

Research and Innovation Ecosystem for Sustainable Development

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Abstract

Universities are essential pillars for advancing sustainable development through innovation ecosystems. These ecosystems are networks that foster collaboration among universities, research organisations, public institutions (including innovation hubs), and private sector entities. The university's role encompasses promoting research, technology transfer, innovation, and industrialisation (known as Education 5.0 in Zimbabwe), all of which are aligned with sustainability objectives. This positions universities not just as repositories of knowledge but as central hubs that drive progress by connecting and engaging stakeholders. Research and innovation ecosystems act as catalysts for achieving sustainable industrialisation, supporting industrial and economic growth. They are vital in developing and deploying advanced technologies, processes, and business models that enable industries to operate efficiently and sustainably. This includes creating innovative products and materials with lower environmental impact and encouraging circular economic models that focus on reuse, recycling, and resource recovery. Research and innovation activities cultivate a dynamic landscape that unlocks transformative solutions to complex sustainability challenges and helps industries contribute to a greener future. This paper examines the essential role of research and innovation ecosystems in fostering sustainable industrialisation, highlighting key elements such as fostering collaboration, leveraging digital technologies, integrating circular economy principles, and mobilising investment for impactful research development.

Keywords

Research, Innovation, Sustainable Development, Industrialisation, and Ecosystems

1. Introduction

Research and innovation are vital catalysts for achieving sustainable employment, industrialisation, economic growth and development. Investment in research and development (R&D) in institutions of higher learning, such as universities and other research institutions, provides a playground that drives industrial innovations (Salah et al. 2024). Research and innovation play a crucial role in developing and deploying cutting-edge technologies, processes, and business models that enable industries to operate more efficiently and sustainably (Alliou et al. 2023). Furthermore, considering the complicated and dynamic market context, these cutting-edge developments are essential for businesses to maintain their competitiveness. Research and innovation have fostered a rapid development of high-tech industries;

therefore, unbundling the research perspective of industrial innovations that have gradually evolved from a research and innovation system paradigm to a research and innovation ecosystem paradigm (Alliou et al. 2023). The drive for efficient user-friendly ecosystems has seen a rapid rise in the development of high-tech industries, particularly in the developed world, for example, China. These high-tech industries present a noticeable paradigm shift in research activities, especially industrial innovation, from an ordinary innovation system to a more sophisticated innovation ecosystem (Li, et al., 2023). A thriving research and innovation ecosystem defines the roadmap for game-changing ideas that tackle intricate sustainability problems. The problem has been, “What is the role of universities in fostering research and innovation ecosystems for sustainable development?” This paper, therefore, explores the crucial role of research and innovation ecosystems at universities in driving sustainable industrialisation. It explores key elements for promoting collaboration, leveraging digital technologies, integrating circular economy principles, and mobilising investment in impactful research and development (R&D) programmes that lead to cutting-edge innovative solutions for sustainable development.

1.1 Objectives

The objectives of this paper are to highlight and demonstrate the practical role of research and innovation activities in transformative solutions. This paper examines the essential role of universities and other research institutions in creating research and innovation ecosystems that drive sustainable industrialisation. It examines key elements necessary in fostering collaboration, leveraging digital technologies, integrating circular economy principles, and mobilising investment for impactful research development. It looks at the impact of collaboration, the role of government, funding bodies and research institutions, especially universities, in promoting a sustainable research and innovation ecosystem.

2. Research Methods

The research was conducted using published literature, research and innovation activities in the Innovation Hub at a local university and innovation hubs of other local research institutions.

3. Research as a Pacesetter for Economic Industrialisation and Job Creation

Research plays a pivotal role in driving economic industrialisation and job creation by enhancing continuous improvement to match the ever-changing customer needs (Nicolaidis, 2014). It propels problem-solving innovations, leading to the development of new technologies, products, and services. This, in turn, creates opportunities for industrial growth through the opening up of new industries, businesses, and ultimately, employment. It is evident that research and development drive innovation as a catalyst for economic growth (Szopik-Depczyńska et al., 2018).

4. Innovation Ecosystems and Sustainable Development

The innovation ecosystem is a dynamic network that stimulates value creation by encouraging competition and collaboration among researchers, organisations and enterprises, resulting in long-term economic growth and development (Hacıoğlu, 2019). It derives its development strength from technology, its management support from organisations, and its guiding influence from the created value (Yan et al. 2021). Innovation and sustainability are critical for business success, knowledge creation and sharing initiatives. It includes problem identifications, investigations and debuts of novel goods, production techniques, markets, supply chains, and industrial associations (Liu et al., 2019). An effective innovation ecosystem drives the interventions needed to promote and incentivise the achievement of business start-ups that lead to sustainable entrepreneurship (Bakry, et al., 2024). A sustainable innovation ecosystem presents a shared communication platform where enterprises with a common good can generate and profit from the innovations (Nylund, et al. 2021). As such, innovation has become a major force behind economic development and growth. Hence, countries are realising its significance for raising competitiveness and productivity (Jegade, 2024).

For a sustainable business transformation to be successful, it is imperative to position the enterprise strategically within the economic landscape while taking into consideration societal, environmental, and economic possibilities and challenges (Ghobakhloo, 2021). The application of the principles of Design Thinking and adopting the Industry 5.0 Philosophy in the research and innovation process propels organisations to stand a chance of developing a sustainable, innovative business environment (Niehaus et al. 2024).

5. The Research and Innovation Ecosystem

An ecosystem for research and innovation comprises a dynamic set of related actors, activities, facilities and rules that are important for the research and innovation capability. In this context, individual actors and groups have the potential to create value (Dias Sant' Ana, 2020). The guiding principle of the research and innovation ecosystem is a well-designed policy framework (Budden et al. 2018). Figure 1 outlines the Research and Innovation Ecosystems. The framework includes the research policy, innovation and technology transfer policy, and the commercialisation policy. A well-established and funded research and innovation ecosystem fuels technological advancements, establishing new industries, improving existing ones, and augmenting productivity. It spearheads the development of new technologies, systems, products, and services, while also facilitating the commercialisation of research outputs. The road map to the commercialisation of research output begins from the technology transfer paradigm, which defines the technology to be transferred and also the technology transfer ecosystem.

Ecodesign (or environmental design) emphasises the product life cycle during the design phase and integrates environmental considerations throughout product development to reduce negative impacts across the entire product lifecycle (Brambila-Macias, et al. 2021; Van Doorselaer, 2022). This approach looks at the whole value chain of product development, from raw material extraction through manufacturing, operation, to the product end-of-life and disposal (Manuboluet al. 2025). Ecodesign is a catalyst for sustainable innovation, thus driving innovation ecosystems and the circular economy, which are vital tools for eco-innovation and sustainable development (Alka et al. 2024). It is imperative to note that Research trends in the innovation ecosystem and circular economy tend to focus on the circular economy for eco-innovation and resource recovery, circular business models that promote sustainable innovation, sustainable renewable energy, sustainable business models that drive green innovation, entrepreneurship, Artificial Intelligence (AI) and the circular business models, all driven by the sustainable development goals (Alka et al. 2024).

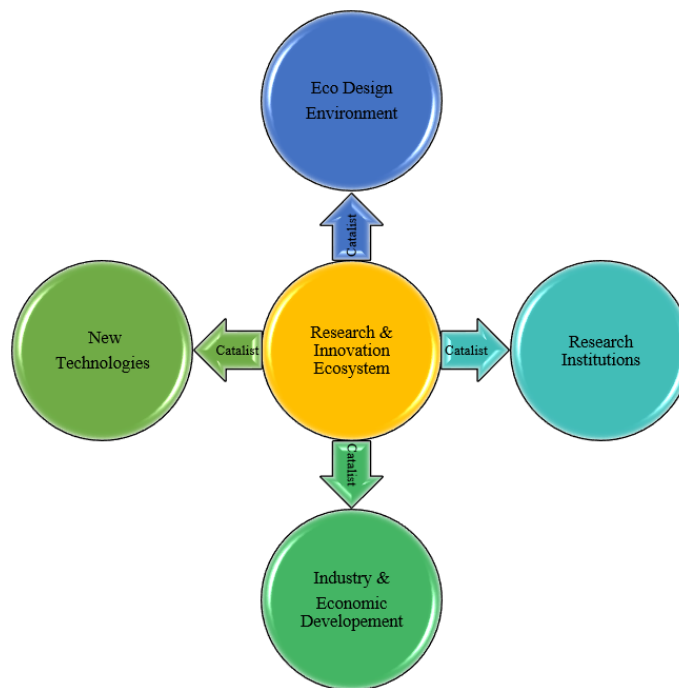


Figure 1. Research and Innovation Ecosystem.

Figure 1 presents four critical catalytic components driving the research and innovation ecosystem. Working in collaboration with industry, the research institutions develop innovative solutions to problems that affect industrial progress and economic development. New technologies are thus developed to tackle industrial challenges and boost economic activity and growth. At the same time, the industry provides a platform, in collaboration with academic institutions, that act as learning factories, where new technologies are developed and tested before adoption by industry. These new technological innovations are controlled and linked to environmental needs, as the world is focused on eco-design principles that are environmentally conscious and friendly. The four principal components,

namely New Technologies, Eco Design Environment, Research Institutions and Industry & Economic Development, are catalysts that form the backbone supporting the Research and Innovation Ecosystem.

Universities are increasingly perceived as agents for economic development through research and innovation activities. As outlined in the Zimbabwe Heritage Education 5.0 Doctrine, academic institutions contribute to the socioeconomic environment by going beyond scientific investigation (research) and teaching, and community activities, to innovation and industrialisation, which incorporates market-oriented initiatives into the academic vision and mission (Chigwada et al, 2025; www.zimche.ac.zw, The Doctrine). The essence of Education 5.0 is to ensure that research output, which may result in the development of new inventions, transforms those inventions into business start-ups that support industrial growth. Figure 2 demonstrates the Education 5.0 philosophy.

The Education 5.0 Philosophy is developed from the existing Education for 3.0 philosophy, which primarily viewed the 3 core activities of universities as research, teaching, and community service. Two more principles (Innovation and Industrialisation) were added, leading to the Education 5.0 philosophy. The primary goal was to ensure that universities and other institutions of higher learning not only remain centres for generating new knowledge but also become centres for creating new industries through innovation and commercialisation of research output, hence boosting industrialisation.

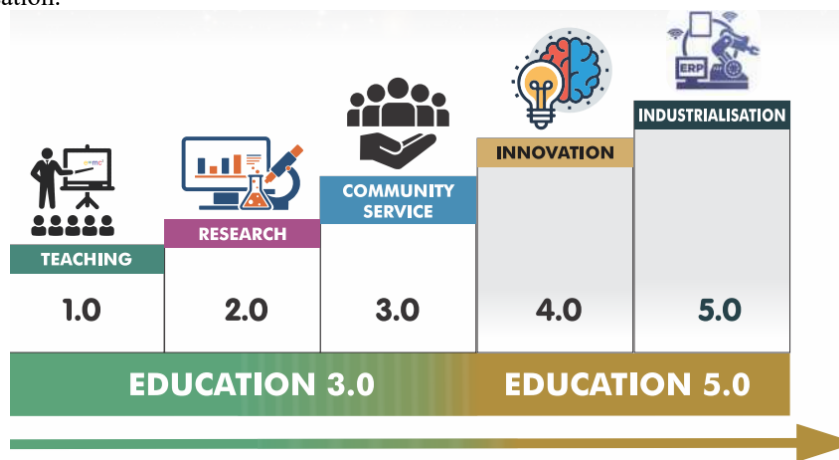


Figure 2. Summary of Heritage Education 5.0 (www.zimche.ac.zw, The Doctrine).

Institutions of higher learning, such as universities, are potential catalysts within the research, innovation and entrepreneurial ecosystem. They contribute in several different ways through their academic programmes. The programmes provide graduates with knowledge and skills that contribute to the development and sustainability of new and existing companies (Schaeffer et al. 2018). They foster and support problem-solving initiatives, the creation of new ideas, leading to innovation and commercialisation. With the support of Innovation Hubs, academic institutions play a vital role in converting research outputs into entrepreneurship and in the growth of small and medium enterprises (SMEs) (Mazzarol et al., 2016).

Sustainable technological innovations drive industrialisation, leading to high-quality economic development (Tang, 2024). Universities and other institutions of higher learning are involved in cutting-edge research and development activities that generate new knowledge and disruptive technologies, as seen in the acceleration of artificial intelligence, automation, robotics, the Internet of Things, the digital revolution, and the expansion of data acquisition (Valavanidis, 2020). Universities have developed research centres, Innovation Hubs, which provide an interdisciplinary platform for research and innovation activities that result in the development of new technologies (Haidegger et al, 2024). These technologies drive significant economic and social advancements that support sustainable development. Universities, research institutions, and high-tech industry collaboration present an ecosystem that catalyses growth, creating an environment for research, innovation and entrepreneurship (Bayramova, 2024). Entrepreneurship creates commercial entities through technology transfer processes, including intellectual property rights protection, startups, incubation, and spin-offs, thereby translating ideas into businesses and establishing industries. On this front, universities maintain greater independence of action and can be seen as direct and indirect drivers of technology transfer activities (D'Alonzo, C., 2021). However, research institutions also work through industry partnerships to foster the development and sustainability of new inventions.

The manufacturing industry, as one of the most prominent industries, is an institution responsible for manufacturing activities resulting in the production of goods and services. These activities technically encompass mechanical invention and technological innovation aimed at maximising production processes at minimal cost (Mohammed, 2019). Industrialisation is one of the pathways for achieving economic development and growth. Through industrial growth, diversification manifests as expanding production systems that ensure the fulfilment of economic development needs, fostering accelerated technological change and integration into global production networks (Bokosi, 2022). Industry is the centre pivot and crucial driver of economic development. It transforms nations and fosters innovation, productivity, and employment creation, leading to economic growth, which ensures social stability (Prabhakar, 2024). Economic development includes the structural transformation of a society, which initially depends on productive traditional economic activities that culminate in enhanced production systems of complex products and services (Naudé et al. 2015).

A research and innovation ecosystem catalyses economic development and growth (Sagar, 2024). It provides a playground where ideas are generated, evaluated and allowed to evolve and flourish. Such an ecosystem presents opportunities for businesses to tap into the rich network of resources, expertise, collaboration and other opportunities to strengthen their development initiatives. The involvement of industrial players in the ecosystem creates a synergy for a strategic relationship to foster a sustainable research and innovation culture with a bias towards industry-related needs (Haidegger et al. 2024).

The research and innovation ecosystem fosters a culture of creativity and continuous improvement by working with an interconnected web of technocrats, including researchers, students, and employees. Collaborations create a synergy of ideas and best practices to accelerate an innovation pace that single entities can rarely achieve on their own. From a problem identification through to a business start-up point of view, it is imperative to recognise the whole spectrum of activities.

5.1 From Research to Business Start-Up - Fostering Research and Innovation Ecosystems for Development

The key interdisciplinary research, development and innovation activities of the University are conducted in the units of the University's Research and Innovation Centres (Innovation Hubs), which ensure a properly coordinated and directed set of activities. Fig. 3 shows the whole spectrum of activities that drive the research and innovation culture at the universities, sometimes in collaboration with industries. The research challenge is initiated through problem identification, which could largely be attributed to societal or industrial challenges, and to a lesser extent, through research students' initiatives. The identified problem is then solved using the conventional research process, where a viable, innovative solution is developed. The process includes problem identification and definition.

In innovation ecosystems, innovation activities are driven by real-world problems that can be addressed through research, yielding solutions. As shown in Figure 3, the research process generates a potential novel solution that can be evaluated in the innovation hub to identify possible intellectual property (IP). If potential is identified, a provisional patent may be filed. This allows research to continue while the solution receives IP protection. The solution is then documented in a research report, which is assessed to determine its potential to solve the identified problem. A viable solution then proceeds to the development of a prototype, which is tested to verify its effectiveness in solving the identified problem. As depicted in Figure 3, there are two routes to the commercialisation of a research output. The first is the usual research problem-solving pathway, following standard research process guidelines. The second, shown at the bottom of Fig. 3, involves developing an industry solution or invention and bringing it to the innovation hub through specified processes for final commercialisation. In both cases, the commercialisation pathway depends on factors such as funding availability or lack thereof, which influences the choices made based on specific criteria. Throughout all these options, understanding the value of IP is essential for making informed decisions. If, for instance, the inventor does not have the funds to commercialise the invention, then the value of the IP becomes a bargaining tool with potential funders or partners.

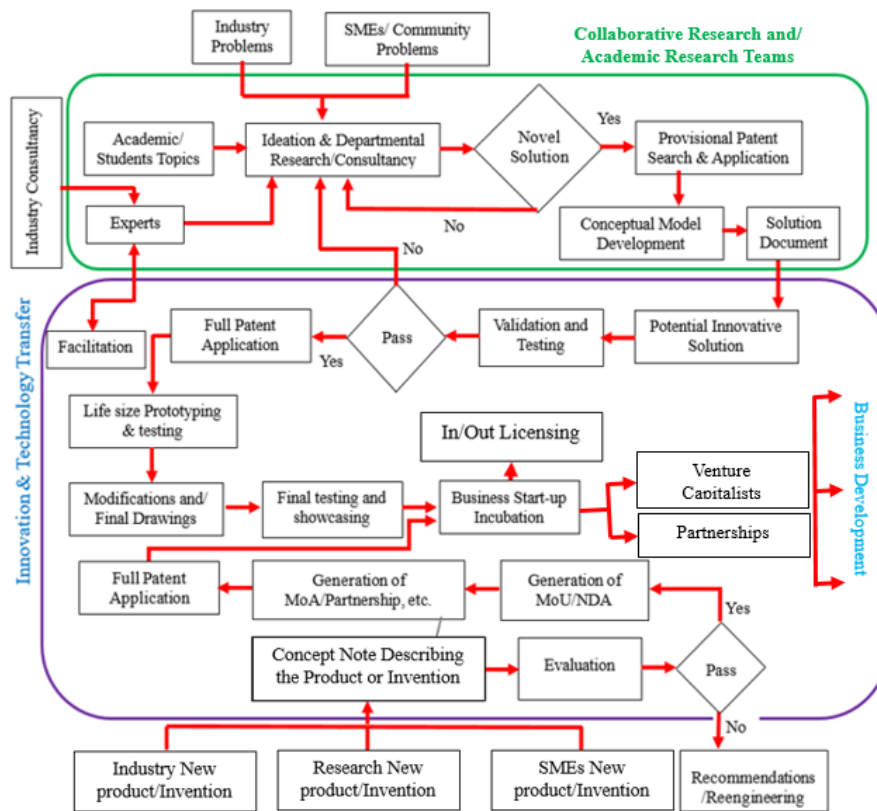


Figure 3 . Research, Innovation ecosystem architecture

Outlined in Figure 3 is a roadmap for research and innovation activities, both from theoretical and practical perspectives. The sequence of events is not necessarily linear, but demonstrates the approaches that are feasible from an academic approach and from a practical industrial approach. It highlights that, from all approaches, a need should have been identified in the form of a problem as defined by the nature of the need, whether industrial, societal or disruptive technology response. The ultimate solution is a developed new product, system or service that can be commercialised using various approaches based on available funding alternatives.

6. Mapping the Research and Innovation Ecosystem

Mapping the research and innovation ecosystem for sustainability predominantly includes understanding the key players, strategic priorities and funding sources that support the sustainability of the ecosystem. It is a fact that an innovation ecosystem is based on a business ecosystem. A business ecosystem is a network of institutions, individuals, technologies, and resources that together interact to create and deliver value. That is, an organisation works with various institutions, such as suppliers, finance institutions, strategic partners, customers, competitors, and regulatory authorities that play specific roles in the quest to stimulate each other's success. A business ecosystem is built on a business model platform that describes the methods an organisation uses to create, deliver and capture value using operational and support resources. The value creation itself is a result of a business model canvas that defines a value proposition for a system, product or service that the organisation seeks to provide. The essence of an ecosystem can be referred to as a structure formed by integrating agents, elements and systems that offer a specific value proposition as they work together or independently to provide a valuable product, system or service. The value created is the target and the reason for being in business. All the systems used for value creation provide a business ecosystem on one hand, and on the other, the innovation ecosystem is developed to rejuvenate the existing business, create a new product, system or service using primarily various inputs like the laboratory and other supporting infrastructure as demanded by the type of output sought. The ultimate is a new value created that will start a new business or boost an existing one. Both systems, working in unison in an organisation, present a sustainable development environment through value creation and continuous improvement. Figure 4 indicates some of the activities and processes at individual and collective levels of the innovation ecosystem and the business ecosystem. A comprehensive ecosystem

constitutes networking and building communities of practice. This creates a culture of shared participation in identifying challenges, developing solutions, learning from peers, and therefore developing long-term relationships to enable future collaborations.

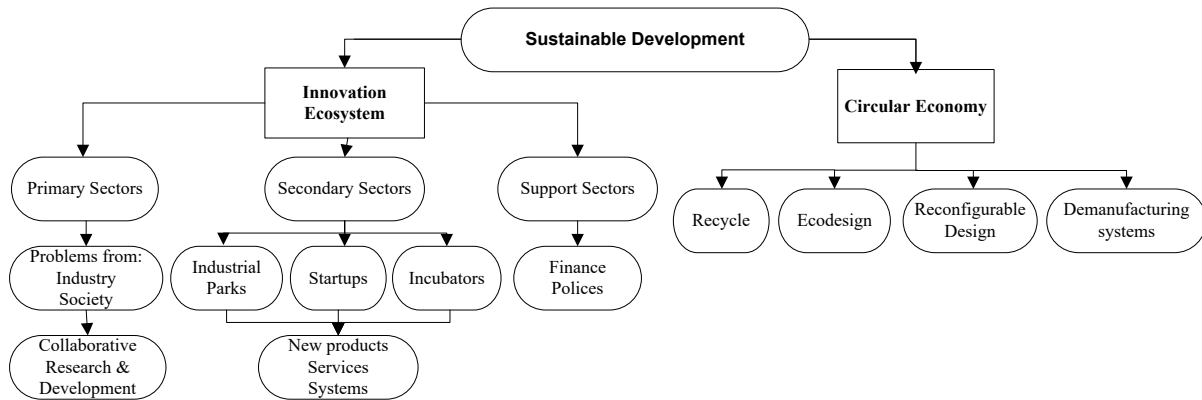


Figure 4. Sustainable development architecture

In Figure 4, it can be appreciated that sustainable development comprises, but is not limited to, the circular economy and the innovation ecosystem. However, these two present critical components and building blocks that form the fundamentals of both the circular economy and the innovation ecosystem. Looking at some of the components, for instance, recycling. Recycling could be a full industry on its own, driven by the need to solve economic waste problems, hence developing innovative solutions that ensure the development of environmentally friendly recycling technologies. These innovative solutions then fall under the innovation ecosystems value chain, creating a continuous, sustainable link through the two paradigms.

The research and innovation ecosystem is driven solely by resource availability, particularly funding, to sustain the activities of the research value chain. Similarly, policies define and provide guidelines for the research and innovation road map. It is important to note that Innovation is the end process of the innovation ecosystem, where the invention goes to the market as a revenue-generating product, system or process.

A successful innovation ecosystem fosters a culture of collaboration, knowledge sharing, and openness. It is rooted in open communication, cross-pollination of ideas, and the generation of strategic partnerships or alliances among different fields of specialisation. It is a collaborative responsibility seeking to develop unmatched new solutions for identified industrial or societal problems.

In sustainability, the funding platforms are centred on a variety of available models. These could include grants rising to some intricate ecosystem of market-related and supported alternatives, or well-defined collaborative partnerships that enable reducing risk levels in innovation ecosystems and promote faster commercialisation. In some sectors, innovation funds are supported by the government through specific funding institutions, where competitive bidding is encouraged to access funds. Key factors that influence success in securing funding include the problem-solving capability of the research package, potential for viability and sustainability, intellectual property prospects, and the technology readiness level, as defined by their criteria. As the technology readiness levels define the state of newly developed inventions, they also lead to the promotion of funding support, in some cases, through public-private partnerships (PPPs), targeted fiscal incentives, and venture capital options.

7. Drivers for Sustainable Technological Innovation

The need to prevail in a highly competitive and continuously evolving market-driven world is a catalyst driving a continuous shift towards a sustainable economy. This shift is propelled by a complex mix of forces, which compel organisations and societies to maintain a sustainable, innovative rhythm. Sustainability results from technological innovations in innovation ecosystems that inspire the integration of technologies in support of economic growth and environmental protection. Collaboration among big institutions like the government, universities, the private sector, investors and communities creates sustainable ecosystems. These institutions play different but vital roles in driving the sustainable technological innovation ecosystem. Governments create conducive environments by formulating

Policies and Regulatory Frameworks that govern innovation operational playgrounds. These environments provide platforms for co-creation, experimentation, and real-world testing of the developed sustainable solutions. Figure 5 gives an overview of the inputs from different institutions into the innovation ecosystem. Research and innovation ecosystems are recognised by their dynamic, interconnected, collaborative networks of diverse actors with a primary aim of co-creating value. On this end, industry and academia have a chance to create a network through the combined development of learning factories that become a base for collaborative research in problem-solving. These learning factories are kind of mini industries where developed technologies are tested, modified and rebuilt, at the same time providing practical training and production facilities for new inventors. With the availability of patent search facilities, researchers and industrialists it forms an important platform for industrial growth on a large scale. In essence, this approach creates a new research and innovation ecosystem that has an added learning factory run by both academia and industry experts, with facilities to support a diverse range of problem-solving innovative research projects.

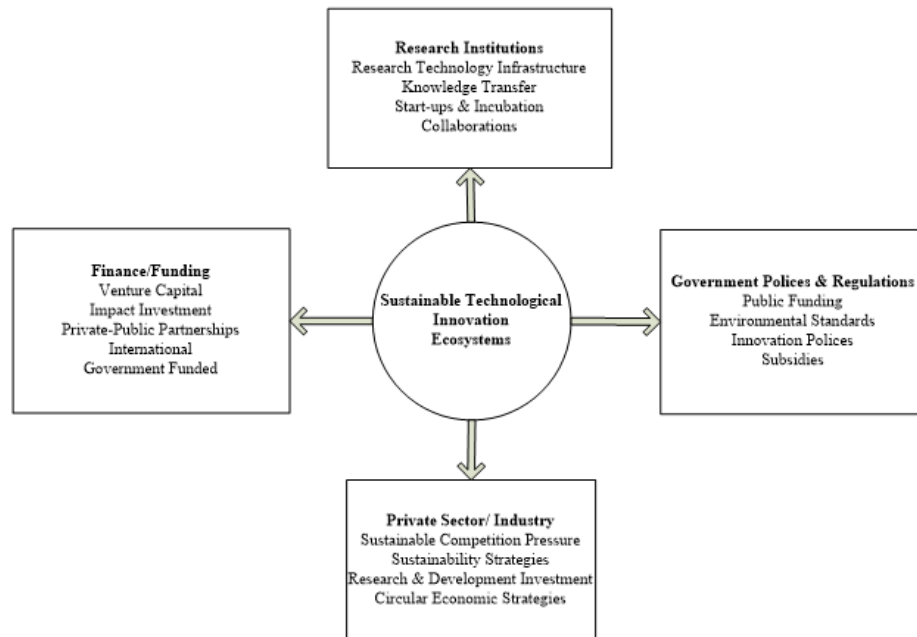


Figure 5. Inputs to the innovation ecosystem.

From Figure 5, it is evident that four critical players support the sustainability of the technological innovation ecosystems. The government, the private sector, finance/funding institutions, and research institutions can collaborate in ensuring the success and sustainability of innovation ecosystems. The government, as a regulator, creates the environment and support systems. The private sector can present problem areas that need solutions and work with research institutions under specific agreements. Funding institutions, similarly, can provide finance to support research innovation efforts that lead to commercialisable output. However, not all research output can be commercialisable.

8. Upskilling and Capacity Building for Innovation

These primarily focus on the development of human skills, knowledge, and organisational or institutional capabilities is designed to create, adopt, and scale up developed technologies, particularly within innovation ecosystems. Thus, the development and equipping of centres of excellence in innovation hubs, industrial parks, incubators and accelerators, and technology exchange platforms. Upskilling and capacity building are drivers of innovations that empower people to determine the value of developed technologies and their potential to solve problems. As a result, skills and knowledge are matched to keep pace with technological changes. Upskilling is a process that centres on knowledge and technology transfer. Figure 6 provides an overview of the critical skills required in incubation centres and startups.

Upskilling and capacity building are technology transfer processes that aim to equip innovators and Institutions with the knowledge and practical skills needed to translate research and development outputs into a production value chain.

These cover manufacturing, commercialisation, and revenue generation, which are essential components for sustainability. The training is usually specialised, combining theory and practice to enable the research innovator to fully understand the real-world application of the required skills and knowledge. Key areas of technology transfer include intellectual property management, regulatory compliance, and navigating licensing agreements, all of which are crucial in selecting the appropriate commercialisation route for a research innovator, considering the invention's value and available funding options.



Figure 6. Critical skills

Many organisations have lost funds by investing in non-viable businesses. In the incubation centres, four important technology transfer skills are taught to the incubatees as outlined in Figure 6. These ensure that the incubatee understands and knows how to start and run a business, opportunity assessment, that is, synthesising market research and client data to identify opportunities, perform a viability assessment to determine the business's chance of survival in the market, understands how to choose the right tools, equipment, skills and technologies to meet their requirements, understands how to market their products, understands how to manage the enterprise and how to deal with financial issues. The importance of these skills is that an innovator/incubatee will have a choice and a full understanding of the business to make meaningful decisions and take appropriate actions as and when required.

9. Discussion

The Research and Innovation ecosystem for sustainability is not defined by what is known as a linear model, which refers to a system based on a linear progression process, where a problem is identified, then research is conducted, leading straight to market entry. It is, in fact, a combination of iterative processes, in some cases through simulation, to determine the best possible outcome. The whole ecosystem comprises the infrastructure, governance, and technology transfer practices that drive towards meeting sustainability. The major factor in sustainable innovation ecosystems is funding, which facilitates capacity building, talent retention, and intellectual property protection. In comparison, the university has created what is known as the Technovation Centre, which provides a state-of-the-art infrastructure for research, innovation and incubation services. Working in collaboration with the Local and Regional Intellectual Property offices, a centre was founded to support innovation activities through the provision of patent information that helps researchers and innovators to ensure they create problem-solving technologies that respond to real-world challenges. The centre works as a collaborative hub for research and innovation activities in the region. As a centre of excellence, it provides the link centred on the innovation ecosystem with branches as outlined in Figure 5. Thus, the innovation ecosystem is not a standalone unit but a collaborative unit that functions through its catalysts, named as research institutions, the government, industry and the funders. Furthermore, to ensure sustainable development, key components, the innovation ecosystem and circular economy are the drivers that together form a web for sustainability. However, the success of an innovation ecosystem is based on the level of skills, funding models, ability to take risks, availability of technological research labs, workshops and most importantly, collaboration. The government plays a vital role in all this by creating a research-oriented environment through policies and regulations.

10. Conclusions

Governments and funding bodies play critical roles in ensuring that the ecosystem develops and remains sustainable. Some of the vital contributions are defining grand challenges and mobilising the entire innovation value chain, from basic research to market deployment and infrastructure development. The number of patents and publications produced may not be used as a measure of success, but jobs created, carbon abatement, and improvement in the quality of life for marginalised communities. It can therefore be concluded that the research and innovation ecosystem for sustainable development demands co-creation, fosters collaboration and partnerships to ensure that intellectual property rights (IPR) are equitably shared, and local manufacturing capacity is prioritised. The results are that solutions are contextually appropriate, affordable, and resilient to local environmental and social conditions. The addition of the innovation support centre gives more impetus to the research and innovation ecosystem. Researchers and innovators can readily access information in any area of their research interest and determine at what level the technology is before they can start their own new development. This creates a ground for impactful new developments, particularly disruptive technologies. The paper highlights and demonstrates the practical role of research and innovation activities in transformative solutions. It presents the essential role of universities and other research institutions in creating research and innovation ecosystems that drive sustainable industrialisation.

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Disclosure Statement

No potential conflict of interest was reported by the authors.

Data availability Statement

The datasets used are available within the article, all cited in the reference list. The rest of the data used in this study are available from the corresponding author upon request.

Author Contributions Statement

The two authors of the manuscript were involved in compiling, revising, and finalising the paper, and they are accountable for all aspects of the work.

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