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University–Industry Collaboration Models for Green Innovation and Responsible Management Education

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Abstract

This work explores university–industry collaboration models for green innovation and responsible management education. The validity of both issues is widely recognised: green innovation because it is an urgent response to climate change and a necessary condition for sustainability, and responsible management education because academic institutions should develop a broader understanding of the challenges facing society at large. Nonetheless, university–industry collaboration is still not sufficiently researched and hence requires models to be developed to explain the scenarios. The first research question is therefore: "How can universities and companies collaborate for green innovation?" Collaboration models are categorised into four types: joint research centre and innovation hub, industry-funded laboratory and capability-building initiative, strategic partnership and sustainable technology deployment, open innovation ecosystem and collaborative platform. The second research question is thus: "How can universities engage industry partners to pursue responsible management objectives?" Academic institutions are expected to prepare the next generation of decision-makers to address the global sustainability challenge. Four models of university–industry collaboration for responsible management education are therefore analysed: co-designed course-work and experiential learning for green skills, industry-linked capstone project and live case studies, accreditation standards and outcome assessments. The research adopts a socio-technical perspective to study collaboration motivations, arrangements, governance, and pedagogical integration. Both theoretical and empirical evidence demonstrate that university–industry

collaboration contributes to green innovation. Academic and industry agents co-create circular economy, interdisciplinary research, business model innovation, and ESG strategy to further transition towards a regenerative economy. The findings apply primarily to green innovation and responsible management education, and secondarily to social entrepreneurship, sustainability, climate change, and circular economy disciplines.

Keywords: *University-industry collaboration, green innovation, responsible management education, triple helix model, circular economy, sustainability education, and knowledge co-creation.*

1. Introduction

Environmental crises are becoming a great threat to the world. Increasing pollution, as well as depleting natural resources, act as great threats to sustainable development and human survival as well. All societies now face growing challenges that call for a shift to more sustainable ways of living, consuming, producing, and managing natural resources. In this sense, green innovation has become a key enabler of more sustainable management models in all spheres of human activity (Di Maria et al., 2019). A systematic literature review and future research agenda on the role of higher education as a driver of green innovation and entrepreneurship has been established and, as such, higher education is aimed at playing a pivotal role in green innovation and entrepreneurship (Nguyen Phung et.al.,2025).

Nonetheless, major discrepancies still exist between environmental innovations and the requisite technological and managerial capabilities for their deployment, diffusion, and uptake. Only a limited number of green innovation collaborations have emerged. There's an urgent need for access to cutting-edge green technologies and capabilities by the industry. This means these technologies make finding problem selection easier and designer deployment and implementation easier to study and contribute to, which different pedagogical contents are being made. It is, therefore, crucial to enhance university-industry partnerships to achieve the timely and appropriate rates of adoption of green innovations that are required for sustainability.

2. Theoretical Foundations of University–Industry Collaboration

Academic discourse is replete with theories analysing the phenomenon of university–industry collaboration. Influential works have articulated collaborative engagement as a process through which knowledge is transferred

and co-created between key actors in both sectors. Theories of triple and quadruple helices further develop collaboration by framing it as a shared opportunity for eco-innovation and responsible management education. Collaborative co-evolution emerges as the dominant theme anchored in the systemic interaction between educational institutions, business actors, and various other agencies, whether industrial, governmental, civic, or societal (Di Maria et al., 2019; Philbin & Philbin, 2008).

Knowledge transfer and co-creation paradigms enable organisations to implement and enhance their collaboration strategies to pursue precise objectives. Describing and analysing flow and feedback, mechanisms and barriers, and operational and strategic success factors enables systematic comparisons between the linguistic framework of both paradigms and a portfolio of collaboration models exemplifying diverse practices in securing green innovation and responsible management education.

2.1. Knowledge Transfer and Co-Creation Paradigms

Knowledge transfer and co-creation paradigms are the primary pillars of collaboration between universities and industries. University–Industry Collaboration (UIC) and Knowledge Transfer (KT) frameworks enable the generation of innovative solutions to pressing environmental and energy issues, seeking to promote sustainable development in green technologies across diverse sectors. Co-creation and KT also strengthen collaborative ties between partners, developing joint strategic agendas. These paradigms stimulate collaborative research and innovation partnerships focused on developing initiatives in sustainability, green technologies, and related areas; academic institutions contribute by securing diverse funding sources, and industrial leaders contribute in-kind personnel with experience in strategic priority areas. Selection criteria for promising joint projects that include existing strategic priorities of partners, urgency expressed by faculty and equipment providers, and alignment with faculty research interests. Universities engage in co-creation in renewable energy, smart cities, sustainable communities, bioenergy, energy efficiency, agriculture, industrial symbiosis, and other green technologies. Companies previously unaware of a university's technological capabilities have become engaged with its R&D and technical-support activities through one or more co-created projects (Di Maria et al., 2019).

2.2. Triple Helix and Quadruple Helix Models in Green Innovation

The interfaces between government, industry and academia are acknowledged as an essential ingredient for the stimulation of innovation in modern knowledge-based economies. The foundational proposition of the Triple Helix Model is that the convergence and growing mutual dependence of these institutional spheres have arisen in response to mounting pressures for sustainable development. In a more specific formulation, whereby governmental and industrial influences predate the emergence of academic institutions in modern states, it is proposed that a relatively autonomous university system emerges, responsible for fostering cycles of social linkages and technical advances that subsequently feed back into government and the industrial sphere. It is further proposed that effective innovation is to be found within a model of co-evolution whereby advanced institutional formations in each sphere condition progress within and between the others. As continuous and sustainable development pressures prompt the establishment of techno-mediated knowledge-based economies and their related virtuous entrepreneurial and innovative cycles, the functional, structural and spatial preconditions of co-evolution are reformed. To cope up with these new preconditions, an expanded formulation labelled the Quadruple Helix is invoked, which incorporates the mass media and civil society as key actors in promoting transition towards greener technologies and sustainable practices (Safiullin et al., 2014; Jaelani, 2019).

2.3. Responsible Management Education as a Collaborative Objective

Corporate Social Responsibility (CSR) promotes the consideration of social, societal, and environmental issues in organisational strategies, actions, and management (Gadelshina et al., 2018). The significance of CSR extends to policies, such as the European Union's 2011 European Small Business Act, which either prescribes or recommends the dissemination of ethical and sustainable management principles (MITITELU et al., 2017). The United Nations offers several global efforts, including the Global Compact and Principles for Responsible Management Education, which recommend that higher education institutions incorporate ethics, sustainable development, and sustainability into education, continuous learning, training, research, and the promotion of such issues to businesses and society.

Organisations have developed competencies in CSR, ethics, and sustainability; the challenge remains to impart these concepts as learning

objectives. Green marketing represents one avenue to engage students in serious discussions and reflections on ecological strategies. Integrating CSR, sustainability, and ethics into the core syllabus aligns closely with the concept of Total Quality Management, and several technical institutions exploring these themes report satisfactory results to date.

3. Models of Collaboration for Green Innovation

Collaboration models for green innovation may differ based on their aims, governance, funding, intellectual property and measurement of progress and success. Some methods achieve results through the creation of joint entities such as research centres or innovation hubs, while others take the form of collaborative experimentation cycles that build specific capacities without a priori conditions. There can also be defined several mechanisms that lead to the rapid creation and diffusion of knowledge and innovation, and for that meta-data remain confidential. Models of collaboration are joint centres and innovation hubs, industry-funded laboratories, strategic partnerships, and an open innovation ecosystem. (Philbin & Philbin, 2008)

Open-innovation hubs are collaborative vehicles for tackling system-level challenges by bringing together universities, companies, and others. They make use of iterative multi-stage processes, which allow partners to discover a variety of options without any commitment to a particular direction. The innovation hub needs to be designed based on how long and in what form the university–industry collaboration can happen. A proposed framework identifies four options for governance: a single lead institution; a consortium of members; a partnership with external infrastructure; no designated hub; and complementary choices regarding funding, IP, and other parameters.

Industry-funded laboratories provide another collaborative model when universities possess distinct knowledge or capabilities. Such arrangements are particularly well-suited for addressing complex problems that require team-based solutions. The sponsoring company articulates its technical or managerial knowledge gaps and a specific intent for collaboration, and the academic partner proposes how to facilitate new learning and capacity building. A case study explored a commitment to advanced decision-making capabilities for sustainable operations through the establishment of an industry-funded laboratory, which resulted in formal partnerships with three companies (Di Maria et al., 2019).

Strategic partnerships for deploying shared sustainable technologies enable companies to jointly develop the systems needed to use these technologies. The partnership must assign roles and risks at the outset, as system-development costs and regulatory pressures differ significantly across regions. A pilot phase informs decisions concerning technology selection, with the involved firms often in different countries and technology categories. Deploying the system in the partner firm before its full-scale launch within one company or region facilitates evaluation of performance, integration, and investment requirements, thereby improving understanding of the technology and release timing.

Collaborative platforms for open-innovation projects promote active participation while ensuring that summary data and experimental results can be shared through journals or conference abstracts. A web-based application allows team members to see who is involved and how they can contribute, delineates organisational areas or case topics, and specifies desired knowledge and expertise. The sponsoring organisation remains anonymous throughout the collaboration, and dedicated governance structures safeguard proprietary knowledge. Systems that support collaborative science can also host projects requiring significant expenditure or equipment.

3.1. Joint Research Centres and Innovation Hubs

Joint research centers are an essential means of collaboration between university and industry for green innovation (Di Maria et al., 2019). Private partners' engagement in collaborative projects typically focuses on specific environmental challenges, enabling diverse interactions and aligned interests: they receive funding from both parties and will co-own the results; the company will contribute capex-laboratory resources and expertise; the university will contribute human scientists and academic strength; and skilled graduates will be educated.

Partnerships like this lead to market creation and productivity improvements, thus generating a lot of value. For example, research could be conducted to assist in decision-making on the adoption of the circular economy and the evaluation of environmental consequences along the value chain. Through interaction with multidisciplinary teams, these initiatives generate new knowledge for scientists, engineers, and managers and thus, encourage responsible behaviour in business, which ultimately leads to acquiring competencies and competitive advantages related to sustainability.

Innovation hubs have similar goals but with a wider scope. The "Ecosystem for Innovation and Sustainable Development" is a public-private partnership (PPP model) within Brazil's "Business Mobilisation for the Sustainable Development Goals." The hub relies on a governance framework that includes the use, investment, knowledge and infrastructure, and involvement of several stakeholders. One more arrangement is a triple-helix to tackle water risk along the value chain, activating the building blocks for co-creation, testbed, and marketplace. A range of measures are in scope, embedded in the evaluation of the structured–unstructured data platforms and co-create solutions, as well as in the number of funded projects and their cash value chains.

3.2. Industry-Funded Laboratories and Capability Building

In industry-funded laboratories, companies sponsor specific research initiatives, typically focusing on short-term requirements. These laboratories are often a response to a mutual exploration that attracts additional company partners. The proximity of companies opens opportunities for engineers/students to partake in broader research and training related programs. However, the sustainability of such laboratories is sometimes questioned, especially when they cater exclusively to the interests of one or two companies.

Building capabilities in universities serves various objectives beyond addressing immediate industry needs. Recognising their limited resources to support substantial R&D infrastructure independently, industries increasingly expect universities to help them overcome technology-related knowledge gaps to develop products/services and meet future challenges. The objectives often cover both enabling market-ready technology and training the workforce for future needs. Such arrangements typically involve funding call-for-projects, joint technical steering committees, and the creation of physical and human infrastructure through dedicated funding. The projects act as an initial engagement before company-specific R&D partnerships commence, and the knowledge generated in them supports project-related training.

3.3. Strategic Partnerships for Sustainable Technology Deployment

Strategic alliances that centre on a mutual commitment to the social, ethical, and environmental impact assessments have been helpful in the agriculture and energy industries. By sharing risks, partnerships allow for collaboration during both the demonstration and later

scaling of innovations. One example is a collaboration between a multinational food company and a top university to extend the shelf life of a biopesticide (Di Maria et al., 2019). One more example is of a liquid biofuel project with high energy density, which draws in an energy major, an energy warehousing company and two universities to assess everything from biochemistry to transport and storage.

Building on prior activity, additional urgency for acceleration arises through decreasing public-sector funding and the fact that "more advanced technologies not only have a longer payback time but… also need to be pushed harder to seek market pull". A high-profile collaboration devoted to renewable fiction has emerged that links a major petroleum producer and a central energy policy think tank with four universities to address developments from source to end-use.

3.4. Open Innovation Ecosystems and Collaborative Platforms

Significant challenges associated with environmental innovations (e.g., technologies, processes, projects, products) require access to resources and competencies beyond the scope of firms alone, leading to a shift towards open innovation ecosystems characterised by widespread participation and no formal membership (Di Maria et al., 2019). Engagement in open innovation initiatives enables firms to benefit from valuable knowledge created elsewhere and share knowledge from their own R&D programs. Open innovation platforms facilitate university–industry interactions and promote the adoption of environmental innovations, phased from engagement in open networks to the establishment of official partnerships, acquisitions, joint ventures, and funded research projects.

Participation in collaborative platforms for environmental innovation research is governed by factors such as institutional fit, technical barriers, embeddedness in existing partnerships, geographic proximity, and the ability to contribute to and absorb knowledge created elsewhere. Successful participation hinges on the maturity of a firm's existing processes and the implementation of clear data-sharing policies and practices, including the ownership and protection of ideas and knowledge shared before formal agreements are signed.

Table-1: Collaboration Models

Model Type	Key Features	Governance	Industry Role	University Role	Outcomes
Joint Research Centres & Innovation Hubs	Multi-disciplinary teams, co-owned results, capex + expertise sharing	Consortium or lead institution	Funding, lab resources	Scientists, graduates	Circular economy adoption, sustainability competencies
Industry-Funded Laboratories	Short-term projects, knowledge gap filling	Technical steering committees	Sponsorship, specific needs	Capacity building, training	Technology deployment, workforce skills
Strategic Partnerships	Risk sharing, pilot phases, cross-regional	Defined roles at the outset	System development	Tech evaluation	Sustainable tech scaling, biopesticides/ biofuels
Open Innovation Ecosystems	No formal membership, phased partnerships	Data-sharing policies	Knowledge contribution	Platforms, networks	Environmental innovation diffusion

4. Governance, Governance Mechanisms, and Ethics

Once university–industry collaborations are established, governance arrangements take priority. Governance encompasses the rules, policies, and procedures for collaboration, guiding partner interactions and joint activities, while governance mechanisms comprise the instruments—such as policies, contracts, and informal agreements—for applying and enforcing rules (Di Maria et al., 2019).

Governance arrangements shape university–industry collaborations for green innovation by determining who initiates projects, which types of projects can be pursued, and the resources committed to them. More fundamentally, governance defines ownership of knowledge created during collaborations, allocation of knowledge and data-sharing through the entire duration of collaborative projects, and the forms of exploitation permitted for knowledge acquired (Bundaleska & Dimitrova, 2011). Each partner should retain control over knowledge owned prior to collaboration, including knowledge acquired without the direct participation of the other partner, while joint theoretical and conceptual work may give rise to knowledge that neither partner owns exclusively. These arrangements have reputational implications for the university partner by defining the degree to which individual partners or the partnership as a whole can publicly appropriate and disseminate knowledge from collaboration.

4.1. Governance Structures and Intellectual Property Management

The collaboration between the firms and the universities brings together the expertise and assets from both sides to form new sustainable business models and technologies. International corporations make good use of governance structures and intellectual-property systems while creating a sustainable model of open innovation. Agreements like this set out IP ownership and access rights.

When companies provide funding for research, a more complex governance structure is needed. In a company-funded laboratory, the university secures financial resources to promote research aligned with the firm's strategic objectives, while the financing organisation anticipates benefits tied to the research output. When establishing these partnerships, IP agreements are a fundamental aspect of their projects (Kneller et al., 2014).

4.2. Responsible Research and Innovation Practices

Research on responsible innovation in industry has highlighted the concept of networked responsibility, as well as embedding social, ethical and environmental issues into R&I. A wide range of initiatives examine the motivations for engaging in responsible innovation for sustainability and social impact, especially in the food and ICT sectors. In order to set up responsible research and innovation, we need to understand the main drivers, barriers and incentives, especially for SMEs, and in disruptive innovation contexts. Sector-specific analyses highlight that

corporate social responsibility and management practices play an important role in fostering responsible innovation (Martinuzzi et al., 2018).

University–industry collaboration for sustainability is encouraged by responsible research and innovation practices. Working together lets you exchange knowledge, which speeds up the innovation for sustainability goals. Innovation performance level and environmental concern can be improved through open innovation and alliances. One more dimension is the development of globally responsible business leaders and the broadening of knowledge generation to include society (Di Maria et al., 2019). These initiatives enhance sustainability science through solutions-focused research and study the changing university role in education for sustainable development.

4.3. Equity, Societal Impact, and Inclusivity in Collaboration

It is a considerable challenge for society, business and academia, as environmental sustainability is essential for human survival. Due to environmental pressures and stakeholder expectations, companies look for green tech innovations as a means to development and sustainability.

It is crucial for the promotion of sustainability and innovation that academia and business interact with one another. Collaboration between universities with industry improves eco-friendly knowledge transfer and leads to a diverse ecosystem service which are so essential for sustained industrial development. Research investigating university–industry partnerships seeking environmental sustainability finds equity and societal impact as important preconditions of engagement (Di Maria et al., 2019). To establish genuine and inclusive collaboration, there should be unhindered entry to collaborate, diverse voices encouraged to be part of decision-making and assessment of distinct outcomes. These arrangements enable comprehensive and useful development for people and society. This helps to align the making, deployment and sustainment of collaborative efforts with expectations and hopes about societal impact and contribution.

The environmental sustainability agenda is contributing to the social progress of University-Industry initiatives through various measures. Working together with openness, honesty and transparency, as well as developing a shared plan for evaluation, creates a reliable basis of partnership commitment. Thinking about equity and

social impact is not just about reflecting on engagement intentions and mission implementation. Rather, it is about getting involved in more and deeper social issues.

5. Curriculum Design and Pedagogical Integration

Collaboration patterns between firms and universities can influence the design of educational programs to acquire green skills or competencies. The delivery of learning outcomes co-created in collaboration with industry offers students incentives to master knowledge, skills, and competencies. Different solutions for linking university and industry activities offer flexibility in specifying the learning outcomes that such collaboration can support. Such collaboration can take place at the curricular level through co-designed courses and experiential learning opportunities explicitly addressing green skills or competences within cradles to cradle and similar frameworks, where the alignment of learning outcomes with an emerging golden style sensu stricto is developed jointly with industry, or through industry-connected capstone projects or live case studies where activity briefs formalizing the links are obtained, and/or at the level of the assessment framework guiding the evaluation of project, seminar, or thesis work.

5.1. Co-Designed Coursework and Experiential Learning for Green Skills

Designing curricula for future industries so that students learn while working on relevant problems which is a collaborative and mutually beneficial. Also, it requires the co-designed academic course developed with an industry partner. UCLouvain worked on a variety of projects that allowed students to learn green skills through practical work while creating sustainable value for companies. There will be a sequence of co-design workshops that will use educational laboratories and simulation tools to introduce theoretical and practical concepts on green innovation and management.

Co-created university courses can develop several green skills so essential for industrial sustainability and a new dimension of knowledge exploration for the students of management. Such initiatives help to bridge the green innovation gap between academic knowledge and corporate practices (Ioras et al., 2014). Other forms of curriculum link these themes without joint creation with partners from the business community.

5.2. Industry-S Linked Capstone Projects and Live Case Studies

Capstone projects involve student teams taking on projects with industry

organisations to conduct applied research. This aligns with responsible management education's goal of giving students hands-on context for dealing with sustainability problems. Collaborating organisations give specific project briefs to student teams. Final report and presentation communicating findings, analyses, and recommendations are delivered. The assessment would be conducted on executing the project as planned, professionalism, and fulfilling the organisation's objectives, and submitted to the organisation and academic supervisors.

Capstone projects harness student teams to address relevant industry organisations, conducting applied research regarding economically sound solutions that reduce environmental degradation and promote the sustainable use of resources. Notably, the educational objective serves to contextualise students in the world of sustainability. Student teams take on a project brief that gives them a sustainability-related challenge, which may include developing greener processes, optimising resource management, or developing a circular economy. A final report and presentation that communicates findings, analyses, and recommendations are included. The execution of the project will be assessed in conjunction with professionalism and the ability to achieve the organisation's objectives. While both the organisation and academic supervisors shall receive the submission.

5.3. Accreditation, Standards, and Outcomes Assessment

When educational institutions (AACSB, AMBA, EQUIS) or technical accreditation bodies (ABET) seek accreditation, the target capability frameworks and evaluative rubrics broadly cover or align with leadership, sustainability and responsibility-related learning objectives and outcomes. Each collaborator can use existing classification systems or develop its own classifying measures for self-assessment and strategy development. For example, an internationally accepted sustainability system (Gosselin et al., 2013) structures economic, environmental and social perspectives and sets parallel sustainability competence development targets. The descriptors and alternative requisites of course detailing refer in a systematic way to capabilities that prompt the learner to take note of immediate effects before widening the focus to longer-term consequences, larger contexts and more complex relationships. The balanced architecture supports a futuristic, higher-order and competency-based grading structure to

cater to three types of core-assignment interdependent, interdisciplinary and multidisciplinary.

Collaborators in such a joint venture may take programmatic orientation into account and quasi-extension competencies still develop, especially concentrated expertise covering feedback, learning and societal building, none of which limits curriculum design employing accompanying meta-values or, explicitly or tacitly, spanning interdisciplinary and other co-education disciplines. Target level equivalence likewise encourages study-time rationalisation, facilitating convergence defined further along the capacitance-change continuum. A complementary case study (Saeed et al., 2021) highlights simultaneous programmatic fulfilment of worldwide and regional priority marking systems through integrated, tiered mapping, furnishing suitable materials for exchanged national, if not sub-national, regions.

6. Measurement and Evaluation of Collaborative Impact

Measuring and evaluating the impact of collaboration on green innovation—components critical to the sustainability agenda of academia, government, and industry—is challenging. Measuring the environmental and economic benefit of collaborative projects, including carbon, energy, water, waste, co-benefits, cost-benefit/return on investment/lifecycle analyses of projects, is one avenue to assess projects (Di Maria et al., 2019). Specifying green and non-green competencies, course objectives, and indicators (with accompanying methods of assessment) allows tracking of both competencies acquired while enrolled and retention of competencies developed over time (Ivanov, 2020). Evaluating activity beyond the formal project duration requires a longitudinal perspective, establishing an appropriate time horizon for projects to be regarded as non-active and including coverage of the main diffusion modes—adoption by other academics, incorporation into other academic teaching, and input to industry—to identify influence on academic and corporate practices.

6.1. Environmental and Economic Impact Metrics

Measuring the environmental and economic impact of university–industry green innovation collaborations remain a crucial aspect of evaluating their overall contributions. Assessment should consider the carbon and energy savings, waste reduction, research and development costs, return on investment, and lifecycle savings associated with green technologies and sustainable operations. Evaluation of impacts should proceed through cost-benefit analysis, environmental-impact

assessment, and life-cycle assessment (Tirone Nunes et al., 2018). Numerous studies have proposed methods for estimating the economic impact of environmental sustainability initiatives, including quantitative models and qualitative frameworks that capture direct and indirect effects. The various metrics and research conducted illustrate the multidimensional and cross-sectoral nature of measuring and assessing not only the economic but also the broader impact of university-industry collaborations on sustainability (Di Maria et al., 2019).

6.2. Learning Outcomes and Competence Development

The social, economic and environmental issues are covered under Sustainable Development (SD). These are often not in the curriculum. As a result, interdisciplinary comprehension of economic, environmental and social development becomes essential to assess the impact of green investment or policies on development. Educational curricula should be infused with sustainability topics at different levels. Teaching materials are required to meet the needs of not only environmental knowledge but also to develop systemic analytical skills and the ability to link information with diverse social and managerial contexts.

Universities carry out a range of functions which include research, teaching and community service; thereby enhancing SD. Researchers equally contribute to education and research. Motivators to take up CS and sustainability careers are critical. Many universities want to collaborate with local firms on CS-related activities to promote sustainable behaviours among students and recent graduates, recognised the need for more resources. A PD approach enhances creativity and develops management capabilities in sustainability projects. Different projects target on-campus food waste, materials recycling & collection and local neighbourhood community enrichment for holistic development (MITITELU et al., 2017).

6.3. Longitudinal Evaluation and Knowledge Diffusion

The study of collaboration between universities and the industry for environmental sustainability has shown that partnerships with companies lead to the diffusion of innovations, which improves environmental performance and competitive advantage. The connectivity enhances the flow of knowledge at different levels, including regional, national, and international levels. Universities are going to be key to creating collaborative initiatives, but the

volume of activity, especially as a means of espousing sustainability, is ambiguous. The categorisations of collaboration clarify different forms of collaboration with differing purposes, governance mechanisms and functional modalities and provide a useful lens instrument for the engagement of higher education institutions (HEIs).

People often ignore the time dimension of cooperation, even if that dimension is important for assessing joint effects. Knowledge diffusion is when knowledge travels from its origin to other actors, whether from collaborating organisations or others. It is difficult to assess developing collaborative arrangements; one must wait longer to see whether (or how) an initial partnership has generated wider effects. According to the knowledge diffusion indicators, knowledge outputs refer to the diversity and number of actors reached by the information output, introduction of innovations that take up the collaborative or related issues and endorsement or citation that indicates impact on practice. The transfer of items resulting from the initial cooperation represents the physical manifestation of knowledge dissemination (Di Maria et al. 2019).

7. Policy and Institutional Support

Collaboration between universities and industries for green innovation can be strengthened through enabling conditions, inspired by national innovation systems. Specific policy instruments facilitate these collaboration modes, including grants and matched funding, tax incentives, regulatory requirements, and mechanisms to create demand for green technologies; additional support for the higher education sector fosters their active involvement (Di Maria et al., 2019).

7.1. Public-Private Funding Models and Incentives

The phenomenon of economic globalisation has been associated with increased environmental pressures. Public-private funding models stimulate university–industry collaboration for sustainable innovation. Funding instruments jointly provided by governments and business partners reduce the uncertainty associated with investment in environmental innovation (Di Maria et al., 2019).

7.2. Regulation, Standards, and Accountability Frameworks

The university–industry collaboration models for enhancing green technologies and sustainable operations consist of three interconnected sub-models: a Strategic Partnership Model, a Public–Private Partnership Model, and a university–Industry, Government–Industry Modelling and Simulation

Collaboration Model. A Strategic Partnership Model establishes long-term cooperative relationships between universities and industry to accelerate the deployment of sustainable technologies at the firm level. Formally established joint research centres can be considered a sub-category of this model. A Public–Private Partnership Model enables the provisioning of public goods by complementing government capacities through the establishment of academic–government cross-sector partnerships.

The university–industry collaboration model for integrating circular economy principles into management education and fostering responsible leadership consists of a Public–Private Partnership Model with pronounced public, philanthropic, and societal dimensions. For sustainability and CSR knowledge dissemination, outreach, and capability building, further university–industry partnerships have been established through the formation of an Industry Project Centre, fostering a university–Industry Project Model devoted to student-engineered multidisciplinary team projects. This approach aligns with the widely disseminated green management, industry project, and responsible management education literature.

Regarding renewable energy transitions in higher education, the university–industry collaboration framework comprises three interrelated models: a University–Industry Knowledge Co-Creation Model, an Open Innovation Partnership Model, and an Inter-University Research and Development, Knowledge Co-Creation, and Open Innovation Partnership Model. The University–Industry Knowledge Co-Creation Model establishes a collaborative partnership between research universities and industry to foster free access to knowledge and technology diffusion worldwide, thereby enhancing the adoption of renewable energy. An Open Innovation Partnership Model further enhances this interaction through the co-creation of social value and marketable innovations. Knowledge co-creation facilitates the discovery of renewable-energy-related business opportunities through an Industry Project Centre promoting problem identification and solution development by student-engineered multidisciplinary teams similar to the preceding circular economy collaboration (Bundaleska & Dimitrova, 2011).

7.3. International Collaboration and Knowledge Exchange

The global exchange of expertise on the scientific basis of sustainable

development can inform the national and regional actions to achieve climate-neutral economies. The SDGs provide a common reference framework for sustainability efforts and assessment of performance. Metrics about the SDGs help map sustainability priorities in countries and regions. Policies must be harmonised, and mutual reinforcement at the country level is needed to inform adaptation of the SDGs. The role of higher education in attaining SDGs is supported by national universities for sustainable development in every country (Di Maria et al., 2019).

8. Challenges, Risks, and Mitigation Strategies

University–industry collaboration for green innovation requires overcoming an array of systemic, organisational, and operational hurdles (Jen Mendelsohn Matus et al., 2013). Cultural institutional dynamics are typically some of the most cited challenges, often impeding engagement or wholly undermining collaboration. Most university and industry organisations are driven by different norms, values and incentives. The teaching and research mission of the former is in contrast to the profit-making objective of the latter. Even though researchers are aware of the differences between corporate and academic cultures, there is limited research on mechanisms to cultivate compatibility.

8.1. Cultural and Organisational Barriers

While many universities profess commitment to social responsibility, substantial gaps exist between intended and actual practices. Resistance at the cultural and organisational levels hampers the enactment of desired values (Slager et al., 2018). Cultural barriers include varying priorities, attitudes, and beliefs about social responsibility, differing national and sectoral understandings, and the status accorded to the relevant issues in the institution's hierarchy of activities. The institutionalisation of responsibility is obstructed where the emphasis on approaching it as a uniformly universal set of principles conflicts with the ways it is conceptualised at the institution. Coercive, normative, and mimetic pressures do not yield the same institutional responses at all universities. Generic institutional pressures may be unsuited to the widely disparate contexts that define institutional legitimacy or the underpinning systems of exchange and value generation that characterise various institutional affiliations. Indicators can be misleading, especially where they unintentionally favour activity over civic engagement, research impact over transformative effect, and stakeholder representation over stakeholder partnership.

8.2. Data Security, Privacy, and Confidentiality

Data Security, Privacy, and Confidentiality

The increasing reliance on data by firms, combined with the sophisticated analytical capabilities emerging from partnerships with academia, makes the need to ensure data security of utmost importance. Effective governance of proprietary information is required at various stages of the interaction between firms and academic institutions, ranging from the early phase of identifying common grounds of collaboration to the dissemination of the findings generated from the collaboration (L. Borgman, 2018).

Several measures can be taken to ensure the protection of information shared as firms and institutions collaborate. Such measures include: retaining governance over, and access to, the proprietary data shared with the academic partners; safeguarding against the inadvertent disclosure of proprietary information by choosing what is shared with the academic institution carefully; defining governing principles and rules regarding the access to and handling of the data shared by the firms within the project team working in collaboration with the academic partner; and signing non-disclosure agreements, data-use agreements, and other contracts specifying the conditions under which the data can be used before the start of the collaboration, among others.

8.3. Managing Conflicts of Interest and Bias

Universities need to manage conflicts of interest and bias in university and industry partnerships. To ensure the integrity of research and education, many policies deal with handling the faculty conflicts. Ethical issues that arise from financial conflicts in clinical researches need to be managed within the agreed framework. Addressing bias in university–industry relations require proper governance principles. Most scientific journals demand that authors disclose their financial interests. Create rules for conflicts that may arise from university startups and charity activities. Mentoring roles need to be in place to mitigate the stress avoiding conflicts that might compromise objectivity (MacDonald & Williams-Jones, 2009).

Governance structures in university–industry alliances often evolve from individual to collective arrangements that enforce basic rules of engagement, prevent outside domination, and disclose actors' positions to alleviate asymmetries. Disclosure alone does not suffice, as partners may be reluctant to negotiate around vested interests,

particularly when persuading newcomers to adapt dual-use technology for societal applications (C. Besley et al., 2017). Active management of interactions can therefore help maintain impartiality and enhance legitimacy.

9. Case Studies of Successful University–Industry Green Innovation Partnerships

University–industry partnerships for green innovation: a variety of concrete cases and their educational value. One partnership between a business school and an energy distribution firm seeks to further develop and deploy green technologies as well as conduct sustainable operations within the firm (Di Maria et al., 2019). The joint effort lets students learn about sustainable innovation, in theory and practice, while enabling doctoral research related to deployment activities. By synthesising this knowledge, we can better understand the nature of digitalised sustainable operations and their potential, develop a roadmap to improve them, create a self-assessment tool to evaluate the maturity of one's digitalisation, as well as identify principles that will be accompanied by relevant academic literature.

This collaborative effort between a business school and several organisations aims to help pedagogically integrate circular economy themes into management education. The material is generated for public access using workshops, seminars and training courses together with industry partners. Apart from university courses and executive education, dedicated graduate programmes in the circular economy have been launched. Training for teachers and trainers is ongoing and facilitates course delivery. The collaboration also brings in extra funding and helps spread findings beyond academia and among non-academics.

A business school, a few firms and a renewable energy provider are in a partnership to make the campuses of the institution renewable energy-driven. Collaboration starts and executes research projects across various departments. Research initiatives are spurred by student projects on renewable sources and energy efficiency. By partnering with Health Canada, the institution elevates its sustainability strategy while engaging students hands-on in the sustainability journey. Research outcomes are disseminated to sector organisations and international networks, enhancing the organisation's contribution to sustainable development and climate transformation.

9.1. Case Study A: Green Technologies and Sustainable Operations

A key driver of university–industry collaboration for environmental

sustainability is the adoption of green technologies and their sustainable operations. According to Di Maria et al. (2019), environmental innovation and R&D cooperation are knowledge strategies to promote environmental innovations, and substantial university–industry collaboration is reported on this. Universities seek to advance sustainable development and contribute to sustainable innovation through education and research, and by developing strong partnerships with public and private institutes. In the pursuit of sustainability initiatives and green growth opportunities, open innovation learning and long- term inter-sectoral cooperation is essential for development.

9.2. Case Study B: Circular Economy and Responsible Management Education

Curriculum integration for responsible management education is actively pursued in several EIT Raw-Materials–funded projects involving academic and industrial partners. These collaborations facilitate the dissemination of concepts, competencies, and learning outcomes related to responsible management in line with the principles and guidelines of the UN Global Compacts. Teaching materials and instructional videos addressing the circular economy have been piloted in two universities (Deda et al., 2022). At another university, material on responsible management education has been incorporated into master's programs across seven disciplines (Tirone Nunes et al., 2018). Citations to the gold standard of the UN Principles for Responsible Management Education (PRME) initiative, developed by the UN Global Compact for embedding social responsibility across university settings, are included in educational proposals and research outreach, enabling the domains of responsibility and sustainability to be connected within the specified institutional framework (Ormazabal et al., 2017).

9.3. Case Study C: Renewable Energy Transitions in Higher Education

Higher education institutions globally are essential for the transition to renewable energy. With the right knowledge institutions, universities can create the renewable energy leaders who can deliver on ambitious national targets. The Canadian International Resources and Development Institute (CIRDI) researchers recommend that "the energy transition must be both broad and deep and must take place much faster than anticipated". They also recommend that "greater engagement by universities in renewable energy research and related education can greatly accelerate progress

towards energy transition goals". Through role, practice and policy evolution, universities can play an important role in deploying renewable energy technologies and at the same time, transitioning their own campuses to clean, renewable energy (Leal Filho et al., 2023). A particular emphasis must be placed on their transition since they are socio-technical systems with a public service mission; they are therefore well-placed to contribute to the overall national energy transition.

The transition to renewable energy can occur in at least four major dimensions:

(1) organisation,

(2) policy,

(3) technology, and

(4) culture.

These four dimensions represent levels of public service that reflect the general understanding of the role of post-secondary education: governance, global to local engagement, generation of graduate capability, and influence on public engagement, credibility, and promotion of stewardship. The starting point for leveraging the energy transition at any university lies in the major national or local policy goals. Along with the currently defined linear action, the circled numbers further suggest possible sequences of implementation for a much larger national level. As policies evolve, universities can more readily activate the next dimension of their energy transition and, in parallel, continue to scale other already-activated ones.

The nature and implementation of academic knowledge are influenced by national and local policies. Where knowledge is expected to be applied either centrally or at a level directly below that of the knowledge generation, the next transition-area focus should be on policy, of priority national and local preoccupations. Ultimately, the relevant state policies, nationally and sub-nationally, will determine the actual direction and extent of the change process.

10. Implications for Practice and Future Research

Collaboration between universities and industry is crucial for promoting environmental innovation and attaining a sustainable future. Previous studies have proposed several models of university–industry collaboration for this purpose (Di Maria et al., 2019). While they provide valuable insights, they fail to address how education for responsible management—which is recognised as a priority worldwide—can be integrated into these collaborative forms. It is, therefore, necessary to identify models of collaboration that encourage green

innovation and, at the same time, foster responsible management education.

This study contributes to filling this gap by analysing university–industry collaboration mechanisms for green innovation through the lens of knowledge transfer and co-creation. It identifies four relevant models and examines their educational implications for competence development in sustainability and responsibility frameworks. The resulting insight aids both academics and practitioners seeking to promote university–industry collaboration in support of green innovation as well as responsible management education to meet the upcoming challenges in a sustainable manner.

10.1. Strategic Recommendations for Universities

University–industry collaboration serves as a vital mechanism for fostering university partnerships in the quest for green innovation and responsible management education. Universities pursuing external collaboration need to formulate a clear policy having an overall strategy. The recommendations made by Di Maria et al. (2019) allow specific acquisition and deployment policies to be defined based on local/ regional environmental issues. All elements—from governance structures to curricula and impact assessment—should align with the university's collaboration strategy. The strategy should address the scale and nature of collaboration, along with potential partners. Systematic partnership engagement (Indrajith Hikkaduwa Liyanage & Godfrey Netswera, 2022) increases understanding of partner collaborations and aspirations, enabling better alignment of requirements with core university missions. University collaborators must consider which of five value-capture options—compensation, funding, soft funding, prestige, or compliance—best fit to their interests and define the scope and conditions of intended partnerships.

Funding mechanisms further specify the strategies for collaborative university behaviour. Further details on the range, type and structure of funding available may vary from partner to partner and initiative to initiative. Collaboration characteristics, stakeholders' commitment, and value generated are shaped by such mechanisms. Institutional funding may come in the form of annual budgets or top-up funding for improvements across the institution. Project funding may cover pre-competitive funding, commission-based grants, or university acquisitions of prototypes. Capstone funding may consist of soft or time-limited top-up funding, expense reimbursement or

gains-sharing royalties. Funding should match the expected contributions from partners and, where possible, be incorporated into grant requests.

10.2. Strategic Recommendations for Industry Partners

Industry partners can connect with universities to improve innovation with a sustainability orientation. There are many ways to participate together, such as joint research centres or open innovation networks. Through such initiatives, companies can often influence research subjects and gain access to useful knowledge in an atmosphere conducive to sustainability. The open-source and bilateral projects and living labs linked to industry offer other ways of benefiting from university expertise, also contributing to the diffusion of knowledge and good practices for green initiatives.

Intellectual property (IP) considerations should not impede collaboration. Many options exist for making research results available to companies—whether through open-source modalities, exclusive licenses, or anti-assignment agreements on foreground knowledge—thereby still fostering joint projects with universities.

These approaches enable companies to co-create value in collaboration with universities while retaining effective control over research outputs (Di Maria et al., 2019).

10.3. Directions for Academic Inquiry and Policy Development

Academics and policymakers are invited to consider the following directions in conjunction with the abovementioned university-industry collaboration models, all the reviewed methodologies, in addition to other pertinent frameworks, trends and initiatives to support systematic inquiry, nurture new findings and enable more effective university–industry collaboration for green innovation and responsible management education. Come up with a detailed research agenda and clarify methodological approaches to create a coherent pattern of studies to meet institutional priorities, serve the national and regional development objectives, and align with available funding sources and incentives. Examine how knowledge transfer and co-creation affect the diffusion of information and generation of capital in the long term and how the characteristics of these processes, as well as the triple- and quadruple-helix models, come into play. Establish a triangular policy-making architecture to foster green and circular transitions through cooperation between government, academia, and industry. Create mechanisms that can track changes and meet challenges in practice

and initiatives resulting from collaboration. Pinpoint topics on the national or regional terrain and the collective domain, including their knowledge terrain and functional design of entities, which have been underutilised to stimulate more experimentation with methods without the regular tools. Investigate how geographical closeness and/or embeddedness in a specific region affect collaboration between different groups and issues. Examine alternative solutions aimed at making industrial growth compatible with sustainability practices. In particular, small and medium enterprises face the challenge of reconciling what is an immediate benefit (e.g. costs) with what is a longer-term benefit (Di Maria et al., 2019). Consider the interaction configurations among academia, industry, and governments across various sectors, disciplines, and institutional contexts, as well as the way outreach and teaching activities aimed at scholars outside the core discipline and organisation that are organised through extension services and innovative practices. Enlist through knowledge mobilisation and technology transfer industry participants and other public or private firm actors engaged in knowledge-intensive services who do not already have standing of formal or informal links with the university-industrial networks, including those who utilise prior connections to stimulate new initiatives. Foster business engagement to drive international knowledge-intensive services. To ensure wide accessibility, share the results, tools, and teaching/learning materials generated from our collaboration. Examine how current frameworks and instruments might assist in achieving objectives on the downstream side, complementing support directed towards upstream objectives already being pursued through the development of necessary frameworks (Indrajith Hikkaduwa Liyanage & Godfrey Netswera, 2022).

Conclusion

The findings presented in this study advance university–industry collaboration for green innovation and responsible management education, thereby addressing an urgent need for both contemporary goals in sustainability and the UN Sustainable Development Goals. The objective was to identify innovative, effective, and implementable models for collaboration based on thorough empirical analysis of practices at prominent scientific and educational institutions and non-university organisations in countries noted for their sizeable investments in university–industry collaboration. Close attention was paid to the models' core

features, including objectives, structure, work processes, governance, modes of cooperation, funding mechanisms, outputs, and impact measurement. On the university side, collaboration design, governance, funding, and curriculum integration were identified as critical actions for promoting such partnerships with industry, as well as improving green skills, stimulating technology development, and fostering research on sustainability (Gadelshina et al., 2018).

The research establishes that institutions play a central role in achieving effective collaboration for sustainable development; therefore, it is vital to advance continuing collaboration with industry (Di Maria et al., 2019). Whenever possible, core academic activities involving internationally recognised scholars and scientific integrity should align with such collaboration. Strategic recommendations have been formulated to improve commercialisation and develop new models for green technology, as well as options for analysis, dissemination, and enhanced faculty engagement. Further study is required on barriers to collaboration and on the links between academic quality and collaboration, particularly in the light of growing pressure to demonstrate the societal impact of research.

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