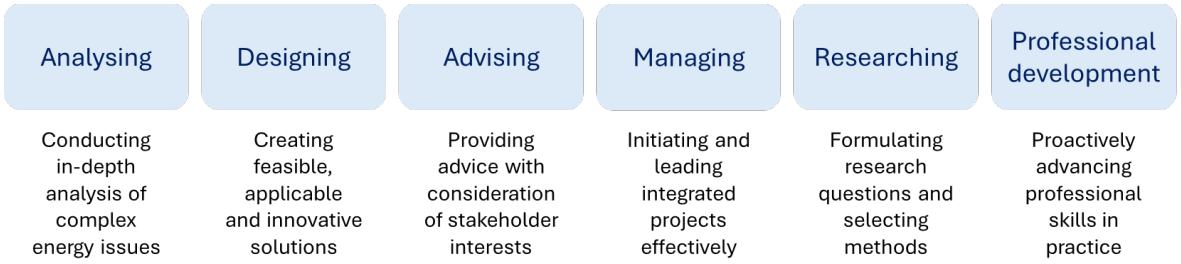
Managing: The professional initiates and manages complex projects, combining technical, organizational, financial and social aspects. Work is project-based with attention to planning, feasibility and stakeholder engagement.

Researching: The professional formulates research questions and applies suitable methods such as literature review, data analysis or experiments. Information is critically analysed and conclusions are communicated clearly to stakeholders.

Professional development: The professional develops within a multidisciplinary context, collaborates effectively, reflects critically and builds a professional identity guided by responsibility and integrity.

The EDO program combines technology with societal, economic, business and ethical dimensions, resulting in broader learning outcomes than traditional technical profiles such as Bachelor of Engineering or Built Environment.

Fig. 1 - Overview of the set of competencies



2.4 BoKS and Learning tracks

The Body of Knowledge and Skills (BoKS) and learning tracks of the EDO program were defined through extensive consultation with professionals, research groups, companies and students. Four learning tracks form the foundation:

Energy Technology in Transition (ETT): Students acquire technical knowledge of energy systems and installation technologies. They learn how energy technology interacts with societal and spatial contexts and apply data analysis and simulation tools for system design. Topics include energy generation, storage, transport and consumption, as well as challenges

such as grid congestion and smart grids. Graduates design integrated energy solutions, provide technical and techno-economic advice and lead projects.

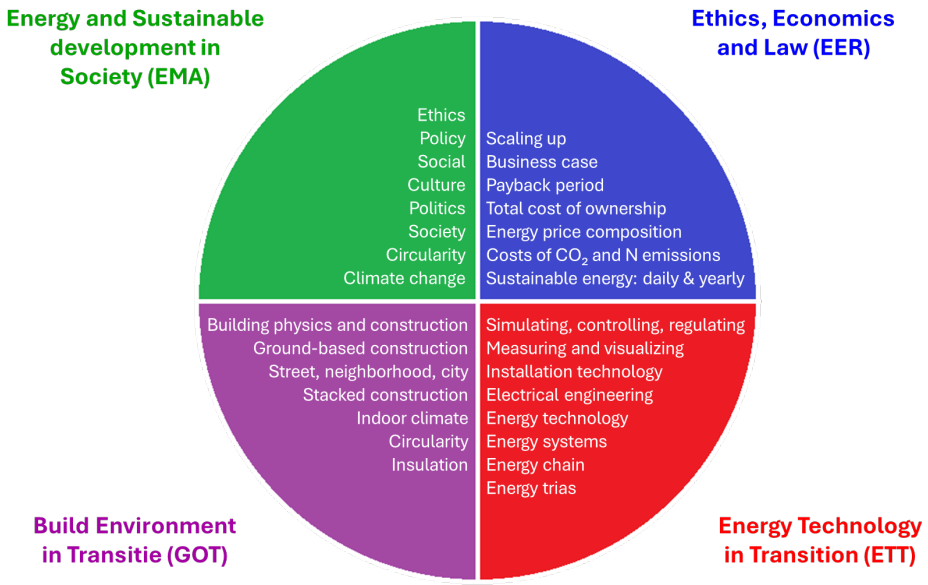
Built Environment in Transition (GOT): Students develop expertise in building physics and construction technology. They apply principles of insulation, ventilation and circular construction to design high-performance buildings. Digital tools support design choices and compliance checks. Solutions integrate user needs, legislation and technical constraints, preparing students to manage renovation and energy projects.

Ethics, Economics and Law (EER): Students gain insight into economic, legal and ethical aspects of the energy transition. They learn to justify decisions using analyses such as Total Cost of Ownership and business cases, while considering market dynamics and financing structures. Legal knowledge includes spatial planning, permits and liability. Ethical perspectives address fairness, inclusion and societal impacts.

Energy and Sustainable Development in Society (EMA): Students explore sustainability themes such as climate change, circularity and biodiversity. They analyse stakeholders, assess social impacts and apply communication strategies for sustainable interventions. Policy frameworks and models like SDGs, Energy Trias and Life Cycle Assessment guide decision-making. Emphasis is placed on inclusivity and socially grounded solutions.

Figure 2 gives an overview of the learning tracks and the corresponding Body of Knowledge and Skills (BoKS) in the first year (propaedeutic year).

Fig. 2 - Overview of the learning tracks and the corresponding Body of Knowledge and Skills (BoKS) in the first year (propaedeutic year)



3 Educational concept

3.1 Admission requirements

The EDO bachelor's program trains students for the energy transition, aiming to attract a broader audience beyond traditional technicians. It targets those motivated to tackle sustainability challenges from an interdisciplinary perspective. Admission includes a non-binding interview and requires a diploma at NLQF/EQF level 4 (mbo4, havo, vwo) or 5 (associate degree).

Students without prior science subjects receive structured support in the first three months. The curriculum covers essential math and physics, preparing graduates for roles such as system engineer, designer, advisor, or project manager, while collaborating with specialists for advanced tasks.

3.2 Didactic concept

The program aligns with HU's vision by integrating education, research and practice into projects, learning communities and field labs, creating a rich environment for innovation and professional development.

It adopts a social constructivist approach based on three principles: constructive, contextual and collaborative. Competencies build progressively, projects address real-world cases and collaboration occurs among students and teachers.

Students work in learning teams, engage in interdisciplinary design and receive formative evaluation through feed-up, feedback and feed-forward. Guidance emphasizes interaction with peers, teachers and professionals. Development toward integrated competence takes place in a blended learning environment through learning tracks linked to the Body of Knowledge and Skills.

The curriculum is practice-oriented, with projects in authentic settings on campus, off campus and hybrid, designed in co-creation with the regional professional field and aligned with energy transition challenges.

3.3 Program and Curriculum overview

The program consists of four academic years. The first year (propaedeutic year) and second year are divided into four equal terms of 10 weeks each (term A–D). Each term includes one course worth 15 ECTS credits. The third and fourth years are divided into two equal semesters of 20 weeks each (Semester 1 and 2). Each semester includes one course worth 30 ECTS credits. Figure 3 gives a curriculum overview.

Fig. 3 - Curriculum overview at a glance

Curriculum structure

Year 1	**Term 1A** (15 EC) Introduction EDO	**Term 1B** (15 EC) Comfort-oriented Home energy advice	**Term 1C** (15 EC) Energy solutions for the neighborhood	**Term 1D** (15 EC) Energy in business
	Practicals	Project	Project	Project
	Supporting Knowledge and skills	Supporting Knowledge and skills	Supporting Knowledge and skills	Supporting Knowledge and skills
	Learning team	Learning team	Learning team	Learning team
Year 2	**Term 2A** (15 EC) Utility building under development	**Term 2B** (15 EC) Short Internship	**Term 2C** (15 EC) Sustainable energy design for smart cities	**Term 2D** (15 EC) Energy Challenges that make a Difference
	Project	Short Internship	Project	Project
	Supporting Knowledge and skills	Supporting Knowledge and skills	Supporting Knowledge and skills	Supporting Knowledge and skills
	Learning team	Learning team	Learning team	Learning team
Year 3	**Quest** (30 EC)		**Internship** (30 EC)	
	Learning team		Learning team	
Year 4	**Minor** (30 EC)		**Graduation** (30 EC)	
			Learning team	

3.4 Learning environment

The learning environment begins at the university while students work on professional products for companies, businesses, or government organizations. Over time, activities increasingly take place in professional settings, fostering student independence as task complexity grows (Bouw, Zitter, de Bruijn, 2019).

The learning environment begins at the university while students work on professional products for companies, businesses or government organizations. Over time, activities move increasingly to these professional settings, fostering independence as complexity grows.

The program admits students with diverse backgrounds, enriching collaboration. In the first year, students create individual products to build foundational skills and address gaps. The first term includes technical modules for those without prior technical knowledge.

Each course generally consists of three components:

- **Project or internship**: Students develop competencies through professional products. Each course delivers one or more products, with complexity increasing toward the graduation project. Competency development is monitored through structured feedback. Projects are completed in assigned teams.
- **Supporting Knowledge and Skills / Learning tracks**: Students attend lectures, tutorials and workshops to acquire knowledge and skills for professional products. Modules are linked to learning tracks and the Body of Knowledge and Skills.
- **Learning team activities**: Students reflect on competencies and personal development in learning teams of 6–10 members. Activities emphasize metacognition, self-reflection and lifelong learning. Coaches guide the process and provide individual study and career counselling when needed.

4 Graduation

The program concludes with an individual graduation project in the professional field, where the student works on one or more professional products. The assignment is pre-assessed for suitability to demonstrate competencies, including the corresponding learning outcomes, at the required level.

Students focus on two of the three roles system designer, advisor and project manager by achieving competencies in advising, designing and managing. In the proposal, students specify which roles and competencies they will demonstrate.

Graduation includes an Action Plan describing an energy challenge, a design for a solution and related advice. This involves interdisciplinary collaboration, project management and research based on professional standards and validated sources.

Supervision is provided by a lecturer and a professional mentor, with progress discussed in the learning team. Assessment consists of a portfolio review, an interview and a presentation. Criteria are based on final-level learning outcomes and evaluation is carried out by the HU supervisor and an additional examiner.

5 Conclusion

The bachelor's program Energy and Sustainable Development (EDO) addresses one of the most urgent challenges of our time, the transition to a sustainable and climate-neutral society. By combining technical expertise with economic, social and ethical perspectives, the program prepares professionals to tackle energy transition issues in the built environment from an integrated and interdisciplinary perspective.

The program stands out through its strong connection to the professional field, validated by extensive consultations and supported by a Professional Advisory Committee. It applies an

interdisciplinary approach that fosters collaboration across domains to address sustainability challenges holistically. A comprehensive competency framework covers analysis, design, advising, management, research and professional development. The educational concept is innovative, based on social constructivist principles, learning teams and authentic projects in cooperation with the vocational field. Furthermore, the program offers a multidisciplinary Body of Knowledge and Skills that includes energy technology, the built environment, economics, law, ethics and societal aspects of sustainability, structured into four learning tracks.

Graduates will be equipped to design, advise and manage complex energy projects, conduct applied research and continue developing as professionals. They will play a key role in accelerating the energy transition and shaping sustainable urban environments.

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HU University of Applied Sciences Utrecht

Center of Expertise Smart Sustainable Cities

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