Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XV, 2026
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

ASSESSING STUDENTS' COMPETENCIES IN ADVANCED TECHNOLOGIES FOR A SUSTAINABLE GREEN FUTURE IN ENERGY, AGRICULTURE, AND INDUSTRY

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Abstract

A sustainable green future depends on developing competencies in advanced technologies across energy, agriculture, and industry for graduate students of Master`s and Doctoral programs. This study aimed to assess graduate students' perceptions from three European universities regarding the key sustainability strategies through a structured survey focusing on digitalisation, agriculture, biodiversity conservation, and the circular economy. The majority of graduate students agreed that renewable energy reduces carbon footprint, air and water pollution, and enhances public health. Students demonstrated a clear understanding of the EU Green Agriculture objectives, emphasizing food security and environmental footprint reduction. Positive perceptions extended to biodiversity conservation, with support for effective management, monitoring, and clear conservation goals. Respondents endorsed circular economy principles, including resource efficiency, material redesign, and waste recapture, and aligned with the EU's industrial strategy for a progressive and sustainable economic transition. These findings indicate that the graduate students possess both awareness and favourable attitudes toward advanced technological solutions for sustainability. The results underscore the successful implementation of digital resources developed in academic curricula for students from Master`s and Doctoral programs from three European universities.

Key words*: graduate student competencies, green agriculture, sustainable.*

INTRODUCTION

In the context of the profound structural transformations driven by the European Green Deal, European higher education plays a major role in shaping a new professional elite capable of operationalising the transition towards a climate-neutral economy (Borel-Saladin et al., 2013). The success of complex macro-structural initiatives such as the Common Agricultural Policy (CAP) or the "Farm to Fork" strategy is directly contingent upon the translation of theoretical directives into applied technical competencies and digital literacy (Matthews, 2013). These policy frameworks increasingly rely on data-driven decision-making, sustainability metrics, and cross-sectoral knowledge integration (Pe'er et al., 2020). Agricultural digitalisation (smart agriculture), precision farming systems, and the integration of Geographic Information Systems (GIS) are widely recognised as fundamental pillars of modern agro-ecosystem management (Wolfert et al., 2017; Mathenge et al., 2022). In parallel, advanced biotechnologies such as genomics, bioinformatics, and molecular breeding, alongside Big Data analytics and artificial intelligence infrastructures, are reshaping the resilience and productivity of primary production systems (Kamilaris et al., 2017; Liakos et al., 2018). These technological paradigms collectively underpin the ongoing transition towards Agriculture 4.0 and data-intensive sustainability governance (Klerkx et

al., 2019). To mitigate these asymmetries and ensure integrated training, an advanced educational programme was designed and implemented in the form of an intensive course, type blending learning with digital tools. This course adopted an interdisciplinary approach, addressing the pillars of sustainable development, the application of digital technologies in optimising primary production systems, and policy mechanisms for biodiversity conservation and ecosystem resilience The studies performed aimed to assess the competencies of doctoral and master's students in advanced technologies related to a sustainable green future in energy, agriculture, and industry, within the context of completion of a short intensive training program type blending learning, regarding the European Green Deal, using an anonymous cross-sectional survey

MATERIALS AND METHODS

The studies performed were based on cross-sectional survey questionnaires involving 51 doctoral and master's students from five universities that participated at a short intensive learning training teaching program in the field of the European Green Deal. At the end of this session, participants in the intensive courses were invited to answer a specific survey questionnaire anonymously in order to assess their competencies in advanced technologies for a sustainable green future in energy, agriculture, and industry.

The participants (students) belong to the following universities:

- University of Agronomic Sciences and Veterinary Medicine of Bucharest (USAMVB), Romania;
- National University of Sciences and Technology Politehnica of Bucharest (UNSTPB), Romania;
- University Autonoma de Barcelona Spain (UAB Spain);
- University of Porto Portugal (UPorto Portugal);
- Uzhhorod National University Ukraine (Uzhhorod Univ_Ukraine).

Each group consisted of at least 10 participants per university.

The Survey Questionnaires were completed anonymously. Data were structured in a survey questionnaire based on a 5-point Likert scale, as follows:

1 = No, not at all;
2 = Only to a certain extent;
3 = More or less;
4 = Mostly yes;
5 = Yes, always.

The questionnaire assessed the students' perceptions regarding the following sentences:

B1: Do you think that the utilization of renewable energy reduces carbon footprint, air pollution and water environmental impact, but also improves public health?

B2: Do you think that remote sensing and GIS-based technologies for sustainable management of agriculture are important?

B3: Do you consider that the main objective of the EU Green Agriculture politics is to ensure food security by reducing environmental footprint and assuring competitive sustainability from farm to fork?

B4: Do you agree that the EU's Common Agricultural Policy is central to the EU Green Deal & its Farm to Fork and Biodiversity strategies?

B5: Do you think that genomics, bioinformatics, and big data in sustainable food production are useful for agriculture and food production systems

B6: Do you think that the EU target for Biodiversity conservation is effectively managing all protected areas, defining clear conservation objectives and measures, and monitoring them appropriately?

B7: Do you think that digitalization can be useful in the Global Biodiversity Assessment

Statistical analysis: All data are presented as means ± standard errors.

RESULTS AND DISCUSSIONS

The results highlight a high level of student awareness regarding the role of digital technologies and European policies in promoting agricultural sustainability, biodiversity conservation, and the transition towards a green economy. With respect to the environmental impact of renewable energy sources (Figure 1), most respondents assigned

high scores (4 and 5), with 80% of responses falling within these categories. This finding indicates a solid understanding of the benefits of renewable energy in reducing carbon emissions, pollution, and natural resource degradation. Similar results have been reported in studies examining environmental literacy among European students, which indicate growing awareness of renewable energy as a key component of sustainable development and climate change mitigation strategies (Probst, 2022; Sanchez et al., 2025). The increasing visibility of renewable energy within European sustainability policies may further contribute to students' positive perceptions of its environmental benefits. Regarding the importance of GIS in agriculture (Figure 2), responses were largely positive, with 80% of students assigned scores of 4 or 5. This fact indicates strong awareness of the role of geospatial technologies in agricultural monitoring and management optimisation. This result is consistent with recent research demonstrating that GIS, remote sensing, precision agriculture, and artificial intelligence technologies contribute significantly to improving resource-use efficiency, crop monitoring, and sustainable land management practices (Finger, 2023; Wójcik-Gront et al., 2024).

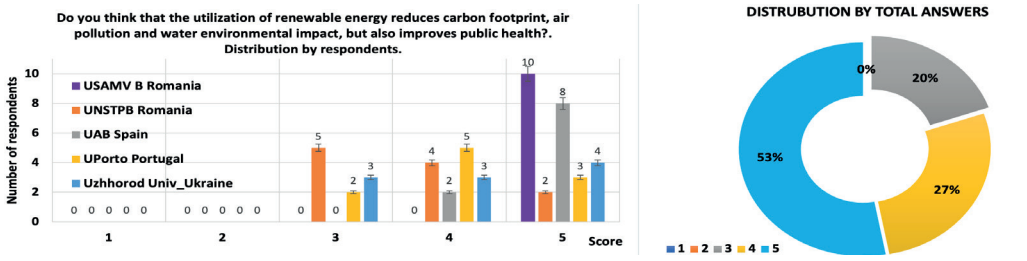


Figure 1. Assessment of the students' perceptions regarding the environmental impact of renewable energy sources

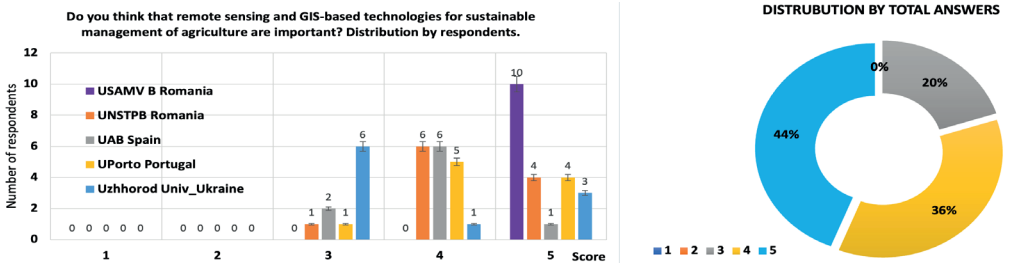


Figure 2. Assessment of the students' perceptions regarding the importance of GIS in agriculture

The high level of agreement observed among respondents suggests that students increasingly understand and recognise the importance of Agriculture 4.0 technologies in supporting sustainable and resilient agricultural systems. Assessment of students' perceptions regarding the objectives of EU green agricultural policies in relation to food security, the reduction of environmental impacts, and the promotion of sustainable competitiveness throughout the food supply chain is presented in the Figure 3.

The predominance of answers with scores 4 and 5 (71%) suggests that respondents understand and recognise the strategic importance of these policies in balancing food security with environmental sustainability This perception aligns with the objectives of the European Green Deal and the Farm to Fork Strategy, which aim to transform food systems by reducing environmental pressures while ensuring food security, economic viability, and social sustainability (Guyomard et al., 2023; Hamam et al., 2021; Radu et al., 2007; Radu et al., 2020). The relatively high proportion of moderate-agreement responses may reflect uncertainties about the practical implementation, economic feasibility, or long-term effectiveness of these measures.

Regarding the connection between the Common Agricultural Policy (CAP) and European Green Deal (Figure 4), the results reveal a predominantly positive perception of the CAP as a key policy instrument supporting the EU Green Deal, the Farm to Fork Strategy, and the Biodiversity Strategy too.

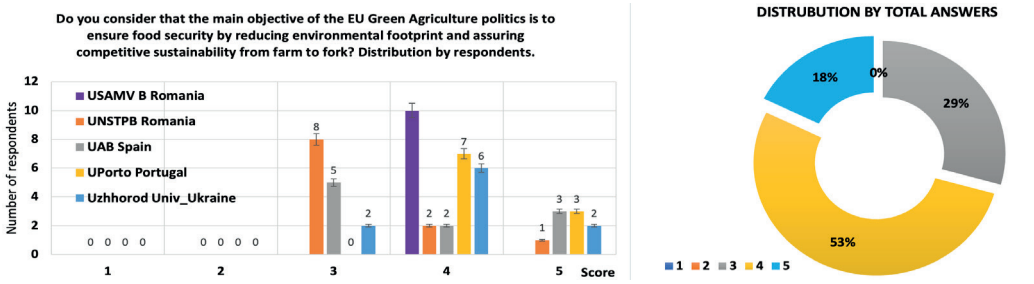


Figure 3. Assessment of students' perceptions regarding the objectives of EU green agricultural policies in relation to food security, the reduction of environmental impacts, and the promotion of sustainable competitiveness throughout the food supply chain

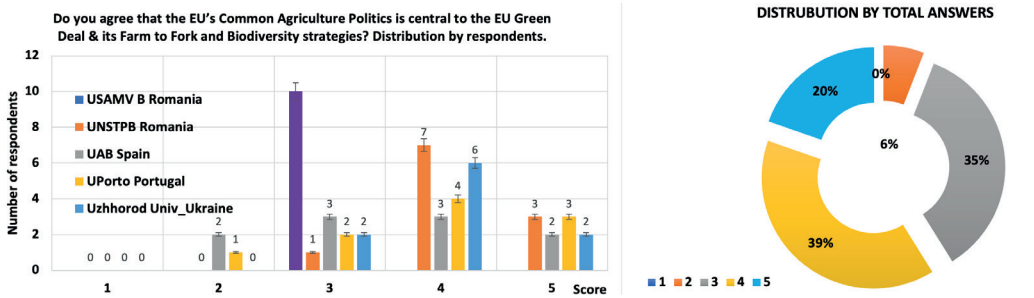


Figure 4. Assessment of the students' perceptions regarding the connection between the Common Agricultural Policy (CAP) and European Green Deal

The combined proportion of agreement and strong agreement responses (59%) demonstrates substantial support for the CAP's role in advancing sustainable agricultural development and environmental objectives across Europe. Similar findings have been reported by (Probst, 2022; Sanchez et al., 2025), who observed that university students increasingly recognise the importance of policy instruments in achieving sustainability transitions within agri-food systems. However, 35% of respondents selected score 3, indicating a moderate level of agreement. The overall findings suggest moderate-to-high awareness of the relationship between agricultural policy and sustainability goals. Responses concerning the contribution of genomics, bioinformatics, and big data to sustainable food systems (Figure 5) were predominantly positive, with 66% of respondents assigning scores of 4 or 5. This finding suggests that students acknowledge the potential of advanced biotechnologies to improve sustainability, productivity, and resource-use efficiency. Recent studies have highlighted the growing role of genomics, artificial intelligence, and data-driven approaches in supporting climate-smart agriculture, precision farming, and sustainable food production systems (Finger, 2023; Getahun et al., 2024; Ronzhin et al., 2025). These technologies are increasingly regarded as essential tools for addressing global challenges related to food security, environmental degradation, and climate change. Biodiversity conservation policies (Figure 6) were strongly acknowledged, with nearly 67% of responses receiving scores of 4-5, suggesting a high level of awareness of ecosystem protection priorities and conservation strategies. This result is in agreement with the increasing of biodiversity conservation within international policy agendas, particularly following the adoption of

the Kunming-Montreal Global Biodiversity Framework, which established ambitious targets for halting biodiversity loss by 2030 (Hughes & Grumbine, 2023).

The findings indicate that students are aware of the importance of biodiversity conservation as a prerequisite for ecosystem resilience and sustainable development. The usefulness of digitalisation in global biodiversity assessment (Figure 7) was positively evaluated, with 75% of respondents assigning high scores. This result demonstrates strong confidence in the contribution of digital technologies to biodiversity monitoring and management. The finding is supported by recent literature highlighting the transformative role of artificial intelligence, remote sensing, geographic information systems (GIS), and big data analytics in biodiversity assessment and conservation planning (Jetz et al., 2019; Hughes & Grumbine, 2023).

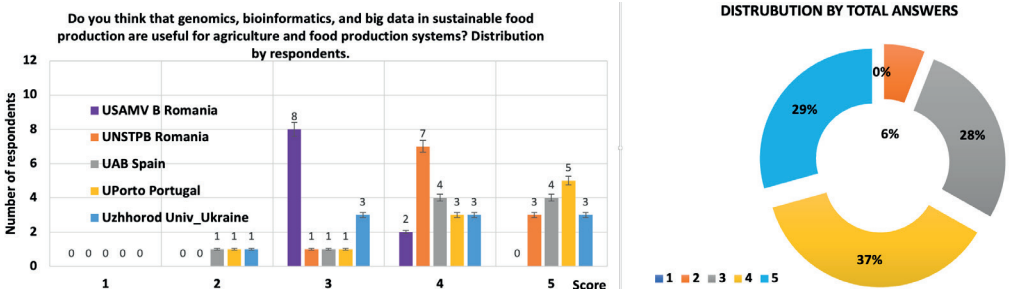


Figure 5. Assessment of the students' perceptions regarding the contribution of genomics, bioinformatics, and big data to sustainable food systems

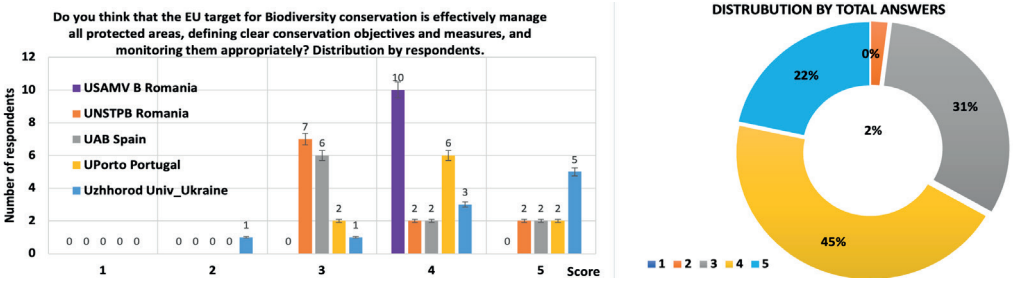


Figure 6. Assessment of the students' perceptions regarding EU Biodiversity conservation policies

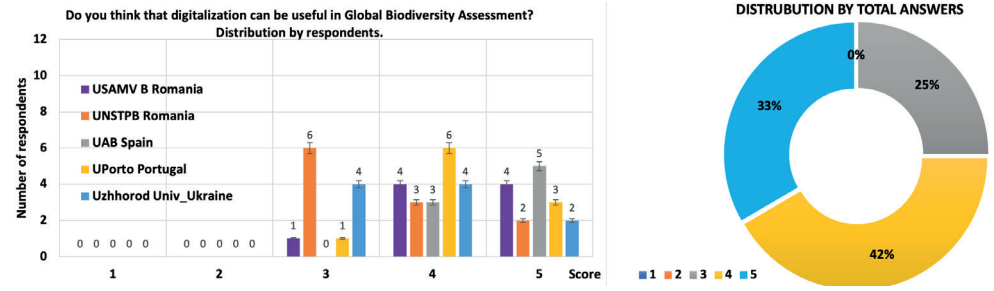


Figure 7. Assessment of the students' perceptions regarding the usefulness of digitalisation in global biodiversity assessment

Digital technologies enable large-scale ecological monitoring, improve data integration, and support evidence-based decision-making processes. Furthermore, advances in digital monitoring systems are considered essential for achieving the targets

established by the Kunming-Montreal Global Biodiversity Framework and for strengthening biodiversity governance at regional and global levels (Hughes & Grumbine, 2023).

Overall, the results indicate high levels of sustainability awareness and understanding among students from Romania, Spain, Portugal, and Ukraine, with limited inter-university variation and broadly consistent response patterns across cohorts.

A high level of environmental literacy among university students across Romania, Spain, Portugal, and Ukraine was obtained, particularly in relation to biodiversity conservation and the perceived role of digital technologies in ecological monitoring. This aligns with a broader shift in environmental education, which increasingly emphasizes systems thinking and the integration of technological competencies into sustainability-related curricula (Pauw et al., 2015; Reid, 2019).

A key finding is the strong endorsement (75%) of digitalisation in global biodiversity assessment. This reflects growing recognition of the role of emerging technologies such as artificial intelligence, remote sensing, geographic information systems (GIS), and big data analytics in transforming conservation science. These technologies enable continuous collection and integration of ecological data across spatial and temporal scales, improving biodiversity modelling, forecasting, and risk assessment (Radu et al., 2006; Dima et al., 2007; Pettorelli et al., 2014; Kissling et al., 2018; Jetz et al., 2019). Recent developments in digital Earth observation systems and AI-driven ecological monitoring further reinforce this transition toward data-intensive conservation paradigms (van der Plas et al., 2025; Miao et al., 2026). The expansion of global biodiversity platforms and digital infrastructure has also been identified as central to strengthening biodiversity governance and decision-making under rapid environmental change (Güntsch et al., 2025). The results are consistent with global scientific consensus that digital innovation is becoming indispensable for biodiversity governance. Similarly, the Kunming–Montreal Global Biodiversity Framework explicitly calls for strengthened monitoring systems, improved data accessibility, and the use of digital tools to support the implementation and evaluation of biodiversity targets. In this context, the positive student evaluations suggest an awareness of not only ecological challenges but also of the governance mechanisms required to address them. Furthermore, the limited variation across universities indicates a relatively homogeneous perception of sustainability and digitalisation in biodiversity contexts. This may reflect the increasing harmonisation of environmental science curricula across Europe, driven by the Bologna Process and the integration of sustainability competencies into higher education frameworks (Malmio & Liwång, 2023). Such consistency is important, as it suggests that future professionals across these countries may share a common conceptual foundation for addressing transboundary environmental challenges.

Overall, the data indicate a strong alignment between student perceptions and current scientific and policy directions in biodiversity conservation.

However, while optimism toward digital tools is justified, the literature also highlights persistent challenges, including unequal access to technology, data governance issues, and the need for interdisciplinary capacity building to ensure effective implementation (Pettorelli et al., 2014; Hughes & Grumbine, 2023).

CONCLUSIONS

The survey revealed a generally high level of awareness among students regarding digitalization, biodiversity conservation, sustainable agriculture, and circular economy principles.

Digital technologies were widely recognized as valuable tools for biodiversity assessment and environmental monitoring, reflecting current trends in digital transformation and ecological management. Students demonstrated a good understanding of the relationship between the Common Agricultural Policy, the European Green Deal, and the Farm to Fork and Biodiversity strategies, although some neutral responses suggest opportunities for further educational interventions.

Genomics, bioinformatics, and big data were perceived as important contributors to future

sustainable food production systems, indicating growing acceptance of advanced agricultural technologies.

Biodiversity conservation and protected area management received strong support, highlighting the perceived importance of effective environmental governance.

The circular economy obtained the highest level of agreement among respondents, emphasizing the increasing relevance of resource efficiency and waste valorization concepts within sustainability education.

Collectively, these findings indicate that students from the participating European universities possess substantial sustainability literacy and recognize the importance of technological innovation and policy integration in addressing global environmental challenges.

ACKNOWLEDGEMENTS

This research work was carried out with the support of the University of Agronomic Science and Veterinary Medicine of Bucharest, Romania, and was financed by the Project number: 2023-1-RO01-KA220-HED-000154433 entitled: Gender, Digitalization, Green: Ensuring a Sustainable Future for all in Europe.

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