

Convergence of Life Sciences, Circular Economy and Sustainable Innovation: Emerging Pathways for Research, Industry and Future Careers

Review Article | Volume 1 | Issue 5 | 2026 | Article Number: 053

Accepted: 29 September 2026 | Published: 10 October 2026 | ISSN: 2979-8582 (Online)



Crossref : <https://doi.org/10.67693/BJCR-VEZ2GNP3>



Er. Natarajan Arunraaj¹, Dr. Sujatha Ilangovan², Dr. P. Senthilkumar³

¹PhD Scholar, Department of Textile Technology PSG College of Technology, Coimbatore, India,

²Head & Assistant Professor, PG & Research Department of Zoology Holy Cross College, Tiruchirappalli, India,

³Professor, Department of Textile Technology, PSG College of Technology, Coimbatore, India

 ENA [0009-0006-5522-1689](#), DSI [0000-0002-7051-9225](#), DPS [0000-0003-2726-7584](#)

Correspondence: Er. Natarajan Arunraaj, info@kirishinc.org

Abstract

The transition towards a sustainable and resilient economy increasingly depends on the convergence of knowledge systems that have traditionally developed in separate domains. Life sciences provide fundamental knowledge of biological resources, organisms, biomolecules, ecosystems and regenerative processes, while circular economy principles provide a systems-oriented framework for eliminating waste, circulating materials and products, and regenerating natural systems. Sustainable innovation connects these foundations with technologies, industrial practices, business models and human capabilities capable of translating scientific knowledge into measurable environmental, social and economic value. This conceptual review examines the emerging convergence of life sciences, circular economy and sustainable innovation and considers its implications for research, industry, entrepreneurship and future careers. The discussion integrates evidence from international organisations, sustainability frameworks, life-cycle thinking, natural-fibre research, digital traceability, green and digital skills literature, and regenerative systems perspectives. Particular attention is given to bio-based materials, circular product systems, life-cycle assessment, digital product passports, interdisciplinary competencies and T-shaped professional capabilities. The review proposes a conceptual pathway —Nature → Science → Circularity → Sustainability → Technology → Innovation → Entrepreneurship → Industry → Global Careers → Impact—to illustrate how biological knowledge can progress from resource understanding and scientific discovery towards circular industrial value creation. A complementary research-to-impact pathway—Question → Hypothesis → Experiment → Evidence → Validation → Prototype → Pilot → Market → Impact—is proposed to strengthen the translation of research into implementation. The review argues that the next generation of sustainability professionals will require not only disciplinary depth but also the ability to collaborate across science, engineering, business, policy and digital technology. The convergence of life sciences and circular economy

therefore extends beyond an environmental transition: it forms an emerging innovation ecosystem capable of generating new research directions, industrial opportunities, entrepreneurial models and future career pathways.

Keywords: Life Sciences, Circular Economy, Sustainable Innovation, Bioeconomy, Sustainable Materials, Life-Cycle Thinking, Natural Fibres, Digitalisation, Green Skills, T-Shaped Professionals, Regenerative Systems, Future Careers

1. INTRODUCTION

Humanity is entering a period in which environmental sustainability, resource security, technological transformation and socioeconomic development can no longer be considered independently. Increasing pressure on natural resources, climate systems, ecosystems and material supply chains has intensified the need to redesign how societies produce, consume, recover and regenerate resources. The *Global Resources Outlook 2024* identifies resource extraction and use as central drivers of environmental pressures and highlights the need to bend the trajectory of resource consumption towards more sustainable pathways (UNEP [11]).

The conventional linear economic model commonly represented as **take–make–use–dispose** has generated substantial economic and technological progress, but it also creates material losses, waste, environmental externalities and dependence on finite resources. A transition towards circular systems requires a fundamental reconsideration of products, materials, production processes, consumption patterns and end-of-life management. The United Nations Sustainable Development Goal 12 explicitly calls for responsible consumption and production, including efficient use of natural resources and reductions in waste generation (United Nations [8, 9]).

Within this transformation, the **bioeconomy** provides an important bridge between biological resources and sustainable economic activity. The Food and Agriculture Organization of the United Nations conceptualises the bioeconomy as involving the production, utilisation, conservation and regeneration of biological resources to support a sustainable economy (FAO [1]). A sustainable bioeconomy further emphasises the responsible use of biological resources to simultaneously address production, nutrition, environmental and livelihood objectives (FAO [2]).

The significance of this transition extends beyond agriculture and food systems. Biological resources can provide fibres, polymers, chemicals, materials, energy and other value-added products. Natural fibres, for example, are increasingly investigated as renewable constituents for sustainable materials and composite applications (Ghalme et al. [13]; Puttegowda [14]). Recent research has also examined natural fibres specifically within the context of fashion sustainability, highlighting opportunities and challenges across raw-material production, processing, applications and end-of-life pathways (Islama et al. [15]).

The emerging opportunity therefore lies not simply in replacing one material with another, but in designing systems in which **biological knowledge, circularity, life-cycle thinking, digital technologies and sustainable innovation operate together**.

Life sciences can explain the biological origin, structure, function and regeneration of resources. Circular economy principles can determine how those resources should be retained in productive use. Sustainable innovation can translate scientific knowledge into products, processes, services and business models. Digital technologies can provide data, traceability, optimisation and decision-support capabilities. Education and workforce development can provide the human competencies necessary to connect these domains.

The convergence can consequently be represented as:

Nature → Science → Circularity → Sustainability → Technology → Innovation → Entrepreneurship → Industry → Global Careers → Impact

This pathway is a conceptual synthesis proposed in this article. It does not represent an established external model; rather, it is intended to provide an integrative way of understanding how biological knowledge can progress towards industrial and societal impact.

The central proposition of this review is that sustainability innovation is increasingly becoming a **convergence discipline**. The future researcher, engineer, technologist, entrepreneur, policymaker and sustainability professional will increasingly need to understand interactions between disciplines rather than operate exclusively within disciplinary boundaries.

2. CONCEPTUAL APPROACH AND SCOPE

This article adopts a **conceptual narrative review approach**. It synthesises authoritative institutional publications and selected peer-reviewed literature relevant to bioeconomy, circular economy, sustainable materials, life-cycle thinking, digital traceability, interdisciplinary competencies, green skills and regenerative sustainability.

The purpose is not to perform a systematic literature search, bibliometric analysis or meta-analysis. Accordingly, the article does not claim systematic-review completeness or statistical aggregation of the literature. Instead, the approach is intended to connect established concepts that are frequently discussed separately and identify their implications for future research, industrial practice and careers.

The conceptual scope encompasses five interconnected dimensions:

1. **Life sciences and biological resources** – understanding nature as a source of renewable resources, biological processes and regenerative knowledge.
2. **Circular economy** – retaining products, components and materials at their highest practical value while reducing waste and environmental pressures.
3. **Sustainable innovation** – converting knowledge into environmentally responsible technologies, products, services and business models.
4. **Digital and life-cycle intelligence** – using life-cycle thinking, data, traceability and emerging digital technologies to support evidence-based decisions.
5. **Human capital and future careers** – developing interdisciplinary, green and digital competencies capable of implementing sustainable transitions.

This conceptual integration is particularly relevant to sectors such as agriculture, food, textiles, fashion, biomaterials, packaging, chemicals, construction, energy, healthcare and manufacturing.

3. FROM LINEAR PRODUCTION TO CIRCULAR AND BIO-BASED SYSTEMS

3.1 Limitations of the linear economy

Linear production systems are predominantly organised around extraction, transformation, consumption and disposal. Such systems can be efficient when environmental and resource constraints are externalised, but their long-term sustainability is challenged when resource extraction, waste generation and ecological degradation increase simultaneously.

The United Nations identifies sustainable consumption and production as a fundamental component of sustainable development and emphasises efficient resource use, waste reduction and technological capacity (United Nations [8, 9]). UNEP's assessment of global resource use further demonstrates the scale of the

challenge associated with continued resource-intensive development (UNEP [11]).

Circular economy thinking responds by shifting attention from waste management alone towards **system redesign**.

The Ellen MacArthur Foundation describes three core principles of a circular economy: eliminating waste and pollution, circulating products and materials at their highest value, and regenerating nature (Ellen MacArthur Foundation [12]).

This distinction is important. Recycling at the end of a product's life is only one component of circularity. A genuinely circular system considers design, material selection, production, distribution, use, maintenance, repair, reuse, remanufacturing, recycling and biological regeneration as interconnected stages.

3.2 Bioeconomy as a complementary pathway

Circularity and bioeconomy are complementary rather than competing concepts. The bioeconomy focuses on the responsible utilisation and regeneration of biological resources, whereas circular economy principles focus on maintaining value and reducing resource loss throughout economic systems.

The convergence becomes particularly powerful when biological resources are integrated into circular design.

For example:

Biological resource → sustainable extraction → functional material → durable product → extended use → repair/reuse → recovery → secondary material/biological regeneration

Such a pathway can potentially reduce dependence on virgin fossil-based resources while creating new value chains.

However, biological origin alone does not automatically make a material sustainable. Resource cultivation, land requirements, water consumption, agricultural inputs, processing energy, transportation, durability and end-of-life options must also be considered. Consequently, bio-based innovation should be evaluated using life-cycle thinking rather than relying solely on the renewable character of the feedstock.

4. LIFE SCIENCES AND SUSTAINABLE MATERIALS INNOVATION

4.1 From biological knowledge to material innovation

Life sciences provide a foundation for understanding biological structures, processes and resources that can inspire new materials and technologies. Biomass can contain cellulose, lignin, proteins, polysaccharides, lipids and other compounds with potential industrial value.

Natural fibres represent a particularly important example. Research on natural fibres has expanded because of their renewable origin, low density and potential application in composites and other sustainable materials (Ghalme et al. [13]; Puttegowda [14]).

Natural fibres can also contribute to textile and fashion applications. Islama et al. [15] highlight the growing importance of natural fibres within the sustainability discourse surrounding fashion materials and production.

The critical transition, however, is from **natural-resource availability to scientifically validated material performance**.

A sustainable material must satisfy multiple criteria, including:

- adequate mechanical and functional performance;
- consistent quality;

- processability;
- durability appropriate to its application;
- safe chemistry;
- responsible resource use;
- economic feasibility;
- scalability;
- traceability; and
- a credible end-of-life pathway.

Therefore, life-science knowledge must increasingly interact with materials science, chemical engineering, textile technology, manufacturing, environmental assessment and industrial economics.

4.2 Underexplored biological resources as innovation opportunities

One of the most promising areas of future research is the investigation of underutilised biological resources and residues.

Plants, agricultural residues, food-processing by-products and industrial biomass can potentially become feedstocks for fibres, composites, bio-based chemicals, packaging, functional materials and other products.

This creates an important research question:

Can a biological resource currently considered low-value or waste be transformed into a technically viable, economically attractive and environmentally preferable material?

Answering this question requires more than extraction experiments. It requires a multidisciplinary research chain involving:

Botany → extraction → chemical characterisation → structural analysis → mechanical testing → processing → product development → life-cycle assessment → techno-economic assessment → market validation.

This chain illustrates why future sustainable materials research must increasingly operate across disciplinary boundaries.

5. CIRCULARITY ACROSS THE PRODUCT LIFE CYCLE

Circular economy principles are most effective when embedded at the design stage rather than introduced only after a product becomes waste.

A circular product strategy should consider at least six interconnected stages:

5.1 Material selection

Materials should be selected according to performance, resource availability, environmental impacts, toxicity, durability and recovery potential.

5.2 Sustainable design

Product architecture should facilitate durability, repair, disassembly, modularity, reuse and recovery wherever appropriate.

5.3 Cleaner production

Manufacturing processes should minimise energy consumption, water use, emissions, chemical hazards and material losses.

5.4 Extended utilisation

Durability, repairability, maintainability and reuse can retain economic value for longer periods.

5.5 Recovery

Products and materials should be designed to facilitate reuse, remanufacturing, recycling or safe biological return.

5.6 Regeneration

Circular systems should ultimately contribute to the regeneration of ecological systems rather than simply slowing resource depletion.

The circular economy therefore moves sustainability from an **end-of-pipe problem** to a **whole-system design challenge**.

The Ellen MacArthur Foundation's principles reinforce this system's perspective by linking waste elimination and material circulation with regeneration of nature (Ellen MacArthur Foundation [12]).

6. LIFE-CYCLE THINKING, DIGITALISATION AND TRACEABILITY

6.1 Life-cycle thinking

Life-cycle thinking provides an essential analytical foundation for evaluating whether an innovation genuinely improves sustainability.

ISO 14040 establishes the principles and framework for life-cycle assessment, including goal and scope definition, life-cycle inventory, life-cycle impact assessment and interpretation (ISO [16]).

This approach is particularly important when comparing conventional and bio-based materials.

For example, replacing a petroleum-derived material with a biological material could reduce fossil-resource dependence but potentially increase land, water or processing impacts. Without life-cycle analysis, such trade-offs may remain hidden.

Consequently:

Renewable ≠ automatically sustainable

and

Bio-based ≠ automatically circular.

Sustainability must be demonstrated across relevant life-cycle dimensions.

6.2 Digital technologies

Digitalisation can strengthen circular systems by improving information availability and decision-making.

Artificial intelligence, machine learning, computer vision, Internet of Things systems, digital twins, advanced analytics and distributed data systems can support:

- material identification;
- quality control;
- predictive maintenance;
- process optimisation;
- waste classification;
- demand forecasting;

- resource efficiency;
- product traceability;
- circular supply-chain management; and
- life-cycle data analysis.

The emerging **Digital Product Passport (DPP)** is particularly significant. The European Union's regulatory framework establishes the basis for digital product information designed to improve transparency, traceability and circularity. Textiles and apparel are among the sectors for which product-specific implementation has been planned under the evolving European framework (European Commission [17]).

For sustainable materials industries, this development may transform product information from a static label into a dynamic information asset.

Future products may increasingly carry information about:

origin → material composition → processing → environmental indicators → repair → ownership/use history → recovery options.

This creates opportunities for researchers and professionals who can combine material science with data science and digital systems.

7. FROM SCIENTIFIC DISCOVERY TO SUSTAINABLE INNOVATION

Scientific discovery does not automatically become innovation.

A laboratory finding may demonstrate a promising material property but still fail to achieve industrial relevance because of cost, scalability, variability, processing requirements, supply-chain constraints or inadequate market demand.

A useful conceptual research-to-impact pathway is therefore:

Question → Hypothesis → Experiment → Evidence → Validation → Prototype → Pilot → Market → Impact

As with the earlier pathway, this sequence is an original synthesis put forward in this article rather than an established model drawn from prior literature.

Each transition requires different competencies.

Stage	Dominant capability
Question	Scientific curiosity
Hypothesis	Scientific reasoning
Experiment	Research methodology
Evidence	Characterisation and analytics
Validation	Reproducibility and testing
Prototype	Engineering and design
Pilot	Process development
Market	Entrepreneurship and economics
Impact	Sustainability and systems evaluation

This pathway highlights a persistent challenge in sustainability research: **the innovation gap between scientific evidence and implementation.**

Bridging this gap requires collaboration among researchers, engineers, manufacturers, entrepreneurs, policymakers, investors and end users.

8. GREEN AND DIGITAL TRANSITIONS: IMPLICATIONS FOR THE FUTURE WORKFORCE

The sustainability transition is simultaneously a technological and workforce transition.

The International Labour Organization has highlighted how the shift towards greener economies changes occupational structures and skill requirements, creating demand for reskilling and upskilling (ILO [3]). The green and digital transitions increasingly overlap, generating new combinations of technical, digital and sustainability competencies (ILO [4, 5]).

Lifelong learning becomes increasingly important because technologies, regulations, business models and sustainability requirements continue to evolve (ILO [6]). The ILO's programme on skills for a greener future further emphasises the importance of green skills for a just transition, productivity and decent work (ILO [7]).

This suggests that future employability cannot depend exclusively on one disciplinary qualification.

A professional may increasingly need:

Domain expertise + sustainability literacy + digital capability + systems thinking + communication + collaboration + innovation.

9. T-SHAPED PROFESSIONALS FOR SUSTAINABLE INNOVATION

One useful competency model is the concept of the **T-shaped professional**.

The vertical dimension of the T represents deep expertise in a particular discipline, while the horizontal dimension represents the capacity to collaborate across disciplinary and organisational boundaries.

McIntosh and Taylor [18] discuss T-shaped water professionals in relation to collaboration, learning and leadership. Similarly, Trogstad et al. [19] demonstrate the relevance of T-shaped engineering skills to complex multidisciplinary projects.

The model is highly relevant to sustainability.

A future sustainable-materials professional, for example, may possess deep expertise in:

Textile technology

while developing working knowledge of:

- life sciences;
- circular economy;
- life-cycle assessment;
- artificial intelligence;
- data analytics;
- ESG;
- carbon accounting;
- digital traceability;
- entrepreneurship;
- policy; and
- stakeholder engagement.

The objective is not to become an expert in every field. Rather, the objective is to develop sufficient cross-disciplinary literacy to communicate, collaborate and make informed decisions. This distinction is fundamental.

Future professionals do not necessarily need broader knowledge instead of deep knowledge; they need broader connectivity around deep knowledge.

10. EMERGING RESEARCH, INDUSTRIAL AND ENTREPRENEURIAL PATHWAYS

The convergence described above is generating multiple opportunities.

10.1 Sustainable materials research

Potential research areas include:

- natural and bio-based fibres;
- bio-based polymers;
- agricultural-residue materials;
- biodegradable composites;
- functional natural materials;
- biomimetic materials;
- bio-derived chemicals;
- sustainable textile materials;
- low-impact finishing technologies; and
- regenerative material systems.

Natural-fibre research demonstrates the potential for biological resources to contribute to sustainable materials technologies, while also revealing the importance of characterisation, processing and performance validation (Ghalme et al. [13]; Puttegowda [14]).

10.2 Circular manufacturing

Industry opportunities include:

- design for disassembly;
- industrial symbiosis;
- material recovery;
- remanufacturing;
- repair systems;
- waste-to-resource manufacturing;
- closed-loop production;
- reverse logistics; and
- circular supply-chain management.

UNEP's work on circular-economy indicators illustrates the growing importance of measurable indicators for understanding and governing circular transitions (UNEP [10]).

10.3 Sustainable digital systems

Digital transformation is likely to become increasingly important in:

- Digital Product Passports (DPP);
- traceability platforms;
- AI-enabled material classification;
- computer-vision-based quality control;

- predictive manufacturing;
- circularity analytics;
- environmental data systems; and
- digital sustainability reporting.

10.4 Entrepreneurship

The transition to circular and bio-based systems also creates opportunities for entrepreneurs.

Potential business models include:

- **Waste → Material**
- **Biomass → Product**
- **Product → Service**
- **Waste stream → Feedstock**
- **Data → Traceability**
- **Research → Technology**
- **Technology → Enterprise**

The most successful ventures are likely to be those that combine technical feasibility with market need, environmental value and scalable business models.

11. REGENERATIVE SYSTEMS: THE NEXT STAGE OF SUSTAINABILITY

Circularity seeks to reduce resource loss and retain value. Regenerative thinking goes further by asking whether economic activity can actively contribute to ecological and social renewal.

The regenerative-systems discussion in this article is conceptual and is not attributed to the previously listed Brown [20] citation, which could not be reliably verified as a published source matching the title, author, journal, volume, pages and DOI originally supplied.

This perspective suggests that sustainability should not be understood solely as reducing negative impacts; it can also involve restoring ecological capacity and strengthening long-term social resilience.

This produces an important conceptual progression:

Linear → Efficient → Circular → Sustainable → Regenerative

The progression should not be interpreted as a rigid hierarchy. Instead, it illustrates increasingly ambitious ways of framing sustainability.

A regenerative textile or materials system, for example, would not merely minimise waste. It would seek to:

- use responsibly managed renewable resources;
- protect biodiversity;
- minimise harmful chemistry;
- maintain material value;
- support responsible livelihoods;
- strengthen local resource cycles;
- reduce dependence on virgin resources; and
- contribute positively to ecological regeneration where feasible.

Such systems require collaboration between life scientists, materials researchers, engineers, designers, economists, policymakers and communities.

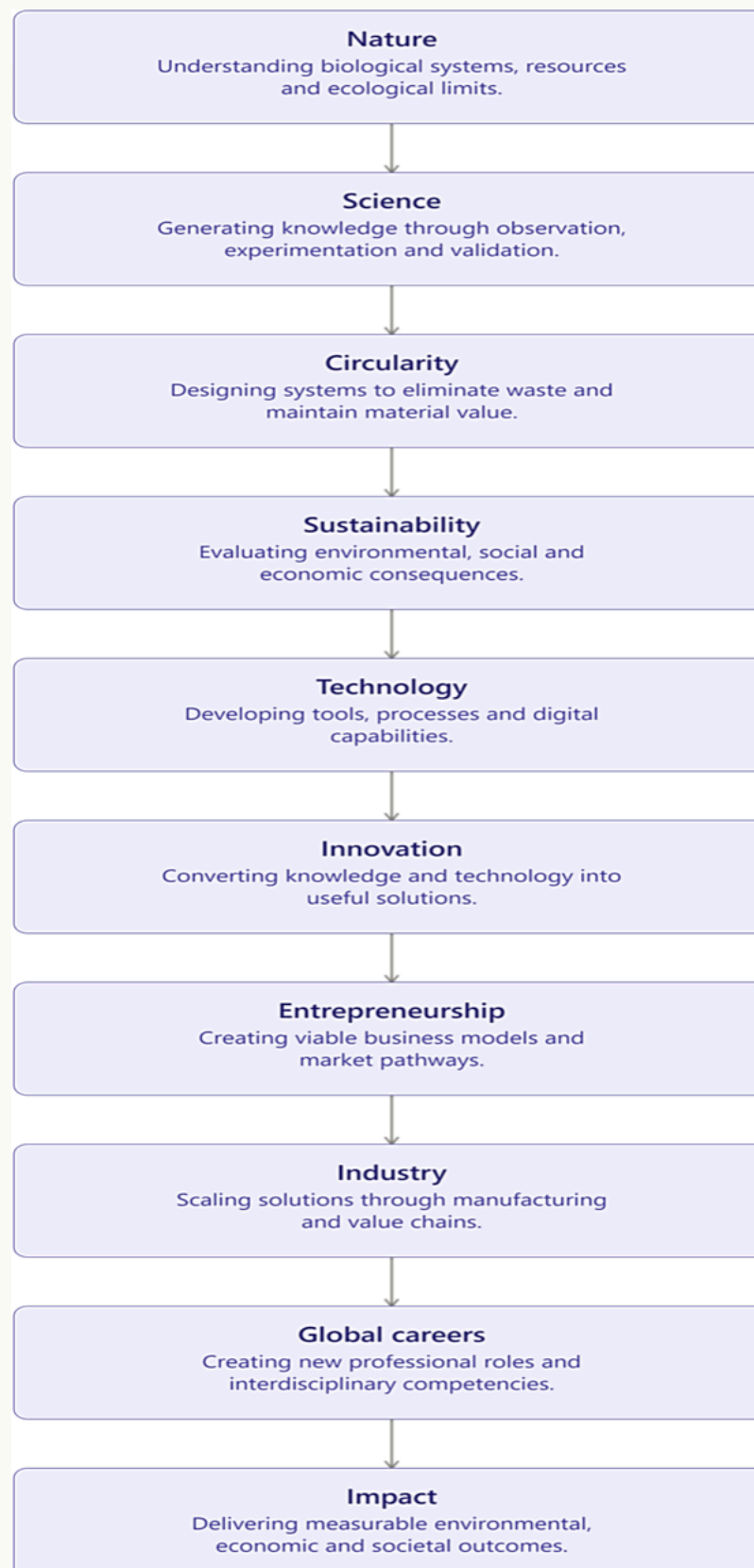
12. A CONVERGENCE FRAMEWORK FOR FUTURE SUSTAINABLE INNOVATION

Based on the synthesis presented in this review, the following conceptual framework is proposed:

This framework illustrates why no single discipline can independently deliver the sustainability transition.

- Life sciences alone, without industrial translation, tend to stay disconnected from market impact.
- Circular economy without scientific understanding may overlook material limitations.
- Technology deployed without sustainability assessment risks optimising for the wrong objective altogether.
- Entrepreneurship without environmental integrity may reproduce unsustainable consumption.

Therefore, the convergence itself becomes the innovation opportunity.



13. DISCUSSION

The evidence and concepts considered in this review suggest that sustainable development is increasingly characterised by **interdependence rather than disciplinary independence**.

The bioeconomy provides a pathway for transforming biological knowledge and resources into economic value while maintaining sustainability objectives (FAO [1, 2]). Circular economy principles provide a

framework for reducing waste and maintaining material value (Ellen MacArthur Foundation [12]). Life-cycle assessment provides an analytical mechanism for evaluating environmental consequences across a product or system's life cycle (ISO [16]). Digital product information can strengthen transparency and traceability (European Commission [17]). Green and digital skills provide the human capacity required to implement these transformations (ILO [3–7]).

These elements are not isolated.

They form an interconnected innovation ecosystem.

13.1 Research implications

Future research should increasingly move beyond single-property investigations towards integrated sustainability assessment.

For natural and bio-based materials, for example, a comprehensive research programme could combine:

Botanical identification → extraction optimisation → chemical characterisation → morphology → crystallinity → mechanical properties → textile processing → product performance → LCA → techno-economic assessment → circularity assessment → digital traceability.

Such research would provide stronger evidence for industrial translation than isolated material characterisation.

13.2 Industrial implications

Industries should increasingly treat sustainability as a design and innovation parameter rather than solely a reporting obligation.

This means embedding sustainability considerations into:

- R&D;
- procurement;
- product development;
- manufacturing;
- logistics;
- marketing;
- finance;
- workforce development; and
- end-of-life management.

The movement towards digital product information reinforces the need for organisations to maintain reliable product and material data throughout value chains (European Commission [17]).

13.3 Educational implications

Universities and professional institutions can play a critical role in developing interdisciplinary sustainability capabilities.

Traditional programmes may continue to provide disciplinary depth, but additional competencies should increasingly include:

Life-cycle thinking + circular economy + digital literacy + sustainability assessment + entrepreneurship + communication.

This approach is consistent with the broader need for green, digital and lifelong learning capabilities identified by the ILO (ILO [3–7]).

13.4 Policy implications

Policy frameworks should support collaboration between research institutions, industry, entrepreneurs and communities.

Policies can accelerate the transition by supporting:

- sustainable material research;
- circular infrastructure;
- green skills development;
- innovation financing;
- technology transfer;
- responsible bioeconomy development;
- digital traceability;
- standardisation;
- resource-efficiency targets; and
- measurable circular-economy indicators.

The United Nations' SDG framework provides a global direction for responsible consumption and production, while UNEP's resource assessments demonstrate the urgency of transforming resource-use patterns (United Nations [8, 9]; UNEP [10, 11]).

14. RESEARCH GAPS AND FUTURE DIRECTIONS

The convergence of life sciences, circular economy and sustainable innovation opens several research priorities.

14.1 Standardised sustainability evaluation

There is a need for consistent approaches that integrate environmental, social and economic indicators without oversimplifying complex trade-offs.

Life-cycle approaches provide an important foundation, but future methodologies should increasingly consider circularity, biodiversity, resource regeneration and social outcomes alongside conventional environmental indicators (ISO [16]).

14.2 Underexplored biological resources

More research is needed on underutilised plants, agricultural residues and biological by-products as potential sustainable material resources.

However, such research should move beyond extraction yield and basic characterisation towards full value-chain assessment.

14.3 Circularity metrics

Circularity should become increasingly measurable.

Future research can investigate indicators related to:

- material circularity;

- recycled and renewable content;
- product lifetime;
- repairability;
- reuse rates;
- recovery efficiency;
- biological regeneration;
- resource productivity; and
- circular business performance.

UNEP's work on circular-economy indicators provides an important policy-oriented foundation for this development (UNEP [10]).

14.4 Artificial intelligence and sustainable materials

AI and machine learning offer opportunities to accelerate:

- material discovery;
- fibre classification;
- image-based quality assessment;
- process optimisation;
- predictive maintenance;
- waste sorting;
- formulation development; and
- sustainability-data analysis.

However, AI applications should themselves be assessed for data quality, energy use, transparency, bias and reproducibility.

14.5 Digital product passports and circular value chains

The development of DPP systems creates a major research opportunity for integrating material science, supply-chain data, sustainability metrics and consumer information (European Commission [17]).

Future studies could investigate how digital product information can support actual circular behaviour rather than merely increase information availability.

14.6 T-shaped sustainability professionals

Further research is needed to determine which combinations of disciplinary and cross-disciplinary skills produce the greatest effectiveness in sustainability innovation.

The T-shaped model provides a useful starting point, but future research could investigate competency frameworks for:

- sustainable materials scientists;
- circularity engineers;
- sustainability data analysts;
- bioeconomy entrepreneurs;
- digital product-passport specialists;
- ESG and life-cycle professionals; and
- regenerative-systems practitioners.

The relevance of T-shaped capabilities to complex multidisciplinary work is supported by McIntosh and Taylor [18] and Trogstad et al. [19].

14.7 From sustainable to regenerative innovation

Future research should examine how circular systems can progress from reducing negative environmental impacts towards generating measurable ecological and social benefits.

The regenerative-systems discussion in this article is presented as a conceptual research direction rather than as a claim supported by the unverifiable Brown [20] reference originally included.

15. CONCLUSION

The convergence of life sciences, circular economy and sustainable innovation represents an emerging paradigm for addressing interconnected environmental, technological, industrial and societal challenges.

Life sciences provide knowledge of biological systems and renewable resources. The bioeconomy creates pathways for responsible utilisation of biological resources (FAO [1, 2]). Circular economy principles provide mechanisms for eliminating waste, circulating materials and regenerating nature (Ellen MacArthur Foundation [12]). Life-cycle assessment provides a structured basis for evaluating environmental consequences (ISO [16]). Digital technologies and digital product passports can strengthen transparency, traceability and information flows (European Commission [17]). Green and digital skills provide the human capabilities required to implement the transition (ILO [3–7]).

Natural and bio-based materials demonstrate how this convergence can move from biological resources to sustainable products. Research on natural fibres illustrates both the opportunities and the scientific challenges associated with renewable material systems (Ghalme et al. [13]; Puttegowda [14]; Islama et al. [15]).

The central message of this review is that the sustainability transition should not be understood as a collection of independent technological substitutions. It is a **systemic transformation of knowledge, materials, production, consumption, business models, technologies and human capabilities**.

The conceptual pathway proposed in this article—

Nature → Science → Circularity → Sustainability → Technology → Innovation → Entrepreneurship → Industry → Global Careers → Impact

—illustrates one possible route through which biological knowledge can be translated into sustainable economic and societal value.

Equally, the proposed research-to-impact pathway—

Question → Hypothesis → Experiment → Evidence → Validation → Prototype → Pilot → Market → Impact

—emphasises the importance of connecting scientific research with implementation.

The future sustainability professional will therefore require both **depth and breadth**: deep disciplinary competence combined with the ability to collaborate across life sciences, engineering, materials, digital technologies, economics, policy and entrepreneurship. The development of such T-shaped capabilities is increasingly relevant to complex sustainability challenges (McIntosh & Taylor [18]; Trogstad et al. [19]).

Ultimately, the objective should move beyond simply producing less waste or consuming fewer resources. The more ambitious goal is to create systems that **retain value, restore natural capacity, strengthen communities and generate sustainable innovation across generations**.

The convergence of life sciences and circular economy consequently functions as more than an

environmental strategy: it is a platform for a new generation of **research opportunities, industrial transformation, entrepreneurial ventures, professional competencies and global career pathways.**

Declarations

Funding

No external funding was received specifically for the preparation of this conceptual review.

Competing Interests

The author declares that there are no competing interests relevant to this manuscript.

Author Contributions

The author conceptualised the review, developed the conceptual framework, synthesised the literature, and prepared the manuscript.

Data Availability

No new datasets were generated or analysed in this conceptual review.

Ethics Approval

Not applicable. This article does not involve human participants, animals or primary human/animal data.

Consent to Participate

Not applicable.

Consent to Publish

Not applicable.

References

1. Food and Agriculture Organization of the United Nations. (n.d.). *Bioeconomy*. FAO. <https://www.fao.org/in-action/sustainable-and-circular-bioeconomy/en>
2. Food and Agriculture Organization of the United Nations. (n.d.). *Sustainable and circular bioeconomy*. FAO. <https://www.fao.org/in-action/sustainable-and-circular-bioeconomy/en>
3. International Labour Organization. (2019). *Skills for a greener future: A global view*. International Labour Office. <https://www.ilo.org/publications/skills-greener-future-global-view>
4. International Labour Organization. (2024). *Navigating the future: Skills and jobs in the green and digital transitions*. International Labour Office. <https://doi.org/10.54394/VGNR3350>
5. International Labour Organization. (2025). *Workforce 2030: Skills for thriving in the green and digital transition*. International Labour Office. <https://doi.org/10.54394/XXZW7148>
6. International Labour Organization. (n.d.). *Lifelong learning and skills for the future*. International Labour Office. <https://www.ilo.org/skills-and-lifelong-learning>
7. International Labour Organization. (n.d.). *Skills for a greener future*. International Labour Office. <https://www.ilo.org/skills-and-lifelong-learning/skills-greener-future>
8. United Nations Department of Economic and Social Affairs. (n.d.). *Goal 12: Ensure sustainable consumption and production patterns*. United Nations. <https://sdgs.un.org/goals/goal12>

9. United Nations. (n.d.). *Sustainable consumption and production*. United Nations Sustainable Development. <https://www.un.org/sustainabledevelopment/sustainable-consumption-production/>
10. United Nations Environment Programme. (2024). *Circular economy: From indicators and data to policy-making*. UNEP. <https://www.unep.org/resources/report/circular-economy-indicators-and-data-policy-making>
11. United Nations Environment Programme, International Resource Panel. (2024). *Global resources outlook 2024: Bend the trend—Pathways to a liveable planet as resource use spikes*. UNEP. <https://www.unep.org/resources/Global-Resource-Outlook-2024>
12. Ellen MacArthur Foundation. (n.d.). *What is a circular economy?* <https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview>
13. Ghalme, S., Hayat, M., & Harne, M. (2025). A comprehensive review of natural fibers: Bio-based constituents for advancing sustainable materials technology. *Journal of Renewable Materials*, 13(2), 273–295. <https://doi.org/10.32604/jrm.2024.056275>
14. Puttegowda, M. (2025). Eco-friendly composites: Exploring the potential of natural fiber reinforcement. *Discover Applied Sciences*, 7, Article 401. <https://doi.org/10.1007/s42452-025-06981-8>
15. Islama, T., Hossain, M. M., & Covington, S. (2025). Natural fibers towards fashion sustainability: A review of raw materials, production, application, and perspective. *Journal of Natural Fibers*, 22(1). <https://doi.org/10.1080/15440478.2025.2462218>
16. International Organization for Standardization. (2006). *ISO 14040:2006: Environmental management—Life cycle assessment—Principles and framework*. ISO. <https://www.iso.org/standard/37456.html>
17. European Commission. (n.d.). *Digital Product Passport*. Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs. https://single-market-economy.ec.europa.eu/single-market/european-sustainability-product-initiative/digital-product-passport_en
18. McIntosh, B. S., & Taylor, A. (2013). Developing T-shaped water professionals: Building capacity in collaboration, learning, and leadership to drive innovation. *Journal of Contemporary Water Research & Education*, 150(1), 6–17. <https://doi.org/10.1111/j.1936-704X.2013.03143.x>
19. Trogstadsæter, I. K., Kokkula, S., & van der Aker, J. (2021). Application of T-shaped engineering skills in complex multidisciplinary projects. *INCOSE International Symposium*, 31(1), 1113–1129. <https://doi.org/10.1002/j.2334-5837.2021.00890.x>



© 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY 4.0) licence (<https://creativecommons.org/licenses/by/4.0/>)