A Competency Framework for Energy Literacy, Sustainability, and Green Transition in Higher Education

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Abstract

Current policies and strategies emphasize the critical importance of advancing a green transition, cultivating sustainability skills, and enhancing energy literacy to effectively address global environmental challenges. Consequently, there is a growing demand for professionals equipped with comprehensive competences in these areas. We have established an integrated framework for assessing competences in sustainability, energy literacy, and biodiversity, organized into five main categories: systems thinking in energy systems, biodiversity, resource management, technology, and policy and regulation. By quantifying these competences, educators and employers have a valuable tool to evaluate and improve graduate preparedness. Our framework was applied to students from three study programs at the University of Maribor in Slovenia: Physics, Mathematics, and Subject Teacher. Using questionnaires, we assessed the competence levels of these students and compared them with market expectations. The findings suggest that, overall, students align well with market requirements, although some variations exist among the individual study programs. Importantly, we identified gaps in policy knowledge and competences related to biodiversity across all programs. These results highlight the necessity of enhancing curricula to better prepare graduates for sustainability-focused careers. By addressing these gaps and refining educational offerings, we can better equip future professionals to navigate and lead in sustainability-driven fields, making a meaningful contribution to global environmental protection and the pursuit of sustainable development goals.

Keywords: Competence Framework, Sustainability, Biodiversity, Energy Literacy, Higher Education

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Introduction

In recent years, the urgent need to address environmental challenges such as climate change, biodiversity loss, and resource depletion has prompted a shift toward sustainable practices across various sectors (United Nations Environment Programme, 2021). Governments, organizations, and educational institutions globally recognize that transitioning to greener practices is essential for achieving ecological balance and economic stability. Policies such as the European Green Deal (European Commission, 2019), the United Nations Sustainable Development Goals (2015), and various national environmental agendas underscore the importance of sustainability-focused actions. These initiatives advocate for the broad development of sustainability skills and enhanced energy literacy to equip individuals and communities for active participation in the green transition. These competences empower individuals and organizations to adopt behaviors and technologies that reduce environmental impact, improve resource efficiency, and support transitions to sustainable energy systems, which are essential for achieving global climate goals such as net-zero emissions by 2050.

Sustainability literacy refers to an individual’s understanding of principles and practices that support the maintenance of ecological, economic, and social systems, while energy literacy involves a comprehension of energy sources, usage, conservation, and impact on the environment (Cotton et al., 2015; UNESCO, 2017). Building literacy in these domains is essential as societies transition to low-carbon economies. As a result, there is a growing demand for a workforce skilled in green competences, particularly in energy and sustainability literacy, resource management, and biodiversity conservation. For instance, the International Labour Organization (Strietska-Ilina et al., 2011) projects that green policies could create 24 million jobs globally by 2030 but notes that workforce readiness in green competences remains a barrier. Employers increasingly seek individuals who can navigate complex environmental regulations, design sustainable systems, and engage in effective resource management. Market demand for sustainability-related skills varies across industries, with sectors such as energy, manufacturing, transportation, and finance actively seeking expertise in environmental management, regulatory compliance, and energy efficiency (UNESCO, 2017).

Additionally, the need for energy literacy is pronounced in engineering and design fields, where professionals can incorporate renewable energy sources and energy-efficient processes into product development and building design.

Global initiatives, including the United Nations Sustainable Development Goals and the European Green Deal, stress the integration of sustainability education to support ecological stability and economic resilience. However, current educational curricula often inadequately prepare graduates for these roles, creating a pressing need for educational models that equip future professionals with the necessary knowledge, skills and attitudes.

There are several established frameworks designed to assess sustainability competences, each with a unique focus. Key frameworks often consider sustainability literacy as part of broader environmental education, encompassing ecological knowledge, ethical considerations, and action-oriented skills (Shephard, 2008). UNESCO's Education for Sustainable Development (2017) focuses on fostering a comprehensive understanding of sustainability within educational contexts by developing the capacities of learners to address sustainability challenges through critical and systems thinking, self-awareness, and integrated problem-solving. It specifies the following competences: systems thinking, anticipatory, normative, strategic, collaboration, critical thinking, self-awareness, and integrated problem solving. Meanwhile, the European GreenComp Framework (Bianchi et al., 2022) identifies 12 competences organized into four areas:

1. embodying sustainability values (valuing sustainability, supporting fairness, promoting nature),
2. embracing complexity in sustainability (systems thinking, critical thinking, problem framing),
3. envisioning sustainable futures (futures literacy, adaptability, exploratory thinking),
4. acting for sustainability (political agency, collective action, individual initiative).

For energy literacy, the North American Association for Environmental Education (NAAEE) provides the Guidelines for Excellence in Environmental Education, which includes energy concepts crucial for informed decision-making on energy use, sources, and conservation (NAAEE, 2010). Additionally, DeWaters and Powers (2011) propose an energy literacy framework encompassing cognitive, affective, and behavioral dimensions of energy-related knowledge and values, further underlining the importance of holistic education that encompasses scientific understanding, personal responsibility, and action-taking capacities.

Based on the U.S. Department of Energy (2014), energy literacy is defined as an understanding of the nature and role of energy in the universe and in our lives. It also encompasses the ability to apply this understanding to answer questions and solve problems. In this framework, seven essential principles are emphasized: 1) energy is a physical quantity that follows precise natural laws, 2) physical and biological processes on Earth are driven by energy flow through the Earth system, 3) energy is essential to life and all human activities, 4) various sources of energy can be harnessed for use by humans, each with costs and benefits, 5) energy decisions are influenced by economic, political, environmental, and social factors, 6) the amount of energy used by human society depends on many factors, and 7) the quality of life of individuals and societies is affected by energy choices. An energy-literate individual uses these principles to make informed decisions about energy use and policies, contributing to a more sustainable future.

Existing frameworks offer comprehensive guidelines for fostering green transitions and promoting sustainability; however, they often lack the specificity needed to address emerging market demands for energy literacy and biodiversity expertise.

To develop the framework, we conducted a comprehensive document analysis (Klemenčič et al., 2024). Focusing on natural sciences programs, we selected three study programs at the Faculty of Natural Sciences and Mathematics (FNM), University of Maribor. Selected study programs are the bachelor's programs in Physics and Mathematics, and the unified master's program for Subject Teacher with tracks in Educational Physics and Educational Mathematics. Graduates of Physics and Mathematics are typically employed in academic and research institutions, the technology and engineering sector, the finance and banking sector, or through self-employment, while graduates of Subject Teacher programs are mostly employed in education sector. The objective of the document analysis is to assess the extent to which the current curricula, the fundamental goals of the programs, and the competences of graduates align with the principles of energy literacy, sustainability, and the green transition. Additionally, we administer questionnaires to graduates to gather their perceptions regarding the development of these competences during their studies and their relevance to the demands of their current professional roles.

Building on these findings, we proposed a tailored framework to evaluate competences in sustainability, energy literacy, and biodiversity, with a particular focus on natural sciences and engineering programs. The framework emphasizes five key dimensions: systems thinking of energy systems, biodiversity, resource management skills, technological competence, and policies and regulations awareness. These dimensions are essential for equipping students with the practical skills needed to effectively address complex sustainability challenges. By applying this framework to three study programs at the University of Maribor, Slovenia, our goal is to identify both strengths and gaps within current curricula. The insights gained will inform targeted improvements, ensuring alignment with industry and societal needs while enhancing graduates' abilities to contribute meaningfully to global sustainability objectives.

Program Specific Competence Overview

We analyzed curricula and the accreditation documents of selected study programs to assess their fundamental goals, and the competences expected of their graduates. We specifically examined how these goals and competences align with digital, natural science, and computational skills, as well as energy literacy.

In the Physics Bachelor's study program, 90% of competences align with science literacy, 57% with computational competences, 10% with digital competences, and only 5% with energy literacy.

In the Mathematics Bachelor's study program, none of the core objectives or competences address energy literacy. Most goals align with computational and natural science competences (88%), with 59% linked to digital competences.

In the Subject Teacher program (Unified Master's degree), we analyzed competences for Educational Physics and Educational Mathematics tracks. Educational Physics focuses primarily on natural sciences (60%) and digital (55%) competences, with 35 % in computational competences. Energy literacy appears in subject-specific competences, representing 40% - the highest proportion across all programs studied. Educational Mathematics track emphasizes digital (100%) and computational (75%) competences, with 38% linked to natural science but none to energy literacy.

Curricula analysis by Klemenčič and colleagues (2024) revealed that most course units in the Physics (BSc) and Subject Teacher (Educational Physics) programs include content and teaching methods that promote the development of natural science competences, which is expected given the focus of the studied programs. Competences related to algorithmic, logical, and abstract thinking are present in some course units, particularly in the study programs Mathematics and Subject Teacher (Educational Mathematics), but they are not explicitly stated in the majority of course units. A significant portion of the course units also incorporate skills supporting the development of digital competences, which are explicitly mentioned mainly in the teaching and learning methods (e.g., use of ICT, simulation environments). Energy literacy is the least represented competence in the course units analyzed. It is explicitly mentioned in only one unit, this is Environmental Physics, which is an elective course in the study program Physics but a compulsory course in the Subject Teacher - Educational Physics program. Similarly, findings related green transition indicate that "green content" is directly included only in the course unit Environmental Physics, suggesting a limited focus on sustainability topics across the study programs.

Graduates’ Perception on Acquired Competences and Market Needs

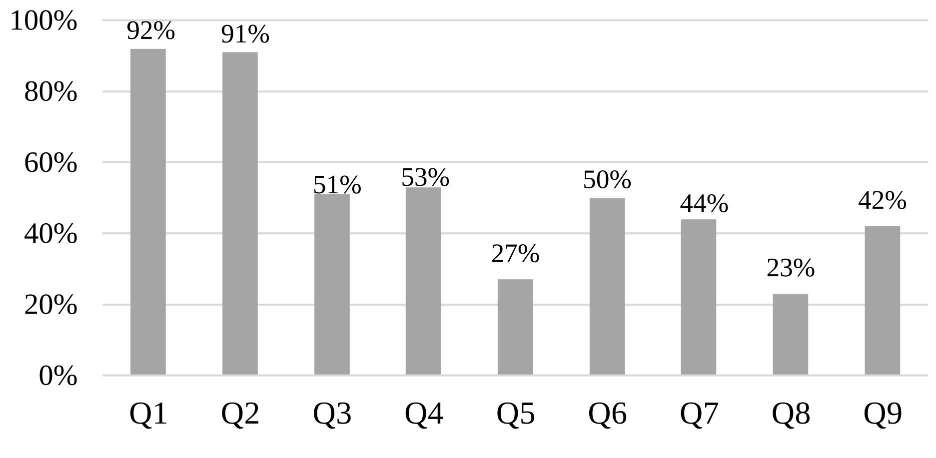
The structured questionnaire for graduates featuring close-ended questions was designed to obtain graduates’ opinions on whether their studies adequately developed the skills needed for the labor market. The survey was conducted using a convenience sample of graduates. A total of 166 graduates from the FNM participated, including 94 from pedagogical study programs and 72 from non-pedagogical programs.

Graduates were inquired about whether their academic programs provided them with the necessary skills and competences in the following areas:

- Q1) Critical thinking skills
- Q2) Problem-solving skills
- Q3) Energy-saving skills
- Q4) Knowledge of energy sources
- Q5) Understanding of energy policies
- Q6) Awareness of climate change
- Q7) Sustainability concepts
- Q8) Circular economy
- Q9) Energy efficiency

Most graduates felt that their study programs placed adequate emphasis on critical thinking and problem-solving skills. However, they expressed lower levels of confidence regarding their knowledge and skills related to energy literacy. For most of the other questions, graduates' responses were more divided. The lowest percentage of graduates who considered their competences sufficient were in the areas of Q5) understanding of energy policies and Q8) circular economy. Figure 1 presents the percentage of graduates who considered the knowledge and skills acquired during their studies to be sufficient for entering the labor market.

Figure 1: Perceived Sufficiency of Competences Acquired During Studies for Entering the Labor Market



Competency Framework in Energy Literacy, Green Transition, and Biodiversity

The proposed competency framework emphasizes the knowledge and skills that graduates in natural sciences, physics, and mathematics should acquire to foster energy literacy, sustainability, and contribute to the green transition. It highlights the importance of key competences such as system thinking, which enables students to understand the interconnectedness of environmental, economic, and social systems; critical thinking, which empowers graduates to analyze complex issues, challenge assumptions, and make informed decisions; and problem-solving, which equips them to design innovative solutions for real-world challenges related to sustainability. Additionally, the framework stresses the significance of mathematical modeling as a tool for simulating and predicting the behavior of systems, aiding in decision-making processes for sustainable development. Furthermore, the framework fosters attitudes and awareness regarding the pressing issues of the "triple planetary crisis"—climate change, biodiversity loss, and pollution—encouraging graduates to be proactive, and solutions-oriented in their approach to these challenges.

The proposed competency framework consists of 12 specific competences organized into five thematic areas: System Thinking of Energy Systems, Biodiversity, Resource Management Skills, Technological Competence, and Policies and Regulation Awareness. The framework aims to guide the development of knowledge, skills, and measurable outcomes for students across three competences levels: Basic, Intermediate, and Advanced. For each of the 12 competences, we have developed descriptors that outline students' progression of knowledge and skills, ranging from foundational understanding (basic) to application and innovation (advanced). The descriptors for each thematic area are listed in Tables 1-5.

Table 1: System Thinking of Energy Systems Competences With Descriptors

Competence	*Basic*	*Intermediate*	*Advanced*
1.1 Understanding systems	Recognize the basic relationships, cause-effect relationships, feedback loops, and energy flows within environmental systems	Analyze relationships, cause-and-effect links within and between systems and use models (e.g., stock-flow diagrams) to understand system dynamics.	Plan and take part in problem-solving (e.g., using mathematical modelling), seek proposals, and design solutions that consider long-term sustainability (interdisciplinarity).
1.2 Understanding the concept of energy	Understand the basic physics concepts of energy, list renewable energy sources, know that solar energy is stored in fossil fuels and biomass.	Explain energy conversions, energy losses and the importance of different energy sources, explain the ways of generating electricity and knows that energy can be stored for later use in diverse ways.	Understand that different energy sources and different forms of energy conversion, transport and storage have their advantages and disadvantages, analyze the efficiency of energy systems and the impact on the environment (carbon footprint).

1.3 Understanding physical processes on earth driven by energy flows	Understand that the sun is a key energy source, and that an internal or external energy source is needed for the flow of matter on Earth.	Understand that energy flows change our planet and knows the most important energy sources for processes on Earth (solar, radioactivity, rotation).	Explain and critically assess the impact of greenhouse gases on energy flows and understand that changes in energy flows at the system-wide level are not at once detected.
1.4 Understanding biological processes on earth driven by energy flows	Know that the sun is the primary energy source for organisms and ecosystems, and that food is biofuel for organisms.	Understand that energy in food chains flows one-way from producers to consumers, know the response of ecosystems to the availability of energy and nutrients.	Understand how ecosystems respond to the availability of energy and nutrients and is aware of the dependence and influence of humans on energy flows through these systems.

Table 2: Biodiversity Competences With Descriptors

Competence	*Basic*	*Intermediate*	*Advanced*
2.1 Understanding biodiversity	Know the basic concepts of biodiversity and is aware of its importance.	Analyze the factors that affect biodiversity and link biodiversity with the energy efficiency of systems.	Formulate and implement strategies for the conservation of biodiversity.
2.2 Biodiversity management	Recognize the basic principles of biodiversity management (protected areas, etc.).	Apply biodiversity management practices in different contexts (species diversity in urban areas, etc.).	Plan and develop biodiversity management programs.

Table 3: Resource Management Skills Competences With Descriptors

Competence	*Basic*	*Intermediate*	*Advanced*
3.1 Sustainability of resource management	Understand the importance of conserving resources (water, energy, etc.).	Identify and apply measures for the sustainable management of resources (e.g., rainwater harvesting, waste management, circular economy).	Analyze and optimize sustainable resource management measures (life cycle analysis, carbon footprint quantification).
3.2 Efficient use of energy	Recognize the day-to-day activities that consume energy, know the basics of saving energy consumption and is aware that the need for energy is growing, and energy resources are limited.	Know that social and technological innovations have an impact on the amount of energy consumed by society, identify and implement energy efficiency measures, is aware of how much energy is used to conduct activities and where energy is obtained from.	Know and use approaches for calculating, measuring, and monitoring the amount of energy consumed, plan and develop methods for efficient use of energy and optimization of energy processes (e.g., in the energy efficiency of buildings, life cycle of buildings)-

Table 4: Technological Competences With Descriptors

Competence	*Basic*	*Intermediate*	*Advanced*
4.1 Understanding renewable energy technologies	Know the basic operation of renewable energy technologies.	Understand and analyze the operation of renewable energy technologies.	Plan and develop innovative solutions for the use of renewable energy sources.
4.2 Understanding green technology	Know the basic green technologies and their advantages (electric vehicles, sustainable materials, etc.). Know the concept of carbon footprint.	Understand basic green technologies and analyze their strengths and weaknesses (e.g., material life cycle analysis).	Plan, develop, and optimize green technologies.

Table 5: Policies and Regulations Awareness Competences With Descriptors

Competence	Basic	Intermediate	Advanced
5.1 Understanding policies	Understand basic environmental policies and regulations, is aware that decisions about the choice and use of energy sources affect the quality of life of individuals and society.	Explain the environmental policies that support the green transition and recognize that economic, political, environmental, and social factors influence decisions on the choice and use of energy sources.	Analyze and predict factors influencing decisions on the exploitation of energy resources, assesses risks, formulates the development of environmental policies at regional, national, or international level.
5.2 Green business	Understand the basics of green business and sustainable entrepreneurship.	Analyze examples of good practices in green business and sustainable entrepreneurship.	Plan and develop strategies for green business and sustainable entrepreneurship.

Students' Assessment of Competences

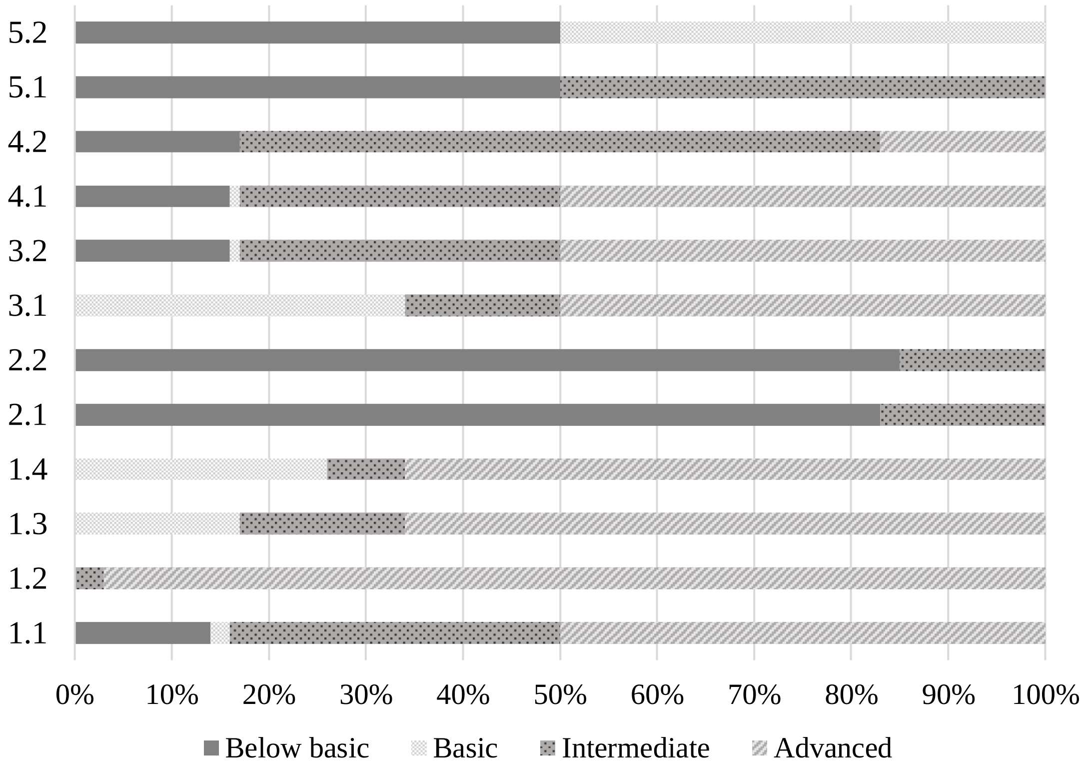
We applied the developed framework to assess the competences of physics and mathematics students at the FNM during the final years of their bachelor's studies. A total of seven students participated. Although the sample size is small, it represents 47% of the cohort. Our aim was to determine the competency levels students achieved based on their self-perceptions. To collect data, we used a close-ended questionnaire in which students evaluated specific competences using a Likert scale ranging from 1, meaning "strongly disagree," to 5, meaning "completely agree".

Table 6 presents the average values and standard deviations for each competence and its level. For clearer visualization, Figure 2 shows the percentage of students achieving basic, intermediate or advanced levels for each competence.

Table 6: Students Answer to Competence Level Using Likert's Scale From 1 (Strongly Disagree) to 5 (Completely Agree)

Competence	*Basic*		*Intermediate*		*Advance*	
	average	st. dev	average	st. dev	average	st. dev
1.1	4,3	0,8	4,0	0,6	3,5	0,5
1.2	5,0	0,0	4,8	0,4	4,7	0,5
1.3	4,8	0,4	4,2	0,8	4,0	0,9
1.4	4,7	0,5	3,8	0,8	3,8	1,2
2.1	3,0	1,3	2,7	1,4	2,2	1,3
2.2	2,2	1,6	2,0	1,3	1,8	1,0
3.1	5,0	0,5	3,7	1,5	3,5	1,0
3.2	4,5	0,8	4,3	0,8	3,5	1,0
4.1	4,5	0,8	4,2	0,8	3,5	0,5
4.2	3,8	0,8	4,3	0,8	2,2	1,3
5.1	3,1	1,7	2,8	1,7	1,5	0,8
5.2	3,0	1,5	1,5	0,8	1,5	0,8

Figure 2: Percentages of Students Achieving Basic (Light Gray), Intermediate (Gray-Dotted), or Advanced (Gray-Dashed) Level. The Percentage of Students Below Basic Level Is Presented With Darker Gray.



Students exhibit a strong performance in competences related to understanding energy systems, particularly at the Basic and Intermediate levels. For example, the competence "Understanding the concept of energy" (1.2) received near-perfect scores, indicating a solid grasp of fundamental concepts such as energy conversions, energy losses, and renewable energy sources. Similarly, students are confident in their understanding of renewable energy technologies (4.1) and the efficient use of energy (3.1 and 3.2). These findings suggest that the curriculum effectively imparts both foundational and practical knowledge about energy systems, an essential domain for addressing global challenges such as climate change and the green transition.

In contrast, the results reveal significant gaps in biodiversity-related competences (2.1 and 2.2), particularly at the Intermediate and Advanced levels. Students scored below 2.5 on average in these categories, indicating limited understanding of biodiversity management and the factors influencing biodiversity. Competences related to environmental policies (5.1) and green business strategies (5.2) also scored low across all levels, with particularly weak scores at the Advanced level. Students' limited confidence in these areas highlights a gap in their understanding of the socio-economic and regulatory frameworks that underpin sustainable practices.

Moreover, there is a noticeable decline in self-assessed competences at the Advanced level across most domains. This may reflect a lack of exposure to complex, interdisciplinary problem-solving or a lack of confidence in applying theoretical knowledge to real-world scenarios. Advanced competences, such as designing innovative solutions for renewable energy systems or optimizing resource management measures, require not only technical expertise but also critical thinking, creativity, and collaborative skills. To bridge this gap, it is important to include experiential learning opportunities, such as capstone projects, internships, and collaborative research initiatives. These experiences can help students apply their knowledge in practical contexts, build confidence in their abilities, and develop the interdisciplinary skills needed to address sustainability challenges effectively.

Conclusion

In this study, we proposed a competency framework centered on natural sciences and mathematics studies, to equip students with the skills and knowledge they need to address global sustainability challenges and navigate and lead the green transition. The framework outlines twelve competences across five thematic areas: System Thinking of Energy Systems, Biodiversity, Resource Management Skills, Technological Competence, and Policies and Regulation Awareness. By structuring competences across three levels, the framework enables to track students' progress, from basic understanding to advanced innovation.

To assess the applicability of proposed framework, we administered a close-ended questionnaire to final-year bachelor’s students. The findings reveal a strong foundation in some areas of energy literacy, but significant gaps in biodiversity competences, policy awareness, and green business knowledge. Given the importance of biodiversity for ecosystem resilience and sustainability, the limited understanding of biodiversity management among students is concerning. Additionally, the findings suggest that students face challenges at the advanced level, indicating a need for greater exposure to interdisciplinary problem-solving and real-world applications of theoretical knowledge.

To address these gaps, curricula should be revised to include biodiversity, energy policy frameworks, regulations, and their global impact. This could be achieved through the involvement of policy experts, policy simulation exercises, and collaborations with governmental and non-governmental organizations engaged in energy policy. Similarly, strengthening the teaching of circular economic principles would enable graduates to gain a more comprehensive understanding of sustainability practices. Universities could introduce case studies, real-world projects, and partnerships with companies that implement circular economy models. Encouraging students to take courses across disciplines, such as environmental science, economics, and engineering, would broaden their perspectives and enhance their competences in these areas. To ensure academic programs remain aligned with labor market needs, institutions should continuously gather feedback from both graduates and industry professionals. This feedback is essential for identifying areas that require improvement and for ensuring curricula remain responsive to the evolving demands of the workforce.

In conclusion, this study highlights both strengths and gaps in student competences and underscores the critical role of a comprehensive, interdisciplinary, and experiential approach to curriculum design. By addressing gaps in energy literacy, biodiversity, policy awareness, and advanced-level skills, study programs can better prepare graduates to contribute effectively to sustainability initiatives and the green transition.

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