Communication in Physical Sciences, 2025, 12(6):1785-1813

Development of Sustainable Finance Strategies for Climate-Resilient Infrastructure Investments Across U.S. States

Forward Nsama
Received: 15 June 2025/Accepted 18 August 2025/Published online: 21 August 2025
https://dx.doi.org/10.4314/cps.v12i6.4

Abstract :*The conceptual paper approaches the specific methods for developing strategies for sustainable finance aimed at those infrastructures in the U.S. states that are climate-resilient and that incorporate ESG factors. With climate change escalated, the world is witnessing increased extreme weather events whose frequency and severity hinder funding models for the traditional infrastructure that pay little attention to factors of long-term vulnerability and social equity. This paper presents a framework geared toward aligning ESG-directed capital with federal and state climate and infrastructure policies such as the Inflation Reduction Act and Infrastructure Investment and Jobs Act. It analyses current financing instruments-greening approaches, public-private partnerships, blended finance, among others-to point out pathways to scaling the ESG investments and providing mechanisms to address regulatory misalignment, lack of data, and regional discrepancies. Subsequently, it describes strategic tools such as an ESG screening mechanism, climate risk appraisal, and performance-based metrics to divert capital towards sustainable infrastructure development. In summation, it suggests policy interventions and implementation strategies for materializing ESG-integrated finance as the backbone for resilient and inclusive infrastructure systems for the United States.*

Keywords: Climate-Resilient Infrastructure, ESG Investing, Green Bonds, Public-Private Partnerships, Sustainable Finance, U.S. Infrastructure Policy

Forward Nsama
School of Business, Avila University, Kansas City, MO, 64145, USA.
Email: nsama529958@avila.edu

1. 0 Introduction

The damages from climate change are intensifying, from storms that pack stronger winds and long heatwaves to different parts of the U.S. These changes threaten infrastructure and call for innovative financing strategies to develop resilience and sustainability (Robinson, 2021). This paper is conceptual in nature as it develops sustainable finance strategies that blend environmental, social, and governance factors with investments in climate-resilient infrastructures. It proposes frameworks for capital deployment and finds alignment of those frameworks with the ESG criteria, not only reducing climate risks but also enhancing social equity and governance transparency, ensuring that infrastructure projects withstand environmental shocks but continue existing economic and societal benefits over the long haul. Its purpose is to develop a channel and roadmap for stakeholders, policymakers, investors, and infrastructure developers about where to invest funds into projects that would have high return against profitability with adaptation against climate before the urgent need of resilient systems against fast-changing environments will be addressed.

From the U.S. context, the policy terrain is firm for sustainable finance towards anywhere about climate-resilient infrastructure (Ali & Kamraju, 2025). For example, the Inflation

Reduction Act (IRA) of 2022 provides a massive $369 billion in grants for clean energy and climate initiatives, where tax incentives would encourage investments in green technologies and resilient infrastructure. The same is true for the IIJA, which pledged $1.2 trillion toward the rebuilding of transportation, water, and energy systems while stressing resilience against climate-related disasters (Guha, 2025). The above policies are a reflection of the federal commitment in curbing effects behind a reported 71% increase in extreme precipitation events by the National Oceanic and Atmospheric Administration (Dax & Copus, 2022) in the U.S. Northeast area between 1958 and 2012, coupled with rising sea levels, which threaten coastal infrastructure (Denning, 2022). Therefore, the intent is that by embedding ESG principles, such policies would ensure that investments address both physical vulnerabilities and equitable access and sustainable development.

The argument for ESG-aligned capital deployment is that it provides multifaceted solutions to challenges arising from climate change while simultaneously developing economic and social resilience (Ghaemi Asl, 2025). Infrastructure financing usually looks at very short-term returns in most cases. Long-term climate risks are not taken into account, and the cost to the U.S. for damages annually seems to be around $150 billion attributed to disasters (Meyer & Schwarze, 2019). Projects in which ESG principles embed investments in fear of damaging carbon footprints; create impact through improving community welfare; and create robust governance will also align with global sustainability goals such as the Paris Agreement. For example, green bonds, which last year alone reached a record $270 billion in U.S. issuances in 2023 (Bloomberg), will be invested in flood-resistant bridges or renewable energy grids to escape damages as Hurricane Ida saw $65 billion damages in 2021. Therefore, emphasizing ESG should imply that such paper will argue that finance strategies can bridge the global $2.6 trillion infrastructure funding gap (Dua, 2022), with resilient systems that safeguard lives and livelihoods across states in the U.S.

The paper in itself is structured to cover a holistic form of sustainable finance for developing climate-resilient infrastructure. The first section reviews the conceptual basis of sustainable finance on ESG integration and its significance in making infrastructure resilient. The second block captures how the U.S. policy framework works, where specific opportunities for ESG-aligned investments have been made possible by the IRA and IIJA. The third section offers finance strategies, including green bonds, public-private partnerships, and impact investing, tailored for varying levels of climate risks across the states. Closing this part will also be implementation challenges, regulatory inconsistencies and funding disparities, while providing recommendations to stakeholder engagement to scale resilient infrastructure investments. Through this structure, the paper is said to make a significant contribution to the discourse on sustainable finance by identifying practical steps in building climate-resilient infrastructure across the U.S.

2.0 Conceptual Framework: ESG, Resilience, and Finance

2.1 Conceptualization

2.1.1 ESG Investing

ESG investing strategies evaluate investments based on environmental, social, and governance (ESG) criteria in asset selection and management. The environmental aspects address greenhouse gas emissions, energy use and efficiency, waste treatment and disposal, renewable resource usage, etc., as pertaining to the company in question (Sciarelli et al., 2021). The social aspects refer to the company's relationships with various stakeholders and include concerns regarding fairness in labor practices, employee well-being, diversity and inclusion, and the impact on society through engagement. Governance relates to how the

company runs itself-such as through board diversity, executive compensation, transparency, and anti-bribery policies (Previtali & Cerchiello, 2023). By integrating all these factors, ESG investing tends to align financial returns with ethical and sustainable outcomes, thus attracting investors who want to create long-term value alongside positive societal impact.

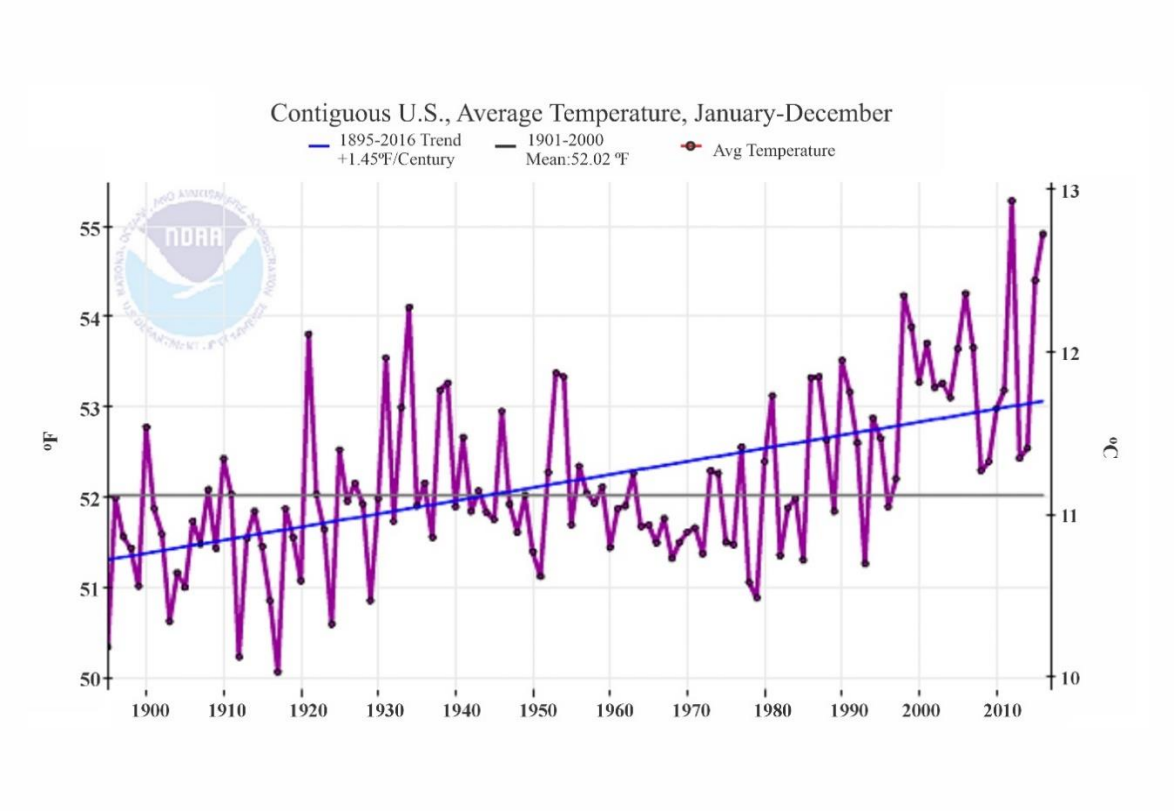

Fig. 1: US Average Temperature/Climate Trends (National Oceanic and Atmospheric Administration (NOAA National Centers for Environmental Information, 2016)

The growth of ESG investing indicates a growing awareness of global challenges ranging from climate change to social inequality and corporate accountability. Investors could look at frameworks revolving around ESG approaches in order to pick firms that effectively identify risks and positively contribute to greater society, mostly relying on ESG ratings or ESG indices for decision-making (Park & Jang, 2021). Such a method can shield investors from financial risks emanating from environmental regulations, labor disturbances, and governance scandals while increasing the likelihood of achieving high returns on investments through sustainable practices. Nevertheless, there are challenges such as inconsistencies in ESG measurement and the risk of "greenwashing", where companies may exaggerate sustainable efforts (Zervoudi et al., 2025). Despite these challenges, ESG investing continues to gain traction and is vying to reshape capital markets with a clear focus on resilience and responsibility over and above just commercialization.

2.1.2 Climate-Resilient Infrastructure

Climate-resilient infrastructure is concerned with physical systems that are actually designed to resist climate change effects—extreme weather conditions, rising sea levels, temperature shifts, etc.—such as roads,

bridges, power lines, water systems, and buildings (Argyroudis et al., 2022). These structures are specifically made to allow for the operation and safety of the structure itself during events like hurricanes, floods, or heat waves, thus minimizing disruptions and economic losses. Features include adaptive design such as elevated buildings in flood-prone areas, use of storm-resistant materials, and green infrastructure such as permeable pavements to reduce water runoff. The focus of this approach is long life service and risk reductions under the increasing climate burden (Stewart & Rosowsky, 2021).

Construction of climates-resilient infrastructure involves raising funds and creating alliances involving the government, private sector, and the communities, with the end goal of integrating climate projections into planning and design (Casady et al., 2024). It may incorporate sustainable technologies, with things like solar-powered grids and water-efficient systems, thereby minimizing environmental impact while creating the resilience. In turn, aspects beyond physical durability, such as economic stability, public safety, and environmental sustainability through repair costs, become beneficial (Dhar, 2025). However, difficulties like upfront costs and needing a newly reformed regulatory framework could act as barriers. Climate change impacts make such investments crucial towards adapting to a vulnerable and ever-changing world Leal (Filho, et al., 2024).

2.1.3 Sustainable Finance

That is to say, sustainable finance implies financial activities that enhance economic growth while also addressing environmental, social, and governance objectives by capital allocation in tandem with long-term sustainability (Junaedi, 2024). It includes various modes of financing like investments, loans, and bonds; and other financial instruments for projects involving renewable energy or sustainable housing or agriculture. By financing projects equal to those that deal with climate change, social inequalities, or ethical governance, sustainable finance incorporates itself into internationally accepted frameworks such as the United Nations Sustainable Development Goals (SDGs) (Grasso, 2010). The positive environmental and social impacts achieved in tandem will appeal to institutions and individuals eager for more responsible investment ventures.

Sustainable finance, by itself, stands for the realization of climate change and social challenges that terribly infringe upon business opportunities- stranded assets in the fossil fuel industries or reputational risks from poor governance-alike in global markets (Richardson, 2009). Important instruments in this area would include green bonds, which finance climate-friendly expenditures, and social-impact bonds, whose proceeds are devoted toward community development. Nevertheless, sustainable finance is faced with challenges like limited standardization, lack of scalability, and an urgent desire for reliable impact measurement. Thus, this will facilitate the redirection of capital into sustainable projects for ushering in a low-carbon, equitable economy, while enhancing innovation and resilience across various domains (Butt, 2024).

2.2 Theoretical Underpinning

2.2.1 Sustainability Transition Theory

In society, sustainability transition theory provides a framework for understanding and facilitating large-scale systemic changes towards more sustainable configurations (Williams & Robinson, 2020). This theory examines how socio-technical systems, which consist of a combination of technology, institutions, and social practices, evolve over time in response to environmental and social challenges. Transition in sustainability involves a fundamental interplay among three levels of actors through niches, regimes, and landscapes or broader societal and

environmental contexts: niches (spaces for innovation, like organic farming), regimes (dominant systems, like conventional agriculture), and landscapes (broader societal and environmental contexts, like economic trends or climate change) (Coenen et al., 2012). Generally, innovations in the niche level disrupt and transform the provoking regime. It may involve changes in policy, culture, and infrastructure to overcome path dependency and lock-in to unsustainable systems (Frantzeskaki & Loorbach, 2010).

Derived from innovation studies, as well as evolutionary economics, this theory utilizes such concepts as path dependency, in which the existing system may resist change due to anchored practices, and multi-level perspective (MLP), which considers interactions across niches, regimes, and landscapes. (Ruttan, 1997). It discusses strategies of governance essential to move systems forward towards sustainability, such as visioning, experimentation, and stakeholder collaboration, as well as instrumental transition management use. One such example can be derived from the Dutch energy transition around the first decade of this millennium, where governments employed transition management to foster the adoption of renewable energy. Critics maintain that the theory ignores capitalism's role in perpetuating these unsustainable systems and fails to capture global South contexts, though it remains a prominent factor in influencing policy and societal change (Næss, 2006).

2.2.2 Systems Finance

Systems finance is a paradigm that applies systems thinking to financial systems while accounting for their interconnectedness to social, environmental, and economic systems. It does not and cannot view finance as an isolated mechanism: rather, it presumes a complex system influencing and influenced by ecological limits, needs of society, and governance structures (Iacovidou et al., 2021). Systems finance cares about long-term resilience rather than short-term profits, as traditional finance would, aligning financial flows toward sustainable outcomes (Bi et al., 2021). It focuses on feedback loops, for example, how fossil fuel investments are sustaining environmental degradation, aiming to redirect capital towards sustainable practices such as renewable energy or green infrastructure in support of systemic change (Nauman et al., 2024).

In practical terms, systems finance produces an integration of ESG factors and sustainability metrics into financial investment-making choices and redirects the attitudinal consideration for policy uncertainty and short-term-ism within the financial market. Systems finance also backs up mechanisms such as the green bond or impact budget that seek to lower the cost of capital for sustainable projects and enhance liquidity for environmentally friendly initiatives (Chourasia & Pandey, 2025). The system aims to contain the market failures by primarily preventing non-financial externalities from climate change and ensuring just economic transitions. The current research emphasizes the potentials of addressing the green finance gap, though scaling it up will require addressing factors such as institutional inertia and aligning financial incentives to long-term societal goals (Nasir & Ahmed, 2024).

2.2.3 Environmental Economics

The Environmental Economics branch is all about studying how those policies affect economies and how to value natural resources for sustainable development. This avenue concentrates on economic activities affecting the environment while giving special attention to market failures, under the headings of externalities (pollution costs borne by somebody other than polluter) and depletion of current resources (Venkatachalam, 2025). These tools, such as cost-benefit analysis,

environmental taxes, and cap-and-trade systems, will help internalize these costs and yield incentives for sustainable behavior. Besides, the same mostly equates with weak sustainability, where technological advances are considered to substitute for natural capital, underpinning the Environmental Kuznets Curve, which argues that economic growth harms the environment at first but benefits it later (Ogwu & Kosoe, 2025).

Environmental economics thus tends to apply a particular neoclassical framework, in which applying market-based solutions-carbon pricing or green technology subsidies (Coffman & Scazzieri, 2024). The examples are the investments in the solar panel production in China to bring the costs down, trying to balance economic growth with environmental goals. Critics think it has, however, put more emphasis on growth than on systemic reform, thereby ignoring even deeper problems like inequality or planetary boundaries. Its strength lies in giving policymakers implementable tools for minimizing environmental degradation while stabilizing economic development (Dale, 2012).

2.3 Relationship between Capital Allocation, Risk-Adjusted Returns, and Resilience Outcomes

Capital allocation signifies the process of disbursing financial resources among investments, hence ensuring that risks are mitigated against rewards and indifferent yet resilient benefits in a manner. Capital allocation possibly would bring about long-term benefits from financial and business viewpoints if the resources were allocated for such areas as less sustainability and climate-resilient investments, such as renewables, infrastructure, etc., due to minimizing long-term risks prevailing due to emerging environment challenges. For example, when capital is invested in technologies that have a lower carbon footprint, potential risk from the market reimbursement levels can drop out from the regulatory constraints such as carbon taxation or, conversely, market risks related to the stranding of fossil fuel assets. Then again, such kinds of investment might mean for higher immediate costs that do not satisfy market-imposed short-term metrics of risk-adjusted returns (Hanson et al., 2011). Hence, investors need to consider environmental, social, and governance factors while making decisions for the sake of aligning the capital allocation with resilience principles and ensuring that the financial strategies support the systems that could withstand economic, climatic, and societal shocks (Junaedi, 2024).

Risk-adjusted returns, which gauge performances against possible risks, is the primary pillar of the evaluation concerning the wisdom of any capital allocation in abiding resilience (Resilience through Capital Allocation Panel). A number of traditional finance models slant under undervaluation policies aimed at the resilience investments based on perceived high risks and little immediate returns, such as green infrastructure and social projects (Brugmann, 2012). The act of incorporating such systemic risks as climate change or social inequality into the calculus will make investment in resilient elements increasingly more profitable over moderate lengths of time. One example that speaks to that is how ESG portfolios often outperform regular ones during the market downturns, given the fact that they are essentially less exposed to volatile stock sectors (Folqué, et al., 2021). Investors need to be encouraged to re-evaluate the risk models to better account for uncertainty in the long term, thereby supporting capital across developmental projects providing these specific outcomes and while gaining financial value.

Investments in climate hardening, whether in resilient systems of infrastructure like flood-immune urban designs or social initiatives of affordable housing, stabilize society and economics toward a lessening of vulnerability to a crisis (Praveen et al., 2025). Mass

reallocation of capital, thus, becomes inevitable from the hugely risky sector with sustainability issues on to resilience building. But, for resilience, there remain barriers such as short-termism of efforts in the financial markets and an absence of universal criteria for evaluation of nonfinancial impacts. Should resilience become embedded into capital allocation practices of all sorts—through tools like green bonds or impact investing—then investors can facilitate the institutional change in the system to be strong enough to make investments simultaneously rewarding financially and fitting for long-term resilience (Brugmann, 2012).

i. The Role of Public-Private Partnerships in Capital Allocation, Risk-Adjusted Returns, and Resilience Outcomes

Big business in public-private partnership (PPP) projects is that it integrates the benefits of both the public and private sectors, chartering out practical means of funding more cost-effective programs for the enhancement of societal welfare with higher resilience and environmental (Al Habsi & Ullah, 2022). While governments typically do not have the funding or knowledge to fully implement enormous projects like climate-resilient infrastructures or sustainable energy systems, private sectors provide capital, creativity, and efficiency (Casady et al., 2024). It is therefore possible to allocate capital more efficiently through a public sector regulatory support, land or money, coupled with the investments, and technological know-how that the private sector provides. An example of such public-private partnerships in renewable energy projects includes the solar farms established in India, which had witnessed a surge in capital investments with reduced dependence on fossil fuels (Giti et al., 2020). Thus, shared costs and responsibilities have enabled scaling up projects that are in consonance with long-term resilience objectives; nonetheless, misaligned incentives or complexity in contract negotiations may hinder this.

To reduce possible financial risks on the return to risk-adjusted performance, public-private partnerships have made financing resilience-centered projects more attractive by making the public make the private bear such costs in whatever project they engage in or put up with their returns (Demirel et al., 2022). Since investments mostly result in uncertainties for private developers regarding sustainability, especially with initial costs being high or government regulations changing, therefore, PPP can opt for some risk-sharing instruments, including government guarantees or models of revenue sharing, and thus ultimately improving return profiles (Ekins, P., & Zenghelis, 2021). In transportation infrastructure, consider PPP projects such as the UK's High Speed 2, which puts the two of public governance and private funding together to find a better balance between risks and returns. The application of ESG criteria in project appraisal can bolster risk-adjusted returns for PPPs by emphasizing those intitiatives that reduce exposure to damages from climate-related shocks or social unrest (Akomolehin, 2025). Poorly structured PPPs would tend to favour the private gain over public gain, thus requiring strong governance to ensure they are aligned with resiliency goals. Public-private partnerships (PPPs) create resilience outcomes by shaping infrastructure and services that can endure economic and environmental shocks (Ampratwum et al., 2023). Such public-private partnerships can create examples such as flood resistant urban drainage systems or resilient health facilities. These areas take advantage of the innovations offered by the private sector and public sectors focused on societal welfare. For example, some partnerships in Singapore are also part of their idea of smart city initiatives that incorporate sustainable technologies into making cities more resilient (Bloch & Bugge, 2013). These partnerships will effect systemic change because they align financial inducements with long-term goals, such as adaptation to climate change or social equity, but have associated

challenges of equitable access to benefits and long-term maintenance costs. Public-private partnerships generate robust systems that yield both public value and financial sustainability where transparency and accountability are incorporated into the design to balance interests among varied stakeholders (Lawal et al., 2024).

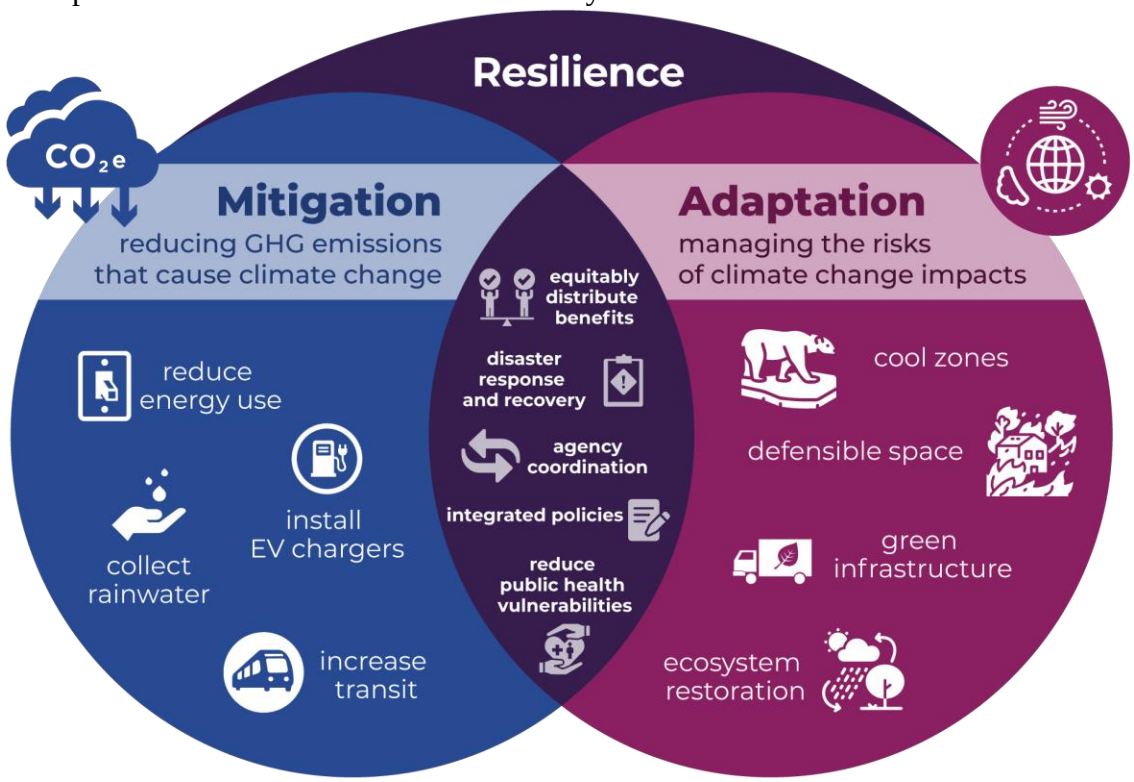

Figure 2: Intersection of ESG, Mitigation, Climate Resilience, and Adaption (San Diego Association of Governments

3. 0 Mapping the Landscape: Climate and Infrastructure Challenges Across U.S. States

i. Overview of Climate Vulnerabilities Across U.S. Regions

Allen et al. (2024) mentioned the Southeast States in America to include states such as Florida, Louisiana, and the Carolinas facing notable climate vulnerabilities, especially hurricanes, sea level rise, and flooding. The analysis shows that global temperatures cause the increasingly warmer oceans, which increase the intensity of storms and rainfall by an increase of 10 to 15% from historical levels. Simplistically put, the models are predicting increases in Category 4 and 5 storms. Storm surge levels are going to be compounded by sea level rise, already on its present rise by over half a foot since 1900 and expected within the next century to rise an extra 1 to 2.5 feet---the maximum surge ever recorded was in Florida during Hurricane Ian in 2022, where it produced a more than 15-foot storm surge (Tebaldi et al., 2012). It also appeared as very slow-moving hurricanes, for instance, Harvey in 2017; these magnified risks of flooding especially for the relatively tongue-in-cheek rapidly urbanizing coastal metropolitan centers hardly preparing for such eventualities. Such vulnerabilities threaten agriculture, infrastructure, and labor productivity, ultimately threatening the economy and disproportionately affecting low-income and minority communities, as evidenced by severe flood damage in Black neighborhoods during Hurricane Katrina (Solecki & Friedman, 2021).

Rising temperatures with a reduction in precipitation render states under the western region of the United States, namely California, Oregon, and Washington, to wildfires, droughts, and heatwaves (Halofsky et al., 2020). Climate change, doubling the area burned by wildfires in the West from 1984 to 2015, has indicated projections whereby any of the regions could experience future years of positive variability of up to 600% concerning burned forest area for every increase of 1°C. Damages surpassed $40 billion, accrued in 2017 and 2018 wildfire seasons, followed by historic fires in California and Oregon in 2020. Drier conditions, longer fire seasons, and insect infestations, such as the mountain pine beetle, worsen fire risks, while decreased snowpack means reduced water supplies for agricultural and urban uses (Crist et al., 2021). More than that, population growth in those wildland-urban interfaces creates more heightened risks to life, property, and air quality with wildfire suppression costs soaring to $3.1 billion in 2018 (Bayham et al., 2022).

Distinct climate challenges other areas of the U.S. are facing-nationally compounded vulnerabilities. Such include extreme precipitation, flooding, and heatwaves, with New York and Vermont part of the Northeast. They stress aging infrastructure and strain agriculture (Hess et al., 2022). A wholesome part of the United States, the Midwest-et-30% of the global yield of corn and soya beans-faces extreme rainfall events, heat, and rapid transitions from wet to dry. This has threats to crop yields and infrastructure (Beeson & Watson, 2019). Hurricanes and rising sea levels are coupled with high temperatures in the Caribbean territories and Hawaii-such as, in 2023, the Maui Wildfires and their increased fire risk owing to drought and higher heat spell. They all compound extremes that climate changes, like simultaneous wildfires and hurricanes, put to emergency response resources. Socially, low-income, minority, and tribal communities face disproportionate impacts due to lesser resources and exposure to high-risk areas, emphasizing equitable adaptation strategies (Smith et al., 2022).

ii. Infrastructure Gaps by Sector (Transport, Water, Energy)

Railways, airways, roads, bridges, ports, and every other transportation infrastructure in a country are indeed dwindling as time goes by. The United States is no exception; in fact, it has probably the most significant infrastructure gap of all these countries when it comes to transport, such as roads, bridges, and public transit systems, which all age and fall short of modern-day demands and climate challenges (Renne et al., 2020). About 43% of public roadways in the U.S. are in fair and poor condition while more than 45000 bridges are structurally deficient (ASCE, 2021). These are some of the findings graded 'C-' on U.S.'s infrastructure by ASCE Infrastructure Report Card. Urban congestion costs around $190 billion annually to the economy in hushed time and lost fuel costs. The public transit systems-a case in point of New York and Chicago cities-witness underfunding issues which have pushed 20% past their useful lives on account of age. High amounts of rising seas along with extreme weather threaten coastal roads and rail lines, while only 15% of transportation projects in 2023 will include resilience features (Hunt, 2007). Insufficient funding called upon $2 trillion by the year 2030 along with slow acceptance of the sustainable technologies as in the case of charging networks for electric vehicles all added up to the widening of the gap and disadvantaged rural and low-income communities with most of the access cut off (Case, 2023).

As aging systems translate into inefficiencies, health risks, and vulnerabilities to climate impacts, the issue of underfunding of water infrastructure in the U.S. becomes very severe. According to EPA, there is an investment gap of $620 billion in the drinking water and wastewater systems over the next 20 years, considering that water quality and reliability

are compromised by 6 million lead service lines and 240,000 water main breaks each year (Moriah, 2025). Disproportionate hardships are faced by rural areas, tribal lands, and low-income urban communities, where 30% of small water systems fail to meet the standards prescribed in the Safe Drinking Water Act (Bettenhausen et al., 2021). Climate change further complicates these problems, as drought reduces water availability in the Southwest, while flooding overwhelms stormwater systems in the Midwest and Northeast, where 40% of wastewater treatment plants are at risk of failure during extreme weather. Only 10% of urban water projects utilize green infrastructure, such as permeable pavements, which illustrates the lag in good and resilient solutions, given the growing menace of flood risks. (Green et al., 2021).

American energy infrastructure suffers gaps with respect to reliable as well as transformed resilience in 2035, needing about $730 billion to upgrade grids to renewables (Ahmad et al., 2023). Outdated grids failed to withstand extreme cold, causing 4.5 million households in Texas to experience power outages as a result of the 2021 Texas power crisis. About 70% of transmission and distribution lines are more than 25 years old in the United States, while 60% of the power outages registered from the year 2000 until 2020 occur due to weather reasons, with associated annual costs of $20-55 billion (Mujjuni et al., 2023). Such an unfortunate case is a consequence of slow integration of renewable energies, where only 20% of the U.S. electricity is fed renewably in 2023, while the 50% target is due by 2030 and delayed by regulation, as well as lack of storage capacity. There is unreliability of access in rural areas with respect to 14% of tribal households that are not connected to electricity, while urban grids suffer increased demand due to electrification. Smart grids and microgrids barely meet the funding for installation, leaving extreme vulnerability against climate-driven disruptions like wildfires and hurricanes (Chaurey et al., 2004).

iii. Regional Disparities in ESG Investment Penetration and Readiness

Granular differences apply to regional penetration of ESG investing within the U.S. itself, depending mostly on economic, political, and cultural aspects (David et al., 2024). Northeast and West Coast regions are leading states in relation to ESG investment, especially California and New York; California, with 25% of U.S. sustainable-investment assets in 2023, is viewed as distinguished in that direction according to Bloomberg data (Wang & Phillips-Fein, 2023). These areas are recipient guests to progressive policies like California's loud target of 100 net-zero emissions by 2045 and a high presence of institutional investors that use ESG metrics, where 60% of West Coast pension funds applied ESG. Urban hubs like San Francisco and New York City reward venture capital with an ESG focus, particularly in clean tech, with an investment of $12 billion just in the beginning of 2024 (Zenghelis et al., 2025). On the flip side, their challenges lie in an inability to scale-up ESG Investments within smaller cities or rural Wests, where beneficial constraints are little-known and where infrastructure is dwarfed for sustainable projects, thus inciting unevenness of penetration state-wise.

ESG investment penetration points that contrast in the Southeast and certain Midwestern states like Alabama and Missouri have a lot to do with weak regulatory frameworks and dependency on traditional industries like fossil fuel and manufacturing (Wells et al., 2022). In the Southeast, only 15% of investment portfolios seriously consider ESG factors, while similar figures stand at 40% in Northeast perspectives according to one report given by Morningstar in the year 2023. Political skepticism and short-term economic downturn concerns often resist ESG adoption, especially in states such as Texas, where anti-

ESG legislation has blocked public pension funds from prioritizing funding into sustainable investments (Wang et al., 2023). We need to handicap the readiness further by limited access to ESG knowledge and information, where only 10% of Southeast financial companies offer any special ESG training. This spirals into lower investment flows into renewable energy or social equity projects, further reinforcing the region's economic vulnerabilities against climate threats such as hurricanes.

The readiness for initiating ESG investment may also vary due to diversified pieces of infrastructure and stakeholder engagement. The financial ecosystem in the West and Northeast is quite advanced, with 70% of major banks in these regions having ESG-focused product offerings like green bonds, versus only 25% in the South (S&P Global, Lorenzi, 2023). Meanwhile, the Midwest is moderately improving: Illinois is positioning itself as a harness for sustainable investing using agricultural innovation, whereas the rural spaces have little capital and technical capacity to apply ESG frameworks. Systemically marginalized barriers impose the lowest readiness of any community investment in ESG on Tribal and low-income communities, notably in the Southwest and Great Plains. Bridging these gaps will require a slew of targeted policies, such as federal incentives for ESG adoption and localized capacity-building, to ensure equitable penetration and resilience across regions (Udohaya, 2025).

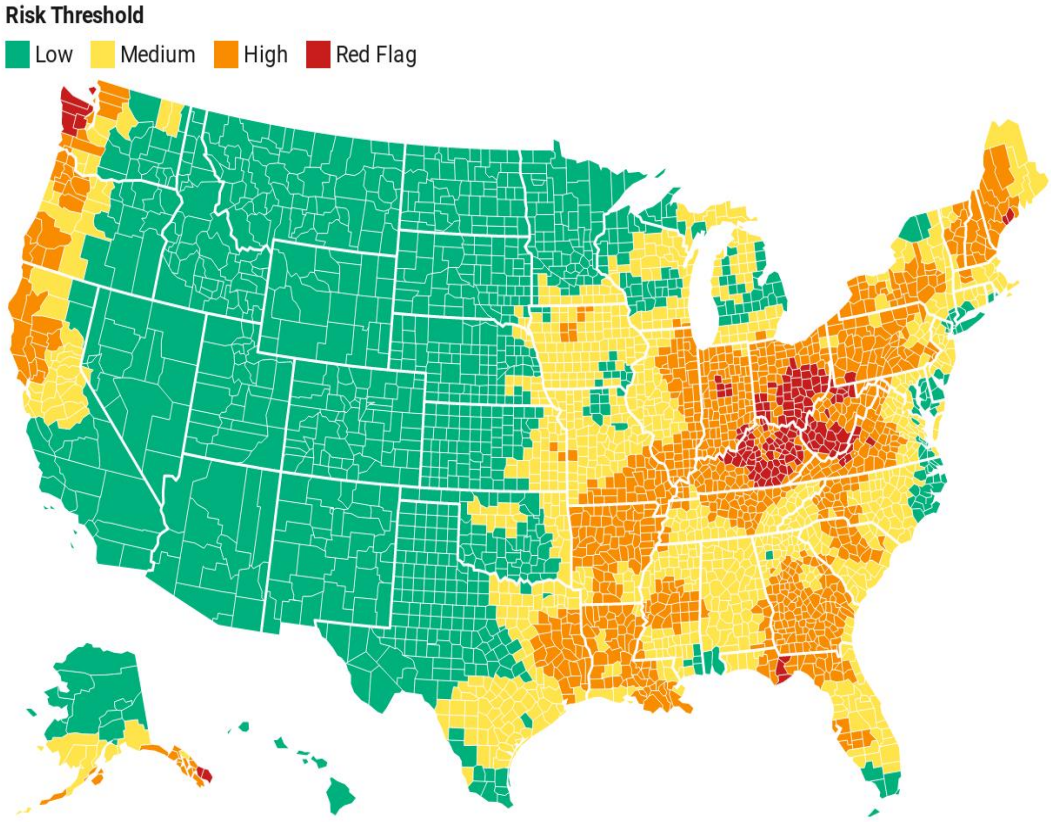

Fig. 3:Map of U.S. showing state-level climate risk exposure and infrastructure investment needs. (GeoDataVision, 2023)

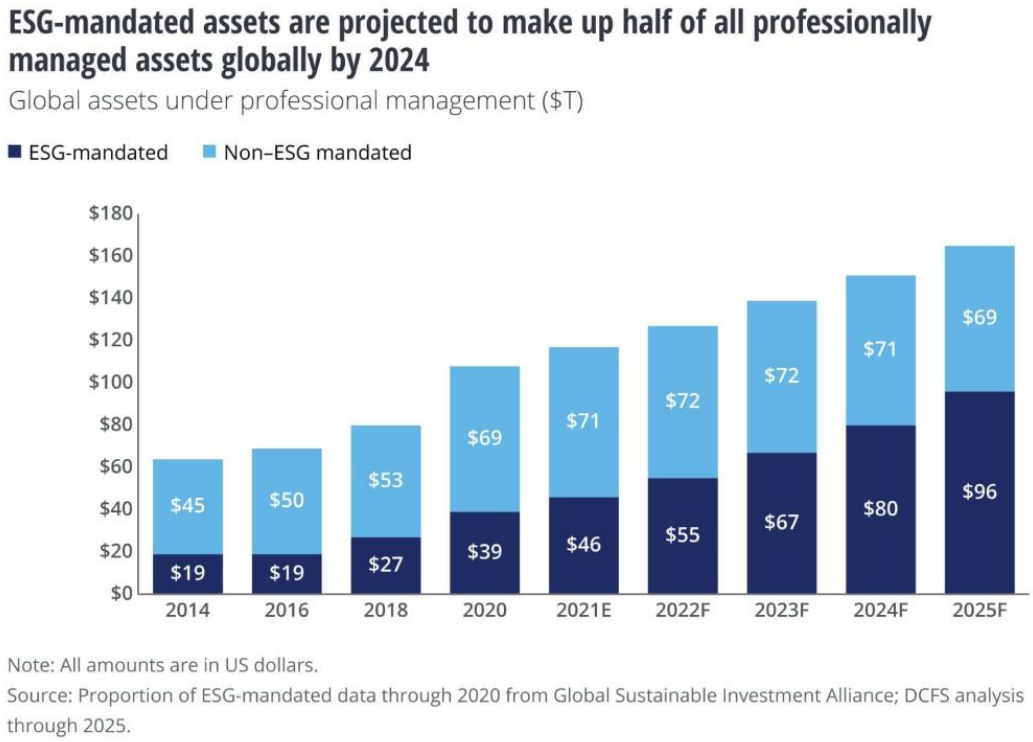

Fig. 4: Bar graph of top US states by ESG-aligned infrastructure investment volume (Global Sustainable Investment Alliance & DCFS, 2020-2025)

4. 0 Current Financial Mechanisms and Gaps

Review of Existing Financing Mechanisms (Green Bonds, Infrastructure Banks, Tax Incentives)

Green bonds are fixed-income instruments designed to find the projects whose environmental benefits include renewable energy, energy efficiency, and climate-resilient infrastructure. Issuance worldwide has been worth $270 billion by 2023 according to the Climate Bonds Initiative (Sartzetakis, 2021). Unlike the traditional bonds, where an earmarked use of proceeds directs funding to projects with environmentally measurable benefits, such benefits are validated through third-party standards such as GBP (Green Bond Principles) or CBS (Climate Bonds Standard). In the U.S., most of such bonds have been issued by municipal and corporate issuers, for instance, Goldman Sachs with its $500 million solar generation bond, although green bonds only account for about 3 percent of total bond issuances (Chan, 2021). Among the benefits are attracting investors focused on ESG purchases and potential cost savings, such as from tax incentives, which are included in the exemptions from interest income for municipal bonds. Risks include greenwashing, no single standards, and prohibitive costs of certification keeping smaller issuers at bay. Green bonds are critical for up-scaling sustainable infrastructure while requiring rigorous monitoring to ensure the environmental impact is not mere window-dressing (Cowan & Cutler 2023). Such an infrastructure bank is the proposed U.S. National Infrastructure Bank (NIB) announced in 2020. This could be classified broadly as public or quasi-public institutions that finance large-scale projects, including those enhancing climate resilience, by leveraging public and private capital (Wijeweera & Rashid, 2023). It seeks to fill funding gaps through low-cost loans or guarantees or equity investment for projects-for example, transport networks or renewable energy grids-which typically have

very high upfront costs. As an example, Britain's Green Investment Bank raised £12 billion between 2012 and 2017 to finance low-carbon projects, prior to being privatized (Agbede et al., 2023). By 2035, infrastructure banks can narrow the projected $730 billion investment gap in the energy sector in the U.S.; however, the full potential of these banks is constrained by the bureaucratic delays involved and lack of political will toward public spending (Kovvali, 2023). While improving resilience in such ways as supporting smart grids, scalability would depend on clear mandates and some form of private sector engagement that would reduce reliance solely on taxpayer funds.

Tax incentives, such as credits or exemptions, are policy tools that stimulate investment in sustainable projects by reducing financial barriers for issuers and investors. In the U.S., such programs as the Clean Renewable Energy Bonds (CREBs) do not pay interest on bonded earnings; instead, they offer tax credits, thereby reducing borrowing amounts to wind projects funded by issuers such as municipalities (Onabowale, 2025). At the international level, tax-exempt bonds provide an example of placing less burden of taxation on investors thereby making it cheaper for green investments evidenced in Brazil's wind sector (Gorelick et al., 2024). Nevertheless, historically, tax incentives were directed to fossil fuel industries with the result that U.S. subsidies for the last century have amounted to $1 trillion and directed capital away from green projects. Effective in spurring growth of green bond markets-Malaysia and Singapore will cover third-party audit costs to encourage issuance-the real short-term impact, however, is due to inconsistency between application and policy horizon, requiring stronger alignment with long-term climate goals to maximize resilience outcomes (Kapoor et al., 2021).

Barriers to Scaling ESG-Aligned Capital Deployment

Regulatory Misalignment

It is hindering the scaling of ESG-aligned capital deployment by creating inconsistent frameworks with many misalignments with regulatory standards, confusing both investors and issuers. The state-level policies in the U.S. complicate matters such as Texas's anti-ESG laws prohibiting public funds from sustainable investment, which counteracts with federal incentives such as tax credits under the Inflation Reduction Act for clean energy, amounting to $369 billion allocated in 2022 (vIlori et al., 2023). This adds a complex patchwork of regulations that engenders uncertainty in deterring investors who must deal with different compliance rules across jurisdictions. In Europe, such as the eco-sustainable finance disclosure regulation (SFDR), stringent ESG disclosures stand as a primary regulatory barrier, whereas the rest of the world lacks such mandates, further cluttering cross-border investments. The recent Deloitte report cites a mere 20 percent of U.S. financial institutions as fully conforming to global ESG standards due to regulatory differences (Flesher et al., 2017). On this account, non-alignment escalates compliance costs and delays investment in ESG projects since investors find conflicting rules confusing.

Regulatory misalignment, additionally, does not usually tend to create considerations of long-term climate and social risk priorities but rather favors immediate economic objectives with disregard of the long-term sustainability outcomes. To cite an example, fossil fuel subsidies reached a global total of $1.3 trillion in 2022 according to the IMF, and hence divert capital from renewable energy investments undermining the essence of ESG aims (Falduto & Rocha, 2020). Low enforcement of existing ESG regulation, such as lack of stiff penalties for greenwashing, tend to further diminish investor trust. Such as in emerging economies, where the legal framework aimed at regulating investments is usually underdeveloped, Bloomberg data indicate that merely 10 percent

of investment portfolios measure ESG due to limited policy support (De Spiegeleer et al., 2023). For the scale-up of sustainable capital allocation, harmonized regulations should come with having clear and enforceable standards in place as well as favorable incentives so that financial systems would adhere to establishing better financial practices in accord to climate investment and social objectives, thus ensuring a flow of capital into resilient and sustainable projects (Rimbono et al., 2025).

Market Fragmentation

Granata and Di Nunno argue that such market fragmentation, with varying investment priorities and financial ecosystems splitting up, is a huge challenge to scale the deployment of ESG-aligned capital: "Market fragmentation among various investment priorities and fragmented financial ecosystems remains a serious barrier to scaling capital investment for ESG considerations" (Gernego et al., 2024). Thus, a 2024 S&P Global report states that the United States faces regional disparities in the adoption of ESG, with 65% of ESG-related assets residing in the Northeast and the West Coast, while only 15% is in the Southeast. Contrasting this, Europeans are focused on carbon neutrality, while Asian markets are more inclined toward a social impact. Helped by these dissimilarities in investor preferences, different investment build silos that further hinder the scaling up of ESG funds (Qi et al., 2022). Most smaller markets mostly found in rural areas or in developing economies do not even have the financial infrastructure to support ESG investments, with evidence showing that only 5% of Sub-Saharan African capital markets offer green bonds. This fragmentation limits liquidity and economies of scale, making it harder to fund large-scale renewable energy grid projects.

Moreover, a variation in ESG methodology and standards across financial institutions also causes increase in fragmentation within markets, making comparison and confidence in investors less possible. According to Chiaramonte et al., . (2022), "For example, ratings from ESG rating-providers like MSCI and Sustainalytics may differ for the same company." Inconsistent metrics reportedly differ by 60% according to a study of 2023 thus "Lack of standardization on ESG complicates capital allocation as it forces investors to struggle in assessing actual ESG performance." In addition, it is very difficult to access private capital in fragmented markets because they lack the competence and connections to attract institutional investors for these kinds of projects. To address these missing links, there will need to be harmonized ESG frameworks, cross-regional collaboration, and specific financial products like blended finance for effective capital channelling to underprivileged areas and enhanced resilience outcomes (Popescu et al., 2022).

Inadequate Data on Climate Risks

The lack of data on climate-related risks greatly undermines capital mobilization into ESG-aligned avenues as the financial consequences of environmental hazards are obscured, rendering it impossible for investors to assess and price these risks adequately (Flesher et al., 2017). As bad data count transition risks like policies toward net-zero or physical risks such as hurricanes or wildfires, the evaluation of both types of risk is often poor. In the TCFD 2023 report, it was shown that merely 30% of U.S. companies operating in high-risk sectors like real estate provide some form of detailed climate risk disclosures, forcing investors to use poorly constructed models. In contrast, weak resources lead to even more significant data-related gaps for developing nations, as reporting of climate risk metrics amounts to less than 10% in Africa. Experience shows that this topographical-lacking data precludes investments into climate-resilient projects because investors cannot credibly assess long-term returns (Ali et al., 2025).

Furthermore, the lack of systematic, forward-looking climate risk information hinders its

adoption in financial decision-making, creating a bottleneck to the growth of ESG investments (David et al., 2023). Current modeling frameworks fail to take into account the compounding nature of risks, arising from climate-exacerbated hazards, such as floods and heatwaves, that together would amount to $120 billion in losses for the U.S. alone as of 2022, according to the NOAA. The big data access conundrum and expensive analytics methods have kept many smaller investors out of the game along with 40% of U.S. asset managers who cited data access as a barrier, according to the 2024 BlackRock survey. This pitiful record increasingly delays investments in areas considered urgent, such as flood defenses or renewable energy, and threatens livelihood prospects in many vulnerable communities (Onabowale, 2025). To remedy this, public-private partnerships should be set up to create open-access high-resolution climate risk databases and standardized reporting frameworks to help investors channel capital towards resilience-oriented ESG strategies.

Table 1: Comparative Table: U.S. Financing Tools vs. Climate Resilience Outcomes

Financing Tool	Examples in U.S.	Climate Adaptation Outcomes	Mitigation Outcomes	Scalability Across States	Private Sector Participation	Challenges & Limitations
Green Bonds	California Green Bond Development Committee, NY MTA Green Bonds	Moderate: Used in some state/municipal-level flood and transit projects	High: Widely used for renewable and clean energy infrastructure	High: Widely issued by states	High: Attracts institutional investors	Lack of unified green taxonomy; adaptation projects underrepresented
State Infrastructure Banks (SIBs)	Texas SIB, California I-Bank	Moderate: Some support for flood control, transportation resilience	Low–Moderate: Varies by state-level ESG integration	Moderate: Uneven across states	Moderate: Through co-investments	Many SIBs lack clear ESG alignment; inconsistent across jurisdictions
Public-Private Partnerships (PPPs)	Long Beach Courthouse (CA), Port of Miami Tunnel (FL)	High: Can finance durable infrastructure like bridges, storm defenses	Moderate: Potential GHG reductions if designs are sustainable	High: Growing interest	High: Private equity & developers	Legal barriers in some states; complex deal structuring; resilience not always prioritized
Federal Grants (BRIC, IIJA, IRA)	FEMA's BRIC, BIL Resilience Grants,	High: Directly supports adaptive infrastructur	Moderate: Includes low-carbon technologies	Moderate–High: All states eligible	Low–Moderate: Mostly public grants	Lengthy approval cycles; uncertain funding

	DOE Grid Resilience Grants	e, grid hardening				streams; often lacks leverage of private capital
Municipal Climate Bonds	Boston, MA, Asheville, NC, King County, WA	Moderate: Local flood protection, stormwater systems, heat mitigation	Moderate: Some tied to clean energy/transport upgrades	High: Issuable by any local gov't	Moderate: Local bond markets	Small market size; inconsistent credit ratings; low investor ESG transparency
Blended Finance Platforms	New York Green Bank, Connecticut Green Bank	High: Supports solar + storage for resilience, energy efficiency retrofits	High: Solar, geothermal, energy-efficient buildings	High: Replicable state models	High: Draws private lenders	Requires technical capacity; success varies by state legislation and leadership
Sustainability-Linked Loans (SLLs)	Utility-scale renewable developers (multi-state)	Indirect: Encourages better resilience metrics via corporate sustainability targets	High: Targets net-zero, emissions benchmarks	Moderate: Mostly for large firms	High: Commercial banks, CDFIs	Not well tailored for public infrastructure; KPIs may lack adaptation relevance
Catastrophe & Resilience Bonds	MetroCat (NYC) (pilot), Florida Hurricane Cat Bonds	High: Post-disaster liquidity, incentivizes pre-disaster risk reduction	None directly, but mitigates economic disruption	Moderate: Used in high-risk states	High: Reinsurance and capital markets	Lack of understanding at municipal level; parametric triggers can be complex
Tax Incentives for Resilient Retrofits	Federal Energy Efficiency Tax Credits, IRS Section 179D	Moderate: Indirectly supports building codes and retrofits against heat/floods	Moderate–High: Building emissions reduced	High: Federally applicable	High: Affects corporate/individual investors	Often not bundled with climate risk assessments; requires local enforcement of building standards
Community Development Financial Institutions (CDFIs)	Opportunity Finance Network, HOPE Enterprise Corporation	High: Funds local climate adaptation (green housing, stormwater in	Moderate: Funds solar, efficient housing	High: In all 50 states	Moderate: Blended public-private	Limited capitalization; sometimes lack technical tools for full climate risk analysis

	disadvantaged communities)	

Comparative Table: U.S. Financing Tools vs. Climate Resilience Outcomes (Author, 2025)

5. 0 Strategic Pathways for ESG-Aligned Infrastructure Investment

i. Integrated ESG Screening Tools for State-Level Infrastructure Planning

These integrated screening tools, which add in ESG (Environmental, Social, and Governance) screening for infrastructure projects within a state-level planning environment, create a structured method of prioritizing investments consistent with sustainability and resilience objectives (Haryani & Anjani, 2023). These assess investments in a possible infrastructure portfolio such as transportation networks, water systems, or energy grids, by subjecting them to evaluations-their environmental impacts, such as carbon emissions or use of resources; social benefits, including access distribution and job creation; and governance issues, such as transparency or anti-corruption measures (Meng, 2025)-for example, the California year's 2023 Sustainable Infrastructure Framework, which uses ESG screening to set up high-speed rail as an emissions-reducing project that serves underserved communities. By embedding ESG criteria into planning, states can direct the capital investments of 2024 states in the Newly Created National Governors' Association (Tyson & Weiss, 2025) towards projects aimed to mitigate risks from climate changes. However, inconsistent ESG standards across states and limited technical capacity in smaller jurisdictions are some challenges leading to uneven application in such cases as well as missed investment opportunities with possible impact.

However, they would better achieve optimization through state customization, incorporation into data-driven platforms such as GIS-based risk mapping, where vulnerabilities have specifically identified areas-prone to flood (Ionescu et al., 2025). New York is one of the states that have established such tools. It also ties into climate projections. It plans to use 30% of its 2024 infrastructure budget to finance resilient urban designs. Adoption has lagged behind states such as Alabama, where 10% of infrastructure projects apply ESG criteria, with regulatory resistance and hurdles to funding thwarting wider application, according to a 2024 ASCE report (Ojo, 2024). Barriers to the development of an effective integrated environment will be removal through federal directives on standardized ESG metrics, capacity-building for local planners, and stakeholder engagement to align projects with community needs (Alhoussari, 2024). Through this streamlining in integrating ESG, infrastructure planning may be assured to promote long-term resilient and equitable economic growth while mitigating risk and maximizing returns in the social and environmental context.

Climate Risk Pricing Mechanisms

Climate risk pricing mechanisms are those that incorporate financial consequences arising from climate risks-such as physical risks (e.g., hurricanes, wildfires) and transition risks (e.g., regulatory changes to net zero)-into investment and planning decisions (In et al., 2022). These assign monetary values to the risks, allowing investors and policymakers to modify the allocation of capital to projects like flood defenses or renewable energy. For instance, banks quantifying losses from climate scenarios were required by the Federal Reserve's 2023 climate stress tests; this process helped identify a potential $500 billion loss by 2050 under scenarios where such risks are left unmitigated (Shin, 2025). Carbon pricing and catastrophe bonds for hurricane damages in

Florida are some means to help internalize these costs. Only 25% of financial institutions within the U.S. consistently apply climate risk pricing, according to a BlackRock survey (Gray, 2021), with data gaps and short-term profit imperatives limiting the scalability of any investments worth their salt in terms of resilience.

For the effective pricing of climate risk, a strong forward-looking data system alongside standardized approaches must be in place to account for both short-term and long-term risks (Birindelli et al., 2020). While something like the TCFD framework is being implemented by 40% of U.S. firms and is a good reference, it is non-enforceable and hence applied inconsistently. In contrast, emissions have been reduced by 35% since 2005 due to EU carbon pricing under the Emissions Trading System, taking its cue from these integrated mechanisms (Xhindole et al., 2025). Uneven exposure from hurricanes in the Southeast to wildfire risks in the West in the U.S. constitutes a unique challenge for creating unit pricing models. Making climate risk data platforms available and integrating them into the financial scheme will increase pricing precision aimed at resilient infrastructure and decrease systemic vulnerability among the regions.

Blended Finance Models

The reason for using blended finance models is to bring together public, private, and philanthropic funds to finance high-impact ESG-aligned projects that would otherwise be considered too risky or too low in return for investment by private investors alone. These models use public or concessional funds to de-risk investments and attract the interest of private capital into sectors like renewable energy or affordable housing (Asa, 2025). For example, the Loan Programs Office of the U.S. Department of Energy leveraged $10 billion in public funds to catalyze private investment of $40 billion in clean energy projects through 2024. According to the OECD, blended finance mobilized $160 billion globally for sustainable development in 2023; an example of this is that 20 percent of rural households in Kenya now access off-grid solar systems. But blended finance accounts for only 2 percent of infrastructure funding in the U.S., which is constrained because of complex deal structures and misalignment between public and private goals, particularly in under-resourced regions (Khalaf et al., 2025).

Building such blended financing laws should include strong governance frameworks besides enabling risk-sharing mechanisms, for example, guarantees or first-loss capital, which form a great impetus for driving confidence among investors (Duan et al., 2024). The partnerships in developing countries under the Green Climate Fund demonstrate how $1 of public funding results in $3 of private investment. State green banks operate at this ratio in the United States through blended financing mechanisms for half of local clean energy projects starting in 2011. One challenge consists of high transaction costs, while limited awareness exists among smaller municipalities, with only 15% of infrastructure projects using blended models, according to a Brookings report 2024. This is because blended finance bridges the funding gap for climate-resilient infrastructure in vulnerable communities, making them less vulnerable economically and environmentally (Ali & Kamraju, 2025).

Performance-Based ESG Metrics

Performance-based ESG measures are verification by performance-and not production-of anticipated returns from investments in the environment, in social terms, as well as governance accountability and alignment with sustainability objectives. Such impacts could be defined; for instance," outcomes of new jobs created for marginalised categories, or carbon emissions reduced, or improvements in governance, such as board diversity" (Mayer, 2021). For instance, the infrastructure plan New York 2024 mandates 30% of state-funded projects report ESG

outcome measures like 25% emission reductions on transit upgrades. Frameworks, like SASB, would, fair to the world, guide 20% of American firms in 2024 for statement performance-based metrics, according to S&P Global; however, inconsistent methodologies and data quality bring way towards limiting adoption, as less than 10% of Southeast projects apply such metrics relative to resource limitations (Odintsova, 2024).

Standardized and transparent frameworks and accessible data platforms would extend further benefits by ensuring the comparability and credibility of measures targeting performance-that is, ESG standards. The SFDR of the European Union has led to a 40% increase in ESG reporting by European companies and formulates a model for outcome-focused metrics, but nothing of the kind exists as a mandate in the U.S. Among challenges are quantification of social impacts, like community resilience, within financial models of measurement without burdening smaller entities. For example, five percent of rural water utilities in the Midwest report compliance with ESG metrics, according to a 2024 EPA study. In this way, investment in training, technology, and public and private partnership is needed for generating performance-based metrics that account for directing capital to projects with defined and measurable outcomes in resilience and sustainability across diverse regions.

ii.Innovations in Climate Disclosure and Resilience Indices

The art of disclosure in climate change has changed the way organizations disclose environmental risks and opportunities, therefore enhancing transparency and ultimately informing the capital allocation for investments focused on resilience (Hahn et al., 2015). Standards including the Task Force on Climate-related Financial Disclosures (TCFD) and the EU's Sustainable Finance Disclosure Regulation (SFDR) have been the enablers of wide adoption. According to S&P Global, in 2024 50% of public companies in the U.S. reported TCFD-aligned disclosures, an increase from 20% in 2020. Advanced solutions like AI-enabled platforms and geospatial analytics incorporate real-time data of climate events like flood risks or carbon emissions into financial reports, thereby facilitating funding kickbacks (Sarker & Jahan, 2025). The Aladdin Climate, used by 30% of large asset managers in the U.S., models physical and transition risks across portfolios. Nonetheless, setbacks exist, such as when data are scanty for smaller companies and huge areas in which only 15% of firms provide reliable climate disclosures, and greenwashing risk is concerned, with a recent SEC review ranging that 25% of disclosures have been found misleading. A worthy area of focus would be the standardization of metrics along with greater affordability concerning data platform access (Figueredo et al., 2020.).

Resilience indices quantifying the degree to which a region or asset withstands climate impacts have become central tools that guide investment and policy decisions. Indices like the Notre Dame Global Adaptation Initiative (ND-GAIN) and the U.S. Climate Resilience Toolkit rank regions on the basis of their vulnerability and adaptive capacity, which may include infrastructure quality, economic stability, and social equity issues (Rezvani et al., 2023). According to FEMA, states like California in 2024 employed resilience indices to prioritize the allocation of $2 billion in infrastructure funding on flood-resistant urban designs.

Machine Learning (ML) and Artificial Intelligence (AI) entered the stage of revolutionizing the interdisciplinary sectors by offering reliable answers to the problems of data interpretation, real-time decision-making, and self- navigating (Farooqi et al., 2024; Ademilua & Areghan, 2025a; Rane et al., 2024; Adjei, 2025a; Adjei, 2025b ; Abolade, 2023; Ademilua & Areghan, 2022; Dada et al., 2024: Adjei, 2025c; Abolade, 2023; Ademilua &

Areghan, 2025b; Utomi et al., 2024; Ndibe; 2025a; 2025b; Okolo et al., 2025). Machine learning-enhanced indices are now pitched as dynamic risk score generators that adjust to real climate events, like the 2023 Maui wildfires, which caused Hawaii to revise its resilience score. However, in equity, under-resourced areas are lagging; only 10% of municipalities in the Southeast US have so far utilized resilience indices, primarily because of limited technical expertise, as reported in 2024 by ASCE. Expanding indices on open access and integrating them with ESG frameworks can direct equitable capital deployment to ensure that vulnerable communities benefit from investments in resilience (Duraisamy, 2025).

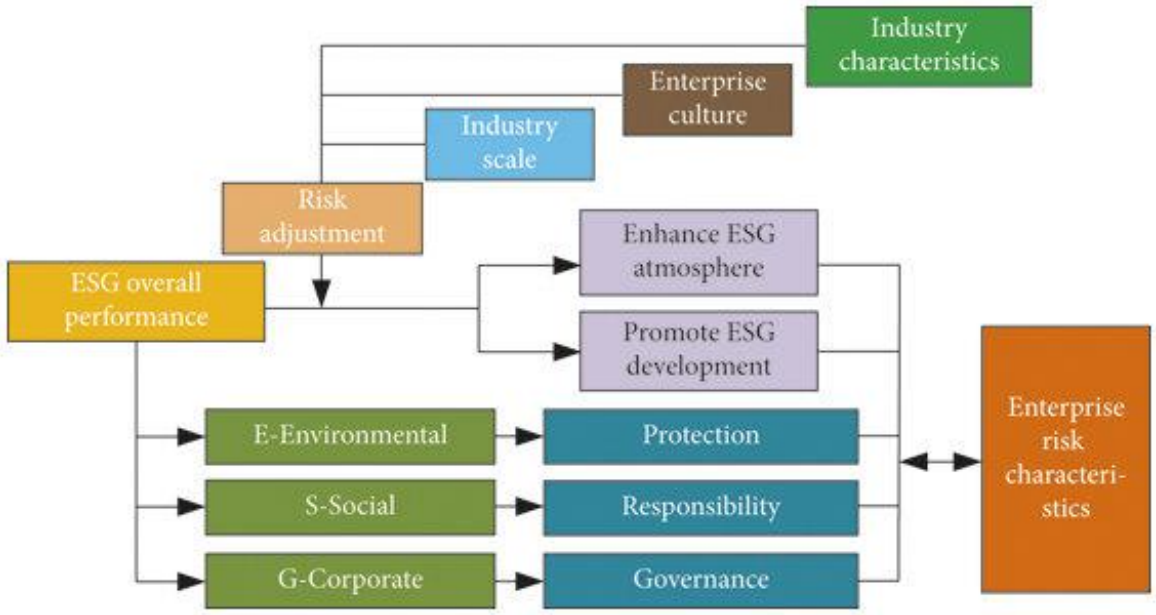

Figure 5: Flowchart: ESG-aligned capital flow from source to climate-resilient infrastructure asset

7. 0 Policy Recommendations

At the federal level, robust enablers like tax incentives, ESG disclosure mandates, and green banks can greatly accelerate capital deployment and resilience outcomes (Saxena & Fouzdar, 2025). Tax incentives, such as those within the $369 billion Inflation Reduction Act of 2022 for clean energy, have shown results: renewable energy investments in the U.S. increased by 30% in 2024 from 2022 levels according to Bloomberg. Standardized ESG disclosures would advance the goals of transparency and accountability, as per a 2024 S&P Global report, with only 50% of U.S. firms providing consistent and reliable climate risk information. The national green bank, modeled after the Clean Energy Finance Corporation of Australia, could potentially mobilize $50 billion every year worth of private capital for financing resilient infrastructure through low-cost loans; however, these plans are hindered by political resistance and disagreements over the allocation of funds (Geddes et al., 2018). Through federal-level implementation, these policies would create a cohesive system that reduces regulatory fragmentation while encouraging private investment toward climate resilience projects such as flood defense mechanisms or renewable grids.

State strategy frameworks with incentives for local authorities and green procurement

policies are critical to tailoring ESG and resilience goals to fit the local context (Ortega, 2023). Incentives such grants and/or tax incentives for municipalities adopting climate-resilient infrastructure have been instrumental in states like California, where 40% of local budgets, as of 2024, supported ESG-related projects per the National Governors Association. Green procurement policies place purchasing emphasis on sustainable materials and services, which have led to some states, like New York, achieving a 15% reduction in public sector emissions since 2020 (Dimand & Cheng, 2023). However, in contrast only 20% of southeastern states have adopted such frameworks mostly due to resource constraints and political skepticism as reported by ASCE in 2024. Partnerships formed from different sectors for the purpose of data standardization and reporting would close these gaps through shared platforms such as the U.S. Climate Resilience Toolkit used by 30% of the states in 2024. These partnerships would be undermined by lack of universal data quality and proprietary barriers, yet establishing fair access and standard reporting frameworks would boost accountability, thereby enabling equitable and effective capital allocation across sectors and regions (George, 2024).

8. 0 Future Research Directions

The study related to data models for ESG impact on the longevity of infrastructure, behavioral finance insights regarding patterns of institutional investment, and the formation of an ESG-based framework for climate risk hedging are important for propagating sustainable capital deployment and resilience (Aggarwal et al., 2025). In terms of the longevity of the infrastructure, another avenue for future research would be to develop AI-powered models that merge ESG metrics—such as emissions-reducing activities or just access—with climate risk data in calculating how long certain assets like bridges or energy grids will last. In 2025, the National Institute of Standards and Technology noted that ESG-associated designs prolonged infrastructure lifetimes by 20% in flood-prone regions, but only 15% of projects in the U.S. have adopted such models, according to ASCE. Behavioral finance research would also explore why institutions resist ESG; despite evidence of ESG outperformance, 40% of U.S. pension funds cite lower returns as a major hindrance, according to a Yale study in 2024. Frameworks for hedging against risk in an ESG manner—climate-linked derivatives for instance—may be useful, although only 5% of U.S. catastrophe bonds incorporated ESG in 2024, according to Bloomberg.

Among the challenges are the gaps in data, high costs, and regulatory inconsistencies, especially across the Southeast, where ESG uptake is at a meager 15% (Singhania et al., 2024). To counter these, research should concentrate on developing standardized open-access tools with an interdisciplinary partake. In terms of data modeling, platforms like the U.S. Climate Resilience Toolkit, which is being utilized by 30% of states, may be leveraged toward creating the scale of longevity predictions, although more focus has to be laid to provide data access in rural areas. The behavioral studies should set out experimental designs with nudges such as transparent ESG dashboards to modify investor behavior for the 25% of institutions currently held back by short-termism (Noronha et al., 2022). Research on hedging needs to focus on the development of scalable instruments integrating ESG with multi-hazard climate scenarios, leveraging the EU's green bond market, which is now worth €150 billion. Federal support for data standardization, together with cross-sectoral collaboration, could help to clear pathways into equity capital for resilient infrastructure while at the same time containing systemic risk across several regions of the U.S (Anjanappa, 2025).

9. 0 Conclusion

It is safe to say that ESG-integration into finance strategies is a necessary for

enhancement of long-term resilience in the US infrastructure rather than being another short-term trend. Stakeholders can better manage systemic risks associated with climate change, economic inequality, and governance failures by embedding environmental, social, and governance metrics into capital allocation processes. ESG-based finance promotes an infrastructure resilience and equity-basis system that can withstand future shocks with delivery of long-term public value. This alignment also addresses a global infrastructure gap of $2.6 trillion by directing capital into projects, such as renewable energy grids, flood-resistant transportation networks, and green housing developments with built-in capacity to mitigate and adapt to the evolving climate threats.

At the same time, an important argument can be made for the urgency of marrying sustainability to infrastructure finance. While federal laws like the IRA and IIJA bring billions into the process of modernization, there has never been such a unique opportunity to shortly embed ESG frameworks into the DNA of infrastructure planning and investment. Not seizing on this moment would expose the continued building of more vulnerable, inequitable systems and an inability to reach global decarbonization targets. The emissions would be reduced and redirected through performance-based metrics and green bonds to blended finance and resilience indices for America's transition: a finance-driven inclusive transition into climate-smart infrastructure. The moral, economic imperative that these agendas drive makes clear that America will need infrastructure that will head into the future for generations.

10. References

Abolade, Y. A. (2023). Bridging mathematical foundations and intelligent system: A statistical and machine learning approach. *Communications in Physical Sciences, 9, 4*, pp. 773–783.

Ademilua, D. A., & Areghan, E. (2022). AI-driven cloud security frameworks: Techniques, challenges, and lessons from case studies. *Communication in Physical Sciences, 8, 4*, pp. 674–688.

Ademilua, D. A., & Areghan, E. (2025a). Cloud computing and machine learning for scalable predictive analytics and automation: A framework for solving real-world problem. *Communication in Physical Sciences, 12, 2*, pp. 406–416. https://dx.doi.org/10.4314/cps.v12i2.16

Ademilua, D. A., & Areghan, E. (2025b). Review and experimental analysis on the integration of modern tools for the optimization of data center performance. *International Journal of Advanced Trends in Computer Science and Engineering, 14, 2*, pp. 2278–3091. https://doi.org/10.30534/ijatcse/2025/061422025

Adjei, F. A. (2025a). A concise review on identifying obesity early: Leveraging AI and ML targeted advantage. *Applied Sciences, Computing and Energy, 3, 1*, pp. 19–31.

Adjei, F. A. (2025c). Artificial intelligence and machine learning in environmental health science: A review of emerging applications. *Communication in Physical Sciences, 12, 5*, pp. 1480–1492.

Agbede, O. O., Akhigbe, E. E., Ajayi, A. J., & Egbuhuzor, N. S. (2023). Structuring financing mechanisms for LNG plants and renewable energy infrastructure projects globally. *IRE Journals, 7, 5*, pp. 379–392.

Ahmad, N., Ghadi, Y. G., Adnan, M., & Ali, M. (2023). From smart grids to super smart grids: A roadmap for strategic demand management for next generation SAARC and European power infrastructure. *IEEE Access, 11*, pp. 12303–12341.

Akomolehin, O. F. (2025). Exploring the role of international development banks in promoting green financing mechanisms.

World Journal of Advanced Research and Reviews, 26, 2, pp. 2498–2513.

Al Habsi, F. A. S. H., & Ullah, A. (2022). The role of the public-private partnership (PPP) in achieving the optimal economic and social benefits through the port sector. *International Journal of Management Science and Business Administration, 8, 5*, pp. 57–65.

Alhoussari, H. (2024). Integrating ESG criteria in corporate strategies: Determinants and implications for performance. *Journal of Ecohumanism, 3, 8*, pp. 11925–11936.

Ampratwum, G., Tam, V. W., & Osei-Kyei, R. (2023). Critical analysis of risks factors in using public-private partnership in building critical infrastructure resilience: A systematic review. *Construction Innovation, 23, 2*, pp. 360–382.

Asa, S. P. (2025). Blended finance for impact: Financing the Nambo waste treatment facility through innovative infrastructure finance scheme. *Jurnal sosial dan sains, 5, 8*, pp. 3326–3342.

Bayham, J., Yoder, J. K., Champ, P. A., & Calkin, D. E. (2022). The economics of wildfire in the United States. *Annual Review of Resource Economics, 14, 1*, pp. 379–401.

Beeson, M., & Watson, N. (2019). Is international leadership changing hands or disappearing? China and the USA in comparative perspective. *Asian Perspective, 43, 2*, pp. 387–415.

Bettenhausen, J. L., Winterer, C. M., & Colvin, J. D. (2021). Health and poverty of rural children: An under-researched and under-resourced vulnerable population. *Academic Pediatrics, 21, 8*, pp. S126–S133.

Bi, J., Yang, J., Liu, M., Ma, Z., & Fang, W. (2021). Toward systemic thinking in managing environmental risks. *Engineering, 7, 11*, pp. 1518–1522.

Birindelli, G., Palea, V., Trussoni, L., & Verachi, F. (2020). Climate change: EU taxonomy and forward looking analysis in the context of emerging climate related and environmental risks. *Risk Management Magazine, 15, 3*, pp. 48–64.

Bloch, C., & Bugge, M. M. (2013). Public sector innovation—From theory to measurement. *Structural Change and Economic Dynamics, 27*, pp. 133–145.

Brugmann, J. (2012). Financing the resilient city. *Environment and Urbanization, 24, 1*, pp. 215–232.

Butt, J. S. (2024). From concept to practice: Innovations driving sustainable economic development. *EIRP Proceedings, 19, 1*, pp. 181–190.

Case, M. (2023). The road to 2035: Developing electric vehicle infrastructure to accomplish federal goals. *Rutgers Business Law Journal, 19*, p. 133.

Chan, R. (2021). Ensuring impactful performance in green bonds and sustainability-linked loans. *The ADELAIDE LAW REVIEW, 42, 1*, pp. 221–258.

Chaurey, A., Ranganathan, M., & Mohanty, P. (2004). Electricity access for geographically disadvantaged rural communities—technology and policy insights. *Energy Policy, 32, 15*, pp. 1693–1705.

Chiaramonte, L., Dreassi, A., Girardone, C., & Piserà, S. (2022). Do ESG strategies enhance bank stability during financial turmoil? Evidence from Europe. *The European Journal of Finance, 28, 12*, pp. 1173–1211.

Chourasia, S., & Pandey, S. M. (2025). Stimulus towards ESG in India and GHG protocol with measurable metrological tools: Progresses and challenges. *MAPAN, 40, 1*, pp. 175–201.

Coenen, L., Benneworth, P., & Truffer, B. (2012). Toward a spatial perspective on sustainability transitions. *Research Policy, 41, 6*, pp. 968–979.

Coffman, D. M., & Scazzieri, R. (2024). A reappraisal of Albert Aftalion's theory of

structural transformation in an era of decarbonization. *Business History Review, 98, 1*, pp. 237–257.

Cowan, M. J., & Cutler, J. (2023). ESG and the demand for state tax incentives. *Florida Tax Review, 27*, p. 78.

Crist, M. R., Belger, R., Davies, K. W., Davis, D. M., Meldrum, J. R., Shinneman, D. J., & Mayer, K. E. (2021). Chapter J. Altered fire regimes. In M. R. Crist, R. Belger, K. W. Davies, D. M. Davis, J. R. Meldrum, D. J. Shinneman, & K. E. Mayer, *Sagebrush conservation strategy–Challenges to sagebrush conservation* (pp. 79–98).

Dada, S. A, Azai, J. S, Umoren, J., Utomi, E., & Akonor, B. G. (2024). Strengthening U.S. healthcare supply chain resilience through data-driven strategies to ensure consistent access to essential medicines. *International Journal of Research Publications, 164, 1*. https://doi.org/10.47119/IJRP1001641120257438

Dale, G. (2012). The growth paradigm: A critique. *International Socialism, 134*, pp. 55–88.

David, L. K., Wang, J., & David, V., Jr. (2024). Economic and governance dimensions of ESG performance: A comparative study in the developing and European countries. *The Journal of Developing Areas, 58, 4*, pp. 221–240.

Dax, T., & Copus, A. (2022). European rural demographic strategies: Foreshadowing post-lisbon rural development policy? *World, 3, 4*, pp. 938–956.

De Spiegeleer, J., Höcht, S., Jakubowski, D., Reyners, S., & Schoutens, W. (2023). ESG: A new dimension in portfolio allocation. *Journal of Sustainable Finance & Investment, 13, 2*, pp. 827–867.

Demirel, H. C., Leendertse, W., & Volker, L. (2022). Mechanisms for protecting returns on private investments in public infrastructure projects. *International Journal of Project Management, 40, 3*, pp. 155–166.

Dhar, A. R. (2025). Building climate-resilient food systems through the water–energy–food–environment nexus. *Environments, 12, 5*, Article 167.

Dimand, A. M., & Cheng, S. (2023). Bottom-up innovation adoption of green public procurement in the United States. *Local Government Studies, 49, 6*, pp. 1359–1385.

Dua, S. A. (2022). ESG-the future of financing for sustainable infrastructure. *IPE Journal of Management, 12, 1*, pp. 104–123.

Duan, Y., Liu, Y., Chen, Y., Guo, W., & Yang, L. (2024). Research on the impact of knowledge sharing on risk control of inclusive finance in rural areas during the post-COVID-19 era. *Journal of Knowledge Management, 28, 3*, pp. 613–630.

Edo-Osagie, E. (2025). Advanced budgeting and dynamic allocation strategies for maximizing financial resilience amid economic volatility and market shifts. *International Journal of Research Publication and Reviews, 6, 3*, pp. 1060–1077.

Ekins, P., & Zenghelis, D. (2021). The costs and benefits of environmental sustainability. *Sustainability Science, 16, 3*, pp. 949–965.

Espinoza, D., Rojo, J., Phillips, W., & Eil, A. (2023). Decoupled net present value: Protecting assets against climate change risk by consistently capturing the value of resilient and adaptable investments. *Sustainable and Resilient Infrastructure, 8, Suppl. 1*, pp. 323–336.

Farooqi, S. A., Memon, A., Zamir, S., Malik, K., Batool, W., & Zahid, H. (2024). Navigating AI in the real world: Transformations, regulations, and challenges. *Policy Research Journal, 2, 4*, pp. 1083–1099.

Figueredo, K., Seed, D., & Wang, C. (2020). A scalable, standards-based approach for IoT data sharing and ecosystem monetization.

IEEE Internet of Things Journal, 9, 8, pp. 5645–5652.

Flesher, D. L., Previts, G. J., & Samson, W. D. (2017). Working on the railroad: Public accounting talent in the United States—The case of Haskins & Sells (now Deloitte). *Abacus, 53, 1*, pp. 133–157.

Folqué, M., Escrig-Olmedo, E., & Corzo Santamaría, T. (2021). Sustainable development and financial system: Integrating ESG risks through sustainable investment strategies in a climate change context. *Sustainable Development, 29, 5*, pp. 876–890.

Frantzeskaki, N., & Loorbach, D. (2010). Towards governing infrasystem transitions: Reinforcing lock-in or facilitating change? *Technological Forecasting and Social Change, 77, 8*, pp. 1292–1301.

Geddes, A., Schmidt, T. S., & Steffen, B. (2018). The multiple roles of state investment banks in low-carbon energy finance: An analysis of Australia, the UK and Germany. *Energy Policy, 115*, pp. 158–170.

George, A. S. (2024). Universal internet access: A modern human right or a path to digital colonialis. *Partners Universal International Innovation Journal, 2, 2*, pp. 55–74.

Gernego, I., Petrenko, L., Lavrynenko, V., & Dyba, M. (2024). Trends and focuses for ESG investment support: A cross country comparative analysis. *European Journal of Sustainable Development, 13, 1*, pp. 167–167.

Ghaemi Asl, M. (2025). A novel AI-driven approach to greenwashing: Breakthroughs in the future fit between domain-specific Islamic enterprises with varying developmental progress and ESG landscapes. *Future Business Journal, 11, 1*, Article 93.

Giti, D. M., K'Akumu, O. A., & Ondieki, E. O. (2020). Enhanced role of private sector through public private partnerships in low income urban housing in Kenya. *Journal of Financial Management of Property and Construction, 25, 2*, pp. 293–312.

Gorelick, J., Cara, E., & Kavoo, G. (2024). The fallacy of green municipal bonds in developing countries. *World, 5, 4*, pp. 929–951.

Grasso, M. (2010). An ethical approach to climate adaptation finance. *Global Environmental Change, 20, 1*, pp. 74–81.

Gray, I. (2021). Hazardous simulations: Pricing climate risk in US coastal insurance markets. *Economy and Society, 50, 2*, pp. 196–223.

Guha, M. (2025). Role of the Inflation Reduction Acts in financing hydrogen energy projects: Opportunities and challenges. In *The role of green and transition finance in achieving carbon neutrality and sustainable energy* (pp. 207–236).

Hahn, R., Reimsbach, D., & Schiemann, F. (2015). Organizations, climate change, and transparency: Reviewing the literature on carbon disclosure. *Organization & Environment, 28, 1*, pp. 80–102.

Halofsky, J. E., Peterson, D. L., & Harvey, B. J. (2020). Changing wildfire, changing forests: The effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. *Fire Ecology, 16, 1*, pp. 1–26.

Hanson, S. G., Kashyap, A. K., & Stein, J. C. (2011). A macroprudential approach to financial regulation. *Journal of Economic Perspectives, 25, 1*, pp. 3–28.

Haryani, D., & Anjani, Z. (2023). The importance of environmental, social, and governance (ESG) principles in public works and housing infrastructure. *Journal of Infrastructure Policy and Management (JIPM), 6, 1*, pp. 15–31.

Hess, S. S., Burns, D. A., Boudinot, F. G., Brown-Lima, C., Corwin, J., Foppert, J. D., & Stevens, A. (2024). New York state climate impacts assessment chapter 05:

Ecosystems. *Annals of the New York Academy of Sciences, 1542, 1*, pp. 253–340.

Hu, Y., & Jin, Y. (2023). Unraveling the influence of green bonds on environmental sustainability and paving the way for sustainable energy projects in green finance. *Environmental Science and Pollution Research, 30, 52*, pp. 113039–113054.

Hunt, S. D. (2007). Economic growth: Should policy focus on investment or dynamic competition? *European Business Review, 19, 4*, pp. 274–291.

Iacovidou, E., Hahladakis, J. N., & Purnell, P. (2021). A systems thinking approach to understanding the challenges of achieving the circular economy. *Environmental Science and Pollution Research, 28, 19*, pp. 24785–24806.

Ilori, O., Lawal, C. I., Friday, S. C., Isibor, N. J., & Chukwuma-Eke, E. C. (2023). A framework for environmental, social, and governance (ESG) auditing: Bridging gaps in global reporting standards. *International Journal of Social Science Exceptional Research, 2, 1*, pp. 231–248.

Ionescu, S. A., Diaconita, V., & Radu, A. O. (2025). Engineering sustainable data architectures for modern financial institutions. *Electronics, 14, 8*, Article 1650.

Junaedi, J. (2024). Understanding the role of finance in sustainable development: A qualitative study on environmental, social, and governance (ESG) practices. *Golden Ratio of Finance Management, 4, 2*, pp. 113–130.

Kovvali, A. (2023). Stark choices for corporate reform. *Columbia Law Review, 123, 3*, pp. 693–760.

Lawal, C., Friday, S., Ayodeji, D., & Sobowale, A. (2024). Advances in public-private partnerships for strengthening national financial governance and crisis response systems. *International Journal of Advanced Multidisciplinary Research and Studies, 6, 4*, pp. 1700–1719.

Meyer, P. B., & Schwarze, R. (2019). Financing climate-resilient infrastructure: Determining risk, reward, and return on investment. *Frontiers of Engineering Management, 6, 1*, pp. 117–127.

Moriah, D. J. (2025). Climate change and its effects on environmental health: Challenges and solutions for vulnerable populations. *Social Sciences, 11, 2*, pp. 34–47.

Mujjuni, F., Betts, T. R., & Blanchard, R. E. (2023). Evaluation of power systems resilience to extreme weather events: A review of methods and assumptions. *IEEE Access, 11*, pp. 87279–87296.

Næss, P. (2006). Unsustainable growth, unsustainable capitalism. *Journal of Critical Realism, 5, 2*, pp. 197–227.

Nauman, M., Naheed, R., & Khan, J. (2024). Navigating sustainable horizons: Exploring the dynamics of financial stability, green growth, renewable energy, technological innovation, financial inclusion, and soft infrastructure in shaping sustainable development. *Environmental Science and Pollution Research, 31, 20*, pp. 29939–29956.

Ndibe, O. S. (2025a). AI-driven forensic systems for real-time anomaly detection and threat mitigation in cybersecurity infrastructures. *International Journal of Research Publication and Reviews, 6, 5*, pp. 389–411. https://doi.org/10.55248/gengpi.6.0525.1991

Ndibe, O. S. (2025b). Integrating machine learning with digital forensics to enhance anomaly detection and mitigation strategies. *International Journal of Advance Research Publication and Reviews, 2, 5*, pp. 365–388.

Ndibe, O. S., & Ufomba, P. O. (2024). A review of applying AI for cybersecurity: Opportunities, risks, and mitigation

strategies. *Applied Sciences, Computing, and Energy, 1, 1*, pp. 140–156.

Noronha, E., Jain, P., Puri, D., Misra, A., Shah, P., Patel, M., & Jain, D. (2022). Social compact: Co-creating socially responsible businesses the Indian way. *Vikalpa, 47, 2*, pp. 119–190.

Odintsova, T. (2024). Accounting transformation for ESG reporting in the sustainability agenda. *SCIREA Journal of Economics, 9, 1*, pp. 1–21.

Ojo, B. (2024). Strategies for the optimization of critical infrastructure projects to enhance urban resilience to climate change. *The Journal of Scientific and Engineering Research, 11*, pp. 107–123.

Okolo, J. N., Agboola, S. O., Adeniji, S. A., & Fatoki, I. E. (2025). Enhancing cybersecurity in communication networks using machine learning and AI: A case study of 5G infrastructure security. *World Journal of Advance Research and Review, 26, 1*, pp. 1210–1219. https://doi.org/10.30574/wjarr.2025.26.1.1098

Onabowale, O. (2025). Energy policy and sustainable finance: Navigating the future of renewable energy and energy markets. *World Journal of Advanced Research and Reviews, 25, 1*, pp. 2235–2252.

Palea, V. (2022). Accounting for sustainable finance: Does fair value measurement fit for long-term equity investments? *Meditari Accountancy Research, 30, 1*, pp. 22–38.

Praveen, G., Vishwanath, N., Sree, C. C., & Rohith, D. (2025). Climate-resilient urban planning. *International Journal of Advances in Agricultural Science and Technology, 12, 3*, pp. 226–234.

Previtali, P., & Cerchiello, P. (2023). Corporate governance and anti-corruption disclosure. *Corporate Governance: The International Journal of Business in Society, 23, 6*, pp. 1217–1232.

Qi, H., Liu, C., Long, F., Gao, X., Hu, L., & Wu, Q. (2022). Linkage and spillover effects of China's carbon market and stock market under the background of carbon neutrality: An analysis based on investor sentiment regulation. *International Journal of Neuropsychopharmacology, 25, Suppl. 1*, pp. A53–A53.

Rane, N. L., Paramesha, M., Choudhary, S. P., & Rane, J. (2024). Artificial intelligence, machine learning, and deep learning for advanced business strategies: A review. *Partners Universal International Innovation Journal, 2, 3*, pp. 147–171.

Richardson, B. J. (2009). Climate finance and its governance: Moving to a low carbon economy through socially responsible financing? *International & Comparative Law Quarterly, 58, 3*, pp. 597–626.

Rimbono, R., Supriatna, J., Koestoer, R. H. S., & Hamzah, U. S. (2025). Economic viability and policy imperatives of carbon capture, utilisation and storage in Indonesia's pathway to net-zero emissions. *Chall Sustain, 13, 2*, pp. 236–253.

Robinson, W. A. (2021). Climate change and extreme weather: A review focusing on the continental United States. *Journal of the Air & Waste Management Association, 71, 10*, pp. 1186–1209.

Ruttan, V. W. (1997). Induced innovation, evolutionary theory and path dependence: Sources of technical change. *The Economic Journal, 107, 444*, pp. 1520–1529.

Sarker, S., & Jahan, F. (2025). Ai-driven mis applications in environmental risk monitoring: A systematic review of predictive geographic information systems. *Asrc Procedia: Global Perspectives in Science and Scholarship, 1, 1*, pp. 81–97.

Sartzetakis, E. S. (2021). Green bonds as an instrument to finance low carbon transition. *Economic Change and Restructuring, 54, 3*, pp. 755–779.

Saxena, A., & Fouzdar, A. S. (2025). Driving ESG excellence: The transformative role of sustainable finance in Indian banks–challenges, opportunities, impact. In

Implementing ESG frameworks through capacity building and skill development (pp. 51–74).

Sciarelli, M., Cosimato, S., Landi, G., & Iandolo, F. (2021). Socially responsible investment strategies for the transition towards sustainable development: The importance of integrating and communicating ESG. *The TQM Journal, 33, 7*, pp. 39–56.

Shin, S. (2025). Green monetary policy: What the Federal Reserve System can learn from the European Central Bank. *New York University Law Review, 100, 3*, pp. 933–970.

Singhania, M., Saini, N., Shri, C., & Bhatia, S. (2024). Cross-country comparative trend analysis in ESG regulatory framework across developed and developing nations. *Management of Environmental Quality: An International Journal, 35, 1*, pp. 61–100.

Smith, G. S., Anjum, E., Francis, C., Deanes, L., & Acey, C. (2022). Climate change, environmental disasters, and health inequities: The underlying role of structural inequalities. *Current Environmental Health Reports, 9, 1*, pp. 80–89.

Solecki, W., & Friedman, E. (2021). At the water's edge: Coastal settlement, transformative adaptation, and well-being in an era of dynamic climate risk. *Annual Review of Public Health, 42, 1*, pp. 211–232.

Tyson, L. D., & Weiss, D. (2025). Climate finance: Progress, challenges, and opportunities on the path to a sustainable planet. *California Management Review, 67, 2*, pp. 5–39.

Udohaya, N. (2025). Current trends in impact investing. In *Impact investing and financial inclusion: Examining the innovations that empower the underserved* (pp. 291–322).

Utomi, E., Osifowokan, A. S., Donkor, A. A., & Yowetu, I. A. (2024). Evaluating the impact of data protection compliance on AI development and deployment in the U.S. health sector. *World Journal of Advanced Research and Reviews, 24, 2*, pp. 1100–1110. https://doi.org/10.30574/wjarr.2024.24.2.3398

Venkatachalam, L. (2025). Environmental economics and ecological economics: Historical evolution and the current status. *Review of Development and Change, 30, 1 Suppl.*, pp. S25–S49.

Wells, E. C., Vidmar, A. M., Webb, W. A., Ferguson, A. C., Verbyla, M. E., de los Reyes, F. L., III, & Mihelcic, J. R. (2022). Meeting the water and sanitation challenges of underbounded communities in the US. *Environmental Science & Technology, 56, 16*, pp. 11180–11188.

Wijeweera, K. R., & Rashid, H. (2023). *Greening the financial system of Pakistan*. United Nations Development Program Pakistan.

Williams, S., & Robinson, J. (2020). Measuring sustainability: An evaluation framework for sustainability transition experiments. *Environmental Science & Policy, 103*, pp. 58–66.

Xhindole, C., Tarquinio, L., & Sierra-García, L. (2025). Climate change and Task Force on Climate-related Financial Disclosures (TCFD) reports. A comparison between Italy and Spain. *Journal of Accounting & Organizational Change, 21, 7*, pp. 1–28.

Zervoudi, E. K., Moschos, N., & Christopoulos, A. G. (2025). From the corporate social responsibility (CSR) and the environmental, social and governance (ESG) criteria to the greenwashing phenomenon: A comprehensive literature review about the causes, consequences and solutions of the phenomenon with specific case studies. *Sustainability, 17, 5*, https://doi.org/10.3390/su17052222.

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data public

Competing interest
Authors declared no conflict of interest.
This work was sole collaboration among all the authors

Funding
There is no source of external funding

Authors Contributions
All aspects of this work were carried out by the author