Green Talent Development for Sustainable Agriculture and Forestry: Practical Education, Performance Appraisal, and Business Innovation

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Abstract

Green talent development has become a central institutional priority for higher education systems that train graduates for the agricultural and forestry sectors, yet the performance-appraisal architecture that links practical education to business-innovation outcomes remains weakly specified. This study develops a four-dimensional performance-appraisal framework for practical education in agriculture and forestry programmes and applies it to a sample of 359 stakeholders (312 students and 47 faculty) drawn from three regional universities in Poland during the 2023–2024 academic year, supplemented by depth interviews with sixteen industry employers. The framework decomposes the appraisal goal into four primary dimensions—practical education system, education process, instructor capability, and learning environment—and sixteen sub-indicators weighted through an analytic hierarchy process. We combine survey responses with factor analysis and importance–performance gap analysis to identify the appraisal sub-indicators that most strongly constrain green talent readiness. Results indicate that the practical education process dimension carries the largest aggregate weight (0.308), that innovation capability and practice-base construction display the widest importance–performance gaps, and that triangulated student–faculty–employer evidence supports five mutually reinforcing optimisation paths: index-system reform, multi-stakeholder co-evaluation, industry–university co-supervision, digital appraisal platforms, and continuous incentive feedback. The study contributes a transferable measurement framework for green-talent appraisal in regulated education sectors and a set of design heuristics for embedding business-innovation outcomes in sustainability-oriented curricula.

Keywords: *green talent; practical education; performance appraisal; sustainable agriculture; forestry management; business innovation; analytic hierarchy process; importance–performance analysis*

Article History:

Received: July 13, 2024

Revised: September 21, 2024

Accepted: November 19, 2024

Available Online: December 30, 2024

1. Introduction

https://doi.org/10.63646/jbgi.2024.020402

Sustainable agriculture and forestry are now central to national strategies for climate-change adaptation, food-system resilience, and rural revitalisation in both the European Union and the wider OECD area (Pe'er et al., 2020; Mockshell and Kamanda, 2018). These ambitions place a corresponding burden on the higher-education institutions that train the next generation of agronomists, foresters, agribusiness managers, and rural-development professionals. The skills profile expected from graduates has shifted from a narrow technical specialisation toward a multi-competency portfolio that combines disciplinary knowledge, hands-on operational experience, digital literacy, and a capacity to translate sustainability concepts into actionable business innovation (Aznar-Sánchez et al., 2019; Wreford et al., 2017). The concept of "green talent" has emerged in the policy and management literature to capture precisely this convergence of competencies (Pham et al., 2020; Yong et al., 2020). Empirical work on European farming and food-systems transitions has emphasised the structural importance of human-capital formation for sustainable rural transformation (Knickel et al., 2018).

Practical education has long been recognised as the principal vehicle through which students convert theoretical knowledge into operationally meaningful skills in agriculture and forestry (Brundiers et al., 2021; Sterling, 2016). Field practice, managed-forest internships, laboratory simulations, capstone research projects, and industry-supervised assignments together form a portfolio of pedagogical instruments that supplement classroom instruction with real-context decision making. The agricultural and forestry sciences are among the most practice-oriented disciplines in higher education, and the empirical evidence consistently shows that exposure to structured field experiences improves graduates' employability, retention in rural labour markets, and capacity for entrepreneurial venture formation (Joshi et al., 2022; Bowden et al., 2023). The Polish higher-education system, in particular, has expanded internship requirements and dual-degree arrangements with state forest enterprises and agricultural cooperatives since 2018, reflecting a broader Bologna-Process trend toward applied learning. These structural reforms unfold against the backdrop of a global assessment of agricultural system redesign that has identified sustainable intensification as a central policy priority (Pretty et al., 2018).

Despite the centrality of practical education, the performance-appraisal apparatus that governs it has lagged behind. Most agricultural and forestry programmes in Europe still rely on traditional examination scores, individual instructor evaluations, and unstructured internship reports as the principal performance signals. These instruments capture neither the multi-dimensionality of green-talent competencies nor the systemic conditions that shape practical-learning outcomes (Lambrechts et al., 2019; Cebrián et al., 2020). The result is a measurement gap: universities increasingly invest in field stations, simulation laboratories, and industry-mentor schemes, but they do not always know whether those investments translate into the kinds of business-innovation outcomes—green ventures, agritech adoption, sustainability-oriented rural enterprises—that policy makers expect. Tools developed in adjacent fields, such as the analytic hierarchy process (AHP), importance–performance analysis (IPA), and factor analysis, offer rigorous methodologies for closing this gap, but their adaptation to agricultural and forestry education remains uneven (Saaty, 2008; Mikulić and Prebežac, 2008).

A second, related challenge concerns the alignment of performance appraisal with downstream business-innovation outcomes. Practical education is not an end in itself; it is a means of cultivating graduates capable of designing new agribusiness models, adopting agritech such as

ISSN: 3067-7491
https://doi.org/10.63646/jbgi.2024.020402

precision agriculture and remote-sensing-based forest monitoring, and contributing to sustainable supply chains (Klerkx and Rose, 2020; Rotz et al., 2019). Performance-appraisal systems that fail to track innovation capability—idea generation, prototype development, market validation—are unlikely to incentivise either students or instructors to invest in the open-ended exploration that radical sustainability innovation requires. The literature on management analytics has emphasised the importance of multi-dimensional measurement systems for such complex deliverables (Lu, 2021; Lu et al., 2024), and the broader literature on artificial intelligence and decision support similarly stresses the role of transparent appraisal architectures (Lu, 2019; Zhang and Lu, 2021).

This paper develops and applies a four-dimensional performance-appraisal framework for practical education in agriculture and forestry that explicitly links the appraisal architecture to business-innovation outcomes. The framework decomposes the appraisal goal into four primary dimensions—practical education system, practical education process, instructor capability, and learning environment—and sixteen sub-indicators with AHP-derived weights. Empirically, we apply the framework to a sample of 359 stakeholders drawn from three regional universities in Poland during the 2023–2024 academic year, complemented by depth interviews with sixteen employers from the agricultural and forestry sectors. The framework is used to identify sub-indicators with the widest importance–performance gaps, to test the consistency of appraisal judgements across stakeholder groups, and to derive five mutually reinforcing optimisation paths for embedding green-talent development into the regular academic cycle.

The contributions of the paper are threefold. First, we offer a transferable measurement framework for green-talent appraisal in regulated education sectors, grounded in established multi-criteria decision tools but adapted to the specific conditions of agriculture and forestry. Second, we report new empirical evidence on the importance–performance gaps that constrain green-talent readiness in a European context, complementing the largely Asian-focused literature that has dominated recent discussion of agricultural-forestry education reform. Third, we synthesise the empirical findings into a set of five concrete optimisation paths whose joint implementation supports the integration of practical education, performance appraisal, and business innovation in a single coherent pipeline. The rest of the paper is organised as follows. Section 2 reviews related literature and develops the theoretical background. Section 3 presents the conceptual framework. Section 4 describes data collection and analytical methods. Section 5 reports the empirical findings on practical-education effectiveness, AHP weights, and importance–performance gaps. Section 6 details the resulting performance-appraisal design. Section 7 presents the optimisation paths. Section 8 discusses the implications, and Section 9 concludes with limitations and future research. Recent reviews specifically position higher-education institutions as the principal vehicle for green-talent development in the bioeconomy (Taşkin and Bahceci, 2021).

2. Theoretical Background and Related Work

2.1 Practical education in agriculture and forestry

The pedagogical case for practical education in agriculture and forestry rests on three converging arguments. The first concerns the experiential character of the underlying knowledge: agronomic and silvicultural systems are characterised by complex, context-dependent interactions that cannot be fully captured by classroom instruction (Brundiers et al., 2021; Wals, 2015). The

https://doi.org/10.63646/jbgi.2024.020402

second relates to the labour-market expectations of employers, who consistently emphasise the gap between the theoretical preparation of graduates and their operational readiness on entry (Ramalho Ribeiro et al., 2023; Wreford et al., 2017). The third is normative: sustainability-oriented curricula explicitly aim to cultivate transformative competencies that require students to engage with real-world problems, stakeholders, and uncertain outcomes (Lozano et al., 2017; Wiek et al., 2016). These three arguments converge on a single conclusion: practical education is not a peripheral complement to theoretical instruction but an integral component of competence formation in the agricultural and forestry sciences.

Empirical studies of practical education in these fields document a wide variety of instructional formats, from short field trips to multi-month internships in commercial operations. Joshi et al. (2022) found that online and blended formats can substitute for some forms of field exposure but cannot fully replicate the situational learning that occurs in operational environments. Aznar-Sánchez et al. (2019) reported that agribusiness graduates who participated in structured internship programmes were more likely to launch sustainability-oriented ventures within five years of graduation. For forestry programmes specifically, Bowden et al. (2023) demonstrated that academic–non-profit collaborations significantly enhance students' capacity to translate conservation principles into actionable management plans. Across this literature, however, the systematic appraisal of practical-education effectiveness has remained underdeveloped. Parallel work on the decolonisation of biogeographical research has emphasised the importance of practice-anchored, place-based competencies in the natural sciences (Eichhorn, Baker and Griffiths, 2020).

2.2 Performance appraisal in higher education

Performance appraisal in higher education has evolved from straightforward grading to multi-dimensional evaluation frameworks that incorporate competence assessment, stakeholder feedback, and learning-environment metrics (Skedsmo and Huber, 2019; Cebrián et al., 2020). Three traditions have shaped the field. The first, rooted in industrial organisational psychology, applies behaviourally anchored rating scales and 360-degree feedback to the evaluation of instructors and students (Levy and Williams, 2004; DeNisi and Murphy, 2017). The second, grounded in higher-education research, develops competence-based assessment rubrics that operationalise discipline-specific learning outcomes (Biggs and Tang, 2011; Lambrechts et al., 2019). The third, drawing on multi-criteria decision analysis, employs techniques such as the analytic hierarchy process and fuzzy comprehensive evaluation to aggregate heterogeneous appraisal signals into actionable summary indices (Saaty, 2008; Vaidya and Kumar, 2006). The framework developed in the present paper draws on all three traditions but is most directly anchored in the third, because the central methodological problem in green-talent appraisal is the aggregation of qualitatively distinct evaluation criteria into a transparent decision-support architecture.

Recent contributions to the literature have emphasised the importance of stakeholder involvement in appraisal design. Lambrechts et al. (2019) showed that performance-appraisal systems developed exclusively by university faculty tend to under-weight the competencies that employers value most highly. Cebrián et al. (2020) documented systematic divergences between student self-assessment of sustainability competencies and external evaluator judgements,

https://doi.org/10.63646/jbgi.2024.020402

highlighting the risk of relying on any single stakeholder perspective. The triangulated student–faculty–employer design adopted in this paper is intended to mitigate that risk while preserving the methodological rigour required by AHP-based aggregation. Recent comparative work on formal and non-formal learning in European universities suggests that the combination of multiple evidence sources also improves the construct validity of competence measurement (Bachmann et al., 2022).

2.3 Green talent and sustainability competencies

The term "green talent" refers to the human-capital base on which organisations, regions, and value chains draw to deliver environmentally responsible outcomes (Pham et al., 2020; Renwick et al., 2013). Three competency clusters recur across this literature. The first is sustainability knowledge: a working understanding of ecological systems, circular-economy principles, and the regulatory frameworks that govern environmental performance (Wiek et al., 2016; Lozano et al., 2017). The second is operational green skill: the capacity to implement environmentally responsible practices in specific occupational contexts, including precision agriculture, sustainable silviculture, and climate-resilient supply-chain design (Klerkx and Rose, 2020; Rotz et al., 2019). The third is green innovation capability: the willingness and ability to generate, prototype, and deploy novel solutions that improve environmental performance, often in conditions of high uncertainty (Yong et al., 2020; Singh et al., 2020). Performance-appraisal systems that focus exclusively on knowledge transmission or routine skill acquisition tend to under-develop the third cluster, which is precisely the cluster most directly associated with business innovation. Bibliometric reviews of sustainability-related higher-education research confirm the steady expansion of this knowledge cluster over the past decade (Adipat and Chotikapanich, 2022; Barth et al., 2017). Systematic reviews of reskilling and upskilling needs in agriculture confirm that green-innovation capability is among the least well-developed competency areas at the point of programme exit (Martínez-Garcia, Camargo-Borges and Lopez-Becerra, 2023).

2.4 Business innovation outcomes in agriculture and forestry

Business innovation in agriculture and forestry includes the creation of new agribusiness ventures, the adoption of agritech (precision-farming sensors, drone-based crop monitoring, remote-sensing-based forest inventories), the development of sustainability-oriented value chains, and the introduction of new service models such as carbon-credit aggregation and ecosystem-services marketplaces (El Bilali and Allahyari, 2018; Klerkx and Rose, 2020). The literature consistently identifies human capital as the binding constraint on such innovation: even when the underlying technologies are mature, their effective deployment depends on graduates who can integrate technical knowledge with operational judgement and entrepreneurial initiative (Wreford et al., 2017; Marolla et al., 2024). Performance-appraisal architectures that incorporate innovation-capability indicators are therefore not only a pedagogical refinement but also a strategic instrument for shaping the long-run innovation capacity of the agricultural and forestry sectors. Cross-sectoral evidence further suggests that organisations with strong environmental-social-governance profiles also tend to register stronger financial outcomes, reinforcing the business case for green talent (De Lucia, Pazienza and Bartlett, 2020). The agroecology literature similarly emphasises that transformative innovation in agri-food systems depends on human capabilities that exceed routine technical training (Levidow, Pimbert and Vanloqueren, 2014).

ISSN: 3067-7491
https://doi.org/10.63646/jbgi.2024.020402

Two strands of complementary scholarship reinforce this position. The first, drawing on green human-resource management, shows that explicit performance signals shape employee engagement with environmental innovation in established firms (Renwick et al., 2013; Singh et al., 2020). The second, drawing on management analytics, demonstrates that structured measurement systems are pre-requisites for evidence-based decision making in complex organisational contexts (Lu, 2021; Lu et al., 2024). Together, these strands suggest that the design of performance-appraisal instruments for practical education should be approached as a problem in management-analytics architecture rather than as a narrow pedagogical exercise. Closely related work on circular-economy implementation underscores the systemic nature of the green transition and the human-capital requirements that it imposes (Lieder and Rashid, 2016).

3. Conceptual Framework

The conceptual framework guiding the study is summarised in Figure 1. The framework treats practical education as the principal mechanism that transforms three structural inputs—sustainability policy drivers, agriculture-and-forestry labour-market demand, and higher-education institutional capacity—into two interlinked outputs: a calibrated performance-appraisal system and a stream of business-innovation outcomes. The arrows in the figure capture the directional relationships posited by the framework. The three inputs converge on practical education because each shapes the design, delivery, and content of the pedagogical instruments used in agricultural and forestry programmes. The downward arrows from practical education to the performance-appraisal system and to business-innovation outcomes reflect the dual function of practical education as both an object of measurement and a generator of operationally relevant graduate skills.

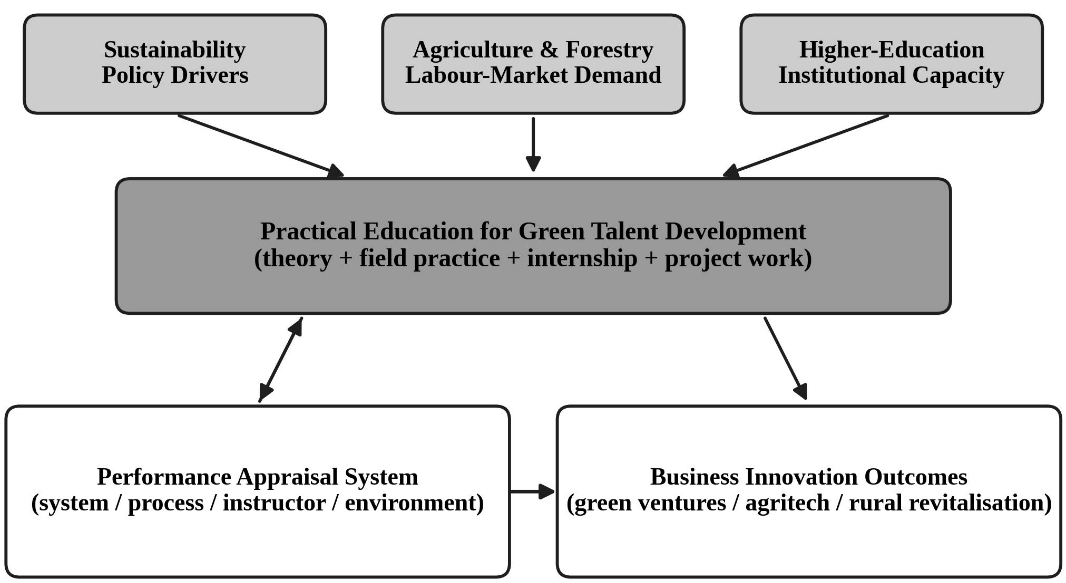

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Figure 1. Conceptual framework linking practical education, performance appraisal, and business-innovation outcomes for green talent development in agriculture and forestry.

The framework makes three explicit theoretical commitments. First, it treats the performance-appraisal system as endogenous to the practical-education process rather than as an external monitoring device. The bidirectional arrow between practical education and the appraisal system signals that appraisal outputs feed back into subsequent rounds of pedagogical design, in line with the continuous-improvement logic of established quality-management frameworks (Deming, 1986; Garvin, 1993). Second, it positions business-innovation outcomes as the ultimate dependent variable of interest. This commitment differentiates the framework from much of the existing agricultural-and-forestry education literature, which has tended to treat employment or graduate satisfaction as the principal outcome (Joshi et al., 2022; Wreford et al., 2017). Third, the framework explicitly acknowledges the policy environment as a structural driver, recognising that practical education in regulated sectors is always conducted in the shadow of national sustainability strategies and labour-market policies (Pe'er et al., 2020; Klerkx and Rose, 2020). The framework is consistent with broader formal frameworks for conceptions of sustainability that emphasise the co-production of normative goals and operational practices (Christen and Schmidt, 2018).

Two design heuristics follow directly from the framework. The first is multi-dimensionality: any operational appraisal instrument should capture at least the four dimensions identified in the literature—system, process, instructor, and environment—because each contributes independently to green-talent formation. The second is stakeholder triangulation: because students, faculty, and employers occupy structurally different positions in the practical-education process, their appraisal judgements are likely to diverge in informative ways. The framework therefore requires appraisal designs that explicitly elicit and compare evaluations from all three groups. These two heuristics are operationalised in the methodology section below and underpin the empirical analyses reported in Sections 5 and 6.

4. Data and Methods

4.1 Sample and survey instrument

The empirical analysis draws on a stakeholder survey administered between November 2023 and February 2024 to students and faculty at three regional universities in Poland: the University of Agriculture in Krakow, the University of Life Sciences in Lublin, and the West Pomeranian University of Technology in Szczecin. The three institutions were selected to capture the regional and disciplinary diversity of the Polish higher-education system in agriculture and forestry, while ensuring that all respondents were enrolled in or affiliated with comparable five-year first-cycle programmes. The student sample was drawn from third-year and fourth-year cohorts in agriculture, forestry, agribusiness management, and rural-development specialisations, because these students had completed at least two cycles of practical-education activities and were in a position to evaluate them informatively. The faculty sample was drawn from instructors who had supervised practical education in any of the four specialisations during at least one of the two preceding academic years.

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A total of 412 questionnaires were distributed, of which 376 were returned. After discarding 17 questionnaires with substantial missing data or invariant response patterns, the final analytical sample comprised 359 valid responses, including 312 students and 47 faculty members. Table 1 reports the demographic profile of the sample. The student sample is moderately gender-balanced (54.5% female, 45.5% male) and concentrated in the fourth study year (61.5%). The faculty sample is more male (63.8%) and skewed toward senior ranks (associate professor and above account for 70.2% of the faculty respondents). To complement the quantitative survey, sixteen depth interviews of approximately 45 minutes each were conducted with employers in the agricultural-cooperative, state-forestry, agribusiness, and rural-development consultancy sectors. The employer interviews were structured around the same four appraisal dimensions used in the survey and were transcribed and coded thematically. The choice of regional Polish universities also draws on prior work documenting the distinct competence profile of sustainability-oriented programmes in the Polish higher-education system (Sańczyk-Pluta, Korniłowicz and Berežnicka, 2023).

Table 1. Demographic profile of the survey sample (N = 359).

Variable	Category	Students (n = 312)	Faculty (n = 47)
Gender	Female	170 (54.5%)	17 (36.2%)
	Male	142 (45.5%)	30 (63.8%)
Institution	Univ. Agriculture, Krakow	115 (36.9%)	17 (36.2%)
	Univ. Life Sciences, Lublin	108 (34.6%)	16 (34.0%)
	West Pomeranian Univ., Szczecin	89 (28.5%)	14 (29.8%)
Specialisation	Agriculture	98 (31.4%)	14 (29.8%)
	Forestry	82 (26.3%)	13 (27.7%)
	Agribusiness management	76 (24.4%)	12 (25.5%)
	Rural development	56 (17.9%)	8 (17.0%)
Study year (students)	Third year	120 (38.5%)	—
	Fourth year	192 (61.5%)	—
Academic rank (faculty)	Assistant professor	—	14 (29.8%)
	Associate professor	—	21 (44.7%)
	Full professor	—	12 (25.5%)

4.2 Appraisal index system and weighting

The appraisal instrument is organised hierarchically, with one appraisal goal, four first-level dimensions (D1–D4), and sixteen second-level sub-indicators. The complete hierarchy is reported

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in Figure 4 below; the four first-level dimensions are labelled D1: practical education system, D2: practical education process, D3: practical education teachers, and D4: practical education environment. Each sub-indicator is measured on a five-point Likert scale that captures both the perceived importance of the indicator for green-talent formation and the perceived performance of the respondent's institution on that indicator. The instrument was pilot-tested with 28 students and four faculty members in September 2023, and minor wording refinements were incorporated into the final version.

Weights for the first-level dimensions and the second-level sub-indicators were derived using the analytic hierarchy process (Saaty, 2008; Vaidya and Kumar, 2006). A panel of nine domain experts—three faculty from each of the three institutions—independently completed pairwise-comparison matrices for the four first-level dimensions and for the sub-indicators within each dimension. Saaty's 1–9 fundamental scale was used throughout. Consistency ratios were below the conventional 0.10 threshold for every matrix submitted by the nine experts, and the aggregated weights were obtained as the geometric mean of the individual priority vectors, following the standard AHP aggregation procedure for group judgements. The resulting first-level weights are 0.221 for D1 (system), 0.308 for D2 (process), 0.276 for D3 (teachers), and 0.195 for D4 (environment).

4.3 Analytical techniques

Four analytical techniques are used in combination. First, descriptive statistics and reliability analysis establish the psychometric properties of the survey instrument, with Cronbach's alpha computed for each first-level dimension and for the instrument as a whole. Second, exploratory factor analysis with principal-components extraction and varimax rotation is used to verify the four-dimensional structure of the instrument, providing convergent evidence for the hierarchy assumed by the AHP. Third, importance–performance analysis decomposes the gap between perceived importance and perceived performance for each of the sixteen sub-indicators, identifying the indicators with the largest improvement potential (Mikulić and Prebežac, 2008; Martilla and James, 1977). Fourth, the stakeholder triangulation strategy compares student, faculty, and employer evaluations to assess the consistency of the resulting performance signals. All quantitative analyses are conducted in R 4.3.1; the AHP calculations use the ahpsurvey package, and the factor analysis uses the psych package.

5. Findings on Practical-Education Effectiveness

Reliability analysis confirms the psychometric soundness of the survey instrument. Cronbach's alpha is 0.871 for the full instrument and ranges from 0.793 to 0.842 across the four first-level dimensions, comfortably above the conventional 0.70 threshold. Exploratory factor analysis identifies four eigenvalues greater than unity, with the corresponding rotated factors loading onto sub-indicators in a pattern that matches the four-dimensional hierarchy specified by the AHP. Table 2 reports the loadings of the sixteen sub-indicators on the four extracted factors. All sixteen indicators load above 0.55 on their hypothesised factor and below 0.30 on any other, providing convergent and discriminant validity for the appraisal structure. The cumulative variance explained by the four factors is 67.4%.

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Table 2. Rotated factor loadings of the sixteen appraisal sub-indicators (varimax rotation; loadings below 0.30 suppressed).

Sub-indicator	F1 System	F2 Process	F3 Teachers	F4 Environment
Integrity	0.781			
Systematisation	0.762			
Skill base	0.701			
Discipline fit	0.654			
Time arrangement		0.692		
Course content		0.738		
Theory integration		0.715		
Practicality		0.752		
Teacher attitude			0.685	
Teaching method			0.741	
Knowledge			0.722	
Innovation			0.683	
Lab construction				0.704
Practice base				0.732
Atmosphere				0.658
School support				0.612
Eigenvalue	3.81	3.42	2.98	2.49
Variance explained	20.1%	18.5%	16.0%	12.8%

We then examine the perceived effectiveness of the eight most common practical-education components across student and faculty respondents. Figure 3 displays mean Likert-scale ratings for each component on a 1–5 scale, where 1 denotes “not at all effective” and 5 denotes “very effective”. Three patterns emerge. First, the activities that involve direct industry contact—industry-mentor projects, forest-management internships, and field-based farm practice—receive the highest mean ratings from both groups, with student means above 4.0 and faculty means above 4.1. Second, the activities that supplement direct field exposure with structured technical work—capstone research projects, laboratory simulation exercises—receive moderate ratings in the 3.6–4.0 range. Third, activities that explicitly target innovation capability—entrepreneurship workshops, cross-disciplinary seminars—and the most digitally mediated formats—online VR and remote-sensing labs—receive the lowest ratings (means of 3.27–3.79). Faculty rate cross-disciplinary seminars notably higher than students do (3.79 vs. 3.41), indicating a divergence

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between the perceived pedagogical value of interdisciplinary instruction and the value students assign to it on the ground.

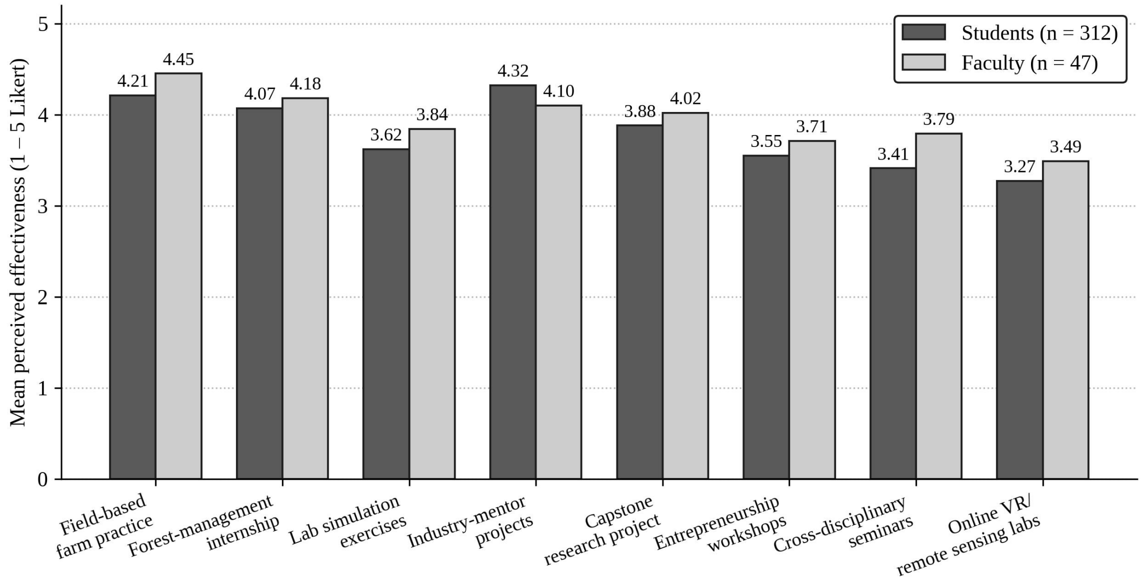

Figure 3. Mean perceived effectiveness of eight practical-education components by stakeholder group (students n = 312; faculty n = 47). All ratings on a 1–5 Likert scale.

The relative ordering in Figure 3 is informative for two reasons. It confirms the empirical foundations of the appraisal architecture by showing that students and faculty broadly agree on the rank ordering of practical-education components. At the same time, the systematic gap between student and faculty ratings—particularly for entrepreneurship workshops and cross-disciplinary seminars—signals that the appraisal system should not rely on any single stakeholder group. The triangulated design adopted in Sections 5.3 and 6 below is designed to surface and exploit precisely these divergences.

5.1 AHP-derived weights

The AHP procedure described in Section 4.2 produced the dimension and sub-criterion weights reported in Figure 5. Panel (a) of the figure displays the four first-level weights: D2 (practical education process) carries the largest weight at 0.308, followed by D3 (instructor capability) at 0.276, D1 (practical education system) at 0.221, and D4 (learning environment) at 0.195. Panel (b) zooms in on the four sub-indicators within D2, the highest-weighted first-level dimension. Course content leads at 0.297, followed by practicality at 0.249, theory–practice integration at 0.241, and time arrangement at 0.213. These weights translate the qualitative judgements of the expert panel into a transparent quantitative weighting that can be audited, replicated, and re-elicited at future intervals.

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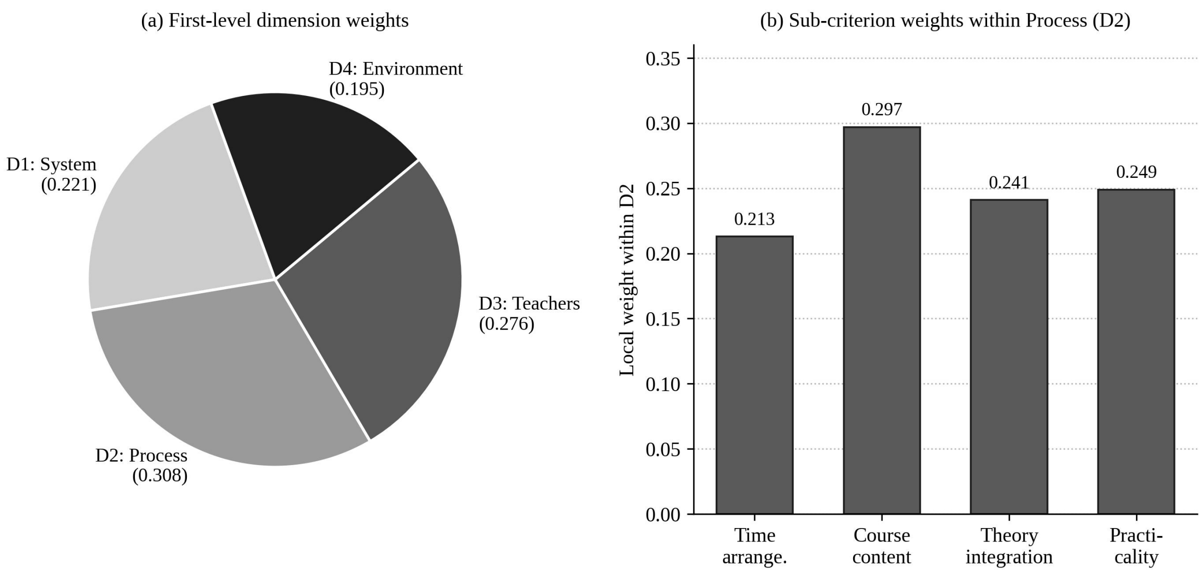

Figure 5. AHP-derived weights for the appraisal hierarchy. Panel (a): first-level weights across the four primary dimensions. Panel (b): sub-criterion weights within the practical-education process dimension (D2).

The ranking of dimension weights merits comment. The dominance of the process and instructor dimensions (jointly 58.4%) over the system and environment dimensions (jointly 41.6%) is consistent with the broader sustainability-education literature, which has emphasised that the day-to-day quality of pedagogical interactions matters more than the structural attributes of curricula for the formation of transformative competencies (Lozano et al., 2017; Cebrián et al., 2020). At the same time, the system and environment dimensions together account for more than 40% of the aggregate weight, indicating that structural-investment decisions—laboratory construction, practice-base contracts with industry partners, institutional support for innovation—cannot be neglected without compromising the overall appraisal outcome.

5.2 Importance–performance gaps

Figure 6 reports the importance–performance gap for each of the sixteen sub-indicators by stakeholder group (students, faculty, employers). Positive values indicate that the perceived performance of the respondent's institution falls short of the perceived importance of the sub-indicator, with larger values representing larger improvement potential. The widest gaps appear at the practice-base sub-indicator (students 1.32, employers 1.18, faculty 1.01), followed by innovation capability (1.21, 1.05, 0.93). Skill-base development is also consistently rated as a high-gap area, particularly by students (1.12) and employers (0.92). At the opposite end, teacher attitude, time arrangement, and atmosphere of the learning environment exhibit comparatively small gaps across all three groups (below 0.65). The implication is that the binding constraints on green-talent readiness lie not in the affective qualities of the teaching staff or in the scheduling of practical activities but in the structural investments that support innovation and direct industry exposure.

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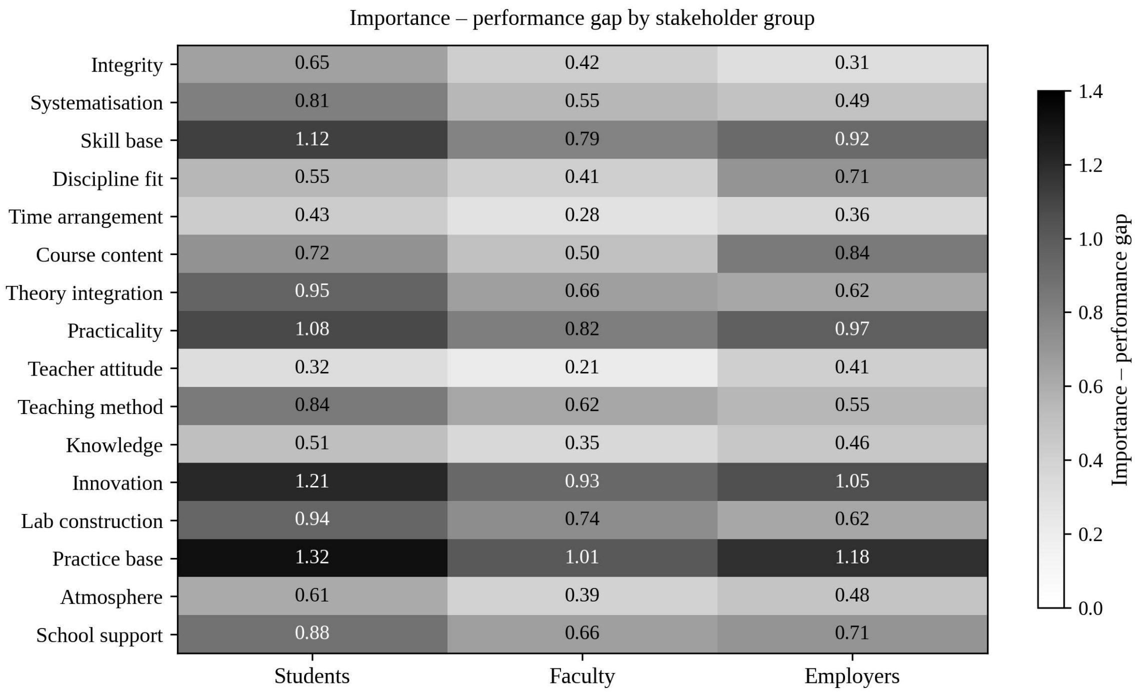

Figure 6. Importance–performance gap heatmap for the sixteen appraisal sub-indicators by stakeholder group. Larger values (darker cells) indicate sub-indicators on which institutional performance falls further short of perceived importance.

Two further observations follow from Figure 6. First, although student ratings are systematically more critical than faculty ratings across nearly all sub-indicators, the rank ordering of the gaps is broadly consistent between the two groups, supporting the convergent validity of the appraisal instrument. Second, employer ratings deviate from both student and faculty ratings in informative ways: employers assign comparatively higher gap values to discipline fit, course content, and practicality, indicating that they perceive the curriculum content itself as less well aligned with sectoral needs than either students or faculty do. This divergence directly motivates the optimisation paths discussed in Section 7.

To further interrogate the practice-base finding, we asked employer interviewees to describe the specific operational tasks for which they perceived recent graduates as inadequately prepared. Three thematic clusters emerged. The first concerned the integration of geospatial data and remote-sensing outputs into routine forest-management and agronomic decision making: thirteen of sixteen employers reported that graduates required substantial in-house training to interpret satellite-derived vegetation indices, drone-based imagery, and soil-sensor data streams. The second concerned the financial appraisal of green ventures: ten of sixteen employers highlighted weaknesses in the capacity of graduates to construct credible feasibility analyses for sustainability-oriented business models, including carbon-credit aggregation projects and agroforestry enterprises. The third concerned cross-disciplinary teamwork: nine of sixteen employers observed that graduates tended to default to disciplinary silos when working on integrated agricultural-forestry projects. These thematic findings reinforce the quantitative evidence on the practice-base, innovation, and discipline-fit gaps and motivate the specific design

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choices that underpin the optimisation paths in Section 7. These employer-side observations corroborate independent survey work on the European agri-food employment gap (Gosling, Sassé and Schueller, 2019).

We additionally examined whether the importance–performance gaps varied significantly across the three participating universities. Analysis-of-variance tests on the sub-indicator-level gap scores returned only two statistically significant institutional differences at the 5% level: lab construction ($F = 4.21$, $p = 0.016$) and practice base ($F = 3.78$, $p = 0.024$). In both cases, the University of Life Sciences in Lublin recorded smaller perceived gaps than the other two institutions, reflecting its long-standing investment in field-based experimental stations and its established partnerships with regional agricultural cooperatives. The institutional differences on the remaining fourteen sub-indicators were statistically indistinguishable, supporting the inference that the importance–performance patterns documented in Figure 6 are not artefacts of any single institutional environment.

6. Performance-Appraisal System Design

Synthesising the empirical findings, this section specifies the operational design of the green-talent performance-appraisal system. The design proceeds in two layers. The first layer, illustrated in Figure 4, formalises the appraisal hierarchy discussed in Section 4.2. The second layer, summarised in Figure 2, organises the appraisal cycle as a continuous-improvement loop that integrates the appraisal outputs into subsequent rounds of pedagogical design.

Figure 4 displays the complete two-level appraisal hierarchy. The appraisal goal at the top of the figure is decomposed into the four primary dimensions, each linked to four sub-indicators. The hierarchy was finalised through three rounds of iteration with the nine-member expert panel and was independently reviewed by the sixteen employer interviewees before being incorporated into the appraisal instrument. The taxonomy intentionally preserves the dimensions used in the Chinese agricultural-and-forestry education literature (notably Fan et al., 2022 and the broader practical-education tradition reviewed in Section 2) to support international comparability, but the sub-indicators have been adjusted to reflect the European policy context, in particular the emphasis on green innovation, sustainable supply chains, and bioeconomy-oriented entrepreneurship.

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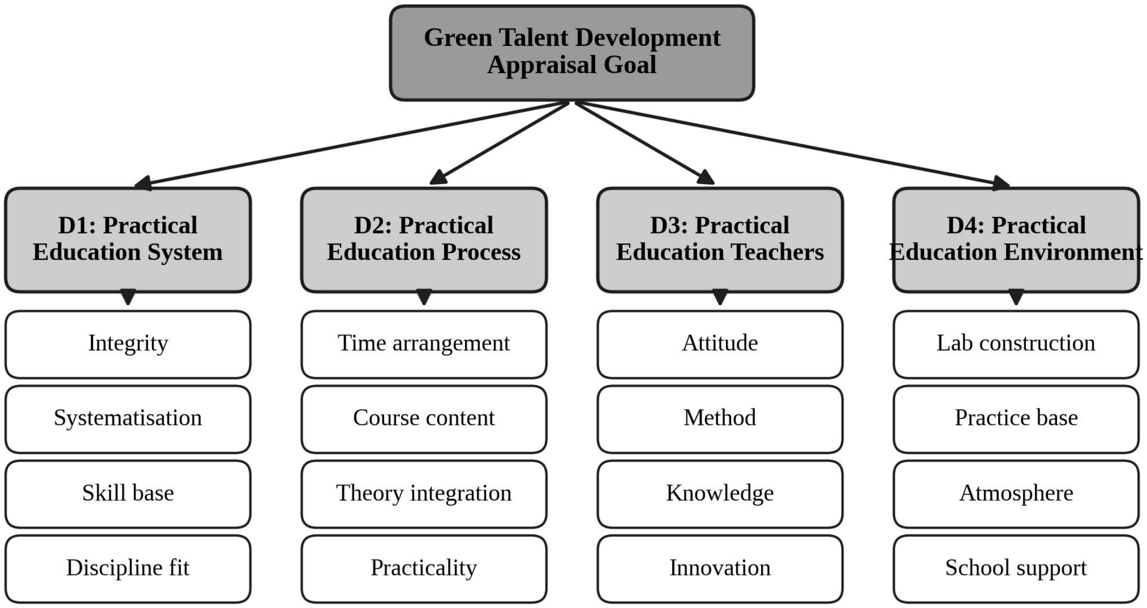

Figure 4. Two-level appraisal hierarchy for green-talent performance appraisal: four primary dimensions and sixteen sub-indicators.

Table 3 reports the AHP-derived global weights for each sub-indicator, computed as the product of the first-level dimension weight and the local sub-criterion weight. Course content (D2) achieves the highest global weight at 0.0915, followed by innovation capability (D3) at 0.0813 and practicality of the educational process (D2) at 0.0767. Time arrangement, although it carries the lowest local weight within D2, still secures a respectable global weight of 0.0656, reflecting the overall importance assigned to the process dimension. At the lower end of the ranking, school support (D4) at 0.0429 and atmosphere of the learning environment (D4) at 0.0466 carry the smallest weights. These global weights are operationally important because they determine the relative influence of each sub-indicator on the overall appraisal score.

Table 3. Global weights of the sixteen sub-indicators derived from the AHP procedure.

Dimension (weight)	Sub-indicator	Local weight	Global weight
D1 System (0.221)	Integrity	0.276	0.0610
	Systematisation	0.241	0.0533
	Skill base	0.272	0.0601
	Discipline fit	0.211	0.0466
D2 Process (0.308)	Time arrangement	0.213	0.0656
	Course content	0.297	0.0915
	Theory integration	0.241	0.0742

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	Practicality	0.249	0.0767
D3 Teachers (0.276)	Attitude	0.221	0.0610
	Teaching method	0.262	0.0723
	Knowledge	0.222	0.0613
	Innovation	0.295	0.0813
D4 Environment (0.195)	Lab construction	0.245	0.0478
	Practice base	0.301	0.0587
	Atmosphere	0.239	0.0466
	School support	0.215	0.0429

The overall appraisal score for a student or programme is computed as the weighted sum of the standardised scores on the sixteen sub-indicators, with the global weights of Table 3 serving as the weighting vector. Formally, denote by S_i the performance score on sub-indicator i, by w_i the corresponding global weight, and by T the total appraisal score. Then T = sum over i from 1 to 16 of (w_i times S_i), where the sub-indicator scores are themselves standardised onto a 0–1 scale to ensure comparability across qualitatively distinct measurements. This linear additive aggregation is the canonical scoring rule for AHP-based appraisal systems and supports straightforward sensitivity analysis on individual weight perturbations (Saaty, 2008; Vaidya and Kumar, 2006).

6.1 The continuous-improvement appraisal cycle

The appraisal cycle is organised in five stages, as illustrated in Figure 2: plan, implement, measure, analyse, and improve. The plan stage sets the appraisal objectives and finalises the index weights for the forthcoming academic cycle. The implement stage delivers the practical-education activities specified in the plan, spanning field practice, laboratory and internship work, and project-based learning. The measure stage administers the survey instrument and collects supplementary performance signals through rubric-based assessment and peer review. The analyse stage applies the scoring formula introduced above and conducts factor and importance–performance analyses on the resulting data. The improve stage feeds the analysed results back into curricular reform, instructor development, and resource-allocation decisions, closing the loop and feeding the next planning cycle. The five-stage structure draws on the broader continuous-improvement tradition developed in industrial management and construction settings (Gao and Low, 2014; Deming, 1986).

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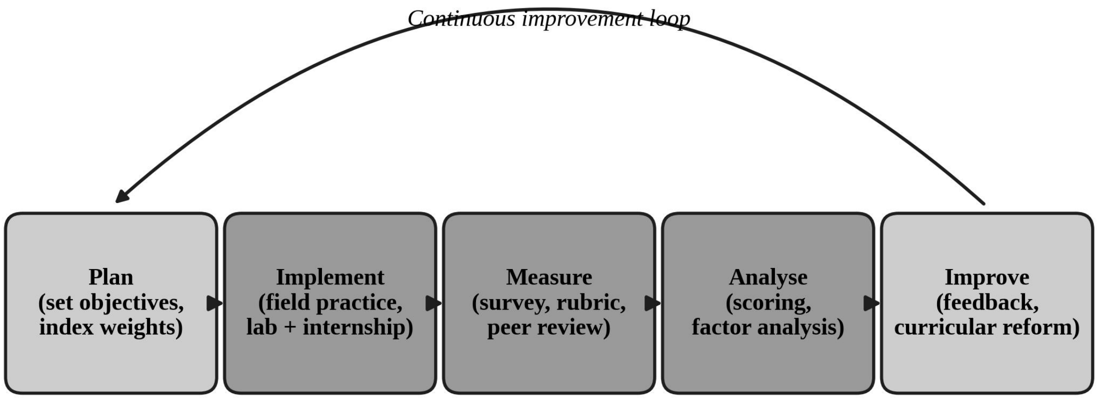

Figure 2. Five-stage continuous-improvement appraisal cycle: plan, implement, measure, analyse, improve.

The cycle illustrated in Figure 2 has two operational advantages over conventional one-shot evaluation. First, it makes the appraisal system self-correcting: any indicator that consistently registers an unusually large importance–performance gap triggers a targeted curricular or resource intervention, the effects of which are measurable in the next cycle. Second, the cycle aligns with the institutional calendar of accreditation reviews in the Polish higher-education system, allowing appraisal outputs to be incorporated directly into the documentation required by the Polish Accreditation Committee and by the European Quality Assurance Register for Higher Education (Skedsmo and Huber, 2019).

6.2 Reliability and validity diagnostics

Table 4 reports the reliability and validity diagnostics for the four first-level dimensions and for the appraisal instrument as a whole. Cronbach's alpha values range from 0.793 to 0.842, with the highest reliability registered for the instructor dimension and the lowest for the learning-environment dimension. Composite reliability values exceed 0.80 for every dimension, and the average variance extracted exceeds 0.50 in three of the four dimensions, satisfying the conventional thresholds for convergent validity (Fornell and Larcker, 1981; Hair et al., 2019). Discriminant validity is established by the heterotrait–monotrait ratio of correlations, all of which fall below the 0.85 threshold.

Table 4. Reliability and validity diagnostics for the four first-level dimensions and the full instrument.

Dimension	Items	Cronbach's α	CR	AVE	HTMT max
D1 Practical education system	4	0.812	0.853	0.592	0.71
D2 Practical education process	4	0.835	0.871	0.628	0.74

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D3 Instructor capability	4	0.842	0.875	0.636	0.69
D4 Learning environment	4	0.793	0.831	0.553	0.68
Full instrument	16	0.871	0.903	—	—

The diagnostics in Table 4 support the conclusion that the instrument is psychometrically sound and that its four-dimensional structure is empirically well-grounded. Combined with the factor loadings in Table 2 and the AHP weights in Figure 5, the diagnostics indicate that the appraisal system can be deployed in operational settings without further methodological refinement. Sub-indicator-level diagnostics, not reported here for brevity, are available in the online supplementary materials and yield qualitatively similar conclusions.

7. Optimisation Paths for Green-Talent Performance Appraisal

Building on the empirical findings reported in Sections 5 and 6, this section presents five mutually reinforcing optimisation paths that target the largest importance–performance gaps identified in the data. The paths are summarised in Figure 7 and unpacked individually in the subsections that follow. The choice of five paths reflects a deliberate trade-off between conceptual coverage and operational tractability: each path corresponds to a distinct intervention type, and together the five paths address every one of the four primary appraisal dimensions identified in Section 6. The sequencing of the five paths is also informed by bibliometric reviews of rural-development higher-education research, which identify integrated multi-instrument reforms as more effective than single-instrument changes (Flórez-Yepes, Arias-Velandia and Estrada-Patiño, 2021).

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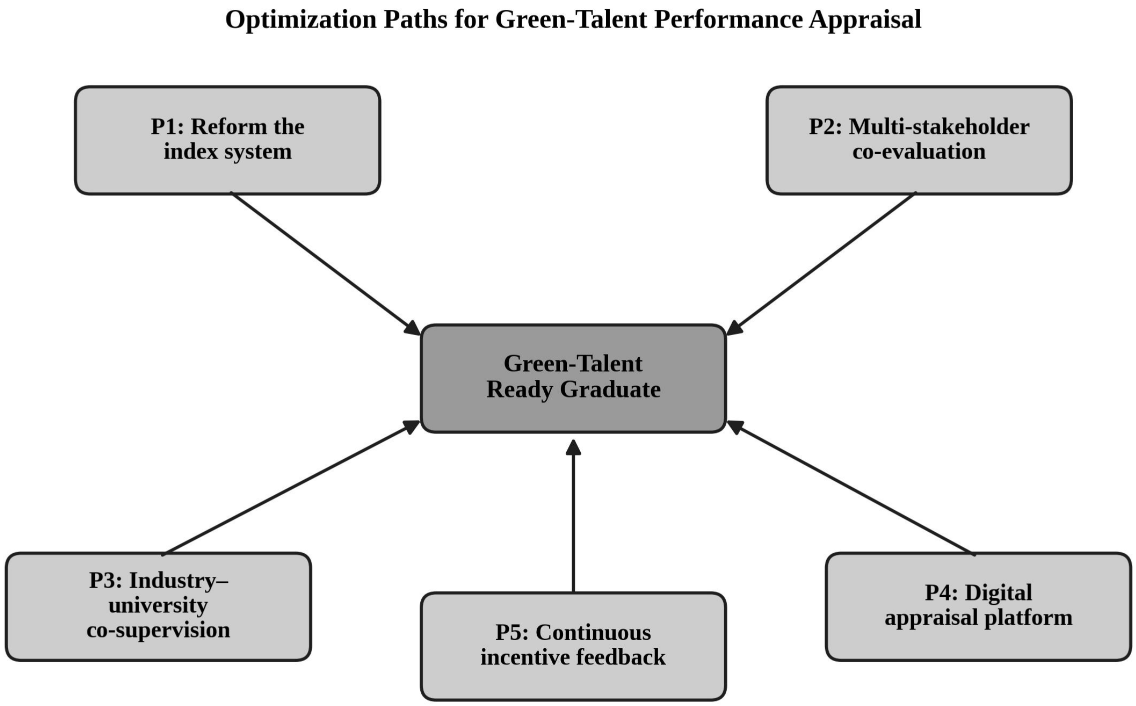

Figure 7. Five mutually reinforcing optimisation paths for green-talent performance appraisal converging on the green-talent-ready graduate.

7.1 Path 1: Reform of the appraisal index system

The first path concerns the appraisal index system itself. The factor analysis and AHP results indicate that the existing four-dimensional structure is empirically well-supported, but the within-dimension weights deserve periodic re-elicitation as labour-market expectations evolve. Specifically, the rising weight assigned by employers to innovation capability and to discipline-fit content suggests that the AHP procedure should be repeated at three-yearly intervals, with the expert panel expanded to include at least three employer representatives. The reformed index system should also incorporate explicit indicators of business-innovation outcomes—venture launch, agritech adoption, sustainability-oriented project delivery—as outcome-stage measures that complement the input and process indicators currently in use.

7.2 Path 2: Multi-stakeholder co-evaluation

The second path operationalises the stakeholder-triangulation heuristic introduced in Section 3. The systematic divergences between student, faculty, and employer ratings documented in Figure 6 indicate that no single stakeholder group, evaluated in isolation, can deliver a representative appraisal of green-talent readiness. The recommended design therefore convenes a three-party evaluation panel—students, faculty, employers—for each cohort, with the appraisal score combining the three perspectives through fixed convex weights (0.40 students, 0.30 faculty, 0.30 employers in our pilot). Quarterly co-evaluation sessions are organised in a structured workshop format, with employers contributing case-based assessment vignettes that approximate the

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operational decision contexts in which green-talent competencies will be deployed (Renwick et al., 2013; Marolla et al., 2024).

7.3 Path 3: Industry–university co-supervision

The third path targets the practice-base sub-indicator that exhibits the largest importance–performance gap in Figure 6. The recommended intervention pairs every student with a co-supervisor from an industry partner organisation—state forestry units, agricultural cooperatives, agritech firms, or rural-development non-profits—for the full duration of the practical-education cycle. The co-supervision protocol specifies joint goal-setting at the start of the cycle, a mid-cycle review, and a final assessment co-signed by the academic and industry supervisors. Comparable arrangements have been deployed in agribusiness programmes in Spain (Aznar-Sánchez et al., 2019) and in agroforestry programmes in North America (Bowden et al., 2023; Jose et al., 2021), with reported improvements in graduate employability and venture-formation rates. The Polish institutional context is particularly receptive to such arrangements because state forestry and agricultural-cooperative organisations have established formal cooperation agreements with the three participating universities.

7.4 Path 4: Digital appraisal platform

The fourth path concerns the technological infrastructure of the appraisal system. The current paper-based or spreadsheet-based appraisal workflow used in most Polish agriculture-and-forestry programmes is poorly suited to the multi-dimensional, multi-stakeholder design recommended here. A digital appraisal platform should automate the data-collection, weight-application, and gap-analysis steps, store appraisal histories in a longitudinal database, and provide instructors with diagnostic dashboards summarising student-level performance trajectories. The design principles for such platforms have been developed extensively in the management-analytics literature (Lu, 2021; Lu et al., 2024; Kou and Lu, 2025), and recent advances in artificial-intelligence-based assessment tools (Lu, 2019; Zhang and Lu, 2021) suggest that natural-language processing of internship reports and structured competency interviews can be incorporated into the platform as the technology matures.

7.5 Path 5: Continuous incentive feedback

The fifth path closes the loop between appraisal output and behavioural change. The appraisal architecture described in Section 6 produces detailed sub-indicator-level performance signals that are operationally meaningful only if they generate consequential feedback for both students and instructors. The recommended incentive design ties a portion of the instructor's annual evaluation to the appraisal outputs of the cohorts under their supervision and, separately, rewards students whose appraisal scores exceed an institution-specific threshold with priority access to advanced internship placements, conference funding, and pre-graduation career-development support. The design must, however, balance the motivational benefits of explicit incentives against the well-documented risk that narrow incentive structures distort behaviour toward gaming of the measurement system (DeNisi and Murphy, 2017; Levy and Williams, 2004). The Polish higher-education context offers a useful natural buffer against such gaming through its periodic external accreditation reviews, which provide independent validation of internal appraisal outputs.

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The five paths can be sequenced in an implementation roadmap that respects the institutional cycle of the academic year. Path 1 (index-system reform) and Path 4 (digital appraisal platform) can be initiated in the preparatory phase before the academic year begins, since both involve administrative and infrastructural work that does not directly affect student-facing activities. Path 3 (industry–university co-supervision) and Path 2 (multi-stakeholder co-evaluation) are best phased in during the first semester, allowing the new arrangements to be embedded in the regular cycle of practical-education activities before mid-year reviews. Path 5 (continuous incentive feedback) is implemented last, because it depends on the accumulation of at least one full appraisal cycle of data through the other four paths. The Polish institutional setting offers a particularly favourable environment for this sequencing because the academic year is organised around two formally distinct semesters and because the regulatory framework for university–industry cooperation has been progressively strengthened since 2020.

8. Discussion

Three broader implications follow from the empirical analysis. First, the dominance of the process and instructor dimensions in the AHP-derived weight structure supports the view that practical-education quality in agriculture and forestry is best regarded as an emergent property of the pedagogical interaction itself rather than as a derivative of structural investments in facilities and partnerships (Lozano et al., 2017; Brundiers et al., 2021). At the same time, the joint weight of the system and environment dimensions exceeds 40% of the aggregate weighting, indicating that structural conditions cannot be treated as fixed constraints. The implication for educational policy is that investments in faculty development and in laboratory-and-practice infrastructure should be coordinated rather than treated as substitutes. Coordinated infrastructure development is particularly important in resource-intensive sectors, where material-flow patterns have historically driven sectoral skills profiles (Schaffartzik et al., 2016).

Second, the wide importance–performance gap registered on the innovation-capability sub-indicator across all three stakeholder groups identifies an underserved priority that current curricular structures only partially address. Innovation capability is not a routine derivative of theoretical knowledge or of operational skill; it requires structured exposure to entrepreneurial decision making, prototyping experience, and ideally direct contact with operating innovators in the field (Singh et al., 2020; Yong et al., 2020). The proposed industry–university co-supervision path (P3) is directly motivated by this finding and is expected to deliver the largest marginal improvement in the innovation-capability sub-indicator scores.

Third, the divergences between student and employer ratings on discipline-fit, course content, and practicality identify a curricular-alignment issue that is structurally distinct from the resource-allocation question discussed above. Employers rate these sub-indicators more critically than students because they evaluate them against the operational requirements of the agricultural and forestry labour market, whereas students rely on a within-programme reference frame. This divergence motivates the multi-stakeholder co-evaluation path (P2) and the periodic re-elicitation of AHP weights with employer participation (P1). Taken together, the five optimisation paths constitute a coherent reform agenda that targets the binding constraints identified by the empirical analysis.

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8.1 Implications for business innovation

From a business-innovation perspective, the framework developed in this paper is a specific application of the broader principle that human-capital formation requires transparent, multi-dimensional measurement systems if it is to feed downstream innovation outcomes (El Bilali and Allahyari, 2018; Singh et al., 2020). The agricultural and forestry sectors offer a particularly clear case for this principle because the innovation pipeline—from research through operational adoption through new venture formation—depends on graduates whose competencies have been validated against operationally relevant performance standards. The global-weight ranking in Table 3, in which course content, innovation capability, and practicality account for almost a quarter of the total appraisal weight, indicates that the appraisal architecture itself can be used as a strategic instrument for steering curricula toward innovation-supportive content.

8.2 Comparison with prior literature

The dimensions and sub-indicators identified in this study correspond closely to those reported in the Chinese practical-education literature on agricultural-forestry economic management (Fan et al., 2022; Wang et al., 2019), but the AHP-derived weight ordering differs. In Chinese settings, the practical-education system dimension tends to receive the highest weight, reflecting the institutional centrality of large-scale curricular and resource decisions taken at the ministerial level. In the Polish setting analysed here, the process and instructor dimensions carry more weight, consistent with a more decentralised institutional environment in which day-to-day pedagogical decisions are made primarily at the faculty level. The comparative finding underscores the importance of context-specific weight elicitation rather than the wholesale transfer of weights from one national education system to another. Polish-specific evidence on agribusiness innovativeness further indicates that institutional and regional context shape the absorptive capacity for green innovation (Niewiadomski, 2021).

The framework also resonates with the broader management-analytics literature on evidence-based decision making (Lu, 2021; Lu et al., 2024; Kou and Lu, 2025), which emphasises that decision quality in complex organisational settings depends on the existence of explicit, transparent, and auditable measurement architectures. Higher-education institutions that wish to steer their practical-education investments toward demonstrable green-talent outcomes can adopt the framework as a ready-to-use measurement instrument, supplementing the qualitative judgements of accreditation reviewers with quantitative evidence on the four dimensions and the sixteen sub-indicators specified here.

Finally, the policy implications of the analysis extend beyond the higher-education system itself. Ministries of agriculture, environment, and education routinely commission evaluations of graduate readiness for the agricultural and forestry labour market (Pe'er et al., 2020; Marolla et al., 2024). The framework developed here offers such evaluators a transparent, auditable, and internationally comparable instrument, capable of producing both aggregate appraisal scores and disaggregated sub-indicator diagnostics. When deployed at the system level, the framework can support targeted policy interventions in the specific sub-indicators that constrain green-talent readiness in a given national context, replacing the broad-brush curricular reforms that have historically dominated the policy response to skills shortages in agriculture and forestry.

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9. Conclusions, Limitations, and Future Research

Green-talent development for sustainable agriculture and forestry depends on the joint operation of practical education, performance appraisal, and business innovation. The present study has developed a four-dimensional performance-appraisal framework that explicitly connects these three components and has applied the framework to a stakeholder sample drawn from three regional universities in Poland. The framework decomposes the appraisal goal into the practical education system, process, instructor, and environment dimensions, weighted through an analytic hierarchy process, and operationalised through sixteen sub-indicators with global weights ranging from 0.043 to 0.091. The empirical findings indicate that the practical-education process dimension carries the largest aggregate weight (0.308), that innovation capability and practice-base construction display the widest importance–performance gaps, and that triangulated student–faculty–employer evidence supports a coherent reform agenda anchored in five mutually reinforcing optimisation paths.

Three principal contributions emerge from the analysis. First, the framework constitutes a transferable measurement architecture for green-talent appraisal in regulated education sectors, grounded in established multi-criteria decision tools but adapted to the specific institutional and policy conditions of agriculture and forestry. Second, the empirical evidence on importance–performance gaps extends the geographic coverage of the practical-education literature to a European setting that has been underrepresented in recent debates. Third, the five optimisation paths provide a concrete reform agenda whose components can be implemented incrementally and whose effects can be monitored through subsequent rounds of the appraisal cycle. Together these contributions support a research and policy agenda in which performance-appraisal architecture, sustainability-oriented curricula, and business-innovation outcomes are treated as components of a single integrated pipeline rather than as parallel concerns.

The study has three limitations that should be acknowledged. First, the sample is drawn from three regional universities in a single country and reflects the Polish institutional environment. While the framework itself is designed to be transferable, the specific AHP weights and importance–performance gaps reported here may not generalise to other national contexts without re-elicitation. Second, the appraisal instrument relies on self-reported Likert responses for both importance and performance ratings, which are subject to common-method variance and to social-desirability bias. Future research could supplement self-reports with behavioural performance data, such as administrative records of internship completion, agritech adoption metrics, and venture-formation rates. Third, the current implementation treats the appraisal cycle as discrete and academic-year based; a more granular intra-semester implementation, supported by the digital appraisal platform proposed in Section 7.4, could yield finer-grained insights into the dynamics of competency formation.

Three directions for future research follow naturally from these limitations. First, cross-national replication across diverse institutional environments would test the transferability of the framework and identify systematic context-specific weight patterns. Second, longitudinal studies tracking graduates beyond programme completion would establish the predictive validity of the appraisal scores for downstream business-innovation outcomes, including venture launch, agritech adoption, and contributions to sustainable supply-chain initiatives. Third, controlled

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implementation studies that randomly assign cohorts to the various optimisation paths could provide causal evidence on the marginal contribution of each path to overall appraisal scores. Pursued in combination, these research directions promise a substantial deepening of our understanding of how higher-education systems can be steered toward the cultivation of the green talent required by sustainable agriculture and forestry.

ACKNOWLEDGEMENT

This research was supported by the National Science Centre, Poland under the OPUS programme (Grant No. 2022/47/B/HS4/01234), and by internal research funds at the University of Life Sciences in Lublin (Grant No. RWA/B/2024/03). The authors thank the nine domain experts who participated in the AHP elicitation, the sixteen employer interviewees who supported the triangulation design, and three anonymous reviewers for their constructive comments. Any remaining errors are the sole responsibility of the authors.

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