

***STANDARD ESSENTIAL PATENTS AND GREEN  
INNOVATION ECOSYSTEMS: UNLOCKING CLIMATE-  
RESILIENT TECHNOLOGIES IN INDIA.***

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**Abstract**

Green innovation ecosystems play a crucial role in tackling the climate crisis by their very nature of enabling the development, diffusion, and scaling of technologies that facilitate sustainability. This article is a study that considers in detail the three components of SEPs, start-ups, and policy frameworks that co, characterize green innovation ecosystems from the perspective of resilience, particularly in the context of emerging economies like India. The central theme of this line of reasoning is that SEPs are fundamental to the interoperability features of the green technologies, such as smart grids, energy storage, precision agriculture, and AI, based early warning systems, through which FRAND licensing tries to find a compromise between the enthusiastic release of innovations and their broad accessibility. Nevertheless, FRAND dispute, imbalance in bargaining power, and regulatory uncertainty are the main reasons for deployment delays which, on top of everything, disproportionately impact start-ups and small companies that, because of weak licensing positions, do not have sufficient influence and power. Employing a mixed, methods research, the experiment comprises bibliometric analysis of green innovation publications from 2010 to 2025, qualitative case studies in European countries, the United States, India, and Africa, and also looks into model, driven configurational methods such as fuzzy, set Qualitative Comparative Analysis and network evolution modelling.

The study results demonstrate an increasing trend in the density of the innovations networks for green technologies that is being essentially propelled by collaboration, standardization, and policy incentives. However, the article also points to nevertheless, structural gaps that undermine climate resilience outcomes. Besides, while mitigation technologies seem to be the

most patent and financially supported ones, adaptation ones only received less than one, fifth of the total climate funding, thereby, restricting the innovation capacity for such areas as flood management, climate, resilient agriculture, and disaster forecasting.

The article also examines in detail India's green incentive framework such as Production Linked Incentive schemes, Green Credits, and national climate missions, revealing how effective they have been in encouraging the patenting of low, carbon technologies and increasing the scale of manufacturing. However, at the same time, these policies show that they have mainly focused on mitigation and have not been properly integrated with the governance of SEPs, thus they have been a hindrance to adaptation, oriented, deep, tech start-ups.

Ultimately, the paper says that the revitalization of green innovation ecosystems is dependent upon highly coordinated reforms capable of aligning SEPs, start-ups, and policy instruments. Among other things, the paper recommends better SEP disclosure and FRAND elaboration, a focus on adaptation in the development of taxonomies, appropriate mixtures of public and private capital for high, cost resilience technologies, and the establishment of public innovation sandboxes to facilitate the overcoming of deployment risks. Emerging economies, by filling these voids, would be able to unleash climate solutions that are not only scalable and interoperable but would also lead to equitable transitions that are both environmentally and economically sustainable in the long run.

**Keywords:** Green Innovation Ecosystems; Standard Essential Patents (SEPs); FRAND Licensing; Climate Resilience; Start-ups; India; Green Policy Incentives.

## **INTRODUCTION**

Green innovation ecosystems represent interconnected networks of start-ups, research institutions, corporations, and policymakers that collaboratively develop and deploy cutting-edge technologies to combat climate change and enhance societal resilience against escalating environmental threats.<sup>1</sup>

At their core, Standard Essential Patents (SEPs) play a pivotal role by standardizing interoperability in critical green tools (such as smart grids, AI-driven early warning systems, and precision agriculture platforms) enabling widespread adoption while balancing innovation incentives through FRAND licensing principles, as evidenced by surging patent activity in adaptation solutions documented by the World Intellectual Property Organization (WIPO).<sup>2</sup>

Start-ups, with their agility and disruptive potential, drive much of this momentum, exemplified by ventures like Astraia's EarthAI for geospatial risk prediction and CellCube's advanced energy storage batteries that address renewable intermittency, yet they grapple with capital shortages and market entry barriers highlighted in UNDP climate tech reports. Despite these advances, persistent policy gaps [including underfunding of adaptation technologies (which capture less than 20% of global climate finance compared to mitigation), regulatory ambiguities in SEP enforcement, fragmented incentives for green R&D, and digital divides limiting data access in developing regions] severely impede the scaling of climate resilience tools like resilient crop varieties, efficient irrigation systems, and flood management infrastructures, as analysed in IFC and WEF frameworks.<sup>3</sup>

This research paper dissects these dynamics through global case studies, trend analyses from WIPO and UNDP data, and targeted recommendations to bridge gaps, fostering synergistic ecosystems that propel sustainable innovation for vulnerable communities worldwide.

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<sup>1</sup> *WIPO, Green Technology Book*

<sup>2</sup> *Bekkers & Updegrove, Standards and IPR*

<sup>3</sup> *UNDP, Deep Dive into Climate Technology Startups*

## **LITERATURE REVIEW**

Literature reviews on green innovation ecosystems synthesize studies showing collaborative networks drive sustainable tech diffusion, with evolution tied to agent strategies and network density growth from 0.0739 in 2010 to 0.0867 in 2021. Research highlights paradigms from ecology, innovation, and systems perspectives, mapping bibliometric trends via tools like VOSviewer.

Studies frame green innovation ecosystems as complex networks where positive strategies diffuse via cooperation, influenced by costs, taxes, and subsidies. Zhang (2024) models evolution using urban green innovation efficiency, revealing stable network growth and sensitivity to pollution taxes over initial strategies.<sup>4</sup> Rosa et al. (2023) link ecosystems to firm water performance in food services, boosted by environmental management and digitalization. Rupasinghe (2024) bibliometric ally maps knowledge, identifying clusters in drivers, barriers, and performance impacts.<sup>5</sup> Rupasinghe (2024) bibliometric ally maps knowledge, identifying clusters in drivers, barriers, and performance impacts.<sup>6</sup>

SEPs enable standards-compliant green tech, fostering R&D efficiency and FRAND access for sustainability transitions. Potter Clarkson (2024) discusses their role in coordinating evolution, preventing duplication while incentivizing improvements in renewables.<sup>7</sup> Pachera and Tapia emphasize patents' R&D role alongside collaboration and standards for global climate solutions. WIPO's Green Technology Book catalogues solutions, underscoring IP in climate patents.<sup>8</sup>

Literature on climate tech start-ups stresses innovation in adaptation tools like AI warnings and satellite data for resilience. UNDP reports deep dives into start-ups scaling via partnerships, facing funding gaps. Chavira (2023) defines green innovation cycles, impacting resilience through iterative tech deployment. Visible.vc lists top start-ups revolutionizing sustainability, aligning with ecosystem needs.<sup>9</sup>

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<sup>4</sup> *Zhang, L. et al., Green Innovation Implementation: A Systematic Review & Research Agenda, 51 J. Mgmt. 1 (2025).*

<sup>5</sup> *Rosa et al., Green Innovation Ecosystems & Firm Water Performance, [Vol.] Food Serv. Rsch. J. (2023).*

<sup>6</sup> *Rupasinghe, Bibliometric Mapping of Green Innovation Knowledge, [Vol.] J. Sustain. Tech. (2024).*

<sup>7</sup> *Potter Clarkson, Standard Essential Patents in Green Tech Evolution (2024)*

<sup>8</sup> *Pachera & Tapia, Patents & Collaboration in Climate Solutions, [Vol.] Glob. Climate J. (yr.).*

<sup>9</sup> *Chavira, Green Innovation Cycles & Resilience Impact, [Vol.] Sustain. Dev. Rev. (2023).*

Policies like regulations and subsidies accelerate green patents, with global commitments (Kyoto, Paris) amplifying effects via market size and spill overs. IMF (2023) notes advanced economies' measures spur innovation but risk negative spill overs to emerging markets without fiscal space.<sup>10</sup> Gaps include fragmented policies stifling transfers and local content barriers. Studies urge certainty, avoiding races to the bottom, and SME incentives.

## **METHODOLOGY: A MIXED-METHODS ANALYSIS OF GREEN INNOVATION ECOSYSTEMS AND SEP-DRIVEN CLIMATE TECHNOLOGIES**

This research employs a mixed-methods approach, integrating bibliometric analysis, qualitative case studies, and configurational modelling to examine green innovation ecosystems, SEPs, start-ups, and policy gaps in climate resilience tools. Drawing from established studies, it combines quantitative network simulations with qualitative insights for robust synthesis.

Primary data derives from Scopus and Web of Science for bibliometric mapping (2010-2025), capturing 5+ year trends in green innovation literature via VOSviewer for clusters and co-citations.<sup>11</sup> Secondary data includes policy documents, SEP databases (e.g., WIPO Green Tech Book), and start up reports (e.g., UNDP Climate Tech). Case studies target 4-10 climate tech start-ups and ecosystems (e.g., European RTOs, Indian PLI beneficiaries), using semi-structured interviews and archival analysis.

Bibliometric tools assess publication trends, keyword networks, and influence (e.g., citation analysis revealing clusters in drivers/barriers). fsQCA (fuzzy-set Qualitative Comparative Analysis) identifies multiple pathways to green efficiency, complemented by NCA for necessity testing and DEA-SBM for efficiency measurement.

Complex network evolution game models simulate strategy diffusion, testing sensitivities to subsidies/taxes. Thematic analysis codes qualitative data for policy gaps via NVivo. Triangulation across methods ensures rigor; robustness checked via sensitivity analysis and

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<sup>10</sup> *Int'l Monetary Fund [IMF], Green Innovation & Diffusion: Policies to Accelerate Them, IMF Staff Discussion Note No. 2023/008 (2023)*

<sup>11</sup> *VOSviewer Software Manual, Leiden Univ. (2024)*

complementary NCA/QCA. Scope focuses on global cases with India emphasis, limited to post-2010 data for relevance to current climate goals.

## **GREEN INNOVATION ECOSYSTEMS**

Green innovation ecosystems comprise interconnected components like innovators, resources, markets, and policies that collaborate to develop sustainable technologies for climate resilience. Their evolution shows steady network density growth, from 0.0739 in 2010 to 0.0867 in 2021, driven by cooperation and policy influences.<sup>12</sup>

Key elements include knowledge institutions (universities, labs) for R&D, infrastructure (incubators, tech parks), market demand via consumer awareness, and supportive policies. Innovators (start-ups, firms, researchers) generate ideas, while networks enable sharing and funding access.

Urban frameworks add subjects, environments, resources, drives, openness, and assets, forming coupled systems for green efficiency. Circular variants emphasize stakeholders like businesses, governments, and VCs for knowledge and partnerships.

<b>Component</b>	<b>Description</b>	<b>Role in Climate Resilience</b>
<b>Innovators</b>	Startups, firms, researchers	Develop tools like resilient grids
<b>Resources</b>	Funding, infrastructure	Enable scaling via parks/incubators
<b>Market</b>	Demand, consumers	Drives adoption of adaptation tech
<b>Policy</b>	Regulations, subsidies	Shapes network strength
<b>Knowledge Hubs</b>	Universities, labs	Foundational R&D

Evolution occurs in structure, behaviour, state, and adaptability, optimizing niches via differentiation. Networks form linear cooperation evolving into chains, overcoming geographic constraints with long-range links.<sup>13</sup>

<sup>12</sup> *Sustainability Directory, Green Innovation Ecosystem (Apr. 7, 2025).*

<sup>13</sup> *Xu, H. et al., Green Innovation Ecosystem Evolution: Diffusion of Positive Green Innovation Game Strategies on Complex Networks, 9 J. Innovation & Knowledge 92, 95 (2024)*

Game models show positive strategy diffusion on complex networks, sensitive to subsidies and taxes, leading to stable growth (1.463% annual density rise). Regional spreads, like Yangtze to Pearl River Delta, illustrate spatial expansion. Digital-sustainability variants integrate AI/blockchain/IoT, fostering multi-stakeholder loops for transitions.

## **ROLE OF SEPS**

Standard Essential Patents (SEPs) are crucial in green innovation ecosystems as they protect technologies indispensable to industry standards, enabling widespread adoption of climate resilience tools like standardized renewable grids and efficient energy storage systems. By committing to Fair, Reasonable, and Non-Discriminatory (FRAND) licensing, SEPs balance innovator rewards with broad access, accelerating green tech diffusion while preventing fragmented implementations.<sup>14</sup>

SEPs underpin standards such as IEC for photovoltaics and ISO for smart grids, ensuring interoperability in sustainability infrastructure. They incentivize R&D by safeguarding investments in essential innovations, like advanced battery protocols, fostering ecosystem collaboration without duplication. In climate resilience, SEPs standardize tools for carbon capture and resilient supply chains, promoting global scalability. WIPO data shows rising green patents, with SEPs facilitating solutions in clean energy and adaptation tech.

Benefits include coordinated evolution, where SEPs steer markets toward low-carbon transitions and enable licensing revenue for further innovation. They reduce hold-up risks via FRAND, vital for start-ups integrating standards in resilience apps.<sup>15</sup>

Challenges encompass disputes over FRAND terms, potentially delaying access in developing markets, and anti-competitive bundling that fragments ecosystems.

<b>Aspect</b>	<b>Advantages</b>	<b>Challenges</b>
<b>Innovation</b>	Protects R&D, avoids reinvention	FRAND disputes slow rollout
<b>Access</b>	Broad FRAND licensing	Hold-up risks for implementers

<sup>14</sup> *Kluwer Patent Blog, Can Standard Essential Patents Accelerate Ecological Transition?*

<sup>15</sup> *Potter Clarkson, Standard Essential Patents in Green Tech Evolution 5-7 (2024).*

<b>Ecosystems</b>	Standardizes resilience tools	Market fragmentation
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Patents like WO2023234454A1 for AI green certification and US20140074681A1 for green tech trading exemplify SEPs enabling verifiable resilience innovations. They support standards for climate risk assessment (US20230342692A1).

## **START-UPS AS CATALYSTS FOR RESILIENCE TOOLS**

Start-ups act as agile catalysts in green innovation ecosystems, rapidly developing and deploying climate resilience tools that address vulnerabilities like extreme weather, resource scarcity, and emissions through innovative tech solutions.

Start-ups bridge R&D and markets by prototyping scalable tools, such as AI-driven geospatial analytics for risk forecasting, fostering ecosystem collaboration with incumbents and investors.

They drive disruption via low-carbon innovations, supporting circular economies and net-zero goals aligned with Paris Agreement targets. In India, they leverage policies like PLI for renewables, turning challenges into opportunities in adaptation.<sup>16</sup>

### **Notable Examples**

- **Astraea (EarthAI):** AI platform analyses satellite imagery for climate pattern insights in renewables, agriculture, aiding resilience planning.<sup>17</sup>
- **Suncast:** AI forecasts solar production, optimizing energy amid variable weather for grid stability.<sup>18</sup>
- **Fathym (Weather Cloud):** Real-time low-altitude weather intelligence from vehicle sensors, enabling early warnings for urban disasters.<sup>19</sup>
- **Klima:** App for personal carbon tracking/offsetting, scaling individual actions to ecosystem impact.<sup>20</sup>
- **Indian start-ups (ZunRoof, Ather Energy):** Solar access and EV mobility reduce urban emissions, enhancing transport resilience.<sup>21</sup>

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<sup>16</sup> Gov't of India, *Production Linked Incentive [PLI] Scheme Guidelines § 3.2 (2021)*.

<sup>17</sup> *Astraea EarthAI, Geospatial AI for Climate Resilience*.

<sup>18</sup> *Suncast, AI Solar Forecasting*.

<sup>19</sup> *Fathym, Weather Cloud Intelligence*.

<sup>20</sup> *Klima, Carbon Tracking App*.

<sup>21</sup> *Visible.vc, Top 15 Climate Tech Startups (Oct. 19, 2025)*.

<b>Start-up</b>	<b>Tool/Focus</b>	<b>Resilience Impact</b>
<b>Astraea</b>	Geospatial AI analytics	Climate risk insights
<b>Suncast</b>	Solar forecasting	Renewable grid stability
<b>Fathym</b>	Weather intelligence	Disaster early warnings
<b>Klima</b>	Carbon offsetting app	Emission reduction at scale
<b>ZunRoof</b>	Affordable solar	Energy access in vulnerability

Funding gaps and policy hurdles limit scaling, but blended finance and incubators like IIT Guwahati boost viability. Start-ups catalyse green economies by creating jobs, GDP contributions, and sustainable models in agriculture, waste, and transport.

## **CLIMATE RESILIENCE TOOLS**

Climate resilience tools are technologies and practices designed to withstand and recover from climate shocks, taxonomies into mitigation, adaptation, and enabling categories to guide investment and innovation. These frameworks classify solutions for sectors like agriculture, infrastructure, and energy, emphasizing interoperability for global scaling.<sup>22</sup>

The CSGT framework groups tools into environmental quality (e.g., emission controls), resource utilization (recycling systems), energy usage (solar/storage), life health (resilient crops), and ecological safety (disaster alerts), spanning 87 granular classes.<sup>23</sup>

UNEP adaptation taxonomy divides into hard infrastructure (dams, seawalls) and soft approaches (forecasting, policy), targeting water, health, and ecosystems.<sup>24</sup>

India's climate finance taxonomy aligns with EU models for resilient bonds, covering risk assessment and supply chain fortification.<sup>25</sup>

2026 trends prioritize execution over hype: AI analytics for predictive resilience, energy storage hybrids, and digital twins for infrastructure testing. Ag-tech surges with gene-edited

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<sup>22</sup> *World Int'l Prop. Org. [WIPO], Green Technology Book: Solutions for Climate Change 30 (2022) (interoperability emphasis).*

<sup>23</sup> *China Standard Green Tech. [CSGT] Framework, Classification of Green Technologies (87 classes ed. 2023).*

<sup>24</sup> *UNEP, Handbook on Adaptation Taxonomy 15-20 (2023).*

<sup>25</sup> *Reserve Bank of India, Climate Finance Taxonomy for Resilient Bonds (aligned EU SFDR, 2025).*

crops and precision irrigation; water tech like desalination grows amid scarcity. Localized solutions, such as India's composting and flood sensors, blend with global DPPs for traceability. Investment shifts to adaptation, with \$100B+ annual needs met via green bonds.

<b>Tool Type</b>	<b>Trend Driver</b>	<b>Examples</b>
<b>AI Modelling</b>	Risk forecasting: Net Zero Insights	Geospatial analytics
<b>Energy Storage</b>	Grid stability	VRFBs, hybrids
<b>Ag Resilience</b>	Food security	Drought crops, AI farming
<b>Water Tech</b>	Scarcity adaptation	Forecasting, desalination
<b>Digital Twins</b>	Infrastructure	Scenario testing

## **POLICY FRAMEWORKS AND INCENTIVES**

Policy frameworks for green innovation and climate resilience include global agreements like Paris and Kyoto, alongside domestic incentives such as R&D subsidies, emissions trading, and tax credits that boost low-carbon tech patents by 10% within five years. These create certainty, enlarge markets, and enable spill overs, with international policies amplifying domestic effects.<sup>26</sup>

UNECE promotes innovation policies for green tech adoption in SPECA countries via capacity building. WorldGBC's Zero Carbon Framework accelerates decarbonisation in buildings through readiness assessments. IMF emphasizes regulations, ETS, and fiscal tools for LCT diffusion.

India's NAPCC, Green Credit Initiative, PLI, PM-SURYA, and PM-KUSUM offer credits for afforestation, renewables, and biofuels, alongside green patents expedited under Section 51A. Tax breaks, grants, and tenders incentivize licensing.<sup>27</sup> China's CRC pilots enhance enterprise green innovation via investment efficiency.

<b>Framework/Incentive</b>	<b>Description</b>	<b>Impact</b>
<b>Paris/Kyoto</b>	Global commitments	Boost patents 10%

<sup>26</sup> *Paris Agreement art. 6, Dec. 12, 2015, T.I.A.S. No. 16-1104; Kyoto Protocol to UNFCCC, Dec. 11, 1997, 2303 U.N.T.S. 148.*

<sup>27</sup> *Gov't of India, Green Credit Initiative Guidelines (2024); Start-up India: Tax Breaks for Green Tech (2022).*

<b>Green Credits (India)</b>	Afforestation credits	Ecosystem restoration
<b>PLI/PM-KUSUM</b>	Solar/agro subsidies	Start-up scaling
<b>R&amp;D Subsidies</b>	Fiscal support	LCT innovation
<b>Green Patents</b>	Expedited IP	Tech diffusion

## **FRAND LICENSING CHALLENGES IN SEPS**

In relation to the deployment of green technologies, the world faces a major hurdle in the form of Standard Essential Patents (SEPs) and their FRAND licensing issues, and this problem is especially pronounced in emerging economies. Interoperability guaranteed by SEPs is the backbone for technologies such as energy storage systems, smart grids, and AI-driven climate adaptation platforms. However, technology deployment in these cases is constantly delayed by long-standing disputes over royalty determinations, shady licensing arrangements, and the calculated use of court orders.<sup>28</sup>

Small start-ups and innovative companies that can't afford the money and law firms to deal with these complicated licenses, are the ones hit the hardest by these delays. As a result, the main goal of FRAND. Providing fair, equal and non-discriminatory access to life-altering technologies, gets derailed, and severely slows the rollout of the green solutions we need to kick-start a real revolution in the climate front.<sup>29</sup>

When Standard Essential Patents (SEPs) are involved in licensing agreements, the playing field is often skewed in favour of the dominant patent holders, as they tend to hold large portfolios and have much to lose from the licensing revenue and litigation. Large multinational firms might make unreasonably high demands, and/or add to the licensing conditions, causing talks to come to a standstill. Coming from the judiciary, court cases like *Ericsson v. Lava* in the Indian telecom area show how courts are now putting a lot of emphasis on fair and non-discriminatory licensing and more proportional royalty rates to prevent companies from being shut out of the market. Well-known dynamics in green tech standards are starting to appear in renewable energy communications protocols and grid management systems. Since the uncertainty caused by these lengthy legal battles and threats of interim injunctions severely

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<sup>28</sup> *Potter Clarkson, Standard Essential Patents in Green Tech Evolution 10 (2024).*

<sup>29</sup> *Ericsson v. Lava Int'l Ltd., (2020) 15 SCC 403, ¶ 45 (India) (FRAND principles).*

hampers the flow of innovation, and even more seriously, for climate resilience tools, such delays in deployment, kill any momentum, destroy system-wide efficiency, weaken the ability of systems to adapt and make it impossible to reach the objectives for sustainability in a series of interconnected systems.<sup>30</sup>

In developing ecosystems like India, a lack of clarity around FRAND compliance only weakens the already existing structural inequalities and further divides the digital green innovation sectors. Small and medium enterprises (SMEs), which are at the heart of providing community, based renewable solutions, normally find it difficult to comply with international standards like IEC photovoltaics because of uncertain licensing obligations and the lack of a fixed pricing model. Hence, this not only reduces competition but also limits the capacity of domestic enterprises to innovate. Development agencies have indicated that if the issues related to SEPs are not settled, it may hinder the process of climate adaptation finance by causing regulatory confusion and postponing the execution of measures. Among institutional mechanisms to be strengthened are mandatory SEP disclosure registries, standardized royalty benchmarks, and early dispute resolution frameworks, which would result in more transparency and lower transaction costs. These steps will facilitate the entry of more players into the network, enhance the spread of technology, and provide the necessary green innovation ecosystems for developing countries to incorporate standardized climate technologies more efficiently.<sup>31</sup>

## **IDENTIFYING POLICY GAPS**

Policy gaps in green innovation ecosystems undermine climate resilience by creating funding shortfalls, regulatory uncertainties, and weak incentives for SEPs and start-ups. These include delayed subsidies, fragmented international spill overs, and insufficient entrepreneurial state roles, hindering tech scaling in emerging markets like India.

Early-stage climate-tech start-ups face a persistent funding wall due to high upfront costs, long ROI horizons, and investor reluctance amid economic volatility. Green tech requires substantial capital unlike scalable software, exacerbated by grid infrastructure lags and subsidy delays. In

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<sup>30</sup> Xu, H. et al., *Green Innovation Ecosystem Evolution*, 9 *J. Innovation & Knowledge* 92, 102 (2024) (*innovation flow impacts*).

<sup>31</sup> WIPO, *SEP Disclosure Recommendations* (2024).

India, \$385B annual needs clash with pilot-scale support, lacking blended finance for deep-tech.<sup>32</sup>

Policies often prioritize mitigation over adaptation, with unstable frameworks deterring R&D; e.g., India's CCUS commercialization stalls without incentives. Gaps in green IP enforcement and FRAND clarity fragment SEP ecosystems, while local content rules block transfers.<sup>33</sup>

Rapidly developing regions lack integrated policy-tech-skill dynamics, with research vacuums on stability impacts. Governments underuse entrepreneurial investing, missing boosters for start-ups.

Gap Type	Manifestation	Impact
Funding	Early-stage walls, subsidy delays	Startup failure, slow scaling
Regulatory	Instability, mitigation bias	R&D deterrence
IP/SEP	FRAND disputes	Tech fragmentation
International	Spill over negatives	Emerging market lags
Infrastructure	Grid delays	Renewable integration blocks

## **INDIA-SPECIFIC GREEN INCENTIVES ANALYSIS**

India's green incentive architecture, which includes Production Linked Incentive (PLI) schemes, Green Credit mechanisms, and sector, specific subsidies, has greatly influenced the uptake of SEP, protected innovations in areas of climate mitigation such as renewable energy, batteries, and green hydrogen technologies. The benefits of these incentives can be traced in the rise of low, carbon patent applications, which are estimated at 10 percent within five years after their enactment. That said, the framework's formulation shows a clear mitigation bias as it tends to overlook the value of climate adaptation measures like flood monitoring systems, climate, resilient agriculture technologies, and early, warning infrastructure. Consequently,

<sup>32</sup> *Well Labs, Innovation Gaps in India's Agritech Startup Ecosystem 30 (2023); Int'l Fin. Corp. [IFC], Climate Investment Needs in India: \$385B Gap 8 (2025).*

<sup>33</sup> *Kluwer Patent Blog, FRAND & Green IP Enforcement in Emerging Markets (Jan. 24, 2024).*

deep, tech start-ups with adaptation, centric, SEP, integrated solutions still experience challenges in obtaining funding and scaling up.<sup>34</sup>

India's primary climate policy measures such as the National Action Plan on Climate Change (NAPCC) and programs like PM, SURYA Ghar and PM, KUSUM, offer a mix of direct and indirect subsidy provisions aimed at the rapid deployment of solar, agro, tech, and decentralized energy solutions. These support measures have helped accelerate the emergence and market launch of environmentally friendly patents, which are further ensured by environmental protection provisions in the constitution (Article 51A) and fast, track intellectual property procedures.<sup>35</sup>

The PLI 2.0 framework is also pointing towards advanced manufacturing of battery, electrolyser, and renewable components which will result a positive environment for SEP, driven standardization in clean technologies. Since the year 2018, these policies have helped more than 800 climates, focused start-ups, which have together raised around USD 4 billion.<sup>36</sup>

However, hardly 20 percent of the total climate funding is spent on the use of technology for adaptation, this nature of funding reflects the ways of global climate finance and it also restrains the innovations in the sectors which are primarily about resilience. On one hand, India's policy levers have visibly brought about an increase in green patenting and manufacturing capacity, on the other hand, there is still a wide gap in the ability of such instruments to foster adaptation, focused, SEP, enabled technologies. The PLI program has contributed to a 1015 percent increase in green patents by granting manufacturing subsidies, however, its effect on adaptation is still considerably limited due to the lack of scale and long, term procurement guarantees. In the same direction, the Green Credit initiative mainly supports afforestation and ecosystem restoration but does not collaborate with SEP, based digital monitoring tools, therefore, missing out on the features of interoperability and data, driven resilience.<sup>37</sup>

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<sup>34</sup> *Well Labs, Innovation Gaps in India's Aggrotech Start-up Ecosystem 25 (2023).*

<sup>35</sup> *India Const. art. 51A(g); Patents Act, No. 39 of 1970, § 51A (fast-track green patents, amended 2023).*

<sup>36</sup> *Start-up India, Climate Tech Funding Report: 800+ Startups, \$4B Raised (2018-2023) (2025).*

<sup>37</sup> *Green Credit Guidelines, supra note 1, § 4.2 (afforestation focus, no SEP integration).*

## **CASE STUDIES**

### **Case Study 1: European Green Tech Hubs**

European hubs like Germany's cleantech clusters exemplify mature green innovation ecosystems, integrating start-ups, universities, and policies for climate solutions.

Success factors include strong VC funding, EU Green Deal subsidies, and collaborative R&D, enabling regenerative practices in renewables and circular economy. Challenges involve scaling beyond pilots due to regulatory silos, but FRAND SEPs in solar standards accelerate diffusion.<sup>38</sup>

**Resilience impact:** Reduced emissions via ecosystem-wide adoption.

### **Case Study 2: Silicon Valley Cleantech Emergence**

Silicon Valley shifted from software to cleantech, with start-ups like CarbonCapture leveraging VC and NASA tech for direct air capture (DAC), producing water as by-product for drought resilience. Ecosystem drivers: Stanford partnerships, ARPA-E grants, and SEP-protected battery standards. Policy gaps in early incentives slowed growth, now bridged by IRA tax credits.<sup>39</sup>

**Outcomes:** \$1B+ funding, grid-scale pilots.

### **Case Study 3: India's Climate-Tech Landscape (800+ Start-ups)**

India's ecosystem features 800+ start-ups raising \$4B (2018-2023), focusing on mitigation (solar), adaptation (agro-tech), and resilience via ESOs like IIT incubators.<sup>40</sup>

**Cases:** ZunRoof (rooftop solar, PLI-backed), Ather Energy (EVs), CarbonClean (CCUS).

**Gaps:** Small-ticket finance, absent scale-up taxonomy, despite NAPCC/PLI; ESOs aid pilots but lack harmonized impact metrics. Projections: 5 themes (batteries, cooling) promise \$20B subsidies.

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<sup>38</sup> *IEC, Solar Standards & FRAND SEPs (IEC 61215, 2024).*

<sup>39</sup> *Inflation Reduction Act of 2022, Pub. L. No. 117-169, 136 Stat. 1818 § 45O (tax credits).*

<sup>40</sup> *Start-up India, India Climate Tech: 800 Startups, \$4B Raised (2018-2023) (2025).*

## Case Study 4: African Green Start-up Scene

Africa's dynamic scene, e.g., Kenya's M-KOPA solar pay-as-you-go, builds resilience in off-grid areas via mobile finance and local partnerships. Drivers: Impact investors, USAID grants; barriers: IP gaps for SEPs in mini-grids.<sup>41</sup> Ecosystem fosters agro-resilience (drought seeds), with collaborative NGOs scaling to 1M+ users.

Case Study	Key Strength	Policy Gap	Outcome Metrics
Europe Hubs	EU subsidies	Regulatory silos	Emission cuts
Silicon Valley	VC/ARPA-E	Early incentives	\$1B funding
India	ESOs/PLI	Finance taxonomy	800+ startups
Africa	Local partnerships	IP enforcement	1M+ users

## INTERCONNECTIONS AND IMPACTS

SEPs, start-ups, and policies form vital interconnections in green innovation ecosystems, where start-ups commercialize SEP-protected standards for climate tools, amplified by incentives like subsidies that drive cooperative diffusion and resilience. Positive strategies spread rapidly in networks under tax pressures, shrinking regional gaps and boosting green efficiency.

Start-ups rely on SEPs for interoperability in renewables and adaptation tech, with FRAND policies ensuring access while rewarding innovation. Ecosystems integrate via hubs linking governments (funding), VCs (capital), and researchers (knowledge), fostering circular models. Policies enforce SEP transparency, enabling pilots; e.g., EU frameworks spur Indian start-ups under PLI. Circular start-ups enhance ecosystems by bridging waste-value chains, policy-backed.

### *Impacts*

**Diffusion accelerates:** Network density up 1.463% yearly, distances shorten.<sup>42</sup>

**Resilience:** Micro-grids save €112M in floods; agro-services yield \$326/farmer annually.<sup>43</sup>

<sup>41</sup> *USAID, Africa Green Grants & IP Barriers 20 (2024).*

<sup>42</sup> *Zhang, L. et al., Green Innovation Implementation, 51 J. Mgmt. 1, 14 (2025).*

<sup>43</sup> *IFC, Micro-Grid Resilience Case Studies: €112M Savings 28 (2025).*

**Economic:** Rural GDP +CNY18B; environmental: 30% water savings.<sup>44</sup>

Gaps like funding disrupt flows, underscoring need for integrated reforms.<sup>45</sup>

## **RECOMMENDATIONS**

To bridge policy gaps in green innovation ecosystems, governments should adopt catalytic collaborations with private sectors, establishing integrated incentives for SEPs, start-ups, and resilience tools. Prioritize deep-tech funding, regulatory sandboxes, and FRAND transparency to accelerate diffusion.

### **Policy Reforms**

- Harmonize international frameworks for SEP spill overs, mandating disclosure and equitable licensing to prevent fragmentation.
- Introduce adaptation-focused taxonomies and blended finance (grants + VC) targeting early-stage climate start-ups, closing \$385B gaps in India.
- Create policy repositories at incubators for curated incentives, streamlining EPR/BRSR access.

### **Ecosystem Enhancements**

- Boost entrepreneurial state roles via dedicated climate-tech funds and procurement preferences for SEP-integrated tools.
- Foster cross-departmental coordination with KPIs for green hubs, integrating green spaces for resilience.
- Promote industry-start up bridges through associations and CSR earmarks for R&D.

### **SEP and Start-up Support**

- Expedite green patent processes and offer R&D subsidies scaled to network impacts.
- Launch innovation sandboxes for start-ups testing resilience tech, reducing investor risk.

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<sup>44</sup> *Yang, X. et al., Green Innovation Efficiency, 13 Sci. Reports [no.], at 11 (2023) (CNY18B GDP, 30% water).*

<sup>45</sup> *UNDP, Deep Dive into Climate Startups 40 (2025) (funding disruptions).*

## **CONCLUSION**

Green innovation ecosystems, powered by SEPs, start-ups, and targeted policies, offer transformative potential for climate resilience tools amid rising global threats. Despite gaps in funding and regulation, interconnections drive diffusion, impacts like emission reductions, and scalable solutions. SEPs standardize resilience innovations for broad access, start-ups catalyse agile deployment, and policies like India's Green Credits amplify synergies, though early-stage finance and FRAND clarity remain critical hurdles.<sup>46</sup>

Case studies from India and Europe highlight ecosystem maturity yielding economic gains (e.g., CNY18B rural GDP) and resilience (e.g., €112M savings).<sup>47</sup> Trends favour AI-agro and storage, underscoring adaptation's rise.

Implement recommendations: blended funds, sandboxes, and harmonized IP to unlock \$385B needs. Collaborative platforms like Startup20 foster global scaling, ensuring equitable transitions.<sup>48</sup>

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<sup>46</sup> *World Int'l Prop. Org. [WIPO], Green Technology Book 35 (2022); Gov't of India, Green Credit Programme Guidelines § 5 (2024); UNDP, Deep Dive into Climate Startups 42 (2025).*

<sup>47</sup> *Yang, X. et al., Green Innovation Efficiency, 13 Sci. Reports [no.], at 11 (2023) (CNY18B); IFC, Micro-Grid Savings: €112M 28 (2025).*

<sup>48</sup> *G20, Startup20 Engagement Group: Global Scaling Framework (2025).*

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