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Green Economy in Focus: A Comprehensive Review of Its Thematic Dimensions

Yeşil Ekonomiye Odaklanmak: Tematik Boyutlarının Kapsamlı Bir Değerlendirmesi

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ABSTRACT

This study provides a comprehensive, interdisciplinary review of the green economy literature, focusing on the multidimensional thematic areas that shape this evolving field. It systematically examines eight key components of the green economy: jobs, finance, innovation, infrastructure, energy, growth, taxation, and education/skills. These eight pillars were selected because they represent the domains most consistently highlighted across both academic studies and international policy frameworks, ensuring that the review captures the core dimensions of the green economy. For each component, the conceptual framework, practical implementations, and existing gaps in the literature are analyzed. Drawing on academic studies and policy documents from 2000 to 2025, the review explores the intersections of the green economy with critical issues such as just transition, digitalization, and social inclusion. The study emphasizes methodological diversity and measurement challenges. It also highlights opportunities for theoretical and policy integration, offering an original contribution that advances both scholarly understanding and practical guidance in green economy research.

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ÖZ

Bu çalışma, yeşil ekonomi literatürüne kapsamlı ve disiplinler arası bir bakış sunarak, bu gelişmekte olan alanı şekillendiren çok boyutlu tematik alanlara odaklanmaktadır. Yeşil ekonominin sekiz temel bileşeni; istihdam, finans, inovasyon, altyapı, enerji, büyüme, vergilendirme ve eğitim/becerileri sistematik olarak incelenmektedir. Bu sekiz sütun, akademik çalışmalar ve uluslararası politika çerçeveleri arasında en tutarlı şekilde vurgulanan alanları temsil ettikleri için seçilmiş; böylece incelemenin yeşil ekonominin temel boyutlarını yakalaması sağlanmıştır. Her bir bileşen için kavramsal çerçeve, pratik uygulamalar ve literatürdeki mevcut boşluklar analiz edilmiştir. 2000–2025 yılları arasında yayımlanmış akademik çalışmalar ve politika belgelerinden yararlanılarak, yeşil ekonominin adil dönüşüm, dijital-

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leşme ve sosyal katılım gibi kritik konularla kesişimleri araştırılmıştır. Metodolojik çeşitlilik, ölçüm zorlukları ve kuramsal ile politik bütünleşme fırsatlarına vurgu yaparak, bu çalışma hem akademik anlayışı derinleştiren hem de yeşil ekonomi araştırmalarına pratik rehberlik sunan özgün bir katkı sağlamaktadır. Çalışma, yöntemsel çeşitliliğe ve ölçümle ilgili zorluklara dikkat çekmektedir. Ayrıca teorik ve politik bütünleşme için fırsatları vurgulayarak, yeşil ekonomi araştırmalarında hem akademik anlayışı hem de pratik rehberliği geliştiren özgün bir katkı sunmaktadır.

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1. INTRODUCTION

Framed around the pillars of environmental sustainability, social inclusion, and economic resilience, the green economy has increasingly become central to global development discourse. High-level policy frameworks such as the Paris Climate Agreement (United Nations Framework Convention on Climate Change (UNFCCC), 2015b), the 2030 Agenda for Sustainable Development and its Sustainable Development Goals (United Nations (UN), 2015), and the European Green Deal (European Commission, 2019) reflect a growing effort to align economic growth with ecological integrity. In addition, successive Conferences of the Parties (COP) under the UNFCCC framework, including COP21 in Paris (United Nations Framework Convention on Climate Change (UNFCCC), 2015a), COP26 in Glasgow(United Nations Framework Convention on Climate Change (UNFCCC), 2021), and COP28 in Dubai (United Nations Framework Convention on Climate Change (UNFCCC), 2023), have further reinforced the global commitment to embedding the green economy within international climate governance. Within this context, the green economy is not merely an environmentally driven transformation; it represents a multidimensional paradigm that seeks to restructure employment, finance, innovation, infrastructure, and education systems.

In the existing literature, both the definition and the implementation framework of the green economy are still evolving. Georgeson et al. noted that the methodological ambiguity surrounding its core components hinders the concept's measurability and comparability (Georgeson et al., 2017). Similarly, a comprehensive indicator-based analysis by Sarkodie et al. revealed major inconsistencies across studies assessing various aspects of green growth and development, noting that many comparisons are akin to "comparing apples and oranges" (Sarkodie et al., 2023). Against this backdrop, the present study is motivated by the need for a measurable, multidimensional analytical framework that enhances conceptual clarity and facilitates meaningful evaluation. This article provides a comprehensive literature review, addressing both theoretical and practical dimensions of the green economy through eight thematic lenses: green jobs, green finance, green innovation, green infrastructure, green energy, green growth, green taxation, and green education and skill development. By conducting multilevel evaluations across these domains, the study offers a holistic framework for understanding the green economy from both interdisciplinary and sectoral perspectives.

Research articles, reviews, and books have been published on the green economy. As illustrated in Figure 1, the number of publications in this field has risen exponentially in recent years, highlighting the green economy's emerging significance as a strategic response to climate change, environmental degradation, and unsustainable economic models. Accordingly, this topical review aims to analyze the existing literature to identify key trends, policy developments, implementation barriers, and emerging opportunities. Through this analysis, the review aims to provide a comprehensive perspective on the green economy's role in advancing global sustainability objectives.

This study is grounded in ecological economics, post-growth theory, environmental externality theory, and sustainable development principles. Ecological economics highlights the need for economic systems to operate within planetary boundaries (Daly, 1997), while post-growth theory calls for alternative development metrics beyond Gross Domestic Product (GDP) growth (Raworth, 2018). Environmental externality theory supports a rationale for internalizing negative externalities through taxation and regulation, forming the basis for discussions on green taxation (Pigou, 1920). These theoretical perspectives, collectively, shape the study's normative and analytical framework.

The article provides a multidimensional analysis of policy models, financial instruments, technological applications, data-driven indicators, and research gaps, combining conceptual insight with practical examples. It further integrates institutional perspectives by drawing on reports from the Organization for Economic Co-operation and Development (OECD), the United Nations Environment Programme (UNEP), the International Labour Organization (ILO), the United Nations Development Programme (UNDP), the International Renewable Energy Agency

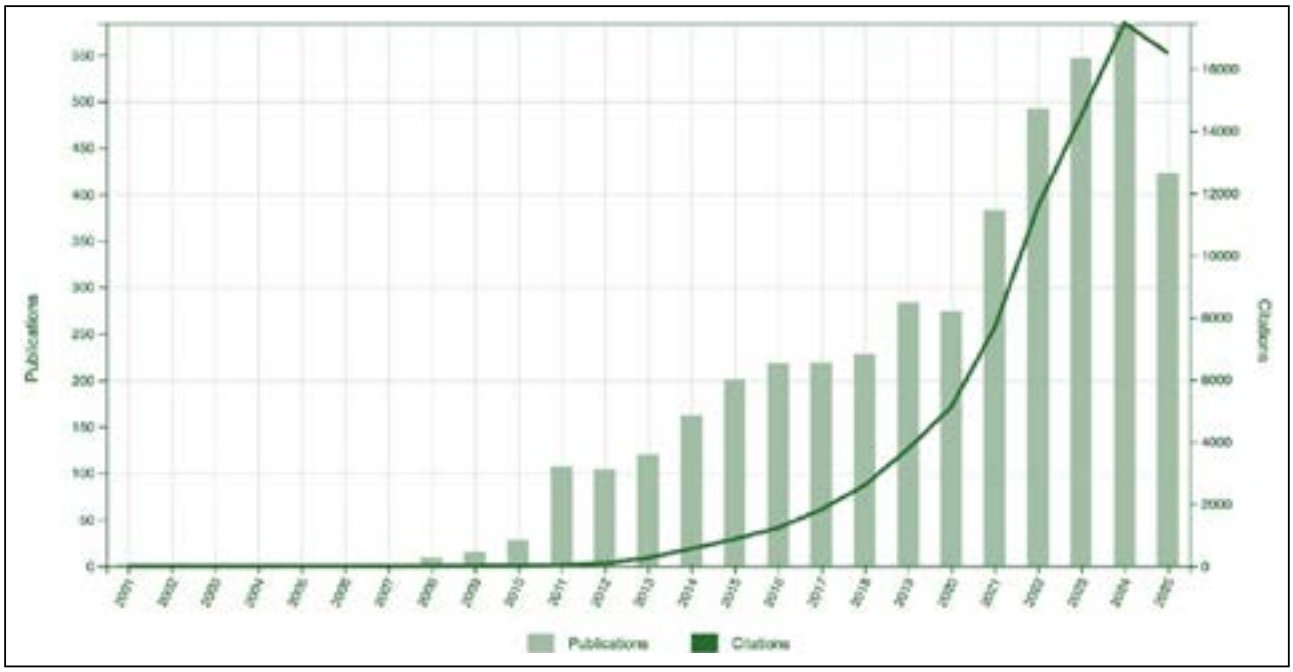

Figure 1. Trends in the number of publications/citations per year resulting from a Web of Science search using the keyword "Green+economy" for the period 2000-2025.

Source: Web of Science, data retrieved in November 2025.

(IRENA), and The European Centre for the Development of Vocational training (Cedefop).

This work contributes to the literature by framing the green economy as a comprehensive development model rather than solely an environmental agenda, emphasizing just transition, social protection, financial inclusion, and education reform, while promoting conceptual clarity, measurement consistency, and policy alignment.

This study thus provides an original synthesis that strengthens both academic debate and policy practice. The identification of the eight pillars was based on a systematic screening of both academic literature and institutional policy frameworks. Across sources such as the UN, OECD, ILO, and UNEP, these domains emerged as the most consistently highlighted dimensions of the green economy. Their recurrence provided a coherent structure for analysis, while ensuring that the review reflects the area's most widely recognized in both scholarly debates and international agendas. Although the broader sustainability literature includes additional concepts, the chosen pillars represent the core fields where academic and policy discussions converge, thereby offering a balanced and comparable framework for evaluation.

In addition, foundational economic analyses such as the Stern Review on the Economics of Climate Change emphasize that the benefits of strong and early action on climate policy far outweigh the costs of inaction, providing a critical rationale for integrating environmental externalities into the green economy framework (Stern, 2006).

The remainder of the article is structured as follows: Section 2 outlines the methodology, Sections 3–10 analyze the eight pillars, and the final section concludes with implications and future directions.

2. METHODOLOGY

In here, the multidimensional nature of the green economy is examined through an interdisciplinary lens, using a qualitative literature review complemented by thematic and systematically structured content analysis.

Analysis focuses on eight thematic areas (green jobs, green finance, green innovation, green infrastructure, green energy, green growth, green taxation, and green education and skill development), organized around the key subsystems of the green economy, as illustrated in Figure 2. This framework enables evaluation at both conceptual and sectoral levels. The methodology is carried out in two main stages:

2.1. Literature Review Strategy

The literature review, covering 2000-2025, was conducted using keywords such as "green economy," "green jobs," "green finance," "sustainable growth," "green taxation," "green skills," and "green infrastructure" across Scopus, Web of Science, and Google Scholar. Three databases were used to balance coverage and quality: Web of Science to ensure high impact, indexed journals; Scopus to widen interdisciplinary reach (including social sciences); and Google Scholar to capture grey literature (policy reports, books) relevant to the green economy. To prevent

Figure 2. Conceptual structure of the green economy and its eight thematic pillars.

duplication across sources, records were de-duplicated through manual screening based on exact matches in title, author(s), and year; where duplicates occurred between Google Scholar and an indexed source, the indexed record was retained. Bibliometric methods guided the review, with particular focus on systematic reviews (Georgeson et al., 2017; Kozar & Sulich, 2023; Mathieu, 2024; Sarkodie et al., 2023; Stanef-Puică et al., 2022). The search employed Boolean operators (e.g., 'green economy' and 'jobs'; 'green finance' or 'sustainable finance'), English-language filters, and document-type limits (articles, reviews, books, institutional reports) within 2000–2025. Inclusion criteria required conceptual or empirical relevance to the eight pillars and traceable sources; exclusion criteria removed non-scholarly content without identifiable provenance or incomplete records. In parallel, strategic documents and technical reports published after 2010 by institutions including the OECD, UNEP, ILO, UNDP, IRENA, International Finance Corporation (IFC), and Cedefop were analyzed. This phase involved a comparative assessment of conceptual definitions, policy models, and measurement tools related to the core components of the green economy.

2.2. Thematic Analysis and Conceptual Structuring

The study employs a thematic analysis strategy, examining each domain at three levels: (i) conceptual definition and theoretical framework, (ii) implementation models and policy orientations, and (iii) gaps in the literature and future research directions. This approach follows a systematic theory → practice → critique progression. Sections on green growth, green finance, and green education further provide comparative analyses that highlight measurement inconsistencies and methodological divergences.

The analysis draws on four theoretical foundations: ecological economics (Daly, 1997), post-growth models (Raworth, 2018), environmental externalities and Pigouvian taxation (Pigou, 1920), and the principles of sustainable development and social inclusion (International Labour Organization, 2015). These frameworks ensure theoretical consistency and enhance the interdisciplinary scope of the study.

Overall, content from both academic and institutional sources is integrated through systematic literature review, thematic analysis, and conceptual structuring. This methodology provides a robust foundation for analyzing the green economy's components in a manner that is measurable, comparable, and critically informed.

3. GREEN JOBS

The employment dimension of the green economy reflects a broad transformation that reshapes occupational structures and skill requirements. This section provides a multidimensional analysis of the evolving concept of green jobs, their sectoral impacts, the transformation of skills, and the policies supporting a just transition.

3.1. Conceptual Evolution of Green Jobs and the Definition Problem

Labor structures shaped by the green economy are commonly analyzed through the concept of green jobs. Initially associated with environmentally friendly production, the term has evolved into a broader framework aligned with social welfare and sustainable development. According to the ILO (International Labour Organization, 2015), green jobs are defined as employment that preserves ecosystems, promotes efficient resource use, minimizes environmental harm, and ensures decent working conditions.

Considerable conceptual diversity exists in the literature. Stanef-Puică et al.(Stanef-Puică et al., 2022) emphasize the multiple associations of green jobs with concepts such as sustainable development, the green economy, the circular economy, and the welfare economy. Green jobs are linked not only to low-carbon sectors but also to areas including circularity, natural capital management, and ecological restoration (Bradley et al., 2025).

This definitional diversity creates methodological challenges for measurement and comparing green jobs. Some studies focus narrowly on technical changes in production, such as energy efficiency or waste management, while others adopt a broader scope that includes sustainability-oriented service sectors (World Economic Forum (WEF), 2025). Such variation complicates the quantitative tracking and hinders the establishment of clear policy priorities.

Ambiguities in the definition also raise questions about inclusiveness and transformative potential of green jobs. Bibliometric analysis by Mathieu (Mathieu, 2024), shows that while the thematic focus of green jobs research has evolved, its geographical coverage remains limited. These

findings highlight the need for a clearly defined framework that links the concept's normative and analytical dimensions.

3.2. Sectoral Transformation of Green Jobs and Employment Impacts

The green economy reshapes both production methods and the sectoral composition of the labor force. The shift toward low-carbon technologies contracts many traditional sectors while fostering new occupations centered on environmental sustainability. A comprehensive analysis by the UK Energy Research Centre demonstrates that renewable energy investments generate more jobs than those in fossil fuel sectors, and deliver positive local economic impacts (Hanna et al., 2022). Emerging employment hubs include solar energy, electric vehicle systems, building insulation, and carbon accounting.

The sectoral impact of green jobs entails both quantitative and qualitative changes. According to the World Economic Forum's Future of Jobs Report 2025, the rapidly growing roles in the green transition such as wind and solar energy technicians, sustainability consultants, environmental impact assessment specialists, and circular design engineers (World Economic Forum (WEF), 2025). These occupations combine technical expertise with environmental and social awareness, reflecting not only sectoral diversification but also a qualitative redefinition of occupational structures.

However, the transition away from fossil fuels risks exacerbating regional and demographic inequalities. The ILO (2025) emphasizes that a just transition must be central to labor market policies, with training programs addressing both technical skills and social inclusion (International Labour Organization, 2015).

Overall, the expansion of green sectors presents multidimensional policy opportunities, particularly for regional development and the mitigation of skills-based inequalities. Sectoral transformation thus offers more carbon reduction; it provides a crucial pathway toward inclusive and equitable labor markets.

3.3. Skill Transformation in Green Jobs and Education Policies

The expansion of green jobs drives sectoral transformation while simultaneously reshaping workforce skill profiles. This transition requires a new skills architecture built on multidimensional competencies, including technical expertise, environmental awareness, systems thinking, and digital literacy. Recent OECD research highlights the importance of these competencies not only for emerging green occupations but also for the redefinition of existing roles. In particular, workers in manufacturing sectors face substantial reskilling needs to transition effectively into green jobs (Organisation for Economic Co-operation and Development (OECD), 2023).

Sector-specific skill foresight studies by Cedefop, conducted within the framework of the European Green Deal, demonstrated that the green transition requires different degrees of skill transformation across sectors (The European Centre for the Development of Vocational Training (Cedefob), 2021). In areas such as waste management and green urban planning, social communication and problem-solving skills are emphasized alongside technical expertise. This indicates that green skills extend beyond engineering and environmental sciences, becoming equally essential in service and management domains.

The capacity of education systems to support this transformation remains contested. The ILO's *Greening the Global Economy – The Skills Challenge* noted that many countries suffer from a shortage of qualified educators in fields such as environmental awareness, renewable energy, and sustainability, while vocational curricula often fail to adequately integrate green skills (International Labour Organization, 2011). Vocational education and adult learning programs, in particular, struggle to keep pace with the rapid demands of the green transition.

In response, education policies should combine technical training with inclusivity and attention to regional disparities. The OECD's *Greener Skills and Jobs* study argued that a successful low-carbon transition depends on a flexible workforce reskilling, positioning education as a fundamental component of ecological transformation (European Centre for the Development of Vocational Training, 2014).

3.4. Just Transition and Social Protection

The green economy transition should align environmental sustainability with social justice. Central to this balance is the concept of a *just transition*, which refers to social policy measures designed to prevent job losses and regional inequalities arising from the phase-out of fossil fuel sectors. The ILO defines it as an inclusive, human-centered transformation process that ensures no one is left behind while achieving environmental goals (International Labour Organization, 2023).

Robust and adaptable social protection systems form a basis of just transitions. The ILO's research on *Social Protection and Climate Change* highlighted how climate change heightens pressures on these systems, which are vital in easing adjustment costs (International Labour Organization, 2021). For workers in sectors vulnerable to job displacement, instruments such as unemployment insurance, reskilling programs, and active labor market policies are critical to mitigating the social risks.

At the global level, the UN's *Global Accelerator on Jobs and Social Protection for Just Transitions* initiative aims to generate millions of new jobs across the green, digital, and care economies, while expanding social protection coverage (Women & UNICEF, 2024). It provides technical and financial support to help countries integrate climate-sensitive social assistance into development strategies, particularly in low-income regions.

The OECD's report *Labour and Social Policies for the Green Transition* further stresses the importance of linking green investments, such as those in energy efficiency, with social protection systems (Keese & Marcolin, 2023). Such integration not only advances environmental objectives but also strengthens public support. Collective bargaining and social dialogue are also identified as essential to ensuring workers' voices are part of the transition.

In sum, just transition is more than an environmental agenda; it is a strategic framework that promotes social inclusion and economic resilience. Embedding strong social protection within this process is crucial for both the sustainability and legitimacy of the green economy.

3.5. PANEL: Green Jobs

Although research on green jobs has expanded rapidly, notable methodological and conceptual gaps remain. A systematic review by Stanef-Puică et al. (Stanef-Puică et al., 2022) revealed that the concept is interpreted through highly diverse definitions which, while enriching methodological approaches, undermine conceptual clarity and coherence. Much of the literature focuses on broad policy frameworks such as sustainable development, the green economy, and the European Green Deal, whereas sector-specific and occupation-based analyses remain limited.

Mathieu's dataset of 414 articles confirmed that green jobs are most often linked to sustainable development, the circular economy, and the European Green Deal (Mathieu, 2024). Yet, these connections largely remain theoretical, with insufficient attention to implementation and measurement tools, hampering comparability and traceability across studies.

Institutions such as the ILO and OECD also highlighted the lack of a standardized definitions and methodologies for measuring green jobs (Organisation for Economic Co-operation and Development (OECD), 2023; Strietska-Ilina et al., 2011). The use of varying national and institutional definitions complicates data collection, creates uncertainty for policymaking, and weakens cross-country comparability. Moreover, empirical research addressing job quality, covering dimensions such as security, wages, and social protection, remains scarce.

Future research should develop an analysis of the links between green jobs and skill transformation, their potential to reduce regional inequalities, and their interaction with digitalization. An IMF study further showed that green jobs are disproportionately male-dominated, with women facing limited access, underscoring the need to examine into gender-based skill disparities in the green transition (Fabrizio et al., 2024).

Finally, bibliometric evidence indicates that the definition of green jobs continues to evolve and varies widely across disciplines (Kozar & Sulich, 2023). This features the urgency of interdisciplinary integration and the development of shared conceptual frameworks.

4. GREEN FINANCE

Green finance occupies a central position in both academic and institutional debates as a critical mechanism for channeling investments toward environmental sustainability. This section examines the field systematically, addressing conceptual ambiguities, financial instruments, measurement frameworks, policy and institutional developments, and key gaps that persist within the literature.

4.1. Conceptual Framework of Green Finance and the Definition Problem

Green finance has gained prominence in recent years as a strategy for directing capital toward environmentally sustainable activities. Yet, the literature still lacks consensus on its definition. UNEP's *Definitions and Concepts* report frames green finance as policy and institutional mechanisms that channel capital into areas such as environmental protection, energy efficiency, and clean energy (United Nations Environment Programme (UNEP)-Inquiry into the Design of a Sustainable Financial System, 2016). By contrast, the OECD defines it more broadly as financial activities that support economic growth while reducing resource use and minimizing environmental harm (Organisation for Economic Co-operation and Development (OECD), 2024b).

These definitional variations blur the boundaries between green finance and related concepts. The IFC distinguished green finance, focused on environmental benefits, from "sustainable finance", which covers wider development goals (International Finance Corporation, 2023). Within this framework, green finance covers not only climate-oriented investments but also instruments targeting biodiversity, water infrastructure, and pollution reduction.

Lack of definitional clarity creates methodological challenges for measurement and classification. While the European Union, China, and Singapore have developed national taxonomies, their inconsistencies complicate cross-border investment and raise the risk of greenwashing. To address this, the Common Ground Taxonomy initiative seeks to align national approaches and provide a shared reference framework (International Platform on Sustainable Finance (IPSF), 2022).

Such definitional uncertainties also influence investor confidence and policy effectiveness. M. Ben Ghoul showed that although consumers express environmental concerns, awareness of green finance products remains limited, highlighting the need for clearer definitions (Ben Ghoul, 2019). Similarly, IMF analysis stresses that ESG (Environmental, Social, and Governance) criteria must be transparent, science-based, and standardized to enhance credibility and effectiveness (International Monetary Fund., 2023).

In summary, the conceptual framework of green fi-

nance remains in a state of evolution. Persistent ambiguities in definition and taxonomy hinder coherence across academic, policy, and investment domains. Advancing internationally harmonized and precise definitions is essential for strengthening its legitimacy and impact.

4.2. Financial Instruments and Mechanisms in Green Finance

The most definite expression of green finance lies in the financial instruments and mechanisms that channel capital toward environmentally sustainable investments. These tools direct funding into low-carbon and nature-positive projects, with green bonds standing out as the most prominent example. Sartzetakis described green bonds as debt securities issued to finance projects with environmental benefits, a market that has grown rapidly since its launch in 2007, led by institutions such as the European Investment Bank and the World Bank (Sartzetakis, 2021). Beyond green bonds, established by the Loan Market Association, stipulate that such loans must finance activities with measurable environmental benefits and require transparent reporting. In the Asia-Pacific region in particular, green loans have played a pivotal role in enabling small and medium-sized enterprises to access sustainability-oriented financing (Organisation for Economic Co-operation and Development (OECD), 2022).

Blended finance mechanisms combine public, private, and development resources to mitigate investment risks and boost investor confidence. According to the OECD, such instruments mobilized nearly $70 billion in development-related investments in 2023 (Organisation for Economic Co-operation and Development (OECD)). They are particularly vital for financing climate adaptation and infrastructure projects in developing economies. Institutions such as the World Bank and the Green Climate Fund have effectively applied blended finance models to attract private capital into renewable energy and carbon reduction initiatives.

Carbon markets represent another important component of green finance. By enabling the trade of carbon credits through voluntary and compliance-based systems, these markets channel funding into emission reduction projects. Nonetheless, concerns regarding transparency, verification standards, and risks of greenwashing continue to spark debate (International Organization of Securities Commissions (IOSCO), 2024). The international framework established under Article 6 of the Paris Agreement aims to address regulatory gaps in this area.

In addition, impact investing and ESG integration enable investors to allocate financial returns with environmental and social outcomes. Incorporating ESG principles into investment strategies enhances both the ethical foundations and long-term performance potential of green finance (Meng & Shaikh, 2023).

4.3. Measurement Frameworks and Standards in Green Finance

Reliable and comparable frameworks are essential for evaluating the environmental impacts of investment activities and for ensuring the effectiveness of green finance. Yet, the literature highlights a persistent lack of standardization in this area. While regulatory bodies such as the European Union and China have advanced by creating their own green finance taxonomies, development finance institutions like the IFC provide additional reference frameworks and guidelines, particularly targeting emerging markets. These systems diverge considerably in scope and technical criteria (International Finance Corporation, 2023; International Platform on Sustainable Finance (IPSF), 2022).

The EU Sustainable Finance Taxonomy provides scientifically based technical screening criteria to define economic activities that contribute to environmental objectives. It applies principles such as "Do No Significant Harm" and "Minimum Safeguards" to maintain environmental integrity (European Commission, 2021). By contrast, China's Green Bond Endorsed Project Catalogue adopts a more sector-specific, policy-oriented approach, emphasizing projects that deliver demonstrable environmental benefits (People's Bank of China (PBoC), 2020). A comparative study conducted by the IPSF under the Common Ground Taxonomy initiative identified shared definitions for 72 activities, representing an important step toward international alignment (International Platform on Sustainable Finance (IPSF), 2022).

Nonetheless, discrepancies among national taxonomies create uncertainty for cross-border investment flows and complicate investor decision-making. Aligning domestic regulations with international standards remains a pressing challenge, particularly for developing countries (Organisation for Economic Co-operation and Development (OECD), 2024a). In addition, the datasets used to evaluate the impact of green finance are often incomplete, outdated, or inconsistent. The NGFS *Enhancing Market Transparency* report highlights that such data gaps undermine both market transparency and investor confidence (Network for Greening the Financial System (NGFS), 2022).

Emerging technologies such as blockchain have recently been explored as tools to enhance the traceability and accuracy of green finance data (Li et al., 2025). These innovations could significantly improve transparency in areas like carbon markets and impact investing. However, their effective adoption will depend on the development of robust technical infrastructure and closer regulatory coordination.

4.4. Institutional and Policy Developments

The global advancement of green finance is driven not only by market dynamics but also by institutional strategies and public policies. The OECD's report *Green Finance Policies, Institutions, Tools and Governance* underlines the importance of a holistic policy approach and robust regu-

latory frameworks centered on environmental integrity as prerequisites for effective green finance (Organisation for Economic Co-operation and Development (OECD)). Such an approach calls for an active role of public financial institutions and regulatory authorities in reshaping the financial system.

The IFC has placed particular emphasis on strengthening green banking capacities in developing countries. Programs such as the Green Bond Technical Assistance Program and the Market Accelerator for Green Construction provide technical support and financing models that encourage private sector engagement in green investments (International Finance Corporation (IFC), 2024). These initiatives enhance the capacity for green bond issuance and stimulate investor interest in areas such as energy efficiency and green buildings.

UNEP, through its *Green Financing for SDGs* strategy, aims to align financial systems with the 2030 Sustainable Development Agenda. This strategy recommends reforms in financial regulation, promotion of public-private partnerships (PPP), and integration of inclusive mechanisms such as microfinance into the green transition (United Nations Environment Programme (UNEP)). In parallel, the UNEP Finance Initiative actively promotes the adoption of sustainability principles across banking, insurance, and investment sectors.

Empirical research has also evaluated the effectiveness of institutional strategies. For instance, Meng and Shaikh identified green bonds, ESG integration, and renewable energy funds as central components of green finance strategies (Meng & Shaikh, 2023). Similarly, Iddrisu, Yakubu, and Abor analyzed banks' motivations for adopting green finance practices, highlighting barriers such as limited awareness, insufficient demand for green financial products, lack of technical expertise, weak regulatory frameworks, and inadequate data for environmental impact assessment (Iddrisu et al., 2025).

At the national level, several countries have embedded green finance within their development agendas. *Türkiye's Sustainable Finance Framework* (2021), for example, outlines priorities such as promoting green bond and sukuk issuance, supporting the financial sector's green transformation, and strengthening regulatory infrastructure (Republic of Türkiye Ministry of Treasury and Finance, 2021). When aligned with global institutional initiatives, such national strategies can significantly accelerate the mainstreaming of green finance.

4.5. Challenges and Opportunities in Green Finance

While the global expansion of green finance offers substantial opportunities for advancing environmental sustainability, it also introduces forth structural and implementation challenges. One of the most widely discussed risks is greenwashing, where firms or financial institutions misrepresent or exaggerate their environmental commitments, thereby undermining investor and consumer trust. Hao et al., using Evolutionary Game Theory, analyzed greenwashing in ESG disclosures and its effects on stakeholders, including firms, investors, and rating agencies (Hao et al., 2025). Their study indicates that a greenwashing-free equilibrium is possible, but only if market-based mechanisms are complemented by strong government oversight.

From the perspective of investor behavior, the growing number of ESG-conscious investors faces significant obstacles due to the inconsistency and diversity of ESG evaluation methodologies. Poiriazi et al. demonstrate that many institutions report high ESG disclosure levels despite weak environmental performance, raising doubts about the reliability of ESG scores as credible investment indicators (Poiriazi et al., 2025).

In developing countries, access to green finance remains limited by regulatory shortcomings and underdeveloped financial markets. According to the IFC (2023), green finance initiatives in these regions are often catalyzed by international investor pressure or guidance from development finance institutions (International Finance Corporation, 2023). However, local financial institutions are frequently reluctant to introduce green financial products due to concerns about the "first-mover disadvantage".

Despite these challenges, the sector offers considerable opportunities. Analysis by the World Economic Forum highlights that the transition to a low-carbon economy creates avenues for banks and investors to pursue long-term business model transformation and innovative product development (McWaters et al., 2016). Moreover, the growth of green bond markets allows financial centers to position themselves as global leaders in sustainable finance.

4.6. PANEL: Green Finance

Although research on green finance has expanded significantly over the past decade, important methodological, conceptual, and practical gaps persist. Georgeson et al. show that many indicators used to measure the green economy remain underdeveloped and often misaligned with existing definitions, limiting the ability to evaluate the true impact of green finance instruments (Georgeson et al., 2017).

A systematic review by Akomea-Frimpong et al. highlights that, despite the diversification of green finance products in the banking sector, empirical evidence on their effectiveness is still scarce (Akomea-Frimpong et al., 2022). In particular, the social inclusiveness of green loans, green bonds, and ESG integration in developing countries has received little attention, raising concerns that environmental priorities may overshadow social objectives.

Mohanty et al., through bibliometric analysis, demonstrate that green finance scholarship is largely concentrated in economics, finance, and business disciplines (Mohanty et al., 2023). While links with environmental and social sciences are emerging, the field's multidisciplinary potential remains underdeveloped, creating methodological chal-

lenges for building a framework that fully reflects the multidimensional nature of green finance.

Digitalization and fintech integration have recently emerged as promising research directions. Zaid et al. emphasize the enabling role of fintech in expanding access to green investment opportunities, yet questions remain regarding their implications for social equity, data transparency, and investor behavior (Zaid et al., 2025). The IMF's *Fintech Applications for Climate Finance* report acknowledges the potential of such tools while also warning of regulatory risks and gaps in data infrastructure (Loukoianova, 2024).

Finally, the relationship between green finance and social inclusion remains insufficiently understood. An empirical study by Han and Gao finds that social inclusion policies exert no statistically significant effect on green economic growth in OECD countries (Han & Gao, 2024). This result underlines the need for deeper inquiry into how green finance mechanisms can be structured to advance not only environmental sustainability but also social equity.

5. GREEN INNOVATION

Green innovation represents a strategic domain encompassing transformative changes in products, processes, and systems that contribute to environmental sustainability. This chapter examines its conceptual foundations, pathways of technological diffusion, and the interactions between policy frameworks and research and development (R&D). It also identifies methodological gaps in the existing literature. The discussion is organized under dedicated subheadings to ensure a systematic and comprehensive analysis.

5.1. Conceptual Framework and Definition of Green Innovation

Green innovation is increasingly recognized as a multidimensional concept encompassing product, process, and system innovations that prioritize environmental sustainability. Guinot et al. define it as the development of environmentally friendly, non-harmful, and sustainability-oriented products and services (Guinot et al., 2022). Beyond reducing ecological impacts, green innovation also functions as a strategic instrument to strengthen firms' competitiveness.

The term frequently overlaps with related concepts such as eco-innovation, environmental innovation, and sustainable innovation. Chen et al. describe green innovation as technological advancement in areas including energy conservation, pollution prevention, waste recycling, green product design, and corporate environmental management (Chen et al., 2006). This definition has since expanded to include both hardware and software innovations. Similarly, Leal-Millán et al. emphasize its role as a strategic imperative that enables firms to respond to environmental demands while capitalizing on emerging market opportunities (Leal-Millán et al., 2020).

Tseng et al. classify green innovation into four categories: managerial, product, process, and technological innovation (Tseng et al., 2013). This typology highlights that corporate environmental strategies extend beyond production to encompass organizational structures, management practices, and technology integration.

Another distinction lies between radical and incremental innovation. Chen, Chang, and Lin argue that radical green innovations represent transformative shifts departing from established knowledge, while incremental innovations involve gradual improvements that build on existing ecological practices (Chen et al., 2014).

Over time, the conceptualization of green innovation has evolved from a narrow focus on environmental impact reduction toward broader systemic transformation goals. These include social responsibility, ethical production, the circular economy, and sustainable consumption. Guinot et al. further observe that while green innovation often emphasizes production processes, some firms extend it across business functions, such as distribution channels and after-sales services (Guinot et al., 2022).

Taken together, these perspectives illustrate how green innovation has emerged as a strategic transformation tool that integrates environmental sustainability with competitive business models within an interdisciplinary framework.

5.2. Technological Applications and Sectoral Diffusion of Green Innovation

The practical impact of green innovation is evident in the diffusion of technological applications across diverse sectors. These applications contribute to sustainable development goals by reducing environmental impacts, improving resource efficiency, and lowering carbon emissions. According to the IMF's *Green Innovation and Diffusion* study, although the patenting and diffusion of low-carbon technologies (LCTs) has recently slowed, targeted policy interventions could help revitalize this process (Hasna et al., 2023).

In the energy sector, notable green innovations include renewable energy technologies such as solar and wind systems, high-efficiency panels, smart grids, and energy storage solutions. The World Intellectual Property Organization's (WIPO) *Green Technology Book* highlights the increasing adoption of urban-scale technologies, including waste heat recovery, microgrids, and prosumer energy models (World Intellectual Property Organization, 2023). These advances not only reduce energy demand but also promote decentralized and participatory energy systems.

In transportation, green innovation is revolutionizing mobility through electric vehicles (EVs), hydrogen fuel cells, and smart mobility technologies. The International Energy Agency's *Global EV Outlook* reported that demand for EV batteries rose by 25% in 2024, reaching over 950 GWh, with passenger vehicles accounting for more than 85% of this demand (International Energy Agency, 2025).

Innovation efforts center on battery technology, charging infrastructure, and recycling systems, while digital tools such as route optimization and fleet management reduce transport-related emissions.

Green innovation also plays a role in expanding energy access. WIPO highlights rural deployments of microgrids and solar-powered irrigation systems that improve livelihoods while limiting environmental pressures (World Intellectual Property Organization, 2023). In industry, green innovation is expressed through low-carbon production methods, waste recycling, eco-certification schemes, and the use of sustainable materials. In energy-intensive sectors such as cement, steel, and chemicals, carbon capture, utilization, and storage (CCUS) technologies are increasingly prioritized. The International Energy Agency estimates that CCUS could deliver about 15% of emissions reductions in these industries (Maldonado & Gallagher, 2022). Although CCUS in steel production remains in early stages, Sun et al. underscore its importance for achieving carbon neutrality targets (Sun et al., 2025). Digital optimization and process modeling tools further enhance industrial efficiency and accelerate adoption.

From a sectoral diffusion perspective, progress is uneven. Clausen and Fichter note that innovation spreads more quickly in information technology and energy efficiency products, while sectors such as transportation and agriculture show slower uptake (Clausen & Fichter, 2019). These disparities reflect differences in technological infrastructure, investment capacity, and policy support.

5.3. Policy and R&D Ecosystem

The diffusion of green innovation depends on both the technological capacity of the private sector and the enabling role of public policy and research systems. Countries where green innovation has advanced most rapidly typically benefit from strong public–private partnerships and university–industry collaboration. The OECD's *Exploring New Metrics to Measure Environmental Innovation* report argued that environmentally friendly innovations cannot rely solely on market dynamics; instead, direct incentives, tax benefits, and strategically targeted R&D grants are essential to accelerate their adoption (Dussaux et al., 2023).

Empirical studies show that strengthening environmental innovation capacity requires access to external knowledge, active support from university partnerships, and the use of open innovation models (Torres de Oliveira et al., 2022). This is particularly important in fields such as renewable energy, waste management, and environmental engineering, where the transfer of academic research into industrial practice determines innovation outcomes.

The European Commission's *Horizon Europe* program illustrates the strategic role of public R&D investment. With a budget of €95.5 billion for 2021–2027, the program prioritizes projects in areas such as the circular economy, low-carbon production, sustainable urban development, and biotechnology (European Commission & European Economic and Social Committee, 2025). Annual allocations for environmental themes are estimated between €8–10 billion, fostering not only technological breakthroughs but also cross-sectoral learning and knowledge diffusion (Clausen & Fichter, 2019). Despite these efforts, regional disparities remain significant. Zhang and Meng find that digital transformation and green innovation efficiency yield stronger effects in disadvantaged regions, where limited financing, educational resources, and technology transfer capacity constrain progress (Zhang & Meng, 2023). This highlights the importance of designing green innovation ecosystems that integrate both technological development and socio-economic equity.

The UNEP's *Global Resources Outlook* further emphasizes that R&D investments should generate not only environmental gains but also social inclusion and equity in order to contribute meaningfully to sustainable development goals (United Nations Environment ProgrammeUnited Nations Environment Programme). Within this framework, micro-enterprises, community-based initiatives, and localized technological solutions are identified as crucial elements of a holistic green innovation ecosystem.

5.4. PANEL: Green Innovation

Although research on green innovation has expanded rapidly, significant methodological, thematic, and contextual gaps persist. There is no consensus on the diversity or consistency of indicators used to measure its impacts, highlighting a lack of reliable analytical tools for policy formulation and strategic decision-making aligned with environmental sustainability goals. Many studies also overlook the environmental and institutional dimensions of innovation, underscoring the need for more holistic theoretical and practical approaches.

A systematic review by Rupasinghe et al. identifies green innovation as an emerging field that requires deeper exploration in areas such as behavioral dynamics, financial integration, product innovation, and technological diffusion (Rupasinghe et al., 2024). Their bibliometric analysis of 381 articles published between 2015 and 2023 maps the knowledge landscape and proposes future research themes, including green innovation behavior, green finance, innovation barriers, environmental regulations, organizational learning, and capabilities.

Thirakulwanich conducted a bibliometric analysis revealing regional disparities in green innovation management literature (Thirakulwanich, 2024). The study shows that policy frameworks in developing countries significantly shape academic output and emphasizes the importance of examining green innovation beyond technology, incorporating governance and institutional capacity perspectives. Structural factors behind these disparities are further elucidated through analyses of institutional collaborations and research networks.

Xu et al. noted that concepts such as digital sustainability orientation and capability restructuring are insufficiently addressed in research on the integration of green innovation and digitalization (Xu et al., 2024). While research on the transformative effects of digital technologies, including Internet of Things, artificial intelligence, and big data, are increasing, their implications for organizational behavior, strategic orientation, and environmental performance remain underexplored.

An empirical study by Zhou et al. further revealed that resource orchestration mechanisms, which explain how digital technologies influence green innovation, are inadequately covered in the literature (Zhou et al., 2024). The study outlines two critical phases shaped by digitalization, green technology R&D efficiency, and successful technology transfer, supported by structures such as digital resource integration, resource synergy, and optimized portfolio management. These findings suggest that future research should extend beyond technological factors to encompass strategic resource management and organizational structuring within green innovation.

6. GREEN INFRASTRUCTURE

Green infrastructure represents a holistic planning approach that integrates nature-based systems to enhance ecological functionality and improve urban quality of life. This chapter examines its multidimensional character, technological applications, and financing mechanisms, and highlights key research gaps identified in the literature.

6.1. Conceptual Framework and Dimensions of Green Infrastructure

Green infrastructure is an interdisciplinary concept involving the strategic planning and integration of natural and semi-natural elements into urban environments to deliver environmental, social, and economic benefits. Benedict and McMahon defined it as "an interconnected network of green spaces that conserves natural ecosystem values and functions and provides benefits to human communities" (Benedict & McMahon, 2002). This definition underscores that green infrastructure extends beyond physical layout, emphasizing ecological functionality alongside societal benefits.

The concept spans multiple disciplines, including ecological planning, landscape architecture, urban design, environmental engineering, and sustainable development (Hansen & Pauleit, 2014; Whitten, 2023). This interdisciplinary reach highlights its multidimensional potential and capacity for integration across diverse areas of expertise.

Green infrastructure is typically analyzed through three core dimensions:

Ecological Dimension: Green infrastructure restores urban ecosystems, preserves biodiversity, and sustainably provides ecosystem services. Umoh et al. note that it reshapes intra-urban ecosystems through ecological networks, green corridors, and nature-based solutions (Umoh et al., 2024). By creating interconnected green spaces that emulate natural ecosystems, green infrastructure enhances urban ecological functionality.

Social Dimension: Green infrastructure improves public welfare, strengthens community spaces, and promotes social inclusion. Whitten emphasizes that planning should incorporate sociocultural values and community participation to enhance urban resilience and adaptive capacity (Whitten, 2023). Parks, green streets, and community gardens act as social hubs, supporting physical and mental health, fostering social interaction, and cultivating a sense of belonging.

Economic Dimension: Investments in green infrastructure yield long-term economic and societal benefits. Shakya and Ahiablame highlight its role in reducing stormwater management costs, enhancing urban livability, creating recreational spaces, and generating green employment opportunities (Shakya & Ahiablame, 2021). By transforming built environments into more livable and aesthetically appealing spaces, green infrastructure also reduces maintenance costs and indirectly strengthens local economies.

6.2. Application Areas and Technological Components

Green infrastructure practices are implemented across multiple sectors and scales to enhance urban sustainability, build climate resilience, and improve quality of life. Literature typically classifies these practices into thematic domains, including urban green infrastructure, water management systems, energy infrastructure, transportation solutions, and sustainable construction technologies, as given in Table 1 (Ashinze et al., 2024; Sitzenfrei et al., 2020).

In urban environments, common applications include green roofs, green walls, permeable surfaces, and rain gardens. These systems provide ecosystem services such as stormwater management, air quality improvement, carbon sequestration, and mitigation of urban heat islands (Ashinze et al., 2024). Green roofs are particularly effective for energy efficiency and microclimate regulation, retaining rainwater through vegetation and stabilizing indoor temperatures (Vink & Vinke-de Kruijf, 2023).

Water infrastructure integrates nature-based solutions like Sustainable Drainage Systems (SuDS), biofiltration zones, rainwater harvesting, infiltration trenches, and permeable pavements. These alternatives to conventional grey infrastructure enable onsite water retention, filtration, and reuse. Bioretention systems improve water quality through chemical and biological purification while mitigating flood risks (Sitzenfrei et al., 2020).

Energy infrastructure also benefits from green innovations. For example, energy recovered from metro braking systems can power electric vehicle charging

Table 1. Thematic classification of green infrastructure applications and associated technologies

Thematic area	Technological components	Key functions & benefits
Urban green infrastructure	Green roofs, green walls, permeable surfaces, rain gardens	Stormwater management, air purification, carbon sequestration, urban heat island mitigation
Water management systems	SuDS, biofiltration zones, rainwater harvesting, infiltration trenches, permeable pavements	Onsite retention, filtration, reuse; flood risk reduction, water quality improvement
Energy infrastructure	Metro brake energy recovery, data center waste heat reuse	Energy efficiency, carbon footprint reduction, climate resilience
Transportation solutions	Bicycle lanes, tree-lined boulevards, sustainable transit stops	Emission reduction, ecological connectivity, public space enhancement
Sustainable construction tech	Recycled aggregates, bio-based composites (e.g., bamboo, hempcrete), low-carbon concrete	Reduced environmental impact, improved thermal performance, long-term durability

*Developed by the author based on interdisciplinary literature published between 2017 and 2025.

stations, while waste heat from data centers provides supplementary energy. Such solutions, documented by WIPO, enhance urban energy efficiency and resilience against climate impacts (World Intellectual Property Organization, 2023).

Transportation infrastructure incorporates green elements through bicycle lanes, tree-lined boulevards, and sustainable transit stops. These interventions reduce carbon emissions, strengthen ecological connectivity, and improve public spaces and social interaction (United Nations Development Programme (UNDP), 2023).

Sustainable construction technologies further support green infrastructure using environmentally friendly materials, such as recycled aggregates, bio-based composites (e.g., bamboo, hempcrete), and low-carbon concrete (Abera, 2024). Geopolymers and fly ash-based concretes, in particular, offer significant potential to reduce carbon emissions while improving energy efficiency, thermal performance, and durability.

To provide a structured overview of these applications, Table 1 summarizes the main thematic areas of green infrastructure together with their associated technologies and functions. This classification is designed to highlight the breadth of recent interdisciplinary research and to facilitate comparison across domains.

6.3. Financing Models and Policy Approaches

Green infrastructure investments deliver substantial long-term environmental and social benefits, yet they often face financing challenges due to high upfront costs and uncertain returns. The literature emphasizes the need for hybrid and innovative financing models tailored to these projects. The OECD's *Approaches for Financing Climate-Resilient Infrastructure* report highlights public-private partnerships and green investment banks as strategic actors in enhancing both climate resilience and financial viability (G20/Organisation for Economic Co-operation and Development (OECD), 2024).

Public-private partnerships are particularly effective for green infrastructure, enabling risk-sharing, securing long-term financing, and facilitating technical knowledge transfer. Owojori and Erasmus identify critical success factors for green-oriented PPPs across sectors such as renewable energy, sustainable urban mobility, water and wastewater management, solid waste management, green buildings, and urban greening (Owojori & Erasmus, 2025). Their findings indicate that the importance of supportive institutional frameworks, committed financing, and collaborative governance. Shamanina further illustrates how PPPs can be integrated with green financing instruments, demonstrating their applicability in Russia and Europe (Shamanina, 2023).

Financial instruments such as green bonds and sustainability-linked loans play a key role in mobilizing private capital. In 2023, the World Bank issued bonds totaling USD 42.2 billion, including USD 0.5 billion in green bonds (World Bank, 2023b). Municipal governments and infrastructure agencies increasingly leverage these products to attract investors, particularly in transportation and energy projects.

Blended finance models, which combine public, private, and development resources, are critical in mitigating investment risks and enhancing project feasibility in developing countries. These mechanisms mobilize roughly USD 70 billion annually and help address infrastructure inequalities in low-income regions.

Policy frameworks and institutional regulations also shape investment patterns. UNEP (2023) highlighted the importance of integrating nature-based solutions and ecosystem services into financing decisions (United Nations Environment Programme (UNEP)). The Inter-American Development Bank's *Resilient PPP Toolkit* provides a multi-sectoral roadmap for embedding climate resilience throughout the design, implementation, and lifecycle management of PPP projects (Donadi et al., 2024).

6.4. PANEL: Green Infrastructure

Despite rapid growth in the literature over the past decade, significant gaps remain in conceptual clarity, measurement consistency, and performance evaluation methodologies for green infrastructure. A major limitation is the insufficient availability of comprehensive data systems capable of holistically assessing the environmental, social, and economic impacts of green infrastructure components, which hampers the evaluation of their long-term effects. Existing studies tend to emphasize the technical dimensions of green infrastructure, while crucial sustainability principles, such as social inclusion, local participation, and equity-based distribution, are often underrepresented. This gap underscores the urgent need to develop integrated, multi-actor approaches in green infrastructure planning.

Sitzenfrei et al. note that research on green infrastructure predominantly focuses on water management systems, yet analyses of long-term performance and system resilience remain limited (Sitzenfrei et al., 2020). Similarly, Vink and Vinke-de Kruijf argue that current models inadequately capture holistic impacts on water and energy resources, while social adaptation and community participation are frequently overlooked (Vink & Vinke-de Kruijf, 2023).

Whitten emphasized that although technical knowledge dominates green infrastructure policymaking, the sociocultural contributions of local communities are often marginalized or treated as subjective, resulting in limited integration into planning processes (Whitten, 2023). This finding points to the the importance of design frameworks that balance technical requirements with social inclusion.

Empirical evidence from Shakya and Ahiablame indicates that green infrastructure projects can increase property values; however, quantitative data on the equitable distribution of benefits across income groups is scarce (Shakya & Ahiablame, 2021). Economic models often rely on assumptions rather than direct observational data, reducing the robustness of conclusions.

A comprehensive review by Ashinze et al. acknowledges the critical role of green infrastructure in climate adaptation, disaster resilience, and ecosystem service integration, while highlighting persistent methodological constraints in developing interdisciplinary data models (Ashinze et al., 2024). The study stresses the importance of multi-stakeholder collaboration and integrated planning, arguing that such approaches are essential for managing the complexity of green infrastructure and enabling sustainable urban transformation.

7. GREEN ENERGY

Green energy has emerged as a cornerstone of sustainable development, encompassing energy production methods that rely on low-carbon and environmentally friendly sources. This section adopts a multi-level approach to explore the definition of green energy, the range of technologies involved, relevant policy and financing mechanisms, as well as key methodological gaps identified in the literature.

7.1. Conceptual Framework and Definition of Green Energy

Green energy refers to energy production methods that use natural resources while minimizing environmental impacts and aligning with sustainable development goals. While often considered a subset of renewable energy, not all renewable sources qualify as green; for instance, certain biomass applications can generate significant carbon emissions, complicating their classification as environmentally "green" (Constellation Energy, 2022; International Renewable Energy Agency, 2022).

Aktar et al. define green energy as "clean energy sources that generate lower environmental impact compared to conventional energy technologies," highlighting its role in combating climate change and driving sustainable economic and social transformation (Aktar et al., 2020).

A recurring theme in the literature is the distinction between green and renewable energy. While renewable energy broadly covers naturally replenishing sources, green energy emphasizes the net environmental impact of energy production. It is inherently linked to low-carbon energy systems: the International Energy Agency's "Net Zero by 2050" roadmap projects that by 2050, 90% of global electricity generation will derive from renewable sources, aiming to reduce carbon emissions to near zero (International Energy Agency, 2021). This transition affects not only energy production but also consumption patterns, infrastructure, and policy frameworks.

IRENA further highlights green energy as a strategic tool for achieving climate goals, expanding energy access, creating jobs, and fostering socio-economic development (International Renewable Energy Agency, 2023). Accordingly, green energy plays a multidimensional role within the broader sustainable development agenda.

In summary, green energy functions as a transformative instrument integrating environmental sustainability, low-carbon transitions, and social inclusion. Its diverse definitions reflect the interdisciplinary nature of the concept and its adaptability across contexts and applications.

7.2. Technology Types and Application Areas

Green energy technologies encompass environmentally friendly systems developed to reduce reliance on fossil fuels and lower carbon emissions. In the literature, these technologies are typically classified by energy sources: solar, wind, hydroelectric, geothermal, biomass, and green hydrogen, the latter recognized by the OECD as a strategic element in the green transition (International Renewable Energy Agency, 2023; Paunov et al., 2025). Table 2 provides a concise overview of these technologies.

Solar energy is harnessed for electricity and heat generation through photovoltaic panels and solar thermal sys-

Table 2. Renewable Energy Technologies: Sources, Applications, and Strategic Insights

Technology type	Energy source	Key applications	Strategic notes
Solar energy	Sunlight	Residential, industrial, agriculture	Cost-effective, scalable
Wind energy	Wind (onshore/offshore)	Urban grids, industrial zones	Offshore systems offer higher efficiency
Hydroelectric energy	Flowing water	Large dams, small rivers	Environmental impact must be assessed
Geothermal energy	Earth's heat	Heating, electricity, greenhouses, tourism	High efficiency in volcanic regions
Biomass energy	Organic waste	Biofuel production, rural energy access	Supports energy equity
Green hydrogen	Water + renewables	Energy storage, transport, industrial use	Enhances supply security and flexibility

*Developed by the author based on recent interdisciplinary literature.

tems. Applied across residential, industrial, and agricultural settings (e.g., irrigation), solar energy is valued for its technical contribution to decarbonization, cost-effectiveness, accessibility, and versatility. Its growing strategic importance underscores its central role in low-carbon transitions.

Wind energy converts kinetic energy into electricity via onshore and offshore turbines. Offshore turbines benefit from stronger, more consistent winds, improving efficiency, while onshore turbines are optimized for lower wind speeds. Wind farms supply electricity to both industrial and urban grids, supporting large-scale renewable energy deployment (International Energy Agency (IEA), 2025).

Hydroelectric energy generates power by utilizing the potential energy of water through large dams or small-scale river systems. While renewable, hydroelectric projects require careful environmental planning due to ecological impacts and high capital costs (International Finance Corporation, 2015).

Geothermal energy exploits heat from beneath the Earth's crust for electricity generation and direct heating applications. Particularly effective in volcanic regions, geothermal energy supports building heating, greenhouse climate control, and thermal tourism.

Biomass energy is derived from converting organic materials such as agricultural residues, animal waste, and forest products into biofuels and energy. By converting these materials into biofuels or electricity, biomass enhances energy access, particularly in rural and semi-urban areas (Alao et al., 2024).

Green hydrogen is produced via water electrolysis powered by renewables, green hydrogen serves as a zero-carbon energy carrier and storage medium (Nnabuife et al., 2024). Integrating green hydrogen with solar and wind systems enhances production stability and energy security, supporting broader low-carbon infrastructure (Bernadett, 2025).

Across sectors, green energy technologies are increasingly deployed to reduce emissions and enhance efficiency. In transportation, these include electric vehicles, hydrogen fuel cell buses, and biofuels; in industry, low-carbon production processes and green steel; and in buildings, solar panels and geothermal heat pumps play a critical role (International Renewable Energy Agency, 2023).

7.3. Policies, Regulations, and International Developments

The acceleration of the green energy transition relies not only on technological innovation but also critically on effective policy and regulatory frameworks. At the global level, the Paris Agreement serves as the cornerstone guiding green energy policies. Through Nationally Determined Contributions (NDCs), countries commit to carbon emission reductions, many of which prioritize renewable energy targets. According to IRENA, 90% of the 156 submitted NDCs incorporate renewable energy measures focused on the electricity sector, and 67% set quantitative targets for renewable electricity generation (World Health Organization, 2021).

In the European Union, the European Green Deal and its follow-up, REPowerEU, prioritize green energy investments to enhance energy security and accelerate the phase-out of fossil fuels. By 2023, renewable sources accounted for 47% of EU electricity generation, with solar and wind energy surpassing natural gas (Eurostat (European Commission), 2025). REPowerEU also includes legal and regulatory measures promoting energy efficiency, grid modernization, and industrial decarbonization.

International organizations, including IRENA, United Nations Conference on Trade and Development (UNCTAD), IEA, and UNDP, provide technical guidance, policy recommendations, and financial assessments to support the diffusion of green energy strategies. IRENA's *Policies for the Energy Transition* report emphasized the need for comprehensive policy packages across all technological sectors to achieve deployment targets by 2030 (International Renewable Energy Agency, 2023). UNCTAD highlighted a substantial annual investment gap of USD 2.2 trillion for energy transition efforts in developing countries, stressing the urgent need for balanced and inclusive policy instruments (United Nations Conference on Trade and Development (UNCTAD), 2023a).

At the national level, Türkiye ratified the Paris Agreement in 2021 and committed to achieving net-zero emissions by 2053. Initiatives under the National Energy and Mining Policy include Renewable Energy Resource Zones (REZ) projects and the development of a Green Taxonomy aligned with EU standards. The Investment Strategy 2024–2028 by the Presidency of the Republic of Türkiye Investment Office targets the expansion of green energy capacity, domestic technology development, and the implementation of carbon pricing mechanisms. Despite these efforts and capacity increases in 2022, Türkiye's overall energy dependency remains high, with continued fossil fuel consumption driven by rising demand (Erdemir, 2022).

Regulatory tools such as feed-in tariffs, carbon taxes, renewable portfolio standards, and net metering have been widely adopted to incentivize green energy investments. Successful examples include Germany's Energiewende, the UK's Contracts for Difference scheme, and Canada's carbon tax regime, which collectively serve as models for promoting clean energy transitions (Energy Evolution Conference, 2024).

7.4. Economic Impacts and Financing Mechanisms

The green energy transition drives substantial economic effects by fostering environmental benefits, stimulating investment flows, and reshaping global energy markets. According to BloombergNEF's Energy Transition Investment Trends Report (2023), global investments in the energy transition rose by 11% in 2024, reaching USD 2.1 trillion (BloombergNEF, 2023). This increase is largely attributed to record-level funding in sectors such as solar energy, electrification, and energy storage (BloombergNEF, 2025).

Data from the IEA indicated that global energy investments exceeded USD 3 trillion for the first time in 2024, with approximately USD 2 trillion allocated to clean energy technologies (International Energy Agency, 2024). Investment in renewable and low-carbon technologies now nearly doubles that in fossil fuel sectors. Concurrently, the cost of solar photovoltaic technologies has declined by 30% over the past two years, driven by technological innovation, economies of scale, and improvements in global supply chains (International Energy Agency, 2024).

Financing the green energy transition increasingly relies on innovative mechanisms that go beyond traditional capital models. A systematic review by Long et al. categorizes financing tools into six groups: public finance, private finance, market-based instruments, innovative financing models, risk mitigation mechanisms, and institutional capacity development (Long et al., 2024). This framework offers a comprehensive lens to evaluate which financial instruments are most suitable at different stages of energy transition projects.

High upfront capital requirements and perceived investment risks remain major barriers for green energy projects. In developing countries, additional challenges such as political instability, currency fluctuations, and regulatory uncertainties complicate project financing and affect banking sector readiness. To address these challenges, blended finance models, which strategically combine public and private resources, have emerged as effective instruments to mitigate risks and mobilize investment, particularly for large-scale renewable energy projects (Institute for Energy Economics and Financial Analysis (IEEFA), 2024).

7.5. PANEL: Green Energy

Although the rapid growth of academic research on green energy, several critical gaps persist, particularly in the integration of technology, policy, and finance, as well as in understanding the social dimensions of the energy transition. Most studies focus heavily on resource development and financial instruments, whereas energy justice, behavioral transformation, and socio-political influences remain underexplored. A bibliometric analysis by Sahin and Ok Ergün highlighted that current research predominantly emphasizes technological and financial aspects (Ok Ergün & Şahin, 2025). Similarly, Hayford et al. underlined the complex yet under-investigated interactions between energy efficiency and green technology integration, pointing to the urgent need for more comprehensive, interdisciplinary studies (Sam Hayford et al., 2025).

The role of digital technologies, including the Internet of Things, big data analytics, and artificial intelligence, has gained attention in green energy scholarship. However, there is still a lack of quantitative models assessing how these technologies influence decision-making, consumer behavior, and infrastructure performance. Olson noted that these gaps hinder a holistic understanding of the synergy between digitalization and the green energy transition (Olson, 2024).

In the financing domain, Long et al. revealed that existing research is fragmented, lacking a comprehensive classification of financial mechanisms suitable for different stages of the energy transition (Long et al., 2024). This fragmentation complicates the development of coherent strategic models and underscores the need for a unified theoretical framework to guide investment deployment effectively.

Spatial and regional disparities in energy investments further exacerbate global inequalities. According to IRENA, per capita renewable energy investment in Europe was 41 times higher than in Sub-Saharan Africa and 57 times greater than in North America (Climate Policy Initiative, 2023). Such disparities lead to uneven energy access, divergent development outcomes, and varying levels of environmental resilience, highlighting the necessity of research grounded in energy justice principles.

Finally, while green energy financing research has largely focused on advanced economies, hybrid and context-specific financing models for developing countries remain underrepresented. Expanding the research scope to these regions is essential for designing inclusive, universally applicable strategies that support a global and equitable energy transition.

8. GREEN GROWTH

Green growth represents a holistic development paradigm that seeks to align economic progress with environmental sustainability. The OECD defines green growth as a strategy that promotes economic development while ensuring that natural assets continue to provide essential resources and ecosystem services for human well-being (Organisation for Economic Co-operation and Development (OECD), 2011). By challenging the perception of a zero-sum relationship between economic growth and environmental protection, green growth emphasizes that both objectives can be pursued simultaneously through appropriate policy instruments. The concept gained prominence as an "exit strategy" for both developed and developing countries following the 2008 global financial crisis. UNEP further characterizes green growth as a low-carbon, resource-efficient, and socially inclusive transformation process with the potential to reduce poverty, generate employment, and support sustainable development (United Nations Environment Programme (UNEP)).

8.1. Conceptual Framework and Definition of Green Growth

Academic literature conceptualizes green growth through three principal theoretical lenses:

Neoliberal Approach: Focuses on market-based mechanisms and technological innovation to address environmental challenges. Central policy tools include carbon pricing, green taxation, and incentives for private sector investment (Hallegatte et al., 2012).

Ecological Economics Approach: Emphasizes that economic activity must operate within ecological limits. Daly and others advocate for development that prioritizes qualitative improvements over quantitative expansion, recognizing the finiteness of natural resources (Daly, 1997).

Post-Growth Approach: Questions the compatibility of traditional economic growth with sustainability goals, promoting alternative models such as degrowth and doughnut economics to redefine prosperity and human well-being (Raworth, 2018; Schulz & Bailey, 2014).

Despite its growing influence, green growth suffers from definitional inconsistencies and methodological misalignments, as highlighted by Georgeson et al., particularly between theoretical constructs and available measurement tools (Georgeson et al., 2017). These gaps pose challenges for evaluating the effectiveness of green growth policies and initiatives.

Operational frameworks, such as the Green Growth Index developed by the Global Green Growth Institute, translate these objectives into measurable dimensions: efficient and sustainable resource use, natural capital protection, green economic opportunities, and social inclusion (Global Green Growth Institute, 2020). Green growth thus functions as a strategic, multidimensional framework that bridges economic development, environmental sustainability, and social equity, providing guidance for both policymakers and researchers.

8.2. Green Growth Policies and Implementation Models

Green growth policies comprise multi-level strategies aimed at harmonizing economic development with environmental sustainability. The OECD's *Towards Green Growth* strategy emphasizes that successful green growth requires correcting market failures, pricing environmental externalities, and fostering technological and institutional innovation (Organisation for Economic Co-operation and Development (OECD), 2011). Key policy instruments under this framework include carbon taxes, green subsidies, environmentally responsible public procurement, and support for R&D activities.

Integrated modelling approaches are increasingly recognized as essential for guiding green growth strategies. UNEP's Green Economy Modelling framework employs tools that simultaneously address economic, environmental, and social dimensions, enabling policymakers to evaluate sectoral transitions, project policy impacts, and assess synergies among interventions (United Nations Environment Programme (UNEP); World Economic Forum (WEF), 2025). For example, the Integrated Green Economy Modelling framework combines system dynamics, general equilibrium models, and social accounting matrices to analyze the multidimensional effects of green growth policies.

Social inclusion and equity are central to green growth implementation. The World Bank's Inclusive Green Growth strategy emphasizes integrating environmental objectives with social policies, such as labor market transformation, skills development, and reducing regional inequalities, to achieve equitable and sustainable outcomes (World Bank, 2012).

Several countries have pioneered practical green growth policies: South Korea launched its Low Carbon Green Growth strategy in 2009, focusing on investment in 27 priority green technology areas, supported by R&D funding and commercialization incentives (Jung et al., 2022). China, through its 12th Five-Year Plan, aimed to create one million new jobs and reduce rural poverty via green industrial policies and sustainable natural resource management (Green Growth Best Practice Initiative, 2014). The European Union has advanced its energy transition via the Green Deal and REPowerEU, expanding carbon pricing mechanisms and promoting sustainable finance to restructure markets toward low-carbon outcomes (European Commission, 2019). Türkiye has integrated green growth into strategic planning, including the 2024–2028 International Direct Investment Strategy by the Presidency of the Republic of Türkiye Investment Office. Key priorities include green energy, circular economy investments, green infrastructure, enhanced investor access, Green Taxonomy development, and prepa-

ration for an Emissions Trading System aligned with international standards (Investment Office of the Presidency of the Republic of Türkiye, 2024).

Guidance for national-level implementation is also available through frameworks such as the Global Green Growth Institute's 18-step Green Growth Planning Guidelines (2018). This tool-based, participatory framework covers diagnosis, assessment, action planning, and implementation, helping policymakers strengthen capacities for sectoral transitions, data-driven analysis, and informed decision-making (Global Green Growth Institute, 2018).

In sum, green growth policies combine regulatory, fiscal, and strategic instruments with integrated modeling and planning frameworks to facilitate sustainable, equitable, and economically viable development pathways.

8.3. Measurement Tools and Indicators

Effective monitoring of green growth necessitates both conceptual clarity and robust, multidimensional measurement tools. The OECD's Green Growth Indicators framework provides over 30 indicators organized into four key dimensions: environmental and resource efficiency in production and consumption, the natural asset base, environmental quality of life, and economic opportunities alongside policy responses (Organisation for Economic Co-operation and Development (OECD), 2011). These indicators enable multi-level tracking of green growth by measuring metrics such as energy and carbon intensity, natural resource consumption, green employment shares, and environmental R&D expenditures, allowing policymakers to evaluate both efficiency and sustainability outcomes.

To assess the sustainability of economic growth beyond conventional GDP metrics, the Inclusive Wealth Index (IWI) developed by Managi and Kumar (Managi & Kumar, 2018) offers a comprehensive evaluation by integrating natural capital, human capital, and produced capital. A 2024 study analyzing 163 countries over 30 years demonstrated that the IWI provides a more realistic depiction of long-term wealth accumulation and depletion than traditional economic measures (Managi et al., 2024). Notably, the IWI functions as an early warning system, revealing instances where short-term income gains may mask losses in natural capital, thereby guiding more sustainable policy interventions.

The Inclusive Growth Index by UNCTAD evaluates the equitable distribution of economic growth, incorporating social and environmental dimensions (United Nations Conference on Trade and Development (UNCTAD), 2023c). Data reveal significant disparities: developed countries score an average of 42.5 on environmental criteria, while developing countries average 31.3, highlighting persistent equity gaps in green growth outcomes.

In addition, the Environmental Kuznets Curve (EKC) literature has extensively examined the hypothesized inverted U-shaped relationship between income and environmental degradation, providing a widely used framework for analyzing growth–environment dynamics (Grossman & Krueger, 1995).

The broader Beyond GDP movement includes a variety of alternative measurement systems designed to overcome GDP's limitations. The WISE (Wellbeing, Inclusion, and Sustainability Evaluation) Metrics platform, developed by Jansen et al., integrates over 60 indicators into a triangular model of sustainability, inclusion, and wellbeing (Jansen et al., 2023). This platform allows for comprehensive policy assessment by comparing multiple indices, including the Human Development Index (HDI), Genuine Progress Indicator (GPI), Index of Sustainable Economic Welfare (ISEW), SDG Index, Doughnut Economics frameworks, and Planetary Boundaries.

Principles for effective green growth measurement include: First, utilizing data-driven, reliable, and comprehensive indicators. Second, assessing multidimensional indicators in an integrated manner to capture policy complexity. Third, ensuring that short-term economic gains do not obscure natural capital losses. Finally, explicitly considering social inclusion and regional inequalities to promote equity. By adhering to these principles, measurement frameworks can effectively guide green growth policies, ensuring that economic development aligns with environmental sustainability and social inclusiveness.

8.4. PANEL: Green Growth

Despite the rapid expansion of the green growth literature over the past decade, notable gaps remain in conceptual consistency, indicator alignment, social inclusion, and engagement with post-growth debates.

A comprehensive review by Georgeson et al.(Georgeson et al., 2017) highlighted critical definitional inconsistencies between green economy and green growth, which lead to misalignments with measurement tools and hinder effective policy analysis. Ambitious frameworks such as the "transformational green economy" cannot be adequately monitored using current green growth indicators, underscoring the need for conceptual clarity.

Sarkodie et al.(Sarkodie et al., 2023) examined green growth indicators across 203 countries and identify substantial methodological challenges. The indicators rely on diverse data sources and lack a unified theoretical foundation, limiting cross-country comparability. Their analysis, based on five dimensions (natural resources, environmental efficiency, policy responses, quality of life, and socio-economic outcomes), does not fully correspond with the green growth conceptual framework, limiting the robustness of policy evaluation.

Regionally tailored approaches offer partial solutions but also present their own limitations. The Africa Green Growth Index (AGGI), developed by Kararach et al.(Kararach et al., 2018), offers context-specific insights for 22 African countries. However, applying international metrics

directly at the regional level constrains comparability with other country groups, suggesting that indicator frameworks must be adapted to local socio-economic and environmental realities.

Social inclusion emerges as a particularly underexplored dimension in the green growth literature. Pegels(Pegels, 2015) emphasized the importance of integrating green growth policies with social development objectives, especially in developing and emerging economies where poverty reduction is urgent. The social impacts of green growth are frequently overshadowed by economic and environmental considerations, and explicit assessments of these impacts are limited. Genuine transformation through green growth requires participatory governance and inclusive policy design, which remain insufficiently addressed in current frameworks (Green Economy Coalition, 2016).

Finally, the post-growth discourse challenges conventional green growth paradigms by prioritizing environmental and social outcomes over GDP expansion. The Multifutures (2025) report (MultiFutures Consortium, 2025) analyzed four paradigms (Green Growth, Mission Economy, Post-Growth, and Great Mindshift) and found that the green growth approach largely treats GDP growth as the primary pathway to sustainability. In contrast, post-growth frameworks treat GDP as a secondary outcome, fostering a more holistic integration of social welfare and environmental goals.

In summary, advancing green growth research and policy requires:

- Harmonized conceptual definitions to align indicators with policy objectives.
- Robust and context-sensitive measurement frameworks for cross-country and regional comparability.
- Explicit integration of social inclusion and participatory governance into policy design.
- Engagement with post-growth paradigms to explore alternative pathways beyond GDP-focused development.

9. GREEN TAXATION

Green taxation is a key instrument that integrates environmental externalities into market mechanisms and provides an economic orientation for sustainability policies. This section explores the theoretical foundations of green taxation, its implementation methods, socio-economic impacts, and existing research gaps through a multidimensional perspective.

9.1. Conceptual Framework and Definition Distinctions

Green taxation refers to fiscal policy instruments designed to internalize environmental externalities, reshape market behavior by pricing environmentally harmful activities, and promote sustainable development. Within this framework, tax systems reflect the economic costs of environmental degradation, thereby increasing public revenues while steering environmentally conscious behavior (United Nations Environment Programme (UNEP)).

From the standpoint of core economic theory, green taxation is grounded in the externality theory formulated by British economist Arthur Pigou. Pigou argued that the social costs associated with activities generating negative externalities can be internalized into private costs through appropriate taxation, guiding producers and consumers toward a socially optimal equilibrium (Pigou, 1920). This principle underpins the "double dividend" hypothesis, which posits that taxing environmentally damaging emissions can yield simultaneous environmental improvements and increased public revenue. Wallace E. Oates(Oates, 1995) further reinforced this framework by emphasizing that green taxes serve both environmental and fiscal objectives, thereby offering an essential mechanism to integrate environmental concerns into fiscal policy.

In the literature, green taxation encompasses various related mechanisms, including carbon pricing, environmental taxes, energy taxes, emissions trading schemes, and resource use levies. According to the World Bank's State and Trends of Carbon Pricing Report(World Bank, 2023a), 73 carbon pricing instruments were operational as of 2023, covering about 23% of global greenhouse gas emissions. These instruments, comprising carbon taxes and emissions trading systems (ETS), aim to embed environmental costs into market operations to incentivize behavioral change while generating public revenue.

A carbon tax places a direct price on each ton of greenhouse gas emissions, internalizing the environmental costs they generate. The OECD's Green Budgeting Framework highlights that carbon taxes not only encourage emission reductions but also increase funding for green R&D, thereby fostering innovation in low-carbon technologies (Organisation for Economic Co-operation and Development (OECD), 2021).

Green taxation functions as an environmental policy instrument, a central component of fiscal policy, a driver of energy transition strategies, and a pillar within broader societal transformation frameworks. The Parry, et. al.(Parry et al., 2021) report underlines carbon pricing as a cost-effective instrument that balances macro-fiscal stability with climate objectives. It stimulates innovation in low-carbon technologies, mobilizes private sector investments, and enhances government revenues. Consequently, reforming tax systems is strategically critical for financing low-carbon transitions and supporting societal adaptation (Parry et al., 2021).

In summary, green taxation provides both a theoretical foundation and a practical mechanism to internalize environmental externalities, correct market failures, and align fiscal policy with the goals of environmental sustainability.

9.2. Implementation Models and Instruments

A carbon tax seeks to discourage environmentally harmful activities by assigning a monetary cost to specific levels of greenhouse gas emissions. Several countries provide illustrative examples of long-term, systematic carbon tax implementation that serve as benchmarks for policy design. Sweden introduced its carbon tax in 1991, which by 2025 had reached €134 per ton, placing it among the highest carbon pricing levels globally (Government of Sweden, 2024). Likewise, Canada established a national carbon pricing framework aimed at reducing fossil fuel consumption, stimulate investment in clean energy, and advance its climate commitments. These experiences demonstrate that carbon taxation operates not only as an emission reduction mechanism, but also as a strategic instrument for financing the energy transition and strengthening policy coherence (Government of Canada, 2025).

The European Union Emissions Trading System is a market-based mechanism that allocates tradable carbon allowances to firms under a capped total emissions limit. Since its inception in 2005, it has developed into the world's largest carbon market, covering over 11,000 installations across the electricity, heat generation, industrial, and aviation sectors. In 2023, carbon prices at ETS auctions ranged between €66.49 and €96.33 per ton, averaging €83.60. These price signals have accelerated renewable energy investments and contributed to a 16.5% reduction in emissions within the regulated sectors (European Commission, 2024).

Environmental taxes target a wide spectrum of externalities, including air pollution, waste management, water use, and plastic consumption, aiming to internalize ecological costs within economic systems. Germany's environmental tax model represents a comprehensive framework combining revenues from energy, motor vehicle, and national emissions trading taxes. In practice, sectors such as agriculture, forestry, and manufacturing benefit from reduced taxation on specific energy inputs, whereas households and the service sector face comparatively higher tax rates. According to the European Environment Agency, sectorally differentiated taxation constitutes an effective policy instrument for reducing resource consumption and advancing environmental sustainability (Umweltbundesamt (UBA)-German Environment Agency, 2025).

Green subsidies and tax incentives represent essential fiscal tools for promoting investments in clean energy, energy efficiency, and environmentally sustainable production. The United States' Inflation Reduction Act of 2022 allocated approximately $369 billion in public funding to address climate change while reinforcing domestic industrial capacity. These measures have catalyzed record levels of investment in solar and wind energy, establishing them as the most cost-effective pathways for emission reduction in the U.S (BloombergNEF, 2023).

At both local and regional levels, South Korea supports its green growth strategy through strong institutional monitoring and evaluation systems. The country is recognized in the *Green Growth Best Practice* report for its comprehensive "government-wide monitoring and evaluation" framework, reflecting a holistic approach to implementing environmental policies. Meanwhile, China has introduced pilot emissions trading systems in five provinces and eight cities, laying the groundwork for a unified national ETS aimed at reducing carbon emissions and energy intensity across the country in a cost-effective manner (Green Growth Best Practice Initiative, 2014).

9.3. Economic and Social Impacts

While the primary aim of green taxation is to mitigate environmental harm, its economic consequences are broad and multifaceted, extending far beyond mere reductions in carbon emissions. These effects include significant shifts in price formation, employment patterns, income distribution, and social transition justice. According to the IMF/OECD (2021) report, environmental taxes raise the prices of carbon-intensive fuels, and the goods produced from them, thereby encouraging market behavior that favors more sustainable outcomes. At the same time, these taxes generate clear price signals that stimulate private investment in clean technologies, helping to expand the overall tax base (International Monetary Fund (IMF)/Organisation for Economic Co-operation and Development (OECD), 2021).

One of the most debated aspects of green taxation is its effect on energy prices. According to the IMF/OECD, increases the cost of carbon-intensive fuels and the products derived from them, yet it simultaneously incentivizes businesses and households to shift toward cleaner energy sources. Modeling studies by Gerlagh and van der Zwaan(-Gerlagh & Zwaan, 2006) show that carbon tax scenarios can significantly reduce energy consumption, enhance energy efficiency, and lower overall energy costs in the medium term. These results suggest that, although carbon taxes may raise costs initially, the efficiency gains over time can help offset these short-term increases (Gerlagh & Zwaan, 2006; International Monetary Fund (IMF)/Organisation for Economic Co-operation and Development (OECD), 2021).

Employment impacts of green taxation vary across sectors. While carbon-intensive industries often see job reductions, labor-intensive sectors, such as renewable energy and environmental technologies, tend to experience job growth. Bowen and Fankhauser(Bowen et al., 2011) argue that low-carbon technologies can be more labor-intensive than capital-intensive, offering significant employment potential, particularly in less developed countries. For a successful transition, however, supportive mechanisms, including technical assistance, skill development, and workforce retraining, are essential. From a social justice perspective, green taxation policies should be coordinated with local development programs to ensure equitable and inclusive outcomes (Bowen et al., 2011).

In terms of income distribution, carbon taxes often have regressive effects, especially in higher-income countries. Low-income households spend a larger share of their income on energy, making them disproportionately affected by carbon pricing. Dorband et al.(Dorband et al., 2019) showed that as income decreases, the relative burden of carbon pricing on poorer households rises compared to the national average, suggesting that such policies may exacerbate income inequality. Therefore, green tax reforms should be paired with complementary measures that address social equity while advancing environmental goals (Dorband et al., 2019).

Just Transition policies are crucial for integrating the social dimension into green taxation frameworks. The ILO's Just Transition Guidelines emphasize that effective and legitimate green tax policies require: (i) prior assessments of employment and socio-economic impacts, (ii) provision of adequate and sustainable social protection to mitigate job losses and displacement, and (iii) inclusion of social dialogue throughout policy development and implementation to ensure broad stakeholder participation. These principles enhance both economic efficiency and social justice, ensuring legitimacy in transitions driven by green taxation (International Labour Organization, 2015).

9.4. PANEL: Green Taxation

Although the literature on green taxation offers interdisciplinary insights across environmental economics, public finance, and sustainable development, it still faces significant, particularly in methodological diversity, availability of micro-level data, and integration of social justice dimensions. The "double dividend" hypothesis, introduced by Oates(Oates, 1995), proposes that environmental taxes can deliver both environmental protection and improved efficiency within the tax system. Yet, Freire-González's(-Freire-González, 2018) comprehensive review of empirical models finds finds the efficiency dimension of this hypothesis to be inconclusive. Similarly, Dorband et al.(Dorband et al., 2019), in a global comparative study of 87 countries, emphasize that categorical limitations and unequal access to detailed household consumption data hinder accurate assessments of carbon pricing's distributional impacts. These challenges highlight the need for richer panel databases and country-specific micro-simulation models capable of capturing both equity and efficiency outcomes of green tax reforms (Dorband et al., 2019; Freire-González, 2018; Oates, 1995).

In a comprehensive analysis, Sarkodie et al.(Sarkodie et al., 2023) highlight major inconsistencies in the measurement tools applied to green growth and taxation concepts. Their study categorizes green growth indicators across 203 countries into five dimensions, such as natural asset base, environmental efficiency, policy responses, quality of life, and socio-economic outcomes, but finds that these indicators often lack alignment with the underlying conceptual framework. In addition, the heterogeneity of datasets and methodologies employed by different countries reduces the reliability of these indicators for monitoring the impacts of green taxation and complicates methodological consistency in cross-country policy comparisons (Sarkodie et al., 2023).

The UNCTAD (2023) report(United Nations Conference on Trade and Development (UNCTAD), 2023b) identifies several structural constraints that limit the applicability of green taxation in developing economies. Rising debt burdens, limited access to finance, and higher borrowing costs weaken these countries' ability to invest in climate action and social programs. Ongoing monetary tightening further exacerbates income inequality and fuels societal resistance to green reforms. In regions such as Sub-Saharan Africa and South Asia, data scarcity and infrastructural gaps in carbon pricing systems hinder direct assessments of behavioral impacts, forcing reliance on indirect inference methods (United Nations Conference on Trade and Development (UNCTAD), 2023b).

The BloombergNEF report(BloombergNEF, 2023), which evaluates the global impact of tax incentives on investment flows, criticizes widely used climate scenario models for insufficiently accounting for regional disparities in capital expenditure. It argues that factors such as economic development stage, demographic growth, and energy mix diversity strongly shape public investment capacity in low-income countries, thereby reducing the effectiveness of incentive schemes. This underlines the need for comparative assessments of green subsidy and incentive frameworks across different national contexts and calls for a methodological reassessment of their generalizability (BloombergNEF, 2023).

Finally, the IMF (2021) report(Maldonado & Gallagher, 2022) examines the macroeconomic and financial stability implications of climate change, stressing the need for comprehensive, long-term fiscal analyses that account for public debt sustainability, asset valuation, and trade balances. It proposes embedding climate policies within macro-fiscal frameworks through institutional mechanisms such as its annual "Article IV" consultation dialogues with member states. The report further advocates systematic assessments of climate adaptation and transition policies, particularly in countries with high greenhouse gas emissions or significant climate vulnerability, to ensure strategic alignment between climate objectives and public finance management, not only in terms of short-term budgetary impacts but also long-term institutional resilience (Maldonado & Gallagher, 2022).

10. GREEN EDUCATION AND SKILLS DEVELOPMENT

Establishing the societal and professional foundations for the green transition requires more than environmental expertise; it demands a transformation grounded in behavioral change, ethical responsibility, and continuous skill

development. This section examines the concept of green education, the structuring of curricula, and lifelong learning strategies, while also highlighting persistent gaps in the literature.

10.1. Conceptual Framework and Definition of Green Education

Green education is an interdisciplinary, action-oriented approach to learning that equips individuals with the knowledge, skills, and attitudes needed for environmental sustainability, climate change mitigation, and resource management. Within UNESCO's Education for Sustainable Development framework, green education is framed not simply as knowledge transfer but as a catalyst for behavioral transformation through systems thinking, future-oriented reflection, and value-based learning. Its ultimate aim is to foster both environmental awareness and a strong sense of responsibility, empowering learners to actively contribute to societal transformation (United Nations Educational Scientific and Cultural Organization (UNESCO), 2020).

The European Commission's GreenComp (the European Sustainability Competence Framework) defines 12 core competencies organized into four categories: embodying sustainability values, understanding complexity, envisioning sustainable futures, and acting for sustainability. These competencies address cognitive, interpersonal, and ethical dimensions, fostering empathy, responsibility, and planetary sensitivity in learners' thinking, planning, and actions. GreenComp is designed to help learners not only comprehend environmental challenges but also build systematic capacity to develop solutions (Bianchi et al., 2022).

While green education overlaps with related concepts such as climate education, environmental education, and sustainability education, it is distinct in its scope and focus. Leal Filho et al.(Leal Filho et al., 2023) emphasize that higher education institutions foster attitudinal and behavioral change through climate awareness, capacity building, and interdisciplinary collaboration. Such transformation enhances adaptive capacity and societal preparedness, equipping individuals to navigate evolving climate realities. In this sense, green education is not merely the transfer of knowledge but a pedagogical instrument for social and cultural change (Leal Filho et al., 2023).

UNESCO's 2024 Greening Curriculum Guidance offers a standardized framework for designing green education curricula across formal, informal, and non-formal learning environments. It identifies four core learning domains: environmental knowledge, skills, attitudes and values, and action orientation, aimed at integrating climate change and sustainability topics. The guidance stresses that green education must go beyond knowledge transfer to foster value-driven, behavior-transforming learning. It promotes action-oriented teaching that develops ethical reasoning, systems thinking, and social responsibility, supporting societal-level climate action and long-term problem-solving (United Nations Educational Scientific and Cultural Organization (UNESCO), 2024).

10.2. Mapping Green Skills: Transformation Strategies in Vocational Education

Technical and Vocational Education and Training (TVET) comprises workforce-focused educational programs that equip individuals with sector-specific skills. In the green transition, TVET serves as a platform for developing technical expertise alongside ethical reasoning and systems thinking, ensuring alignment with environmental sustainability.

ILO Green Skills Map (Strietska-Ilina et al., 2011) organizes green skills into areas such as energy efficiency, clean production, ecosystem management, and the circular economy. For example, energy sector skills include solar panel installation, wind turbine maintenance, and smart grid management, while agriculture emphasizes climate-resilient farming, sustainable fertilization, and waste management. Combined with Cedefop's sectoral skill profiles (The European Centre for the Development of Vocational Training (Cedefob), 2021) and UNESCO-UNEVOC's *Greening TVET* guide (Cedefob & UNESCO-UNEVOC, 2025), these frameworks support vocational curricula that integrate technical proficiency with environmental awareness and ethical responsibility. Greening TVET strategies further prepare learners for evolving labor market needs through digital skill mapping, simulation tools, micro-credentials, teacher training in green competencies, and applied internships via public–private partnerships, transforming the system into a dynamic driver of sustainable development goals.

10.3. Lifelong Learning and Community Capacity Development

Green education extends beyond formal schooling, encompassing lifelong learning that cultivates sustainability awareness and skills throughout individuals' lives. UNESCO's Greening Education Partnership initiative advances this transformation through four core components: greening school environments, curriculum integration, teacher training, and community-based capacity development (United Nations Educational Scientific and Cultural Organization (UNESCO), 2024). Lifelong learning within this framework is central to fostering climate-resilient and inclusive societies.

Community-based learning mechanisms seek to cultivate collective awareness and behavioral change in response to environmental challenges within local contexts. UNESCO emphasizes its potential to strengthen climate resilience through lifelong learning. A notable example is Morocco's "One Student, One Tree, One School, One Forest" project, which involved around six million students in tree-planting activities on school grounds, serving as an effective model for increasing environmental literacy and ecological awareness (Global Education Monitoring Report Team, 2024).

In adult education, Colombia is implementing innovative models that incorporate traditional knowledge into formal curricula to tackle climate change. Global Education Monitoring Report noted that learning processes rooted in local ecological observations and practices have enhanced climate adaptation capacities among rural farmers while supporting the transfer of technical knowledge. Similarly, Kenya is advancing adult climate education through teacher training and community-based programs, aiming to foster climate-resilient lifestyles.

Micro-certification and short-term training programs provide flexible pathways for acquiring skills essential for green and circular transitions. UNESCO-UNEVOC's *Building Skills for the Green and Circular Transition* initiative encourages TVET institutions to strengthen the competencies of young graduates and new labor market entrants in sustainable production practices. Supported by trainer education, digital learning modules, and a "Train the Trainer" approach, these programs enable participants to apply circular economy principles across sectors such as construction, agriculture, textiles, recycling, and design (UNESCO-UNEVOC (UNESCO International Centre for Technical and Vocational Education and Training), 2022).

In conclusion, lifelong learning strategies play a crucial role in equipping individuals with both knowledge and sustainability-oriented behaviors, thereby enhancing societal resilience. By ensuring that green education is inclusive, flexible, and context-sensitive, these approaches provide a strategic foundation for transforming education systems and supporting long-term sustainable development.

10.4. PANEL: Green Education and Skills Development

The literature on green education and skills development is growing within the sustainable development framework; yet notable theoretical, methodological, and practical gaps persist. Leal Filho et al.(Leal Filho et al., 2023) point out that environment-focused curricula often lack consistency in content and show significant conceptual and pedagogical differences across countries. This variability makes it challenging to assess how effectively curricula incorporate elements such as systems thinking, value-based decision-making, and behavioral transformation.

UNESCO's Greening Education Partnership report(United Nations Educational Scientific and Cultural Organization (UNESCO), 2024) highlights a lack of comparative analyses across countries on key transformation components, such as teacher training and community engagement. Data gaps and limited implementation models regarding teachers' acquisition of green competencies hinder the evaluation of educational impacts. Although digital learning tools are increasingly adopted in green education, research on their long-term effects on behavior and attitudes remains limited. Few comparative case studies examine the effectiveness of digital solutions for micro-skills acquisition and lifelong learning, complicating impact assessment. Huang et al.(Huang et al., 2024) note that while digital pedagogical transformation is essential for sustainable education systems, current practices predominantly focus on short-term outputs, and systematic models to measure behavioral change are still underdeveloped.

Definitions of green skills within TVET systems vary considerably across sectors and regions. Albertz and Pilz (Albertz & Pilz, 2025) identify differences and regional disparities in connecting green skills to labor market needs, which complicate the identification of skill clusters and the integration of curricula. While frameworks such as the ILO's Green Skills Map provide clear guidance on sector-specific micro-competencies, there remains a notable lack of applied studies examining their implementation in education systems.

The literature on green skills development also reveals significant gaps from a social justice perspective. Kwauk and Casey (Kwauk & Casey, 2022) note that green skills training is often concentrated in science, technology, engineering, and mathematics fields, limiting access for low-income and marginalized groups to climate-focused education opportunities. Aligning green education policies with the "just transition" framework is therefore crucial for future research, ensuring both inclusive skill development and climate justice. Additionally, the scarcity of comparative analyses on the implementation of UNESCO-UNEVOC's Greening TVET strategies across countries constrains the evaluation of their effectiveness. This highlights a promising avenue for developing data-driven curriculum assessment tools and enhancing pedagogical impact evaluations (Cedefop & UNESCO-UNEVOC, 2025).

11. LIMITATIONS AND FUTURE DIRECTIONS

While this review provides a comprehensive synthesis of the green economy's eight pillars, certain limitations must be acknowledged. The scope of databases and the time frame (2000–2025) may have excluded relevant studies, and definitional ambiguities across concepts such as green finance and green jobs continue to challenge comparability. Moreover, methodological diversity in measurement frameworks limits the generalizability of findings.

Policy implications of the analysis highlight the need for stronger integration of labor, finance, and energy policies, alongside clearer taxonomies and inclusive governance structures. Looking ahead, future policy directions are expected to emphasize carbon pricing, digitalization, and social equity as central priorities. Emerging research areas include energy–growth dynamics, the role of digital tools in sustainability transitions, and the development of new multidimensional indicators that move beyond GDP. Addressing these gaps will strengthen both academic debate and policy practice, ensuring that the green economy evolves as a robust paradigm for sustainable development.

12. CONCLUSION

This study evaluates the multidimensional structure of the green economy through conceptual analysis, systematic implementation review, and literature-based critical reflection, addressing the environmental, social, and economic pillars of sustainable development in an integrated manner. Analyses across green jobs, finance, innovation, infrastructure, energy, growth, taxation, and education reveal that the green economy represents not merely a technical transition, but a paradigm shift grounded in social justice, inclusivity, and resilience.

In the domain of green jobs, workforce transformation involves both the emergence of new occupations and the reskilling of existing roles. Competencies such as environmental awareness, digital literacy, and systems thinking are essential. Vocational education and skills development programs should reflect sector-specific demands within standardized frameworks that integrate social, technical, and environmental dimensions. Strengthening labor market data systems, regional planning, and lifelong learning, supported by digital tools, can reduce skill inequalities and form the foundation for a just transition.

Social protection mechanisms are critical to minimizing the societal costs of phasing out fossil fuel–based sectors. Regional transition plans, workforce support programs, and comprehensive social protection instruments should complement market-based tools such as carbon pricing, environmental taxation, and emissions trading, while redistributive measures and sectoral balancing mitigate potential social impacts.

Green finance remains a key driver of sustainable investment, yet definitional ambiguities, data gaps, and inconsistent taxonomies continue to limit effective policymaking. Aligning financial instruments with international standards, leveraging blockchain for traceability, and supporting *Environmental, Social, and Governance* investments with independent audits and transparent impact reporting are crucial for accountability and reducing greenwashing risks.

Green innovation plays a strategic role in advancing low-carbon production systems. Public–private partnerships, open R&D ecosystems, and university–industry collaborations can facilitate localized technological solutions and enhance social inclusion. Prioritizing green technology deployment in marginalized sectors, alongside digital integration, is particularly transformative in emission-intensive industries such as energy and transportation.

Green infrastructure investments provide broad co-benefits, from disaster resilience and water management to public health and energy justice. Blended finance models, community engagement, and nature-based solutions can improve accessibility and equity. Technological diversification, cross-sectoral integration, and regional strategies that address spatial inequalities are essential for scaling up sustainable energy systems.

Green growth policies should balance economic development with ecological boundaries. Incorporating alternative measurement frameworks, including well-being indicators, natural capital accounting, and social inclusion metrics, enables comprehensive evaluation beyond GDP, ensuring multi-dimensional monitoring of policy effectiveness and sustainability outcomes.

Green education and skills development form the societal foundation of the green economy. Key competencies such as systems thinking, ethical decision-making, and co-creation should be embedded in both formal and informal learning environments. Expanding digital platforms, micro-credentialing, and short-term training modules can enhance equitable access and support behavioral transformation necessary for sustainable development.

In conclusion, the transition to a green economy requires not only technical capacity but also strategic governance, data-informed planning, and cross-sectoral collaboration. Policy frameworks that emphasize definitional clarity, measurement coherence, social equity, and sectoral integration will be essential for aligning sustainability imperatives with economic systems.

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