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Catalysts for Green Economy: How Start-ups in Environmental, ESG, and RE100 Technologies Drive Global and Domestic Economic Growth

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Abstract: This review presents the significant economic contributions of start-up companies focused on environmental, social, and governance (ESG) principles and the RE100 initiative in mitigating climate change and fostering sustainable growth. Traditionally viewed as economic burdens, environmental concerns are now recognized as integral to long-term financial success. Leveraging Schumpeterian creative destruction, endogenous growth theory, and circular economy principles, these start-ups drive innovation, create new markets, and attract substantial investment, reallocating capital towards sustainable ventures. Investment trends in climate technology are analyzed in this review, highlighting increased venture capital, public market funding, and corporate partnerships. Case studies of Northvolt and Beyond Meat demonstrate successful scaling and market disruption, while the challenges faced by A123 Systems and KiOR underscore the need for robust business models, cost competitiveness, and patient capital. The findings emphasize that governments, financial institutions, and start-ups must collaborate through supportive policies, strategic funding, and a focus on scalable, economically viable solutions to maximize the profound and multifaceted economic impact of green innovation and maintain long-term investment in ESG-related projects.

Keywords: Green economy, ESG, RE100, Startup, Global economy

1. Introduction

In the 21st century, the escalating impacts of climate change need to be mitigated to foster inclusive and sustainable economic growth. Therefore, the emergence of start-up companies dedicated to environmental, social, and governance (ESG) and the RE100 initiative has become a focal point in the economy, policy, and investment. Startups are niche players since they represent a fundamental reorientation of economic activity towards sustainability, driven by technological innovation, shifting consumer preferences, and increasing regulatory pressures.

Traditionally, environmental concerns were viewed as external costs or regulatory burdens on economic development. However, a growing understanding is intrinsically linked to long-term financial success and economic resilience due to the increase in ESG and strong environmental performance, social responsibility, and robust governance practices [1]. The RE100 initiative, compelling major corporations to commit to 100% renewable electricity, further accelerates such a transition by creating a powerful demand signal for clean energy solutions, thereby fostering a fertile ground for related start-ups. Start-up companies related to environmental, ESG, and RE100 technologies are disproportionately contributing to global and domestic economic growth, with contributions extending beyond direct revenue generation. By developing new skills and roles in green industries and introducing novel solutions that address unmet environmental and social needs, start-ups are contributing to job creation, innovation, and market creation, which create new market segments. Start-ups also attract significant private and public investment, redirecting financial flows towards sustainable ventures and fostering sustainability adoption across value chains as larger companies seek to meet their ESG and RE100 commitments. Technologies that are developed by start-ups have enhanced resource efficiency, reduced waste, and lowered operational costs for businesses, providing productivity and cost reduction.

In this study, how start-ups contribute to economic growth has been explored by reviewing the evolving landscape of investment in them. By presenting related cases, successful ventures, and those that faced challenges were analyzed to explore the economic effects of those start-ups. Finally, the future direction for these start-ups and investments was proposed, and appropriate strategies were reviewed to amplify their positive impact on global and domestic economies.

2. Contributions to Economic Growth

The economic contributions of start-ups in environmental, ESG, and RE100 technologies are understood with the following economic theories.

2.1. Schumpeterian Creative Destruction

Joseph Schumpeter's concept of "creative destruction" is highly relevant to an understanding of the start-up's contribution to the economy. Start-ups, by their nature, are agents of disruption. They introduce innovations that displace older, less efficient, or less sustainable technologies and business models [2]. In the green economy, start-ups foster the transformation of fossil fuel-based energy to renewable energy, resource-intensive manufacturing to circular economy principles, and unsustainable agricultural practices to regenerative ones. This process contributes to higher productivity, new industries, and overall economic advancement, while sometimes disruptive to existing industries.

2.2. Endogenous Growth Theory

This theory emphasizes that economic growth is primarily the result of endogenous processes, particularly human capital, innovation, and knowledge accumulation [3,4]. Start-ups in the green economy sector embody this by investing heavily in research and development, developing new intellectual property, and fostering a skilled workforce. Their success is predicated on technological breakthroughs that influence the economy, creating spillover effects and generalized productivity improvements. Investments in these start-ups are essentially investments in knowledge and innovation that generate long-term economic returns.

2.3. Resource Economics and Circular Economy

These frameworks highlight the nature of natural resources and the inefficiencies of linear "take-make-dispose" economic models. Green technology start-ups promote resource efficiency, waste reduction, and the circular economy, where materials are reused and recycled [5]. By minimizing resource depletion and pollution, these companies reduce economic externalities and contribute to long-term sustainability, which is recognized as a prerequisite for sustained economic growth. Their innovations reduce costs associated with waste management, pollution control, and resource scarcity, thereby enhancing overall economic efficiency.

2.4. Market Failure and Green Innovation

In the traditional economy, market failures are observed where the market does not efficiently allocate resources, often due to external factors (e.g., pollution). Green technology start-ups have emerged to address these market failures, providing solutions for cleaner energy, waste management, or sustainable consumption that the incumbent market players have overlooked or been unwilling to pursue, due to less interest and passive investment. Government policies (e.g., carbon pricing and renewable energy incentives) lead to the creation of the necessary market conditions to enable these start-ups to thrive by internalizing environmental costs [6].

2.5. Attracting Capital and Investment Reallocation

The growing trend of ESG investment and commitments to net-zero targets of carbon emissions (RE100) have been reallocating significant capital for sustainable development. Start-ups in related industries are beneficiaries of this trend, attracting venture capital, private equity, and public market investments. This capital inflow fuels their growth and stimulates related financial services, research, and development, creating an economic ecosystem for sustainability.

3. Investment Trends in Environmental, ESG, and RE100 Technologies

Investment in environmental, ESG, and RE100-related technologies has seen exponential growth over the past decade. Such an increase is driven by a confluence of factors, such as the increasing awareness of climate risks, evolving regulatory landscapes, growing consumer demand for sustainable products, and the recognition of sustainability by investors. Especially, investors have realized that sustainability is no longer a niche concern but a fundamental driver of long-term value creation.

3.1. Venture Capital and Private Equity

Venture capital and private equity firms are increasingly channeling funds into early- and growth-stage start-ups in the climate and green economy technology. Their investments span a diverse range of sectors, including renewable energy (advanced solar,

wind, geothermal, and energy storage solutions), sustainable transportation (electric vehicles, EVs), charging infrastructure, battery technology, and alternative fuels), circular economy solutions (waste-to-resource technologies, recycling innovation, sustainable materials, and product-as-a-service models), agriculture and food technology (plant-based proteins, precision agriculture, vertical farming, and sustainable food supply chains), carbon capture, utilization, and storage (CCUS) (technologies to remove carbon dioxide from the atmosphere or industrial emissions), ESG data and software platforms for sustainability reporting, impact measurement, and supply chain transparency. Climate technology, in particular, has been invested in venture capital funding, which demonstrates investor confidence in the long-term potential of these disruptive technologies [7]. Breakthrough Energy Ventures, founded by Bill Gates, and Clean Energy Ventures exemplify this trend, committing substantial capital to start-ups with the potential for significant decarbonization impact. The integration of digital technologies such as AI and blockchain is expected to enhance scalability and commercial viability, which enables green startups to optimize operations, build trust, and create innovative business models. Especially, blockchain technology addresses trust issues in the green economy in attracting investment and building a customer base.

3.2. Investments and Green Bonds in Public Market

Beyond private markets, a remarkable change in public market investments has been observed. ESG funds and indices are becoming popular, directing capital towards publicly traded companies with strong sustainability performance. The green bond market has rapidly developed, with governments and corporations issuing bonds specifically to finance environmental projects, including renewable energy infrastructure and sustainable agriculture [8]. This provides an additional avenue for start-ups, particularly those that mature into larger entities, to access significant capital.

3.3. Corporate Venture Capital and Partnerships

The RE100 initiative, which encourages large corporations to commit to 100% renewable electricity, has created demand for renewable energy solutions. Many RE100 signatory companies are investing in renewable energy projects and establishing corporate venture capital (CVC) companies or forging partnerships with start-ups to develop and deploy cutting-edge technologies. Such investment provides early-stage funding, validation, and market access, which are vital for green start-ups. For instance, Google and Apple, both RE100 members, actively invest in renewable energy projects and support start-ups in their supply chains to meet sustainability targets (Table 1).

Table 1. Key investment areas in green technology start-ups.

Investment	Technologies/solutions	Economic impact and potential
Renewable energy and storage	Advanced solar cells, offshore wind, geothermal, grid-scale batteries	Job creation (manufacturing, installation), energy independence, reduced fossil fuel imports, and lower energy costs for businesses.
Sustainable transportation	EV charging networks, battery recycling, autonomous EVs, and hydrogen fuel cells	New manufacturing jobs, reduced air pollution costs, energy security, and infrastructure development.
Circular economy & waste mgmt.	Chemical recycling, bio-based materials, waste-to-energy, and upcycling platforms	Resource efficiency gains, waste reduction, new industries for material recovery, and reduced landfill costs.
Agriculture & food tech	Vertical farming, precision agriculture, plant-based meat, and alternative proteins	Food security, reduced water/land use, lower agricultural emissions, new consumer markets, and health benefits.
Carbon management	Direct air capture (DAC), industrial CCUS, carbon accounting software	New industrial sectors, mitigation of climate damages, potential for carbon credits, and specialized engineering jobs.
ESG and sustainability software	ESG reporting platforms, supply chain traceability, and climate risk analytics	Improved corporate decision-making, enhanced transparency, regulatory compliance, and efficiency in sustainability management.

4. Case Studies: Successes and Challenges

By reviewing related cases, how environmental, ESG, and RE100-aligned start-ups translate their innovations into economic impact, and the challenges were explored in this study. The cases are briefed in Table 2.

4.1. Success Story: Northvolt (Sweden) - Scaling Battery Production

Northvolt is a Swedish start-up focused on developing and manufacturing sustainable lithium-ion batteries with a minimal carbon footprint. Their goal is to supply the growing European electric vehicle (EV) market and grid storage solutions. Northvolt has created thousands of high-skilled jobs in battery research, manufacturing, and recycling. Its gigafactories, such as Northvolt Ett in Skellefteå, are revitalizing regional economies and establishing Europe as a significant player in the global battery supply chain, reducing reliance on Asian manufacturers. The company has secured multi-billion-dollar contracts with major automotive players, including Volkswagen and Volvo. By developing more sustainable battery production methods (e.g., using renewable energy in manufacturing and focusing on recycling), Northvolt contributes to reducing the national carbon footprint of the EV industry globally. It also strengthens Europe's position in the global clean energy transition, promoting diversified supply chains and reducing geopolitical risks associated with critical materials. Northvolt places sustainability at its core for the lowest possible carbon footprint in battery production, emphasizing circularity through recycling programs and plans for its facilities to be powered by 100% renewable energy (RE100-compliant operation). This ESG policy has attracted significant investment from institutional investors and industrial partners. Strong governmental support (e.g., subsidies, favorable regulatory environment), significant private investment rounds, strategic partnerships with major industrial players, and a clear market demand driven by the global transition to EVs and RE100 commitments [9].

4.2. Success Story: Beyond Meat (United States) - Disrupting the Food Industry

Beyond Meat is a leading producer of plant-based meat substitutes by replicating the taste and texture of animal meat without the environmental and ethical costs. Beyond Meat has created new jobs in food science, manufacturing, marketing, and sales. Its products are available in supermarkets and fast-food chains, creating a new market segment for plant-based alternatives. The company's initial public offering (IPO) in 2019 was highly successful, attracting significant investor interest in sustainable food solutions [10]. The success of Beyond Meat has affected dietary habits, encouraging consumers to reduce meat consumption for environmental reasons. It has also catalyzed significant investment and innovation in the broader plant-based food industry worldwide, leading to new companies and diverse product offerings in various countries. The company contributes to reducing greenhouse gas emissions, land use, and water consumption associated with traditional livestock farming. Beyond Meat's core mission is inherently environmental (reducing the environmental impact of animal agriculture) and social (offering healthier and more ethical food choices). While not directly a RE100 company, its impact aligns with broader sustainability goals by reducing the carbon footprint of the food system. Beyond Meat has facilitated strong product innovation, effective marketing that appeals to vegetarians/vegans and flexitarians, strategic partnerships with major food retailers and restaurants, and a growing consumer awareness of the environmental and health benefits of plant-based diets.

4.3. Challenged Case: A123 Systems (United States) - Early Battery Technology Failure

A123 Systems was a prominent US-based start-up founded in 2001, focused on developing and manufacturing advanced lithium-ion batteries for EVs and grid applications, particularly for automotive manufacturers like Fisker and General Motors. A123 Systems received significant government funding (e.g., a USD 249 million grant from the US Department of Energy) to boost domestic clean energy manufacturing and jobs. Its eventual bankruptcy in 2012, however, led to job losses and a significant financial hit for investors and taxpayers [11]. The failure raised questions about the viability of large-scale government investments in nascent clean technologies. A123 failed to compete against Asian manufacturers in the global battery market, highlighting the intense and high capital intensity and long timelines required for commercialization. Risks are involved in investing in technologies that might not be scaled up and achieve cost competitiveness. A123's mission was aligned with environmental goals by developing cleaner energy storage solutions. However, its failure demonstrates that even well-intentioned green ventures require robust business models and competitive advantages beyond environmental credentials. The reasons for its failure include technological hurdles and manufacturing delays, difficulties in scaling up production and maintaining consistent quality at competitive costs, and intense competition against battery manufacturers, particularly from Asia, with lower production costs. Market volatility is also an important reason for failure, as the company depended on the nascent EV market and partners who also failed (e.g., Fisker Automotive). The battery industry is incredibly capital-intensive with long payback periods, making it challenging for a start-up to sustain itself without continuous, large-scale funding.

4.4. Challenged Case: KiOR (United States) - Biofuel Production Issues

KiOR was a US-based start-up aiming to produce renewable crude oil from biomass (e.g., wood chips) using a proprietary catalytic process. It received significant private investment and government loan guarantees. KiOR's expected to create jobs in rural areas (Mississippi) and reduce reliance on fossil fuels. Its bankruptcy in 2014, after receiving substantial investments, resulted in

job losses and significant financial losses for investors, including the state of Mississippi [12]. The failure of KiOR, along with that of other biofuel ventures during that period, increased investor skepticism regarding certain capital-intensive green technologies that struggled to achieve commercial viability at scale. It underscored the difficulty of competing with established fossil fuel industries without significant technological breakthroughs or sustained policy support. Although KiOR aimed to produce renewable fuels and address environmental concerns related to fossil fuel consumption, their technology was not appropriate to achieve the projected yields and efficiency at a commercial scale, making the production process uneconomical. The cost of producing biofuel was significantly higher than traditional petroleum, making it uncompetitive without substantial subsidies, and consistent and affordable biomass feedstock was difficult to secure. As the industry required large capital and long development cycles, investors were not keen on maintaining their funds, especially as immediate profitability was elusive.

Table 2. Case study comparison

Feature	Northvolt	Beyond Meat	A123 Systems
Focus area	Sustainable battery production	Plant-based meat alternatives	Advanced Li-ion batteries (early)
Economic impact	Job creation, regional revitalization, supply chain independence, multi-billion-dollar contracts	New market creation, dietary shift, public market success, job growth	Job losses, investor losses, and highlighted manufacturing challenges
ESG/RE100 alignment	Core environmental mission, RE100 aspiration	Core environmental & social mission	Environmental focus (clean energy storage)
Key to success/challenge	Gov. support, large investments, strategic partnerships, and strong market demand	Product innovation, market appeal, strategic partnerships, and consumer trends	Technical scale-up issues, intense competition, market dependence, and high capital
Outcome	Success	Success	Failure (Bankruptcy)

4.5. Effects on Traditional Industries

The renewable energy sector has provided enormous employment opportunities. According to the International Renewable Energy Agency (IRENA) and the International Labour Organization (ILO), global renewable energy jobs reached 16.2 million in 2023. This job growth was driven by the strong demand for clean energy related to the RE100 initiatives. The solar photovoltaics (PV) industry has created 7.2 million jobs globally. The renewable energy industry also plays a catalytic role for regions that have been dependent on fossil fuel-based industries. Especially, regions with abundant wind or solar resources can establish "RE100 industrial complexes" to create new employment and diversify the local economy. Half of the workers in the fossil fuel industry have skills that are available in clean energy sectors. Many of these workers have transitioned to new jobs with minimal training, ensuring a "just transition" that supports workers and communities through the economic shift, preventing widespread unemployment and economic hardship [13].

5. Mechanisms of Economic Contribution and Future Direction

The case studies illuminate the multifaceted perspectives in which start-ups in the environmental, ESG, and RE100 space contribute to economic growth, as well as the inherent risks. Their impact is not confined to their direct revenues; it extends to broader ecosystem effects.

5.1. Mechanisms of Economic Contribution

Green start-ups are highly specialized, creating demand for engineers, scientists, data analysts, and project managers with expertise in sustainable technologies. This leads to the development of new educational programs and a highly skilled workforce, contributing to human capital development. The attractiveness of the green economy has fostered significant investment flows and reoriented capital from traditional, often less sustainable, sectors towards innovative solutions, accelerating the transition to a low-carbon economy. This reallocation of capital leads to a "crowding-in" effect, encouraging further public and private investment. These start-ups are not just competing in existing markets but creating new ones (e.g., plant-based protein market, carbon capture services), expanding the overall economic size and diversification, and fostering resilience. Green technologies, such as advanced energy management systems or circular production processes, enable significant operational efficiencies and cost reduction for companies and enhance their competitiveness and productivity. This creates a positive feedback loop: businesses adopt green tech to save money, which boosts the green tech market. As large companies commit to sustainability, they exert pressure on their supply

chains to adopt similar practices such as RE100. This creates opportunities for green start-ups to develop and provide solutions (e.g., renewable energy procurement, waste reduction technologies) to these larger entities, driving systemic change. Research and development by green tech start-ups often lead to breakthroughs that have applications beyond their initial intended use, benefiting other sectors and stimulating broader innovation.

To maximize the economic impact of environmental, ESG, and RE100 start-ups, several key strategic focuses are required.

- **Policy and regulatory support:** Clear, stable, and supportive government policies are paramount, including carbon pricing mechanisms, renewable energy mandates, incentives for research and development, and streamlined permitting processes for green infrastructure. Policy certainty reduces investor risk and encourages long-term commitments [6]. The example of A123 Systems shows that even significant government grants are not enough without a robust, supportive ecosystem.
- **Capital and Finance:** Many green technologies, especially those involving hardware or large-scale infrastructure, require significant capital and have longer payback periods than typical software start-ups. "Patient capital" (long-term, risk-tolerant investment) from institutional investors, development banks, and government funds is crucial. Blended finance, combining public and private capital, can de-risk investments and attract greater private-sector participation [14].
- **Focus on scalability and commercial viability:** While innovation is key, start-ups must develop solutions that are technologically sound, commercially viable, and scalable. The failures of A123 Systems and KiOR indicate the dangers of prioritizing technological promise over market realities and cost competitiveness.
- **International collaboration and harmonization:** For global impact, international collaboration is essential. It is necessary to share best practices in green technology development, harmonize ESG reporting standards, and facilitate cross-border investment in sustainable ventures. Such collaboration can accelerate technology diffusion and foster global green markets. The International Sustainability Standards Board (ISSB)'s global baseline for sustainability-related disclosures encourages widespread adoption and endorsement. To balance between regional differences and priorities, the European Union's Corporate Sustainability Reporting Directive (CSRD) and its European Sustainability Reporting Standards (ESRS) need to be referred to as a baseline.
- **Education:** The green economy requires a specialized workforce. It is crucial to invest in education and training programs that equip individuals with skills in renewable energy, circular economy principles, sustainable finance, and environmental data science to meet the growing demand for talent.
- **Digitalization and artificial intelligence (AI) integration:** The integration of digital technologies (the Internet of Things (IoT), AI, and blockchain) significantly enhances the efficiency and impact of green solutions. AI, for example, optimizes energy grids, predicts resource demand, and improves waste management processes [15]. Start-ups leveraging these cross-cutting technologies are likely to see greater success.
- **Circular economy:** An emphasis is put on circular economy principles beyond mere recycling to waste and pollution minimization, to keep products and materials in use, and to regenerate natural systems. This ensures the economic potential for industries [5].

The current investment in climate technology has been growing, but start-ups need to emphasize the economic solutions, not just the green rationale [16]. Maturing the market is significant alongside environmental benefits for financial viability and tangible returns.

5.2. Mechanisms of Attracting and Sustaining Long-Term Investment

For companies committed to the RE100 initiative, long-term investment shows a commitment to ESG principles and contribution to a resilient and economically sound business model. Investors pursuing long-term investment, including sovereign wealth funds and pension funds, are looking for companies with energy transition technology. A growing recognition of the sustainability of long-term business success is regarded as a hedge against volatile fossil fuel prices, regulatory risks, and shifting consumer demands. For the companies, it is critical to secure long-term power purchase agreements (PPAs), through which renewable energy can be purchased at a predetermined price over a long period. These agreements make investment projects appealing to investors. They also allow RE100 companies to maintain stable electricity costs. Recently, virtual power purchase agreements (VPPAs) have appeared as a financial tool for companies to benefit from PPAs [17]. Direct investment in company-owned renewable energy assets, such as rooftop solar panels or a share of a wind farm, can also attract long-term investment. This provides firm control over energy supply, leading to significant cost savings. It shows a commitment to the RE100 initiative, too, with a proactive management strategy. For example, some companies are investing in their own green power generation and battery storage facilities to ensure supply stability [18].

With such projects, transparent reporting on a company's RE100-goal-related business is important for long-term investment. For example, companies that report on their decarbonization plans and the reduction of carbon emissions from purchased electricity

are regarded as low-risk, responsible ones. Many institutional investors are using ESG metrics to decide on investment opportunities and divest from companies that fail to take responsible climate action [19]. Collective action and policy advocacy are also essential to accelerate the energy transition and create investment opportunities. By supporting policies that promote renewable energy and grid modernization, companies can comply with new regulations, such as carbon pricing or stricter emissions reporting, which is a concern for investors [20].

6. Conclusion

Start-up companies operating at the nexus of environmental sustainability, ESG principles, and RE100 technologies are proving to be the engines of economic growth, globally and domestically. They are responding to a crisis and actively driving a fundamental restructuring of the global economy towards a more sustainable and resilient future. Through their relentless innovation, start-ups are creating new markets, generating high-quality jobs, attracting substantial capital, and instigating a ripple effect of sustainable practices across established industries and global supply chains. The success stories of companies such as Northvolt and Beyond Meat demonstrate the potential for start-ups to achieve significant economic scale while delivering tangible environmental and social benefits. Conversely, the challenges faced by A123 Systems and KiOR serve as crucial lessons, highlighting the importance of robust business models, cost competitiveness, patient capital, and supportive policy environments for nascent green technologies. The future of green start-ups is bright but contingent on strategic action. Governments must implement clear and consistent policies and incentivize green innovation and investment. Financial institutions need to reallocate capital towards sustainable start-ups, embracing longer investment horizons and blended finance models where appropriate. Critically, these start-ups must be agile and focus on scalable solutions that offer compelling economic value alongside their environmental credentials. A mature ecosystem nurtures green innovation and prioritizes its commercial viability, a circular, low-carbon economy, ensuring environmental sustainability for long-term prosperity. In addition, efforts to attract and sustain long-term investment must be put by committing to ESG principles with a resilient and economically sound business model, increasing direct investment in company-owned renewable energy assets, and reporting regularly on the company's RE100-goal-related business.

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