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Renewable Energy, Low-Carbon Solutions, and Sustainable Agriculture

Gayatri Sunkad [1]
[1] Post Graduate, Department of Political Science, Independent Researcher, Badami, Dist. Bagalkot, Karnataka, India gayatri.sunkad@gmail.com
Coresponding Author: gayatri.sunkad@gmail.com

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ABSTRACT

Renewable energy, low-carbon technologies, and sustainable agriculture are increasingly recognized as interconnected pillars of inclusive and long-term economic development. This review examines how the transition from finite, polluting energy sources to renewable alternatives solar, wind, and tidal power supports environmental protection while contributing to economic growth. It further explores the role of low-carbon strategies in mitigating air pollution, global warming, and acid rain, and discusses how sustainable agricultural practices, including natural manuring, precision farming, and soil conservation, safeguard food security without compromising ecological balance. Using a qualitative, literature-based methodology, the article synthesizes findings from previous studies to identify pathways linking renewable energy adoption, carbon reduction, and sustainable farming to national economic resilience. The review finds that these three domains are mutually reinforcing: renewable energy lowers production costs and emissions in agriculture, low-carbon practices protect the ecosystems that agriculture depends upon, and sustainable farming reduces the sector's own carbon footprint. These qualitative conclusions are further corroborated by recent empirical indicators including global renewable capacity growth, the sectoral share of greenhouse gas emissions, and national renewable-energy deployment data which illustrate the scale and pace of the transition already underway. The article concludes that policies integrating renewable energy, low-carbon transport, and sustainable agriculture offer a viable route toward long-term economic and environmental resilience, particularly for developing economies such as India.

Keywords: *Economic development; Empirical evidence; Environmental sustainability; Low-carbon transition; Renewable energy; Sustainable agriculture*

INTRODUCTION

The natural resources available to a nation can broadly be classified into renewable and non-renewable categories, a distinction that underlies almost every discussion of long-term energy and economic planning [1]. Renewable resources those that can be reproduced, recycled, or naturally replenished, such as sunlight, wind, and tidal movement are increasingly described as the permanent backbone of a nation's economic condition, precisely because they do not deplete with use and can be drawn upon across generations [2]. Unlike fossil fuels, whose extraction and combustion release finite reserves into irreversible use, renewable sources allow a country to plan its energy security on a multi-generational timescale.

Among the most widely deployed renewable technologies are solar, wind, and tidal energy, each converting a naturally occurring and continuously available resource into usable power without the sustained emissions associated with conventional generation [3]. Solar photovoltaics harness sunlight directly; wind turbines convert kinetic energy from air movement; and tidal systems exploit the predictable rise and fall of coastal waters. Together, these technologies represent a combination of natural resource endowment and human engineering ingenuity directed toward protecting the environment while meeting growing energy demand [4].

A parallel and closely related concern is the transition toward low-carbon transport and industry. Conventional vehicles running on fossil fuels release carbon monoxide and other pollutants that are harmful both to the atmosphere and to human respiratory health; replacing them with low- and zero-emission alternatives is now considered essential to preserving air quality for all forms of life, including animals and birds that share the same ecosystems [5]. Reducing carbon emissions is also directly linked to slowing global warming, since the accumulation of greenhouse gases is the principal driver of rising average temperatures and of secondary effects such as acid rain [6].

The urgency of this transition is reinforced by the finite nature of fossil fuel reserves themselves: continued dependence on coal, oil, and natural gas is not only an environmental risk but an economic one, since depletion trends and price volatility expose energy-import-dependent economies to instability [7], [8] . At the same time, evidence increasingly shows that human activity has already pushed several planetary systems close to, or beyond, safe operating boundaries, underscoring the need for structural change rather than incremental adjustment [9]

Agriculture, meanwhile, remains one of the oldest and most fundamental occupations in India and in most other economies, and it interacts with the energy transition in two directions. On one hand, agriculture is itself a consumer of energy for irrigation, mechanization, and post-harvest processing and can benefit directly from cheaper, decentralized renewable power [10], [11]. On the other hand, agriculture is central to food security, and its long-term productivity depends on a stable climate and healthy soils, both of which are threatened by unmitigated carbon emissions [12], [13]. Agriculture that is profitable for farmers, that supplies sufficient food to the population, and that is conducted in an environmentally responsible manner can be considered sustainable agriculture, and its resilience is increasingly recognized as inseparable from the broader energy transition [14].

This article therefore treats renewable energy, low-carbon solutions, and sustainable agriculture not as three separate topics but as interlinked components of a single development strategy. The Introduction section situates the problem; this is followed by a statement of the review's specific objectives and its significance; the Literature Review synthesizes prior findings on each theme; the Methods section describes the narrative-review approach used, including the empirical statistical sources consulted; the Results and Discussion section draws out the connections between the three themes and presents supporting quantitative indicators; and the Conclusion summarizes the implications for economic policy, particularly in the context of developing economies such as India.

Building on the problem framed above, this review pursues six specific objectives: (i) to examine solar, wind, and tidal power as illustrative renewable energy sources and their contribution to environmentally sound economic development [3], [4]; (ii) to assess how the substitution of non-renewable with renewable energy affects production costs, trade balances, and employment, particularly in energy-importing developing economies such as India [5]; (iii) to analyze the role of low-carbon transport and industrial practice in preventing air pollution and mitigating global warming and acid rain [6]; (iv) to review scientific and natural methods of cultivation including precision farming, natural manuring, and mechanized cultivation that raise agricultural productivity without expanding the cultivated area [12], [13]; (v) to evaluate soil conservation and erosion-prevention practices as levers connecting agricultural productivity to climate mitigation [14]; and (vi) to synthesize how renewable energy, low-carbon solutions, and sustainable agriculture interact as a mutually reinforcing system supporting inclusive economic development.

Understanding these linkages carries practical significance for policymakers, farmers, and energy planners. For developing economies, where energy demand, agricultural employment, and climate vulnerability intersect most acutely, a clear account of how renewable energy adoption, decarbonization, and sustainable farming reinforce one another can inform integrated rather than siloed policy design [2], [5].

The review is also intended to contribute an evidence base drawing on both peer-reviewed literature and recent empirical statistics for tracking progress toward international climate commitments and national energy-transition targets, and for identifying where further primary and quantitative research is needed, particularly on the agriculture–energy nexus in the Indian context [9].

LITERATURE REVIEW

Renewable Energy and Economic Development

A substantial body of literature links the adoption of renewable energy to national economic performance. Renewable sources are typically eco-friendly and, once installed, offer lower marginal operating costs than fossil-fuel alternatives, making them attractive both for environmental protection and for cost-cutting in energy-intensive sectors [2], [3]. Because renewable energy can substitute directly for non-renewable energy in industrial and household use, its expansion is frequently associated with improved trade balances in energy-importing countries and with new employment in manufacturing, installation, and maintenance [4]. For countries such as India, where energy demand continues to rise alongside population and industrial growth, this substitution effect is considered a boon to the wider economic system rather than merely an environmental measure [5].

Low-Carbon Transition and Environmental Protection

The low-carbon literature converges on three protective functions of emission reduction: preventing air pollution, protecting the health of the atmosphere, and mitigating the twin risks of global warming and acid rain [6]. Studies on fossil fuel depletion argue that continued reliance on carbon-intensive transport and power generation compounds both environmental and economic vulnerability, since reserves are finite and their combustion drives measurable increases in atmospheric CO_2 concentration [7], [8]. Global-scale assessments further indicate that several planetary boundaries relevant to climate stability are already under significant pressure, reinforcing the case for accelerated, rather than gradual, decarbonization [9].

Sustainable Agriculture and Food Security

Within the agricultural literature, sustainability is generally defined by the coexistence of profitability for farmers, adequate food supply for the population, and environmentally sound practice [10], [11]. Scholars have shown that feeding a growing global population without expanding the ecological footprint of farming requires sustainable intensification raising yields on existing land through improved practice rather than through further land conversion [12], [13]. Soil management, in particular, has been identified as a critical lever: practices that build soil organic carbon simultaneously improve fertility, water retention, and climate mitigation, linking agricultural productivity directly to greenhouse gas outcomes [14]. Complementary work on ecosystem services demonstrates that sustainable farming practices including reduced tillage, integrated pest management, and organic input use preserve the pollination, pest-regulation, and water-purification services on which long-term productivity depends [15].

METHODS

This article adopts a qualitative, narrative literature-review methodology. Rather than collecting new primary data, the review synthesizes secondary sources peer-reviewed journal articles, review papers, and policy-oriented studies addressing three interlinked themes: (i) renewable energy resources, (ii) low-carbon solutions, and (iii) sustainable agriculture. The synthesis focuses on identifying recurring findings, points of convergence, and gaps across the three themes rather than statistically testing a hypothesis [16].

Wind and solar energy were treated as the primary illustrative cases for renewable resources, both because of their widespread deployment and because of their relatively low ongoing operating cost once installed [17]. Tidal energy was included as a complementary example of a naturally available, human engineered energy source. For the low-carbon dimension, the review concentrated on transport sector emissions specifically the substitution of conventional vehicles with low and zero emission alternatives as the most visible and policy-relevant example of carbon reduction [18]. For the agricultural dimension, the review examined scientific cultivation methods, soil conservation and erosion prevention, natural manuring, and pre- and post-harvest practices as the core determinants of sustainability [19].

Sources were selected for relevance to the title and thematic scope of the review rather than through a systematic database search protocol; as such, the review should be read as a conceptual synthesis rather than a systematic review. This limitation, along with directions for a more systematic follow-up study, is discussed in the Conclusion.

To move beyond a purely conceptual synthesis, the qualitative literature is supplemented, where relevant, with the latest publicly available empirical statistics from international energy and food-system agencies and from national government sources. These quantitative indicators presented in the Results and Discussion section are used descriptively, to illustrate the observed scale and pace of the trends the literature discusses, rather than to test a formal hypothesis.

RESULTS AND DISCUSSION

Renewable Energy Sources: Solar, Wind, and Tidal Energy

Wind and solar energy remain the most widely adopted renewable technologies, in part because their fuel sunlight and moving air is naturally available at no marginal cost [17], [20]. Their appeal rests on a combination of ecological friendliness and long-run economic savings: once capital costs are recovered, operating expenses are low relative to fossil-fuel generation [3]. Tidal energy, while less widely deployed, illustrates a further point emphasized in the literature that renewable energy is best understood as a combination of natural resource endowment and human engineering intelligence directed at environmental protection [4]. Table 1 summarizes the three renewable sources discussed in this review alongside their principal application, environmental benefit, and main deployment challenge.

Table 1. Comparison of renewable energy sources discussed in this review

Energy source	Primary application	Environmental benefit	Key challenge
Solar (photovoltaic)	Household, commercial, and agricultural power supply	Zero direct emissions during operation; low land-use with rooftop siting	Intermittency; upstream manufacturing footprint [10
Wind	Grid-scale and off-grid electricity generation	Zero direct emissions; high energy return on investment	Site-specific resource availability; grid integration
Tidal	Coastal and estuarine electricity generation	Highly predictable output; low visual and land footprint	High capital cost; limited suitable coastal sites

Source: Author, 2026

Low-Carbon Transport and Emission Reduction

A recurring finding across the reviewed studies is that conventional vehicles release carbon monoxide and other pollutants that damage both environmental quality and human respiratory health [6]. Replacing conventional vehicles with low- and zero-emission alternatives is therefore framed in the literature not simply as an environmental preference but as a public-health and atmospheric-protection measure that benefits all living beings sharing an ecosystem, including animals and birds [7]. Because emissions accumulate globally, reductions achieved in the transport sector contribute directly to slowing the two most frequently cited downstream effects of carbon accumulation: global warming and acid rain [8].

Sustainable Agricultural Practices

The reviewed agricultural literature converges on several concrete practices that jointly define sustainability: scientific and mechanized cultivation methods that raise yields without expanding the cultivated area, soil conservation measures that prevent erosion and preserve fertility, use of natural manure in place of synthetic inputs where feasible, and attention to both pre-harvest and post-harvest stages of the production cycle [11], [12]. These practices are mutually reinforcing with the renewable-energy and low-carbon themes discussed above: solar-powered irrigation and processing reduce the energy footprint of farming [21], while soil-carbon-building practices simultaneously improve productivity and act as a climate mitigation measure [13], [14].

Recent studies specifically addressing the intersection of renewable energy, precision agriculture, and low-carbon strategy reinforce this integrated view. Combining renewable energy adoption with precision farming and data-driven techniques has been shown to reduce on-farm carbon emissions while enhancing overall sustainability outcomes, and reviews of renewable-energy-linked agricultural systems similarly report that energy-efficient practices paired with renewable power reduce both greenhouse gas emissions and reliance on non-renewable resources [22]. Analyses framing low-carbon agriculture as a baseline development scenario further find that technology adoption and supportive government policy jointly strengthen food security while mitigating climate risk [23], a pattern also observed in national assessments of India's transition toward low-carbon farming [24].

Taken together, the results indicate that renewable energy, low-carbon solutions, and sustainable agriculture function as a mutually reinforcing system rather than as three independent policy areas. Renewable energy reduces the operating cost and emissions footprint of agriculture; low-carbon practice protects the atmospheric and ecological conditions on which agricultural productivity depends; and sustainable agriculture, in turn, reduces the sector's own contribution to carbon emissions. This circularity is consistent with global assessments warning that stabilizing carbon emissions requires coordinated, cross-sectoral action rather than isolated interventions [25].

India-specific work on climate adaptation and mitigation in agriculture reinforces this picture, arguing that policy support for both energy diversification and farm-level adaptation is necessary given the country's climate vulnerability, although the political economy of energy access including the risk that transition costs and benefits are unevenly distributed remains a caution that the literature raises for developing economies generally.

Empirical Trends: Quantitative Evidence from Recent Global and National Data

Recent statistics from international agencies lend empirical weight to the qualitative patterns identified above. Global renewable power capacity reached 4,448 GW by the end of 2024, a record 15.1% annual increase driven overwhelmingly by solar and wind, with solar alone accounting for roughly 452 of the 585 GW added that year [26]. On the emissions side, global food systems spanning agricultural production, land-use change, processing, and distribution are estimated to contribute close to one-third of global anthropogenic greenhouse gas emissions, underscoring why sustainable agriculture is treated in this review as a climate lever and not only a food-security concern. At the national level, India illustrates how quickly the renewable-energy component of this system can scale: non-fossil generation capacity rose from about 81 GW before 2014 to more than 250 GW by September 2025, and the country reached the milestone of drawing over half of its installed electricity capacity from non-fossil sources in June 2025 five years ahead of its Paris Agreement (NDC) target.

These indicators are illustrative rather than exhaustive, but they are consistent with the literature-derived pattern described above: renewable deployment is accelerating fastest in the solar segment; agriculture and the wider food system remain a first-order lever for global emissions rather than a peripheral one; and at least one large developing economy India has demonstrated that ambitious non-fossil capacity targets can be met ahead of schedule when policy support, cost declines, and grid investment are aligned. This lends empirical support to the review's central claim that renewable energy, low-carbon transition, and sustainable agriculture should be treated as a coordinated policy system rather than as separate programs.

CONCLUSION

This review has examined renewable energy, low-carbon solutions, and sustainable agriculture as interconnected contributors to the economic development of any country. Renewable energy particularly solar, wind, and tidal power offers a permanent, eco-friendly substitute for finite fossil resources and supports economic progress through cost reduction and reduced import dependence. Low-carbon transport and industrial practice protect atmospheric health, reduce air pollution, and mitigate global warming and acid rain. Sustainable agriculture, grounded in scientific cultivation, natural manuring, and soil conservation, secures food supply while preserving the natural resource base on which farming depends. Recent empirical data reinforce this picture: record global renewable-capacity additions, the substantial share of greenhouse gas emissions attributable to global food systems, and India's accelerated progress toward its non-fossil energy targets all indicate that this is not merely a conceptual argument but a transition that is already measurably under way. Together, these three domains support eco-friendly techniques that advance both environmental protection and long-term economic resilience, and policymakers particularly in developing economies such as India are encouraged to pursue them as an integrated agenda rather than as separate policy tracks

REFERENCES

[1] N. L. Panwar, S. C. Kaushik, and S. Kothari, "Role of renewable energy sources in environmental protection: A review," *Renew. Sustain. Energy Rev.*, vol. 15, no. 3, pp. 1513–1524, 2011, doi: 10.1016/j.rser.2010.11.037.

[2] I. Dincer, "Renewable energy and sustainable development: A crucial review," *Renew. Sustain. Energy Rev.*, vol. 4, no. 2, pp. 157–175, 2000, doi: 10.1016/S1364-0321(99)00011-8.

[3] O. Ellabban, H. Abu-Rub, and F. Blaabjerg, "Renewable energy resources: Current status, future prospects and their enabling technology," *Renew. Sustain. Energy Rev.*, vol. 39, pp. 748–764, 2014, doi: 10.1016/j.rser.2014.07.113.

[4] P. A. Owusu and S. Asumadu-Sarkodie, "A review of renewable energy sources, sustainability issues and climate change mitigation," *Cogent Eng.*, vol. 3, no. 1, 2016, doi: 10.1080/23311916.2016.1167990.

[5] M. J. B. Kabeyi and O. A. Olanrewaju, "Sustainable energy transition for renewable and low carbon grid electricity generation and supply," *Front. Energy Res.*, vol. 9, 2022, doi: 10.3389/fenrg.2021.743114.

[6] R. E. H. Sims, "Renewable energy: A response to climate change," *Sol. Energy*, vol. 76, no. 1–3, pp. 9–17, 2004, doi: 10.1016/S0038-092X(03)00101-4.

[7] S. Karekezi and W. Kithyoma, "Renewable energy strategies for rural Africa: is a PV-led renewable energy strategy the right approach for providing modern energy to the rural poor of sub-Saharan Africa?," *Energy Policy*, vol. 30, no. 11–12, pp. 1071–1086, 2002, doi: 10.1016/S0301-4215(02)00059-1.

[8] M. Höök and X. Tang, "Depletion of fossil fuels and anthropogenic climate change—A review," *Energy Policy*, vol. 52, pp. 797–809, 2013, doi: 10.1016/j.enpol.2012.10.046.

[9] J. Rockstrom, "A safe operating space for humanity," *Nature*, vol. 461, pp. 472–475, 2009, doi: 10.1038/461472a.

[10] W. Chen, J. Hong, X. Yuan, and J. Liu, "Environmental impact assessment of monocrystalline silicon solar photovoltaic cell production: a case study in China," *J. Clean. Prod.*, vol. 112, pp. 1025–1032, 2016, doi: 10.1016/j.jclepro.2015.08.024.

[11] J. Popp, Z. Lakner, M. Harangi-Rákos, and M. Fári, "The effect of bioenergy expansion: Food, energy, and environment," *Renew. Sustain. Energy Rev.*, vol. 32, pp. 559–578, 2014, doi: 10.1016/j.rser.2014.01.056.

[12] H. C. J. Godfray *et al.*, "Food security: The challenge of feeding 9 billion people," *Science (80-.).*, vol. 327, no. 5967, pp. 812–818, 2010, doi: 10.1126/science.1185383.

[13] J. A. Foley, "Solutions for a cultivated planet," *Nature*, vol. 478, pp. 337–342, 2011, doi: 10.1038/nature10452.

[14] D. Tilman, C. Balzer, J. Hill, and B. L. Befort, "Global food demand and the sustainable intensification of agriculture," *Proc. Natl. Acad. Sci.*, vol. 108, no. 50, pp. 20260–20264, 2011, doi: 10.1073/pnas.1116437108.

[15] J. Pretty, "Agricultural sustainability: Concepts, principles and evidence," *Philos. Trans. R. Soc. B Biol. Sci.*, vol. 363, no. 1491, pp. 447–465, 2008, doi: 10.1098/rstb.2007.2163.

[16] R. Lal, "Soil carbon sequestration impacts on global climate change and food security," *Science (80-.).*, vol. 304, no. 5677, pp. 1623–1627, 2004, doi: 10.1126/science.1097396.

[17] P. Smith, "Greenhouse gas mitigation in agriculture," *Philos. Trans. R. Soc. B*, vol. 363, no. 1492, pp. 789–813, 2008, doi: 10.1098/rstb.2007.2184.

[18] J. P. Reganold and J. M. Wachter, "Organic agriculture in the twenty-first century," *Nat. Plants*, vol. 2, 2016, doi: 10.1038/nplants.2015.221.

[19] A. G. Power, "Ecosystem services and agriculture: Tradeoffs and synergies," *Philos. Trans. R. Soc. B*, vol. 365, no. 1554, pp. 2959–2971, 2010, doi: 10.1098/rstb.2010.0143.

[20] A. Chel and G. Kaushik, "Renewable energy for sustainable agriculture," *Agron. Sustain. Dev.*, vol. 31, pp. 91–118, 2011, doi: 10.1051/agro/2010029.

[21] A. Bogdanski, "Integrated food–energy systems for climate-smart agriculture," *Agric. Food Secur.*, vol. 1, 2012, doi: 10.1186/2048-7010-1-9.

[22] "Low-carbon agricultural strategies: Toward environmental sustainability through integration of renewable energy, precision agriculture, and artificial intelligence," *Energy Sci. Eng.*, 2025, doi: 10.1002/ese3.70320.

[23] M. K. Sarker, "Renewable energy and sustainable agriculture: Review of the current situation," *Sustainability*, vol.

15, no. 19, 2023, doi: 10.3390/su151914307.

[24] "Low-carbon agricultural practices enhance climate resilience: Baseline scenario analysis of technology adoption and policy," *Discov. Sustain.*, 2025, doi: 10.1007/s43621-025-01675-y.

[25] R. B. Jackson, "Warning signs for stabilizing global CO2 emissions," *Environ. Res. Lett.*, vol. 12, no. 11, 2017, doi: 10.1088/1748-9326/aa9662.

[26] "2013 International Conference on Services Science and Services Information Technology, SSSIT 2013," 2014. [Online]. Available: https://www.scopus.com/pages/publications/84897765170?origin=resultslist