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Innovation and Sustainable Development with Special Reference to India's Innovation Performance: An Economic Analysis

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Abstract
Innovation has emerged as a critical driver of sustainable development by creating new technologies, improving resource efficiency, generating employment opportunities, and addressing complex economic, social, and environmental challenges. In the context of growing concerns over climate change, resource depletion, inequality, and environmental degradation, innovation provides an important pathway for achieving sustainable and inclusive economic growth. Technological advancements in renewable energy, green infrastructure, digital technologies, sustainable agriculture, circular economy, and low-carbon production can significantly enhance productivity while reducing environmental pressures.
This paper examines the role of innovation in promoting sustainable development, with particular emphasis on the relationship between technological progress, economic growth, environmental sustainability, and social inclusion. It explores how innovation can facilitate efficient utilization of natural resources, reduce carbon emissions, strengthen green entrepreneurship, and create new avenues for employment and income generation. The paper also highlights the importance of policy support, research and development, investment in human capital, institutional capacity, and collaboration among government, industry, academia, and communities in fostering sustainable innovation.
The study argues that innovation should not be viewed merely as a means of increasing productivity but as a transformative mechanism for building a resilient, inclusive, and environmentally sustainable economy. It concludes that an appropriate combination of technological innovation, supportive public policies, sustainable financing, and inclusive institutions can accelerate progress towards the Sustainable Development Goals (SDGs) and contribute to the realization of long-term sustainable development.
Keywords: *Innovation, Sustainable Development, Green Technology, Technological Progress, Sustainable Development Goals, Inclusive Growth, Green Economy.*

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I. Introduction

Sustainable development has become one of the most important objectives of contemporary economic policy. Economies throughout the world face the challenge of maintaining economic growth while protecting natural resources, reducing environmental degradation, and improving the quality of life of present and future generations. Conventional models of development have often emphasised increases in production, consumption, investment, and income. Although these factors remain important, economic growth that depends excessively on fossil fuels, intensive resource extraction, and environmental damage cannot provide a durable foundation for prosperity.Innovation provides an important means of addressing this challenge. It involves the introduction and practical application of new or significantly improved products, production processes, organisational methods, and business models. Innovation can increase labour productivity, reduce production costs, improve resource utilisation, create new markets, and facilitate the transition towards environmentally sustainable economic activities.

The relationship between innovation and sustainable development is particularly important for developing countries such as India. India must generate productive employment for a large workforce, improve agricultural productivity, expand access to quality education and healthcare, strengthen industrial competitiveness, and meet growing energy requirements. At the same time, it must address air pollution, water scarcity, climate vulnerability, waste management, and regional inequalities. India’s economic performance demonstrates the importance of examining the quality and sustainability of growth. The World Bank reported real GDP growth of 6.5% for India in financial year 2024–25 in its November 2025 country overview.

World Bank GroupEconomic expansion creates opportunities for investment in technological capabilities, but sustained progress also requires improvements in productivity, resource efficiency, and environmental performance.Innovation can contribute to this transformation through renewable energy, digital public infrastructure, artificial intelligence, precision agriculture, energy-efficient manufacturing, electric mobility, and circular production systems. However, technological advancement does not automatically produce sustainable outcomes. Its benefits depend on institutional quality, access to finance, workforce skills, appropriate regulation, and the distribution of opportunities across social groups.The central argument of this paper is that innovation becomes a driver of sustainable development when economic productivity, environmental protection, and social inclusion are pursued together.

II. Objectives of the Study

The main objectives of the paper are:

1. To examine the conceptual relationship between innovation and sustainable development.
2. To analyse the contribution of technological innovation to economic growth and productivity.
3. To assess India's research and development expenditure and renewable energy development using official data.
4. To examine the role of innovation in agriculture, industry, digital services, employment, and environmental protection.
5. To identify major barriers to inclusive and sustainable innovation.
6. To suggest policy measures for strengthening India's innovation ecosystem and accelerating sustainable development.

III. Research Methodology

The study follows a descriptive and analytical research design based on secondary data and a review of relevant economic literature. It draws on publications and statistical information from the Government of India, the Department of Science and Technology, the Ministry of New and Renewable Energy, the World Bank, and international literature on innovation and sustainable development.

The analysis focuses on India, with broader international concepts used to interpret the relationship between technological change, productivity, environmental sustainability, and social welfare.

The principal indicators considered include:

- Gross expenditure on research and development (GERD).
- R&D expenditure as a percentage of GDP.
- Renewable and non-fossil electricity capacity.
- Economic growth and productivity.
- Technological adoption across agriculture, manufacturing, and services.
- Employment, inclusion, and environmental efficiency.

The study is based on published aggregate data rather than primary field surveys. It therefore identifies economic relationships, policy implications, and emerging trends rather than claiming to establish causal effects through econometric estimation. Figures from different reporting periods are identified separately, and the analysis distinguishes installed capacity from actual electricity generation.

IV. Conceptual Framework: Innovation and Sustainable Development

4.1 Meaning and nature of innovation

Innovation refers to the development and practical application of new or improved products, processes, and methods that create economic or social value. According to the OECD and Eurostat's Oslo Manual 2018, an innovation must be implemented or made available to potential users; an idea or invention alone is not sufficient.

Innovation may take several forms:

- Product innovation: New or improved goods and services, such as energy-efficient appliances, electric vehicles, and low-cost medical equipment.
- Process innovation: Improved production methods that reduce costs, waste, energy consumption, and material requirements.
- Organisational innovation: New management practices, supply-chain arrangements, and institutional systems.
- Digital innovation: Applications of artificial intelligence, cloud computing, digital payments, data analytics, and digital public infrastructure.
- Green innovation: Technologies and practices designed to reduce pollution, conserve natural resources, and minimise environmental damage.

- Social innovation: New approaches to addressing poverty, unemployment, inequality, healthcare, education, and community development.

These forms of innovation are interconnected. For example, a solar-powered irrigation system combines product innovation, digital monitoring, energy substitution, and changes in agricultural practices.

4.2 Meaning of sustainable development

Sustainable development involves meeting present needs without compromising the ability of future generations to meet their own needs. The concept, articulated in the 1987 report Our Common Future, places intergenerational equity at the centre of development policy.

Sustainable development has three closely related dimensions:

Economic sustainability

Long-term productivity growth, economic resilience, employment creation, efficient investment, and stable livelihoods.

Environmental sustainability

Reduced emissions, renewable energy, biodiversity conservation, efficient resource use, and climate resilience.

Social sustainability

Poverty reduction, equitable access to technology, gender equality, quality education, healthcare, and decent employment.

Innovation supports sustainable development when improvements in one dimension do not create disproportionate costs in another. For example, an industrial technology may increase output but fail to qualify as sustainable if it substantially increases pollution or displaces workers without opportunities for reskilling.

4.3 Theoretical foundations

The relationship between innovation and development can be explained through several economic theories.

Schumpeter's theory of innovation: Joseph A. Schumpeter emphasised the role of entrepreneurs in introducing new products, production methods, markets, and organisational arrangements. His concept of creative destruction explains how innovation transforms existing economic structures, although it may also cause the decline of less competitive firms and occupations.

Endogenous growth theory: Paul Romer and other growth theorists highlighted the importance of knowledge, research, human capital, and technological progress in generating sustained economic growth. Unlike physical capital, knowledge can often be reused across multiple activities, creating wider productivity benefits.

Environmental economics: Environmental externalities explain why market prices may not reflect the full social cost of pollution and resource depletion. Green innovation can reduce these externalities, while environmental taxes, standards, incentives, and carbon pricing can encourage firms to adopt cleaner technologies.

Systems of innovation: This approach emphasises the interactions among universities, research institutions, businesses, government agencies, financial institutions, and users. Innovation depends not only on individual inventions but also on institutions, skills, finance, infrastructure, and the ability to convert research into practical applications.

Together, these theories suggest that sustainable innovation requires both entrepreneurial activity and an enabling institutional environment.

V. Economic Mechanisms Linking Innovation with Sustainability

Innovation contributes to sustainable development through several economic mechanisms.

5.1 Productivity and economic growth

Technological improvements enable firms to produce more output with a given quantity of labour, capital, energy, and materials. Automation, digital management, improved machinery, and scientific production methods can lower unit costs and improve competitiveness.

In agriculture, improved seeds, weather forecasting, and efficient irrigation can raise yields. In manufacturing, energy-efficient machinery can reduce production costs. In services, digital systems can expand the reach of financial, educational, and healthcare services.

However, productivity gains depend on complementary investment. A firm cannot fully benefit from advanced machinery without trained workers, reliable electricity, suitable infrastructure, and effective management.

5.2 Resource efficiency and cost reduction

Innovation can reduce the quantity of raw materials and energy required to generate a unit of output. Resource efficiency improves business profitability while reducing pressure on ecosystems.

Examples include water recycling, precision irrigation, energy-efficient buildings, improved industrial processes, and smart electricity grids. These technologies can be particularly valuable in water-stressed and energy-intensive economies.

5.3 Employment and entrepreneurship

Innovation creates employment through research, engineering, renewable energy installation, maintenance, software development, recycling, environmental consulting, and new business formation.

Nevertheless, the employment effect is not uniformly positive. Automation may reduce demand for routine occupations even as it creates new technical and managerial roles. The overall effect depends on the speed of adoption, the elasticity of product demand, worker mobility, and the availability of education and retraining.

Consequently, sustainable innovation policy must combine technological advancement with skill development and social protection.

5.4 Environmental externalities and the green transition

Private firms may underinvest in clean technologies because some benefits—such as cleaner air and lower greenhouse-gas emissionsaccrue to society rather than exclusively to the innovating firm.

Public policy can correct this market failure through research grants, concessional finance, environmental standards, public procurement, and incentives for cleaner production. Such policies can improve the commercial viability of green innovation while advancing broader social objectives.

5.5 Innovation and inclusive development

Digital financial services, telemedicine, online education, low-cost agricultural technologies, and decentralised renewable energy can expand access to essential services. Yet the gains may remain concentrated among urban, skilled, and wealthier populations if digital connectivity, affordability, and literacy are inadequate.

The distribution of innovation benefits is therefore an essential component of sustainable development.

VI. India's Innovation and R&D Performance: An Economic Analysis

India provides an important case study because of its expanding economy, growing technological capabilities, large domestic market, and significant sustainability challenges.

6.1 Research and development expenditure

Gross expenditure on research and development measures total R&D spending across relevant sectors of an economy. It is an important indicator of investment in scientific and technological capabilities, although it does not directly measure the commercial success or environmental benefits of innovation.

Table 1 presents the latest official series identified for India's R&D expenditure through 2023–24.

Table 1. India's gross expenditure on R&D, 2019–20 to 2023–24

Year	GERD (₹ crore)	GERD as % of GDP
2019-20	1,32,567.01	0.66
2020-21	1,27,380.96	0.64
2021-22	1,94,810.83	0.83
2022-23	2,13,378.12	0.82
2023-24	2,44,767.81	0.84

Source: Department of Science and Technology, Research & Development Statistics 2025–26, as reported by the Ministry of Science and Technology, Government of India.

The figures reveal three important trends.

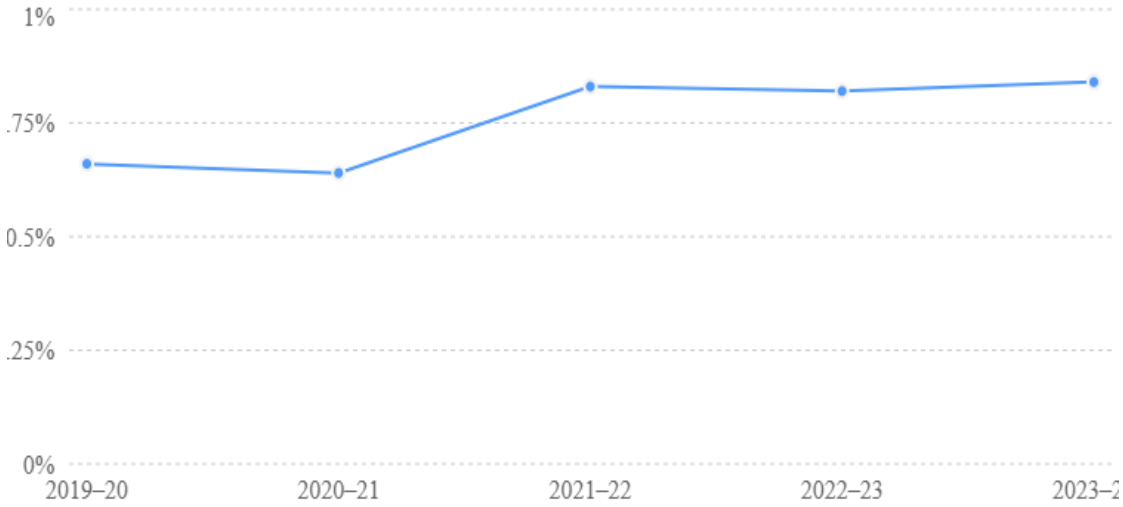
First, total R&D expenditure increased substantially between 2019–20 and 2023–24. It rose by approximately 84.6%, from ₹1.33 lakh crore to ₹2.45 lakh crore. This indicates a significant expansion in the financial resources devoted to research and development.

Second, the R&D-to-GDP ratio increased from 0.66% to 0.84%, but the improvement was relatively modest compared with the rise in nominal expenditure. This distinction matters because nominal spending may increase with inflation and the overall size of the economy. The GDP ratio provides a more informative measure of the relative priority accorded to R&D.

Third, the ratio remains below 1% of GDP. This suggests considerable scope to strengthen research funding, improve university research infrastructure, support industrial R&D, and accelerate the translation of scientific knowledge into commercial and socially beneficial applications.

India's R&D expenditure as a share of GDP

Official reported GERD-to-GDP ratios, 2019–20 to 2023–24.



Source: Department of Science and Technology, Government of India.

6.2 Changing role of the private sector

The composition of R&D expenditure is as important as its total size. Government-funded research often supports fundamental science, public health, agricultural research, and strategic technologies. Businesses are important for product development, commercialisation, industrial process improvements, and scaling up successful innovations.

According to the same official series, the private sector's share of total R&D expenditure increased from 33.8% in 2019–20 to 51.8% in 2023–24. Over the same period, the government's share declined from 66.2% to 48.2%.

This shift indicates a growing contribution from private-sector research. It may strengthen the connection between research and commercial applications. However, it does not remove the need for public investment because firms may avoid research projects with uncertain returns or benefits that are difficult to appropriate privately.

Public policy should therefore encourage business innovation while preserving strong support for basic science, university research, climate adaptation, public health, and technologies relevant to low-income communities.

6.3 Economic growth and technological transformation

India's growth performance provides an opportunity to expand innovation-led development. The World Bank reported 6.5% real GDP growth in FY2024–25 in its November 2025 overview.

The challenge is to translate economic expansion into sustained improvements in productivity, decent employment, energy efficiency, and living standards. Investment in technology can support this objective by enabling firms to move towards higher-value production, improving logistics, increasing the reliability of infrastructure, and strengthening the competitiveness of services and manufacturing.

Yet aggregate GDP growth alone cannot establish whether growth is environmentally sustainable or socially inclusive. A broader assessment must also consider emissions, material consumption, employment quality, income distribution, access to essential services, and the resilience of livelihoods.

VII. Renewable Energy and Green Technological Innovation in India

The energy sector demonstrates how technological innovation can support both economic development and environmental sustainability. India's expanding electricity requirements create a need for reliable, affordable, and increasingly low-carbon energy systems.

7.1 Expansion of renewable energy capacity

Official figures released by the Ministry of New and Renewable Energy reported that India's total renewable energy capacity, including large hydropower, reached 253.96 GW in November 2025. Total non-fossil electricity capacity, including nuclear power, reached 262.74 GW, equivalent to approximately 51.55% of total installed electricity capacity.

Table 2. Selected indicators of India's energy transition, November 2025

Indicator	Capacity
Solar power	132.85 GW
Wind power	53.99 GW
Total renewable energy, including large hydro	253.96 GW
Total non-fossil capacity, including nuclear	262.74 GW
Total installed electricity capacity	509.64 GW
Non-fossil share of installed capacity	51.55%

Source: Ministry of New and Renewable Energy and Government of India releases. Figures refer to installed capacity, not actual electricity generated.

7.2 How green innovation supports economic development

Renewable energy innovation can contribute to development through several channels.

Lower exposure to fossil-fuel price volatility: Domestic solar and wind resources can reduce dependence on imported fossil fuels, although equipment imports, storage requirements, and grid integration create their own costs and dependencies.

Employment and industrial development: Renewable energy creates demand for engineers, technicians, construction workers, manufacturing facilities, installation services, and maintenance professionals.

Technological learning: Research into batteries, power electronics, grid management, green hydrogen, and energy storage can improve domestic technological capabilities.

Decentralised development: Rooftop solar systems, mini-grids, solar pumps, and distributed energy solutions can improve energy access for households, rural enterprises, and agricultural producers.

Climate mitigation: Replacing fossil-fuel-based generation with low-carbon alternatives can reduce emissions, provided that the technologies are integrated effectively and their lifecycle environmental impacts are managed.

7.3 Challenges in the energy transition

Installed capacity does not automatically translate into equivalent reductions in fossil-fuel consumption. Solar and wind generation varies with weather and time of day, requiring flexible power systems, storage, transmission networks, and demand management.

Other challenges include land requirements, financing costs, the recycling of solar panels and batteries, dependence on critical minerals, and the need to maintain affordable electricity for households and small businesses.

Therefore, sustainable energy innovation requires an integrated approach involving technology development, grid modernisation, manufacturing capabilities, appropriate pricing, and environmental safeguards.

8. Sectoral Applications of Innovation for Sustainable Development

8.1 Sustainable agriculture and rural development

Agriculture remains central to rural employment, food security, and livelihood stability in India. Climate variability, water scarcity, soil degradation, fragmented landholdings, and fluctuating market prices create significant challenges for agricultural development.

Innovation can improve agricultural productivity while reducing environmental pressure.

- Precision agriculture: Soil sensors, satellite imagery, and data analytics can help farmers apply water, fertilisers, and pesticides more efficiently.
- Micro-irrigation: Drip and sprinkler systems can improve water-use efficiency where they are technically and economically suitable.
- Climate-resilient crops: Drought-tolerant seeds, heat-resistant varieties, and diversified cropping systems can reduce climate-related risks.
- Digital agricultural services: Mobile platforms can provide weather forecasts, market information, crop advisories, and information about public programmes.
- Post-harvest technology: Cold storage, efficient processing, better packaging, and improved transport can reduce losses and improve farmers' bargaining power.
- Renewable energy in agriculture: Solar pumps and decentralised processing systems can reduce exposure to unreliable electricity supplies, provided groundwater extraction is appropriately regulated.

In arid and semi-arid regions, including western Rajasthan, the relevance of innovation is particularly evident. Rainwater harvesting, traditional khadin systems, moisture-conserving agricultural practices, drought-resistant crops, and improved livestock management can be combined with modern weather forecasting and water monitoring.

Such an approach illustrates that innovation need not always mean replacing traditional knowledge with expensive machinery. It can also involve adapting established local practices through scientific evaluation, better institutional arrangements, and appropriate technology.
The economic benefits should be assessed in terms of farm income, water productivity, production risk, input costs, soil quality, and employment rather than yield alone.

8.2 Industrial innovation and the circular economy
Industrial development generates employment, investment, exports, and technological learning. However, conventional linear production systems follow a pattern of extraction, production, consumption, and disposal, which can lead to resource depletion and waste accumulation.
The circular economy offers an alternative approach based on reducing material use, extending product life, repairing goods, reusing components, and recycling valuable materials.
Industrial innovation can support circular production through:

1. Cleaner production methods that reduce emissions and waste.
2. Energy-efficient machinery and industrial heat recovery.
3. Reuse and recycling of water and industrial materials.
4. Product designs that facilitate repair and recycling.
5. Digital tracking of material flows and supply chains.
6. Industrial symbiosis, in which the waste or by-products of one firm become useful inputs for another.

These approaches can lower input costs and create new business opportunities in recycling, repair, remanufacturing, and resource recovery.
However, firms may face high initial investment requirements, technological uncertainty, limited recycling infrastructure, and weak demand for recycled materials. Targeted finance, standards, producer responsibility, and public procurement can help overcome these barriers.

8.3 Digital innovation and economic inclusion
Digital technologies have transformed banking, commerce, communication, public administration, and the delivery of essential services. Digital payments, online marketplaces, telemedicine, e-learning, and data-based public services can lower transaction costs and improve access to information.
For small enterprises, digital platforms may widen access to customers, reduce marketing costs, and facilitate participation in formal financial systems. Digital records can also improve transparency in supply chains and public administration.
However, digital innovation creates challenges involving cybersecurity, data protection, misinformation, platform concentration, and unequal access to digital skills. Rural households, older people, persons with disabilities, and economically disadvantaged groups may be excluded if services are designed without accessibility and affordability in mind.
The policy objective should therefore be to promote digital inclusion rather than merely increase the number of digital transactions or connected devices.

8.4 Artificial intelligence and advanced technologies
Artificial intelligence, robotics, machine learning, and advanced analytics have the potential to improve productivity across manufacturing, agriculture, healthcare, education, logistics, and financial services.
AI can support early disease detection, crop monitoring, energy-demand forecasting, predictive maintenance, and the optimisation of transport networks. These applications can improve resource allocation and reduce avoidable costs.
Nevertheless, the sustainability of AI depends on reliable data, appropriate governance, computing infrastructure, and responsible use. Data centres consume electricity and water, while automated systems can create employment displacement and algorithmic discrimination.
A development-oriented approach should prioritise AI applications that solve real economic and social problems, establish accountability for consequential decisions, and provide workers with opportunities to develop complementary skills.

8.5 Green entrepreneurship and small enterprises
Small and medium enterprises are important sources of employment and regional economic activity. Green entrepreneurship can create opportunities in renewable energy services, waste management, eco-friendly packaging, water conservation, energy audits, sustainable construction, and repair services.
However, small enterprises often lack access to affordable credit, technical expertise, specialised equipment, and reliable information about green markets.

Incubation facilities, university-industry partnerships, credit guarantees, technology demonstration centres, and targeted procurement can help small businesses adopt cleaner technologies. Public support should be linked to measurable outcomes where feasible, such as reduced energy use, improved water productivity, or lower material waste.

9. Innovation, Employment and Inclusive Economic Growth

Innovation has a complex relationship with employment. New technologies can create jobs in emerging industries while reducing labour requirements in existing activities. The net outcome depends on the balance between job creation, displacement, new demand, and the speed with which workers can transition between occupations.

9.1 Employment creation through new industries

Renewable energy, electric mobility, battery manufacturing, recycling, software services, sustainable agriculture, and environmental management can generate demand for skilled and semi-skilled workers.

The quality of these jobs matters as much as their number. Sustainable development requires decent wages, occupational safety, stable working conditions, and opportunities for career advancement.

9.2 Technological displacement and reskilling

Automation may reduce the demand for repetitive and routine tasks. Workers who lack access to retraining may experience prolonged unemployment or lower earnings.

Policy responses should include vocational education, apprenticeships, recognition of prior learning, digital literacy, and collaboration between educational institutions and employers. Training programmes should respond to actual labour-market demand rather than focus solely on enrolment or certificates.

9.3 Women and disadvantaged groups

Innovation can expand economic opportunities for women and disadvantaged communities through digital entrepreneurship, remote services, accessible financial products, and decentralised energy.

However, technology alone cannot remove structural barriers such as unequal access to assets, unpaid care responsibilities, social discrimination, and gaps in education.

Inclusive innovation requires affordable access, accessible design, financial support, representation in decision-making, and the active participation of communities in identifying local needs.

9.4 Measuring inclusive innovation

A comprehensive assessment should examine not only productivity and profits but also:

- Employment created and displaced across sectors.
- Changes in wages and working conditions.
- Access to technology among small enterprises and rural households.
- Participation of women in technology-related occupations.
- Changes in energy, water, and transport affordability.
- Distribution of productivity gains across firms and regions.

These indicators can help determine whether innovation is broadening economic opportunities or concentrating gains among a limited number of firms and households.

10. Innovation and the Sustainable Development Goals

The United Nations Sustainable Development Goals provide an international framework for integrating economic, social, and environmental priorities. Innovation is relevant to nearly all 17 goals, but its contribution is particularly direct in the following areas.

Table 3. Innovation and selected Sustainable Development Goals

SDG	Role of innovation	Illustrative outcome
SDG 1: No Poverty	Digital finance, productive technology and livelihood innovation	Improved access to income opportunities
SDG 2: Zero Hunger	Climate-resilient crops and precision agriculture	Better food security and resource efficiency
SDG 3: Good Health and Well-being	Diagnostics, telemedicine and medical innovation	Improved access to healthcare
SDG 4: Quality Education	Digital learning and adaptive educational tools	Wider access to learning

SDG 5: Gender Equality	Inclusive digital services and entrepreneurship	Greater participation in economic activity
SDG 7: Affordable and Clean Energy	Solar, wind and energy-storage technologies	Improved access to low-carbon energy
SDG 8: Decent Work and Economic Growth	Productive technologies and green entrepreneurship	Higher productivity and new employment
SDG 9: Industry, Innovation and Infrastructure	Research, industrial upgrading and resilient infrastructure	Stronger technological capabilities
SDG 10: Reduced Inequalities	Accessible services and inclusive innovation	Wider distribution of benefits
SDG 11: Sustainable Cities and Communities	Clean transport and smart urban systems	Improved urban sustainability
SDG 12: Responsible Consumption and Production	Circular production, reuse and recycling	Reduced material waste
SDG 13: Climate Action	Low-carbon technologies and climate adaptation	Greater resilience and emissions reduction
SDG 14 and SDG 15	Environmental monitoring and ecosystem restoration	Better protection of marine and terrestrial ecosystems
SDG 17: Partnerships for the Goals	Research collaboration and technology transfer	Stronger implementation capacity

Source: Author's synthesis based on the United Nations 2030 Agenda for Sustainable Development.

The relationship between innovation and the SDGs is multidirectional. For example, investment in renewable energy can advance clean energy, climate action, employment, and industrial development simultaneously. Similarly, digital agricultural services can support food security, rural livelihoods, and resource efficiency.

However, trade-offs must be evaluated. Mining minerals for batteries may create environmental pressures, while digital infrastructure may increase electricity demand. Sustainable innovation should therefore be assessed over the full lifecycle of technologies and across all three dimensions of development.

11. Major Challenges to Innovation-Led Sustainable Development

Despite its potential, innovation faces several economic, institutional, and social barriers.

11.1 Inadequate research and development investment

India's R&D expenditure remained at 0.84% of GDP in 2023–24.

+1

Limited funding can constrain fundamental research, university laboratories, advanced equipment, scientific careers, and the development of commercially viable technologies.

Research-intensive technologies often require long investment horizons and involve considerable uncertainty. Private firms may consequently underinvest in projects whose social benefits exceed their expected private returns.

11.2 Weak research-industry linkages

Research institutions and businesses do not always operate within an integrated innovation system. Scientific findings may remain unpublished as practical applications, while firms may lack the capacity to identify or adopt research developed by universities.

Technology transfer offices, collaborative research centres, industrial internships, shared laboratories, and joint funding programmes can help bridge this gap.

11.3 Limited access to finance

Early-stage enterprises often lack collateral, established revenues, and a track record. Conventional lenders may therefore hesitate to finance innovative projects, particularly those involving new green technologies.

Venture capital, patient capital, credit guarantees, blended finance, and appropriately designed public grants can help address these financing constraints.

11.4 Skills and human capital constraints

Advanced technology requires scientific knowledge, technical skills, managerial competence, and the ability to adapt to changing production methods. Unequal access to quality education and vocational training can prevent many workers and firms from benefiting from innovation.

11.5 Infrastructure and regional disparities

Reliable electricity, high-speed internet, transportation, logistics, and water infrastructure are necessary for the adoption of many technologies. Rural and less-developed regions may face disadvantages because of limited infrastructure and a shortage of specialised services.

11.6 Environmental and social risks

Not every innovation is sustainable. Electronic waste, battery disposal, excessive water consumption, energy-intensive computing, and poorly managed industrial automation may create new environmental or social costs.

Technology assessment should therefore incorporate environmental impacts, lifecycle emissions, labour-market effects, and distributional consequences.

11.7 Institutional and regulatory barriers

Uncertain regulation, fragmented responsibilities, lengthy approval processes, and inconsistent implementation can discourage investment. At the same time, insufficient regulation may permit pollution, unsafe products, exploitative labour practices, or irresponsible use of data.

An effective institutional framework must balance flexibility for experimentation with appropriate safeguards.

12. Policy Recommendations for Strengthening Sustainable Innovation in India

India requires an integrated policy framework that combines research investment, industrial development, environmental protection, skill formation, and social inclusion.

12.1 Gradually increase R&D investment

Public and private investment in research should increase through a predictable, long-term strategy. Funding should support fundamental science, applied research, university laboratories, climate-related technologies, agricultural innovation, and advanced manufacturing.

An indicative policy objective would be to move progressively towards R&D expenditure of 1% of GDP and subsequently establish more ambitious targets based on fiscal capacity, research outcomes, and international comparisons. Such targets should be treated as proposed policy goals rather than existing commitments.

12.2 Strengthen university-industry collaboration

Universities should be encouraged to work with enterprises, start-ups, public agencies, and local communities. Collaborative research grants, shared technology facilities, internships, innovation hubs, and transparent intellectual-property arrangements can help convert research into practical solutions.

Social science research should also be integrated into technology programmes to evaluate employment, affordability, behavioural change, and distributional outcomes.

12.3 Promote green finance

India should expand access to suitable financing instruments for renewable energy, energy efficiency, water conservation, sustainable transport, recycling, and climate adaptation.

Green bonds, concessional lending, credit guarantees, and blended finance can reduce financing constraints. Strong reporting standards and independent evaluation are necessary to ensure that projects deliver genuine environmental benefits.

12.4 Support start-ups and small enterprises

Technology incubators, university-based entrepreneurship centres, industrial clusters, and rural innovation networks can help new enterprises develop and commercialise sustainable solutions.

Support programmes should include mentoring, testing facilities, affordable credit, access to public procurement, and assistance with intellectual-property protection.

12.5 Invest in skills and human capital

Technical education and vocational training should respond to emerging opportunities in renewable energy, digital services, advanced manufacturing, sustainable construction, and environmental management.

Continuous reskilling programmes should help workers adapt to automation. Training should be accessible to women, rural workers, disadvantaged communities, and employees of small enterprises.

12.6 Strengthen agricultural innovation

Agricultural research should prioritise climate resilience, efficient water use, soil health, livestock productivity, post-harvest management, and affordable digital services.

For arid regions such as western Rajasthan, innovation should combine modern scientific techniques with local knowledge concerning rainwater harvesting, drought-resistant crops, livestock systems, and dryland farming. Technologies should be evaluated for affordability and suitability to local agro-climatic conditions.

12.7 Improve technology transfer and international cooperation

International research collaboration can facilitate access to scientific knowledge, advanced equipment, technical standards, and climate-related technologies.

Cooperation should promote local research capabilities, workforce development, appropriate licensing, and domestic value addition. Technology transfer should not be understood merely as importing equipment; it should also strengthen the ability to maintain, adapt, and improve technologies locally.

12.8 Adopt measurable sustainability indicators

Public programmes should assess both innovation inputs and outcomes.

Table 4. Suggested indicators for evaluating sustainable innovation

Policy area	Suggested indicator
Research	R&D expenditure as a percentage of GDP
Commercialisation	Research-based products and technologies successfully adopted
Productivity	Output per worker and resource use per unit of output
Energy	Renewable generation and energy intensity
Environment	Greenhouse-gas emissions per unit of GDP
Employment	Decent jobs created and workers successfully reskilled
Inclusion	Technology adoption by women, rural households, and small firms
Agriculture	Water productivity, farm profitability, and climate resilience
Circular economy	Material recovery, recycling, and waste reduction
Regional development	Distribution of research funding and innovation activity

These indicators should be disaggregated by sector, region, firm size, and relevant social groups wherever data permit. Evaluation should distinguish between announced investment, actual expenditure, technology adoption, and measurable economic or environmental outcomes.

13. Discussion

The analysis indicates that innovation is an important enabling condition for sustainable development, but its effects depend on economic incentives, institutional arrangements, and the distribution of technological capabilities.

India's R&D expenditure increased considerably in absolute terms between 2019–20 and 2023–24, while its share of GDP remained below 1%. This combination suggests progress in research investment alongside continuing scope for improvement in research intensity.

Similarly, the expansion of renewable energy capacity demonstrates that technological change can occur at scale when infrastructure investment, government policy, market demand, and industrial participation reinforce one another. Nevertheless, capacity expansion alone cannot establish the full economic or environmental impact of the energy transition. Electricity generation, grid reliability, storage, affordability, and lifecycle emissions must also be examined.

The sectoral analysis reveals that innovation has different implications across the economy. In agriculture, its value lies in raising productivity and reducing exposure to climate and water risks. In manufacturing, it can improve competitiveness and resource efficiency. In services, it can reduce transaction costs and expand access to information. In renewable energy, it can support decarbonisation and create new industrial opportunities.

These benefits are not automatic. Technologies can widen inequality when access is concentrated among firms and households with greater financial resources or technical skills. Automation may displace some workers, while poorly regulated innovation can generate environmental damage or new forms of market concentration.

The evidence therefore supports a broader understanding of innovation policy. It should not be restricted to patents, scientific publications, or expenditure on research. It should also evaluate whether knowledge is translated into affordable technologies, productive employment, stronger public services, and improved environmental outcomes.

A sustainable innovation system requires coordination between government, business, universities, financial institutions, workers, and local communities. Public policy must address market failures, invest in public goods, strengthen capabilities, and ensure that the benefits of technological progress are widely shared.

14. Conclusion

Innovation is a critical driver of sustainable development because it can improve productivity, support economic diversification, generate employment, reduce resource consumption, and enable the transition towards environmentally sustainable production and consumption.

The Indian experience demonstrates both the opportunities and the challenges associated with innovation-led development. Gross expenditure on research and development increased from ₹1,32,567 crore in 2019–20 to ₹2,44,768 crore in 2023–24, while R&D expenditure rose from 0.66% to 0.84% of GDP. Meanwhile, official data show that India's non-fossil electricity capacity reached approximately 51.55% of total installed electricity capacity in November 2025.

These developments illustrate growing technological and infrastructure capabilities, although further progress is needed in research intensity, commercialisation, resource efficiency, and the equitable distribution of benefits.

The paper concludes that innovation must be understood as a means of achieving broader development objectives rather than an end in itself. The success of innovation policy should be measured not merely by

technological advancement or economic output, but by its contribution to decent employment, reduced inequality, environmental protection, resilient livelihoods, and improved social welfare.

For India, a forward-looking strategy should combine higher and more effective R&D investment, stronger university-industry partnerships, green finance, advanced skills, agricultural innovation, digital inclusion, and responsible environmental regulation. Special attention should be given to small enterprises, rural communities, women, and regions facing resource constraints.

Ultimately, sustainable development requires a system in which economic incentives encourage environmentally responsible innovation and institutions ensure that technological progress serves society as a whole. Such a system can strengthen India's capacity to achieve the Sustainable Development Goals and build a more productive, inclusive, and environmentally resilient economy.

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