Report

The Silent Adapters: Uncovering the Resilience *of* Smaller Firms *in* Developing Countries

JUNE 2026

International Finance Corporation
WORLD BANK GROUP

About IFC

IFC — a member of the World Bank Group — is the largest global development institution focused on the private sector in emerging markets. We work in more than 100 countries, using our capital, expertise, and influence to create markets and opportunities in developing countries. In fiscal year 2024, IFC committed a record $56 billion to private companies and financial institutions in developing countries, leveraging private sector solutions and mobilizing private capital to create a world free of poverty on a livable planet. For more information, visit www.ifc.org.

Contents

About this report

Measures of adaptation and its financing have focused predominantly on large public climate investments. This focus has created a blind spot: micro, small, and medium enterprises (MSMEs)—which employ the majority of workers in emerging market and developing economies (EMDEs)—are adapting silently and incrementally, often using internal resources or informal finance. This report reveals that adaptation among MSMEs in developing countries is far more prevalent than commonly measured. Financing remains a binding constraint on scaling adaptation further. The severity of this constraint depends on MSME capacity, the acuteness of climate risks, liquidity constraints, and the level of financial system development, institutional quality, and regulation. Standard metrics miss much adaptation by MSMEs because adaptation is specific to countries and regions and difficult to standardize, measure, and classify. We offer a practical MSME Adaptation Finance Typology that maps specific adaptation actions to financing mechanisms. We illustrate it with a detailed review of evidence from research and practitioners across processes, value chains, and sectors. This typology can serve as a tool for banks, development finance institutions, policy makers, and MSME support organizations to identify adaptation demand and design fit-for-purpose financial products.

Acknowledgments

The report was prepared by a team led by Tatiana Nenova, with Ana Luiza Dutra, Camilo Mondragon-Velez, and Thea Louise Jung, under the guidance of Denis Medvedev and Jamie Fergusson. The team acknowledges valuable contributions and thoughtful comments from Stéphane Hallegatte, Peter Zetterli, Howard Miller, Pablo Salas Bravo, Tatiana Didier, Brian Casabianca, and David Bassini Ortiz.

Executive summary

Climate change is affecting developing countries more severely than developed countries, especially micro, small, and medium enterprises (MSMEs). The effect of natural disasters is greater at lower incomes: for every $1,000 increase in gross domestic product per capita, expected climate-induced losses drop by 0.5–0.7 percentage points. Chronic climate impacts could reduce developing countries' gross domestic product by 1–20 percent, with lower-income and hotter economies experiencing the greatest impact.[1] Recent research finds that smaller companies shoulder higher climate costs, more asset damage risk, costlier adaptation, and longer delays to recovery than large businesses.

Firm-level adaptation is underreported, especially in lower-income countries, as standard metrics largely miss their adaptation. Adaptation is underreported globally, and measurement challenges deepen at the country, sector, and firm level. Unlike mitigation, which enjoys universal metrics comparable across settings, adaptation is sector- and location-specific and has eluded a commonly accepted classification. Global adaptation investment figures predominantly capture public funding, as private adaptation reporting is limited—and largely nonexistent among smaller firms. The coverage of estimates for countries and sectors is uneven and does not account for all sources of climate shocks; yet the limited available indirect evidence at country, sector, and firm level suggests significant adaptation activity by private firms.

Adaptation finance is scarce, especially in lower-income countries. Adaptation makes up 3 percent of global climate finance (the balance is mitigation), but it is growing at 26 percent (CPI 2025). Two-thirds of it goes to emerging market and developing economies (EMDEs), mostly to large middle-income countries (GCA 2024). The adaptation finance gap in EMDEs is estimated at $284–$339 billion per year (UNEP 2025). Demand for adaptation is poised to grow with improving data, technology, and capacity building, especially for monetizable adaptation. For example, sustainable cooling in EMDEs is expected to double by 2050, from $300 billion to $600 billion annually (IFC and UNEP 2024). In Africa, bankable adaptation projects are estimated at $100 billion cumulatively by 2040 (Bari and Dessus 2022). As with adaptation measures, research has been unable to directly document the extent of private funding for adaptation.

Based on cross-country climate data for over 20,000 firms across 46 developing countries from the World Bank Enterprise Survey (WBES), we show that an economically significant share of firms use adaptation techniques and that some can afford to fund them in the course of business. Because adaptation is difficult to observe directly at scale, we proxy with resilience-enhancing measures, relying on evidence of strong correlations among different adaptation measures (Li 2025). WBES offers data on heating/cooling improvements, waste management practices, and energy-efficiency management. The latter has especially strong mitigation co-benefits, but all three variables incorporate sufficient adaptation "content" to serve as proxies. For example, energy-efficient MSMEs are less vulnerable to energy price spikes and unreliable power grids, energy efficiency is important for cooling and thus adaptation, and waste management supports adaptation by improving resource efficiency and enabling the circular economy. Across developing countries globally, 8.4 percent of micro firms and 11.5 percent of small firms experienced asset damage due to extreme weather. Only 9.0 percent of MSMEs formally monitored their emissions levels (compared with 24.5 percent for medium and large firms). Measures of adaptation efforts and demand are much higher—22.9 percent of micro firms, 29.8 percent of small firms, and 45.4 percent of larger firms adopted energy management practices. WBES has a more detailed green module for Europe and Central Asia (ECA) and the Middle East and North Africa (MENA), which confirms these results—over the past three years, 19.3 percent of micro firms and 30.5 percent of small firms adopted energy-efficiency measures, 25.4 percent and 32.5 percent adopted heating/cooling improvements, and 19.9 percent and 30.5 percent adopted waste management practices.

The data show significant awareness and adoption of adaptation measures by MSMEs, contrary to implicit assumptions in the literature that little if any adaptation originates with the private sector in EMDEs. Moreover, the findings hold across different firm sizes, through to micro firms. A large share of small and micro firms undertake adaptation actions in this global sample, at 30.1 percent and 20.9 percent, respectively, compared with over half of medium and large firms. The differences are statistically and economically significant, and the results are consistent across several adaptation proxies and robust to controlling for regional climate differences. In ECA and MENA, where more detailed adaptation data are available in WBES, we find that 51.4 percent of small firms and 40.7 percent of micro firms undertake at least one adaptation measure.

Figure ES.1: Firm adoption of adaptation measures by region and size

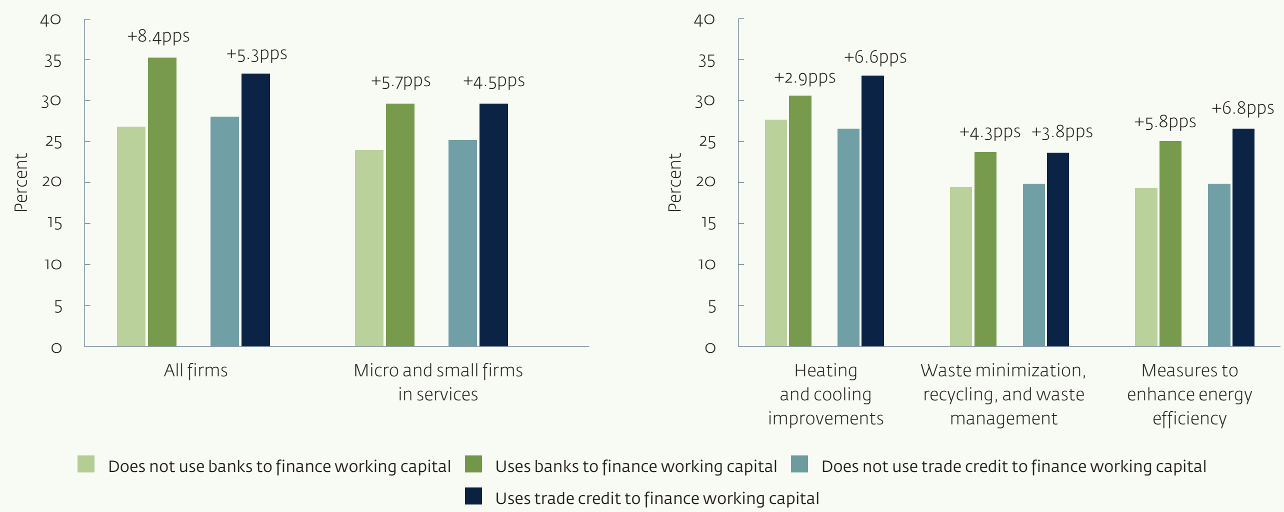
SOURCE: WBES and authors' calculations.

NOTE: The results account for the survey structure of the dataset by applying appropriate weights to calculate country-level averages. For regional averages, each country is treated as one, ensuring that the results are not driven by larger countries, such as Türkiye. In Panel B, we exclude regional averages for MENA as there are only three countries in the sample.

Figure ES.2: Firm adoption of adaptation measures by financing for working capital

Panel A: Global green module, 2021–2024
Percentage of firms that adopted energy management measures (last three years)

Panel B: Detailed green module, 2018–2020, ECA and MENA, micro and small firms only
Percentage of firms that adopted these measures (last three years)—micro and small firms in services



SOURCE: WBES and authors' calculations.
NOTE: The results account for the survey structure of the dataset by applying appropriate weights to calculate country-level averages. For regional averages, each country is treated as one, ensuring that the results are not driven by larger countries, such as Türkiye.

Financing constraints significantly affect firms' adaptation to climate change. While 84.6 percent of MSMEs globally have a checking or savings account, 38.7 percent of micro firms and 32.5 percent of small firms are fully or partially credit constrained. About a third have access to working capital finance—31.0 percent from a bank and 39.5 percent from trade credit. Firms with access to external finance have higher adaptation rates compared to those that do not, and the differences are economically and statistically significant. We also look at the most credit constrained (that is, micro firms in the services sector) to ensure that larger firms or sectoral effects are not driving the results, and the difference remains statistically significant. MSMEs with access to bank financing use adaptation at a 20 percent higher rate on average than those that do not, and the figure is 16 percent for MSMEs with access to external trade credit. These results suggest that access to finance may play an important role in constraining smaller firms' ability to implement adaptation measures.

Probit regression results confirm that firm-level adaptation decisions are related to financial access. Using bank financing increases the latent propensity to undertake adaptation by 0.43 standard deviations; the results are similar and also significant for trade credit and across both available samples. We further explore possible transmission channels through which finance may affect the decision to adapt. We find that capacity and know-how matter for MSME adaptation to some extent, but not for deeply familiar choices like electricity use, underpinned by years of experience and condensed wisdom. While some adaptation is used to manage climate risks, this is not the main story for most firms; this channel is stronger in middle-income countries and for firms with access to bank finance. There is evidence that adaptation is prevented by tight liquidity among firms that borrow for working capital via trade finance, but not among those that have access to banks. Finally, the less developed the financial system is—and the lower the quality of institutions and enabling regulations—the higher the importance of finance for adaptation.

This report proposes a detailed adaptation finance typology tailored to MSMEs, which in future research could contribute to addressing the important data limitations in measuring adaptation and its financing. The typology builds on several notable existing classifications, complementing the dual focus on adaptation and finance, and tailoring it to MSME needs. Having better adaptation financing measures would relax the literature's reliance on isolated surveys or controlled experiments, or on cross-country climate datasets such as the WBES Green Economy Module, albeit at the cost of a more imprecise measurement of adaptation, driven by the available climate-related proxies rather than a more comprehensive taxonomy.

The scope of this report is as follows: Part 1 provides an overview of climate risks, adaptation market barriers, and the business case for adaptation for MSMEs in EMDEs. Part 2 explores measurement—how prevalent adaptation is among MSMEs in developing countries. Part 3 presents a typology of typical adaptation actions and their financing mechanisms. Part 4 focuses on markets for financing adaptation and explores the effect of financing constraints on MSME adaptation.

PART 1

The architecture *of* MSME adaptation *in* EMDEs: Climate costs *and* the barriers *and* drivers *to* adapting

Climate risk costs and adaptation needs are higher in EMDEs, particularly for smaller firms[2]

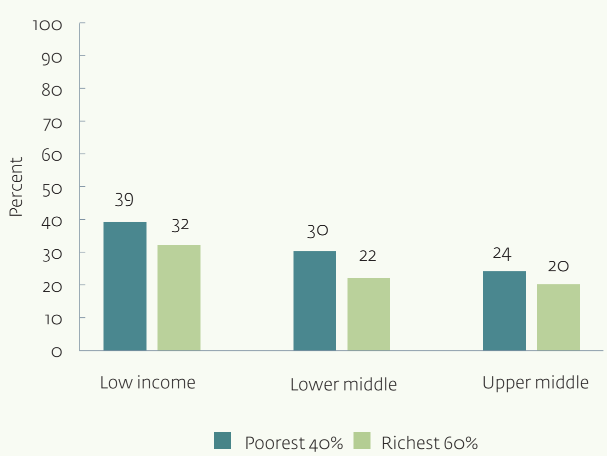
1.1 Climate risks are considerable—adaptation can avoid significant costs globally, especially in EMDEs and for MSMEs.[3] Most of the 3.3 billion people who are at high risk from climate-related hazards[4] live in low- and middle-income countries (LMICs). Chronic climate impacts could reduce developing countries' gross domestic product (GDP) by 1–20 percent, with lower-income and hotter economies experiencing the greatest impact (World Bank 2025).[5] Swiss Re puts the global value of unprotected risk exposure at $1.8 trillion in premium-equivalent terms for 2022. These are underestimates, as private adaptation is poorly measured and reported. In contrast, the literature uses economic models to implicitly deduce unobservable adaptation, which prevents from gleaning any details on firm-specific adaptation actions (Hogan and Schlenker 2024; Kolstad and Moore 2020).

Alternatively, specific adaptive impacts have been explicitly modeled: for example, on international trade, migration, and infrastructure investments.[6] Studies that measure adaptation indirectly find that accounting for adaptation substantially alters estimates of climate damages across a wide range of outcomes—including energy consumption, mortality, labor disutility, ozone concentrations, and fishery output—with substantial welfare benefits from ex-ante adaptation, ranging from 17 percent to 44 percent (Auffhammer 2022; Carleton et al. 2022; Bento et al. 2023; Rode et al. 2021, 2022; Shrader 2023). Infrastructure impact studies find substantial benefits from ex-ante and ex-post adaptation for roads (Chinowsky et al. 2013), bridges (Wright et al. 2012), railroads (Chinowsky et al. 2019), urban drainage systems (Price et al. 2016), water supply (Henderson et al. 2015), multi-sector (Neumann et al. 2015; Melvin et al. 2017), and coastal property (Muis et al. 2015).[7] Both of these research approaches show that climate-related shocks disproportionately affect low-income countries (LICs)—for example, in the case of international trade (Jones and Olken 2010; Li et al. 2015 for China; D'Amour et al. 2016 for Russia). Climate risks are estimated separately from financial and other risks, leading to significant underestimation of the total risks that firms actually face (Hoffmann et al. 2009).

1.2 Poorer countries are more vulnerable to climate risks and shoulder higher climate costs. Most EMDEs are located in areas of higher climate risk, which lowers productivity and economic development (Bakkensen and Barrage 2018). The cost of natural disasters for International Development Association (IDA) countries was 1.3 percent compared with 0.3 percent for other EMDEs over 2011–2022 (World Bank 2024d). In LICs, 35 percent of adults experienced an extreme weather event in the last three years (Figure 1.1A) (Global Findex 2025),[8] and two-thirds of those facing a natural disaster lost income (69 percent) or assets (72 percent) (Figure 1.1B). In Africa, droughts and floods alone have lowered GDP annually by 0.7 percent and 0.4 percent on average, respectively, since 1990 (Bari and Dessus 2022). Inadequate infrastructure and limited

Figure 1.1A: The poor are one-third more likely to face a natural disaster ...

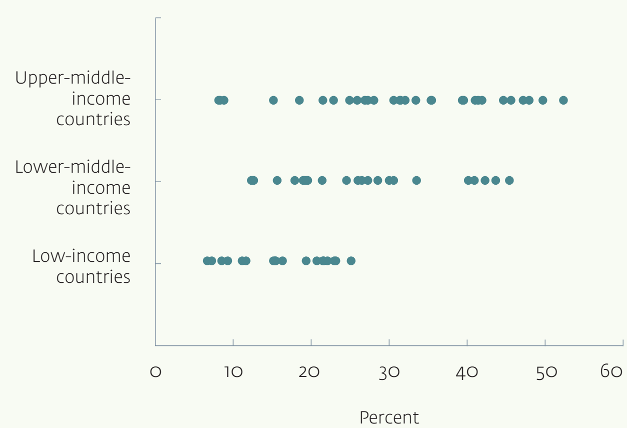
Likelihood of facing a natural disaster



SOURCE: CGAP 2025a.

Figure 1.1B: ... and lose income or assets

Adults who lost income or assets or suffered damage from climate over the past three years (%), 2024



SOURCE: Global Findex Database 2025; CGAP 2025a.

capacity for early warning systems in many EMDEs can amplify the impacts of natural disasters, as can weak governance (Box 1.1). Dell et al. (2012) find higher impacts on growth and minimal ex-ante adaptation in poorer countries (confirmed by Burke and Tanutama 2019).[9] The findings of Kalkuhl and Wenz (2020) imply that ex-ante adaptation may be more substantial than these earlier studies suggest, based on subnational economic output data across 77 countries—and Kahn et al. (2021) confirm this finding. Disasters may even be beneficial via capital reallocation and investment upgrades, but any positive GDP effects vanish over the long term (Hallegatte and Dumas 2009).

1.3 Climate hazards impose direct and indirect costs on firms. Direct losses arise from damage to physical assets and associated repair and replacement costs, while indirect impacts occur through disruptions in infrastructure and supply chains (World Bank 2019b). Evidence from Kampala illustrates the magnitude of these effects: even when few firms are directly flooded, inundated road segments disrupt connectivity across the city. As a result, moderate flooding increases average travel times between firms by 54 percent, with more than a quarter of firms experiencing increases in average travel time of 100–350 percent (Rentschler et al. 2019). At the firm level, climate change negatively affects value and earnings (Venturini 2022; Bansal et al. 2016; Addoum et al. 2021; Hugon and Law 2019; Pankratz et al. 2019; Huang et al. 2018). Firms in poorer countries experience bigger declines in sales revenues (0.12 percent compared with 0.07 percent) due to higher temperature variability. Climate-induced disruptions affect firm performance; for example, in the case of transport, performance suffers for both suppliers and their clients (Pankratz and Schiller 2024), as well as vertically connected firms (Balboni et al. 2023). Rentschler et al. (2021) estimate that 30–50 percent of delays in supplies for firms affected by a flood in Tanzania can be attributed to shocks propagating through supply chains. Inter-firm linkages can propagate economic disruption and damage physical and human capital beyond the affected area, adding to the underestimation of climate impact. More recent literature uses experimental trials to directly measure the impact of specific adaptive actions.[10] Climate impact has been documented further across a wide range of firm outcomes, such as operational status, employment, productivity, investment, and growth; and the intensity varies with firm attributes, such as ownership structure, size, sector, and location (see a review in Grover and Kahn 2024). Importantly, developing-country firms are more affected due to poor-quality infrastructure, limited access to insurance, and shallow credit markets. Firm vulnerability affects investment, asset valuations, and operating costs, in turn curtailing access to finance in a vicious circle.

1.4 Climate impacts are greater for smaller firms, especially in high-risk sectors and LICs. Larger firms are less affected by climate hazards, recover more quickly (Basker and Miranda 2018),[11] and have lower exposure to risk, as they have relatively more resources and can sustain performance better than smaller firms (Birkie et al. 2017). Didier (2024) shows that small and medium enterprises are 50 percent more likely to report asset damage than large businesses, and while supply-chain disruptions affected more than half of all surveyed businesses, smaller businesses were more likely to be affected.[12] As MSMEs represent a significant share of employment and GDP, estimates of climate change impacts on aggregates also provide indirect evidence of MSME impacts, as well as cross-sectoral adjustments (Dell et al. 2012; Pelli and Tschopp 2017). Agricultural MSMEs are particularly sensitive to climate risks. The impact of climate change on crops and livestock in least developed countries and LMICs in 2008–2018 resulted in $37 billion in losses from drought, $21 billion from floods, and $19 billion from storms (cyclones, hurricanes, and typhoons). Sub-Saharan Africa (SSA) absorbed $30 billion of that loss, Latin America and the Caribbean $29 billion, and Asia $49 billion (FAO 2025). Slow-onset climate stressors like heat lower yields as well: up to 30.6 percent of annual growth for rice farms in Asia, 8–22 percent for various crops in SSA by 2050, and a 1.8 percent per standard deviation of heat exposure for agriculture, hunting, and fishing in the Caribbean (Feriga et al. 2025). Climate also affects productivity in the manufacturing and services sectors, but less than in agriculture (Nath 2020).[13] Natural disasters reduce manufacturing productivity, perhaps because adaptation investments displace labor costs or accelerate adaptive automation (see, for example, Brucal and Mathews 2021 for Indonesia; Zhang et al. 2018 for China;

Liu et al. 2023 for India; and Rentschler et al. 2021 for Tanzania[14]). Air pollution also lowers productivity in manufacturing (Adhvaryu et al. 2019 for India). After a storm, capital reallocates toward better-performing industries (Pelli and Tschopp 2017), and the effect is weaker for lower-income countries (Cuaresm et al. 2008) and smaller firms (Vu and Noy 2018).[15] Firms in the retail and wholesale sectors face greater climate-related risks to business continuity than firms in manufacturing and construction, owing to disrupted supply chains and damage to storage facilities (Okubo and Strobl 2021). In the services and transport sectors, climate-related risks—particularly extreme heat, heavy precipitation, and flooding—mostly affect labor. Each year, the transport sector loses $15 billion from climate effects, and 60 percent of these losses occur in LMICs (UNEP FI 2024). The impacts of climate on tourism have been well documented (for example, Hoogendoorn and Fitchett 2018 for Africa). Market frictions such as security, credit constraints, and low-quality institutions may exacerbate climate risks for firms (Goicoechea and Lang 2023).

Adaptation is vital for MSMEs, but they face significant barriers in adaptation markets

1.5 Adaptation investment is highly location- and sector-specific, so it is difficult to define, standardize, measure, and price in a way similar to mitigation. It requires localized risk management strategies tailored to the type of shock and the type of business. This makes classification of adaptation strategies difficult (UNSGSA 2023) and impedes the standardization of measurement. To illustrate, there are numerous measures of adaptation benefits—agricultural yields, health benefits, water stress—compared to universal mitigation measures such as tons of greenhouse gases, which are easy to quantify in monetary terms. Adaptation is also less regulated than mitigation, which is often subject to national or international policy frameworks, frequently with well-defined targets and monitoring procedures—an approach that is harder to implement for adaptation given its localized, system-specific nature. There are both synergies and trade-offs in adaptation and mitigation investments. Some sectors have greater potential for synergies than others, such as energy-related sectors (for example, biomass production and energy use in buildings) and land-related sectors (for example, land management and forestry) (UNFCCC 2022). Some adaptation projects have well-documented mitigation co-benefits—for example, climate-smart agriculture (Smith and Olesen 2010), livestock-sector adaptation (FAO 2023), and urban planning (IEA 2016).

1.6 Addressing the standardization and measurement challenges inherent in adaptation requires improvements in capacity, regulation, technology, and market structure (Carleton et al. 2025), as well as access to finance and risk management (Table 1.1). Adaptation often involves large upfront expenditures (Fowlie et al. 2018), and associated costs are large (Schlenker et al. 2013; Carleton et al. 2022; Hultgren et al. 2025).[16] Improving information and coordination frictions can lower adaptation costs (Karplus and Grover 2021).[17] Lowering the cost of adaptation technologies can help promote adaptation. For example, access to irrigation can moderate the relationship between temperature and agricultural yields (Hultgren et al. 2025). The associated market structure—competition or market pricing—is also an important determinant of adaptation costs.[18] Alternatively, adaptation opportunity costs could be relaxed through changes to the budget constraint; for example, adaptive behaviors increase with income, such as the use of electricity on hot days (Auffhammer 2022; Rode et al. 2021).

Table 1.1: Barriers to adaptation

Standardization	Location- and sector-specific nature of adaptation; barriers to classification, measurement, and pricing.
Capacity	Imperfect information; cognitive/social barriers; capacity constraints for both firms and lenders.
Regulation	Low level of regulation; difficult to have targets and monitoring; limited fiscal measures and incentives; limited enabling regulation; limited access to public information/education; limited concessional lending.
Technology	Low technical capacity; poor technology skill building; insufficient knowledge diffusion; a lack of available and affordable gtreen technologies in remote areas; a lack of partnerships.
Market structure	Competition (for example, trade openness); infrastructure; market pricing; fixed costs; economies of scale; public goods; externalities.
Finance access and risk management	Information asymmetries; difficulties monetizing resilience benefits; unclear metrics to measure success; coordination failure; credit vulnerabilities; limits to property rights; externalities; localized financing solutions; aggregation costs; short-term investment horizons; tenor mismatch; limited options for bankable projects of sufficient size.

SOURCE: Authors' elaboration.

1.7 MSMEs face capacity barriers to adaptation. Improving access to information and training can lower adaptation costs.[19] Capacity issues involve limited awareness, imperfect information, poor knowledge of climate risks and adaptation technologies, low technical capacity to implement adaptation measures, and cognitive or social barriers (Kuruppu et al. 2015; World Bank 2025). Firms misassess impacts and risks (Goldstein et al. 2018; Gine et al. 2015) across different countries and contexts (AXA and UNEP 2015), but correcting inaccurate expectations changes adaptation decisions and returns (see Patel 2024 and Zappala 2024 for agriculture; and Gasbarro et al. 2016).[20] Firms also dedicate insufficient human and financial resources to adaptation (Ingirige and Wedawatta 2016), view climate change as a future risk that does not require immediate action, have limited information on climate risks (Downing 2012), and are reluctant to be distracted from their core business given uncertain benefits (Institute for Public Policy Research 2016). Yet there is ample evidence of firms' learning and updating beliefs (Rosenzweig and Udry 2013; Emerick et al. 2016 for India; Balboni et al. 2023 for Pakistan; Aker and Jack 2023; Boucher et al. 2024 for Mozambique and Tanzania; Patel 2024 for Bangladesh). Past experience feeds positively into subsequent innovation (Hu et al. 2018; Miao and Popp 2014; Abajian et al. 2023). Didier (2024) finds both considerable awareness and information gaps: only 69 percent of small and medium enterprises and 40 percent of small businesses have flood-risk information (compared with 80 percent of large firms)—and even among firms with recurring flood risk, 33 percent consider lack of awareness a top-three issue.[21] An emerging body of scholarship has focused on identifying elements that support small businesses in building capacity to adapt (Ingirige et al. 2008; KPMG 2024), such as management capacity (Bassi et al. 2021; Li et al. 2020). Higher management capacity moderates disaster impacts—reducing capital by 17 percent and value added by 22 percent and increasing firm exit by 11 percent (Van Reenen and Keiller 2024). Financial institutions also have capacity constraints and would benefit from learning and knowledge sharing of best practices to increase their confidence in adaptation investments. Crick et al. (2016) argue for the importance of involving informal sector, women-led, and marginalized MSMEs in capacity building.[22]

1.8 In addition to capacity constraints, important conditions for adaptation include enabling regulations (infrastructure, social support) and technological innovation (climate monitoring and forecasting). An enabling policy environment can take the form of fiscal measures and incentives (tax breaks for adaptation investments, property taxes differentiated by risk, differentiated insurance premiums), regulation (zoning, building codes), or simply education and better information (long-term weather forecasts, agricultural extension services). However, policy has been heavily skewed away from adaptation; for example, public credit guarantee schemes for MSMEs are mostly for mitigation and exist in few countries (OECD 2021; World Bank 2022). Adaptation actions involve technology, skill building, knowledge diffusion, socioeconomic subsystems, and partnerships, which makes enabling regulation difficult. Technological innovation and low-cost digital solutions can build MSME know-how on climate change adaptation techniques, provide early warning information, offer tools tailored to their businesses, and help them understand regulations better (UNFCCC 2023).[23] Green technologies are not available or affordable, especially in remote rural areas and underserved urban areas (Ingirige et al. 2008; Bannock 2015; Crick et al. 2016). Hottenrott et al. (2016) provide an overview of the impact of regulation on adaptation, and CGAP (2025b) suggests a policy approach focusing on financial inclusion. This study does not examine the full range of nonfinancial adaptation barriers, focusing instead on financing constraints to adaptation.

1.9 Financing and risk management round off the list of major adaptation constraints, as adaptation investment needs are considerable. Financing needs for a resilient pathway stand at 8 percent of GDP for LICs, 5 percent for LMICs, and 1 percent for upper-middle-income countries, averaging 1.4 percent of GDP across 24 countries (IFC 2013; World Bank Group 2022b).[24] Not only is the financing gap large, but adaptation finance is riskier than other MSME finance (Ginglinger and Moreau 2019). Box 1.1 lists major market failures in financing adaptation; the last two listed are particularly relevant for MSMEs. Climate-related financial risks are mispriced and not fully reflected in asset valuations (Caselli and Figueira 2020). Public intervention may be necessary to overcome externalities. For example, negative externalities from energy use and groundwater extraction cause overuse (Abajian et al. 2023; Auffhammer 2022), while adaptation innovations may be undersupplied (Zilberman et al. 2012). A weak policy environment and underdeveloped financial and insurance markets can constrain adaptation investment, particularly in developing economies, where long-term, liquid financing is limited or unavailable (Stoll et al. 2021), and where insurance products for extreme events are disappearing (Cole et al. 2024). Coordination failure can lower adaptation in competitive markets (Annan et al. 2024). Adaptation finance is further constrained by the difficulty of monetizing resilience benefits and the high capital costs of adaptation measures, even when resilience investments are low risk and yield high returns. In addition, Carleton et al. (2025) highlight weak property rights and increasing returns to scale as barriers to adaptation financing. The multiple barriers in adaptation finance markets may discourage MSMEs from adopting greener practices, despite the prospect of lower costs, increased operational efficiency, and improved sustainability and resilience over time.

Despite multiple barriers, adaptation is vital for MSME resilience and, in many cases, survival, as it can help them weather disasters better, reduce risks, lower costs, innovate, and remain competitive.

Lenders look for short-term returns with MSMEs and may not account for long-term adaptation benefits, compounding the challenges of long-term financing for adaptation in EMDEs. Continued underfunding of adaptation is risky, however. Inadequate access to land, capital, markets, new technology, and educational opportunities can drive MSMEs toward unsustainable coping strategies, including scaling back operations as a result of reduced profits, lost business, and the sale of valuable assets, undermining their long-term adaptive capacity (Atela et al. 2018).

The business case for MSME adaptation

1.10 Despite multiple barriers to adaptation, the economic benefits exceed the costs. Impact assessments of future climate change find that adaptation is net beneficial despite high uncertainty, multiple metrics, site- and context-specific risks, and dynamically variable benefits over time (UNEP 2025). Economic assessments of short-term projects identify benefit-cost ratios typically above 2:1 and often as high as 10:1, and such projects can generate cost savings (OECD 2015; GCA 2019;

Box 1.1: Major adaptation-related financial market frictions and failures

- ***Incomplete and asymmetric information***: Firms and financiers both face significant knowledge gaps on climate risks, adaptation solutions, and their associated costs and benefits, which raises transaction costs and reduces investor confidence. Informational inefficiencies increase uncertainty, rendering adaptation effectively riskier than conventional investments. This is amplified by limited information on climate change risks more broadly, as well as the underdevelopment of financial infrastructure for climate investments.
- ***Adaptation externalities***: Adaptation measures generate externalities by producing public goods, such as enhanced community resilience or reduced disaster risk. These public goods do not generate direct financial returns, limiting private incentives for investment. For example, while the investor bears the cost of new sectoral or supply-chain adaptation technologies, the benefits extend across firms and industries, enhancing sector stability and improving the resilience of suppliers and customers.
- ***Lagging enabling environment for financing adaptation***: There is no established adaptation taxonomy (as in mitigation), and policies are not balanced toward adaptation.
- ***Lack of unified metrics for pricing adaptation outcomes***: Benefits are specific to sectors and contexts and are difficult to quantify in monetary terms, unlike universal mitigation measures (tons of greenhouse gases, radiative forcing values).
- ***Customization, coordination, and aggregation costs*** arise from multiple stakeholders, the need for customized solutions, and the servicing of numerous small firms. Vulnerabilities vary by geographical location, sector, existing risk management strategies, and the type of shock involved, requiring localized "bottom-up" solutions that can reach large numbers of MSMEs, in contrast to standardized mitigation financing.
- ***Hard-to-monetize adaptation benefits***: Adaptation benefits may accrue through reduced expected losses rather than monetary gains or cost savings obtained directly from adaptation investments. For example, climate-smart measures such as vertical agriculture or improved cooling energy efficiency may strengthen resilience, but their financial benefits can be difficult to quantify, especially given limited information on future risks. For short-horizon MSMEs, these gains may also appear too indirect or immaterial, as benefits are often diffused across outcomes, such as higher productivity (for example, crop yields) or reduced operational costs (for example, electricity consumption).

SOURCE: Based on World Bank 2024e and authors' compilation.

GCA 2021; Climate Change Committee 2021). Benefits can include resource-efficiency savings, energy-source optimization, green products and services, access to new markets, and the broader gains associated with improved resilience.[25] Firm-level adaptation can substantially reduce the economic impact of heat shocks, lowering estimated damages by 20–30 percent (Caggese et al. 2025). Successful firm adaptation to rising weather risks can reduce the broader macroeconomic impact of weather on national growth and employment (Hallegatte et al. 2016; Hallegatte and Rozenberg 2017; Nath et al. 2024). The World Bank (2024a) has collected a number of case studies to show that private investment in adaptation can reduce costs and improve performance; for example, adaptation solutions in agriculture and food systems can increase revenues. The IMF (2023) uses a dynamic stochastic general equilibrium model to show that adaptation investment has large long-term returns in terms of private investment, employment, output, and tax revenue.

1.11 Private investments have the potential to underpin much of the adaptation effort. In Africa alone, the private adaptation investment potential is estimated at $5 billion per year, or 4 percent of the continent's GDP (close to $100 billion over 2021–2041; Bari and Dessus 2022).[26] GIC and Bain (2025) estimate that global annual revenues from a select set of climate adaptation solutions will grow from $1 trillion to $4 trillion by 2050 (see also GARI 2024). The business case has been argued in several sectors. For example, Adhvaryu et al. (2020) study the adoption of energy-efficient LED lighting in garment factories around Bangalore, India, and show that the payback period for LED adoption is less than one-third as long after accounting for productivity co-benefits: the average factory gains about $2,880 in power-consumption savings and about $7,500 in productivity gains. As another example, the market for sustainable cooling in EMDEs is expected to grow from $300 billion to $600 billion a year by 2050, with an additional $800 billion required to close current gaps (IFC and UNEP 2024). Urban nature-based solutions reduce ambient temperatures by over 1°C on average (UNEP 2025). MSMEs can benefit on both the supply and demand sides of climate risk markets—offering, as well as using, adaptation products and services.

1.12 Adaptation investments are likely to become an increasingly important competitiveness driver in global markets. As adverse climate change-related shocks become more frequent and extreme, firms that adapt and become more reliable to their supply chains and final customers will face increased demand, gain market share, enhance their reputation, and potentially bring about economy-wide benefits as well. A total of 73 percent of global consumers say they would or would probably change their consumption habits to reduce their environmental impact (Nielsen 2018). Companies that prioritize sustainability outperform their peers by 4.8 percent in terms of shareholder return (Serafeim 2014). Several studies show that green technologies, tools, and practices are associated with better health outcomes, increased agricultural productivity, new economic opportunities, and women's empowerment (Leapfrog, CGAP, and Temasek 2023). Furthermore, climate-friendly adaptation can itself become a source of competitive advantage. Firms that implement sustainable solutions—such as energy-efficient cooling systems in response to higher temperatures rather than conventional alternatives that consume large amounts of electricity and use polluting refrigerants—can reduce their exposure to regulatory risk, help break negative climate feedback cycles, and position themselves to meet the growing expectations of consumers, investors, and other stakeholders for cleaner, greener technology.

1.13 Climate change can spur the development of new products, services, and markets.[27] Building on their local knowledge, inherent operational flexibility, and swift decision-making, MSMEs can develop climate-resilient goods and services that are affordable to vulnerable populations (IFC 2013; Terpstra et al. 2013; World Bank Group 2022a). MSMEs are particularly well suited to supporting adaptation, which is location- and sector-specific. A GCA survey of African MSMEs shows that 95 percent saw opportunities for business expansion while managing climate risks (81 percent identified new products, 22 percent found new markets for existing products, and 60 percent identified opportunities for new markets). Because MSMEs are embedded in their communities, they can also help aggregate and disseminate innovation and lessons about adaptive practices.[28] MSMEs could play a more active role in local and city-level resilience planning and engage more closely with government and wider society on climate change (AXA and UNEP 2015).

1.14 MSMEs might engage in innovative, resource-sparing, or "in-kind" (nonmonetary) adaptation, such as moving inventory to a higher floor before an expected flood, adjusting hours of operation on hot days, and other solutions that are not resource intensive (Alam et al. 2022). Shilpi et al. (2025) report that about half of small and medium enterprises in Uganda engage in flood adaptation: about 30 percent build pathways for water runoff, 17 percent clear the drainage, 14 percent elevate their firm, and 10 percent place rocks, vegetation, or floodwalls around their establishment. Nguyen and Vu (2022) find that small and medium enterprises in Vietnam adapt via process (rather than product) innovation.[29] These low-cost and in-kind responses are precisely the kinds of adaptation that standard finance and reporting metrics are least likely to capture.

Scope of this report

Given the economic importance of MSMEs,[30] they will likely be responsible for a large share of adaptation efforts, both to survive and to remain resilient. This report examines the adaptation actions they are capable of undertaking. As many adaptation investments are, by their nature, long term, and as MSME financing in EMDEs is short term and scarce, the study asks:

i. What adaptation can realistically be funded by short-term financing?
ii. How can that funding be increased on a market basis?
iii. What share of MSME adaptation is carried out in the form of in-kind contributions?

Part 2 explores how prevalent adaptation is among MSMEs in developing countries.

Part 3 presents a typology of typical adaptation actions, with detailed sector-specific examples relating to processes, products, inputs, and resource use, and links these actions to appropriate financing mechanisms. In developing countries, the scale of MSME economic activity demonstrates their considerable potential to contribute to climate change adaptation, especially in sectors such as agriculture and services/trade where they dominate. MSMEs also have a unique understanding of and foothold in underserved, rural, and remote locations that larger firms have difficulty penetrating. Pricing uncertainty, difficulties in risk measurement, and constrained financing may lead to suboptimal investment in adaptation.

Part 4 focuses on markets for financing adaptation and explores the effect of financing constraints on MSME adaptation.

MSMEs have some natural competitive advantages for undertaking adaptation—such as agility and close links to communities—while also being more financially constrained, especially for longer-term adaptation investments.

PART 2

Measuring adaptation

Adaptation is significantly underreported due to data limitations at the global, country, and sector level

2.1 Adaptation is not well measured at the global level. Global adaptation estimates are made relative to international public sources only, due to the large uncertainty and underreporting of private sector investments in adaptation (GEF and IFC 2012; UNEP and GCA 2019; G20 2017; CIF 2016). For example, CPI (2022) estimates that about 90 percent of climate finance in 2021–2022 went to mitigation and only 5 percent was for adaptation; the World Bank and IFC (2021) report 1.6 percent; and GCA (2024) reports less than 3 percent.[31] Estimates of private sector needs are also underrepresented in modeled adaptation costs and financing needs, and private sector finance flows are unclear (OECD 2023; IMF 2024; Watkiss and England 2025).[32]

The World Bank (2010) estimates that as much as three-quarters of identified adaptation needs would require public expenditure, although the report concedes that this estimate is unlikely to capture the full private investment in adaptation such as insurance against climate hazards and climate-proofing private dwellings, factory buildings, and machinery. The private sector could potentially meet 15–25 percent of adaptation needs by 2035 (about $55 billion per year of the total $310 billion) (UNEP 2023b), while about 75–85 percent is estimated to be publicly funded (about $255 billion per year) (UNEP 2025).[33] For adaptation finance needs, the private share is 33 percent (some $135 billion per year). For actual (measured) adaptation financing, less than 3 percent comes from private sources, compared with more than half for mitigation (CPI 2022). Parry et al. (2009) review a range of research estimates of adaptation costs to illustrate the identification problem of private adaptation. They take the example of the UNFCCC (2007) adaptation figures and find them to be underestimated by at least a factor of two to three. Measurement issues are not the whole story. The much lower adaptation figures suggest that market pressures on firms to adapt and increase their climate resilience are weaker relative to those for mitigation, which attracts considerable funding and policy attention.[34]

2.2 Publicly funded adaptation is well documented, while private adaptation is largely assumed to be negligible and not well measured. As noted in Part 1, adaptation at the national level has a high economic impact over time. For example, Marto et al. (2018) find that Vanuatu would save 10 percent of costs by ex-ante adaptation to cyclones, compared with ex-post international disaster aid, while Cantelmo et al. (2023) find 30 percent savings for ex-ante public investment in resilient capital across disaster-prone developing countries.[35] Such studies largely assume that private adaptation is negligible. This assumption bears re-testing, also in the context of measuring and establishing climate risk exposure. Climate shocks presumably leave little option to surviving private enterprises but to respond. There are objective empirical barriers to measuring adaptation accurately, including poor data, lack of a clear definition given the context-specific nature of adaptation, adaptation not always involving an explicit monetary investment, unreliable adaptation investment categories in corporate reporting, and limited reporting of private adaptation investments funded internally. Didier (2024) finds that businesses in Malaysia can reduce their expected losses due to floods by more than 50 percent by building resilience in supply chains to ensure the continuity of production. Moreover, climate risk information is valued by financial markets.[36] In agriculture, large, short-run forecasts do influence behavior and induce short-run ex-ante adaptation (Burlig et al. 2024; Du Puy and Shrader 2024; Rosenzweig and Udry 2013). Not enough long-run adaptation investments are made (Burke et al. 2015).

Table 2.1: Review of existing literature by adaptation area

Adaptation area	Analytical coverage	Cost estimates	Benefit estimates
Agriculture	Comprehensive	Extensive coverage	Extensive coverage
Coastal zones	Comprehensive	Extensive coverage	Extensive coverage
Water/flooding	Several case studies	Extensive coverage	Extensive coverage
Energy	OECD; EMDE case studies (for example, Brazil)	Extensive coverage	Extensive coverage
Infrastructure	Cross-cutting, partly covered in other sectors	Extensive coverage	Extensive coverage
Health	Selected impacts only	Moderate coverage	Moderate coverage
Tourism and hospitality	Selected areas: Coastal tourism and small island states	Moderate coverage	Moderate coverage
Other services	Adaptation not explicitly assessed	Limited coverage	Limited coverage
Manufacturing		Limited coverage	Moderate coverage
Construction		Limited coverage	Limited coverage
Retail		Limited coverage	Limited coverage
ICT and data	Selected areas: Early warning systems, weather data for agriculture	Moderate coverage	Moderate coverage

SOURCE: Authors' desk research.

2.3 Adaptation measurement issues deepen at the country and sectoral level. Private adaptation data are also limited, especially for MSMEs and in EMDEs, while more data are available in developed countries. With the same caveat about private investment in adaptation being undermeasured, about two-thirds of adaptation funding goes to developing countries, the bulk of it concentrated in a few larger middle-income countries. In Africa, 54 percent of adaptation flows go to 10 countries, and the bottom 10 recipient countries get 1 percent of adaptation finance (GCA 2024). From a small base, climate adaptation finance is growing quickly, at 29 percent in 2022 (CPI 2022). Still,this leaves a sizable financing gap, 12 to 14 times as large as current international adaptation finance flows (UNEP 2025).[37] Sectoral estimates vary more than global figures, because methodologies can fully account neither for extreme events, due to limited predictive powers, nor for adaptation options, due to shortcomings in classifications of adaptation actions.

The literature on measuring adaptation is reviewed in Massetti and Mendelsohn (2018). Research on adaptation has been uneven across sectors, leaving the impression that little adaptation is undertaken in less-studied sectors (Table 2.1 and Carleton et al. 2025). Particularly vulnerable sectors include those that rely on certain seasonal and climate conditions (for example, agriculture and related businesses), those that are vulnerable to the disruption of infrastructure, and those located in areas that are susceptible to physical climate change risks (Weinhofer and Busch 2013). There has been much focus on agriculture and energy (for example, see Deschênes and Greenstone 2011 and Lin et al. 2019 for energy adaptation; Jagnani et al. 2021 for agricultural inputs; Taraz 2017 for irrigation investments; Tambet and Stopnitzky 2021 for soil and water conservation practices; and Aragon et al. 2021 for land adjustments). However, there is far less information on the impacts of a changing climate on manufacturing or services firms and their adaptation responses (Chambwera et al. 2014; Averchenkova et al. 2016; Massetti and Mendelsohn 2018).

Taken together, the sector literature suggests adaptation is occurring, but it is not measured consistently across sectors or firms, especially for MSMEs. In the next section, we review the available sectoral and firm-level coverage of MSME adaptation, as well as evidence from the World Bank Enterprise Survey (WBES) cross-country data.

Research and data availability are skewed toward larger, higher-income countries, public financing, and a few sectors, giving the impression that little adaptation is undertaken elsewhere in the economy.

Adaptation incidence documented in the literature, by sector

2.4 Agriculture is one sector where private adaptation has been relatively well documented (Ortiz-Bobea 2021). Agricultural adaptation has substantial effects. Hultgren et al. (2025) show that accounting for ex-ante adaptation benefits reduces aggregate global yield losses from climate change by 47 percent.[38] Declines in crops and livestock dampen firm sales and job creation by reducing local demand and firm productivity. Costinot et al. (2016) show productivity drops from climate, equivalent to the loss of one-sixth of crop value, and a 0.26 percent reduction in global GDP on data for 10 crops across 1.7 million fields. They also estimate that shutting down crop switching increases the agricultural welfare losses from climate change by 300 percent. The decline in crop yields in turn reduces rural employment: in Mexico, by 1.4 percent over 28 years (Jessoe et al. 2018); in Brazil, by 11 percent per one standard deviation increase in aridity between 2000 and 2010 (Albert et al. 2021); and in China, by 7 percent for every 1°C rise in temperature (Huang et al. 2020). In India, women were 7 percent less likely than men to be employed after a drought and spent 29 percent more days searching for work (Afridi et al. 2022). Gouel and Laborde (2021) find that free trade lowers agricultural damage from climate change by 27 percent. This result was confirmed by Nath (2023), whose estimate is 22 percent, while Conte (2023) finds adaptive benefits within Africa to be below 1 percent.

2.5 Manufacturing has received less attention than agriculture in research on sector-specific adaptation in developing countries. The gains from adaptation are estimated to be about 1 percent of GDP (see, for example, Castro-Vincenzi et al. 2024 and Tokui et al. 2017). The literature has focused on a narrow set of adaptations: within-sector diversification (Pelli et al. 2020),[39] altering the factor mix (Zhang et al. 2018; Albert et al. 2021), across-sector moves (Colmer 2021), and spatial transitions (Linnenluecke et al. 2011; Kato and Okubo 2018).[40] Other adaptation strategies noted in the literature include strategic/safety stock and building larger supplier networks, switching to suppliers with less climate risk, dispersing suppliers or facilities, flexible transportation, backup suppliers, and rerouting (Bret et al. 2021; Ciani et al., forthcoming). Firms with diverse supply bases, both in number and geographic dispersion, manage climate risk better (Tokui et al. 2017). Heat or floods at supplier locations reduce the income of suppliers and their customers, who are 7 percent more likely to terminate the supplier relationship (Pankratz and Schiller 2024). Relocating to avoid climate damage can increase the likelihood of firm exit by disrupting networks and reducing agglomeration benefits (Gechter and Kala 2025). Sophisticated supply chains can experience climate ripple effects (Gouda and Saranga 2018). Didier (2024) finds more supply-chain resilience in large firms than small firms (only around 22 percent of small and medium enterprises not hit by floods had planned resilient supply chains).

2.6 Services have higher adaptation gain potential than manufacturing but receive the least coverage in the literature. The cost of adaptation inaction is particularly high for services. In 28 Caribbean countries, a 1°C increase in temperature reduces output in wholesale and retail trade, restaurants, and hotels by 6.1 percent, and other services by 2.2 percent—substantially larger than the 0.8 percent decline in agriculture, hunting, and fishing.[41] Campbell et al. (2021) examine the impact of climate change on tourism and find that sea-level rise causes a 47 percent reduction in direct tourism revenue. One affordable adaptation strategy is beach nourishment, given that beach tourism constitutes 0.87–1.1 percent of annual tourism revenue.

2.7 The literature extensively documents the adaptation shortfall penalty on labor productivity, labor supply, and relocation/migration. Around 1.2 billion jobs (40 percent of global jobs) are in industries that rely on ecosystem services, including agriculture, tourism, and renewables. The highest shares of these jobs are in Africa and East Asia and Pacific, at 58 percent and 49 percent of total employment, respectively (ILO 2018). Climate also affects jobs in poorer countries more, due to their more climate-exposed locations, poorer adaptive capacity (Adom and Amoani 2021, based on 44 African countries), and economic orientation to more weather-exposed sectors. Slow-onset stressors such as rising temperature impair physical and cognitive working capacity, resulting in reduced work pace and lower labor productivity (ILO 2019; Bijnens et al. 2024 on the European Union). In India, labor productivity declines by 2.1 percent for each degree above 24–26°C (Somanathan et al. 2021), while in Indonesia it drops by 9 percent (Masuda et al. 2021).[42] In China, there is a 2.6 percent loss in total factor productivity for agriculture on days hotter than 33°C (Chen and Gong 2021) and a 0.56 percent loss for manufacturing for temperatures above 32°C, compared with 10–15°C (Zhang et al. 2018). Labor supply has decreased globally due to climate (Rode et al. 2022), driven by increased disease, occupational health risks, absenteeism, and interruptions to transport services. In 2022, heat exposure resulted in a 42 percent higher loss of labor hours globally than the annual average in 1991–2000 (OECD 2024). The effect is stronger in lower-income countries (Carleton et al. 2022). India lost 259 billion labor hours ($624 billion) annually in 2001–2020 to extreme heat and humidity (Parsons et al. 2022). The productivity loss to adaptation inaction is heavier for smaller firms (Ponticelli et al. 2023 for US manufacturing; OECD 2024 for advanced countries), and in lower-income countries. The climate-induced median loss of productivity is 6.2 percent in LICs, 5.7 percent in LMICs, 1.5 percent in upper-middle-income countries, and 0.2 percent in high-income countries (World Bank 2024b). Cai et al. (2016) document the use of labor migration as an adaptation strategy, while Albert et al. (2021) find that Brazilian municipalities at the 90th percentile of dryness experienced an additional 1.8 percent population loss relative to those at the median level of dryness. Finally, the green transition and associated policies will shift market demand (and thus employment) toward low-carbon sectors (IEA 2020), though evidence is inconclusive on the overall effect (Godinho 2022).

Adaptation decisions at the level of firms and MSMEs

2.8 Adaptation at the firm level is carried out "in the course of business" and may not be explicitly identified, especially for MSMEs. Private firms and their financiers find it hard to formally identify adaptation because it is sector- and location-specific, and there is no widely accepted classification of adaptation actions. In addition to a lack of awareness, firms may fail to appropriately categorize their adaptation investments to avoid extra funding costs. Yet substantial private investment is anecdotally undertaken in adaptation and resilience, as most consumption and business decisions are affected by climate directly or indirectly and some investments may entail short-term returns or cost savings. We test this conjecture below. Box 2.1 shows how adaptation financing decisions may be made at the firm level. Firms respond to climate change by mainstreaming adaptation into their business planning and financing it using the same instruments as traditional investments, often without explicitly acknowledging that what is being done contributes to adaptation (UNEP 2016; UNEP DTU 2018). Even less adaptation data are available for MSMEs. Unfamiliar with the terminology, MSMEs may often be unaware that they may be contributing to adaptation through, for example, protecting their own assets, improving water efficiency, or reducing flood risks (Druce et al. 2016; Pauw 2017). Poor data and measurement, lack of a clear definition given the context-specific nature of adaptation, unreliable adaptation investment categories in corporate reporting, and limited reporting of private adaptation investments out of internal funding have prevented research from reliably documenting the extent of firm-level adaptation investment (CPI 2018). Indeed, recent studies suggest that private firms do invest in adaptation (Didier 2024; CGAP 2024b) but often mislabel it (UNEP 2016; CPI 2018). Using a more sophisticated tracking mechanism, CPI (2024) finds private adaptation investments are, on average, more than four times higher than the $1 billion previously tracked from 2019 to 2022, and considers even this figure an underestimate.

Box 2.1: Which adaptation is easier to finance?

Adaptation actions vary by *intent* (responsive, strategic, or systemic/multi-hazard risks), *nature of adaptation* (incremental or transformational), *timing* (ex ante or ex post), and *type of action* (no- and low-regret, climate proofing, adaptive management, transformative change). Private financing is more likely if the benefits of adaptation arise now rather than in the future and have lower uncertainty and complexity.

The market characteristics of adaptation also affect financing: *type of investment* (one-time investment delivering adaptation capital vs. recurring capacity and expenditure on staff, maintenance, social expenditure), *recipient of adaptation* (well resourced or low income), *project size* (large single projects such as infrastructure vs. small and fragmented multiple projects/recipients, especially if involving private and public actors), *adaptation-generated revenue streams* (positive revenue generation or cost savings, whether the co-benefits of adaptation can be monetized), and *context* (in market sectors vs. nonmarket sectors/for public goods). Adaptation to support more anticipatory, strategic, and even transformational adaptation requires larger reliance on public funding.

SOURCE: UNEP 2023b; Watkiss 2022.

2.9 MSMEs are less resilient compared to corporates. Larger firms are more likely to adopt adaptation strategies that require bearing fixed costs and feature economies of scale (Graff Zivin et al. 2018). Unlike corporates, MSMEs often struggle to bounce back from climate shocks due to limited financial capacity, lack of awareness, inadequate skills, weak policy support, and fewer coping mechanisms. Berg at al. (2025) estimate temperature response functions for WBES firms, and find that market frictions limit adaptation, causing a 12 percent revenue drop for small-to-medium firms when temperatures rise 0.5°C above average. The impact stems from declines in labor productivity and wages and holds across manufacturing and services, with stronger effects in heat-sensitive sectors and among less resilient firms. Limited financing, burdensome regulations, and unsafe conditions raise adaptation costs. In Bangladesh and India, about half of all formal MSMEs have invested in adaptation such as cooling technologies, energy management, or contingency plans. In the Middle East and North Africa (MENA) region, the share is about 20 percent (World Bank 2025). Adaptation is particularly challenging for MSMEs in poorer countries, as a greater share of MSMEs operate in climate-sensitive sectors such as agriculture, fisheries, and tourism, and these sectors represent a larger part of the economy. Furthermore, nano enterprises are often underserved and less prepared to handle shocks. Sawhney, Kimani, and Sotiriou (2025) find that women-led nano enterprises show lower resilience to shocks than women-led micro enterprises across India, Kenya, and Uganda.

Evidence of adaptation decisions based on WBES data

2.10 While there is much indirect evidence that viable firms have been funding climate adaptation in the course of business, research has been unable to directly document the extent of private investment in adaptation across countries. We use cross-country data to address the literature limitation of relying on isolated surveys and controlled experiments, which are not generalizable due to small sample sizes and the localized nature of climate risks and adaptation strategies. Even within countries, datasets are often limited to specific sectors. This study relies on the WBES Green Economy Module with global geographical scope (covering 2019–2024).[43] A global climate-related questionnaire was distributed between 2001 and 2004, which included a limited set of questions on climate issues. In 2019 and 2020, WBES ran a more detailed Green Economy Module with over 50 questions on climate practices across Europe and Central

Asia (ECA) and MENA, which provides somewhat broader insights into firm-level climate practices for those regions.[44] The global WBES green module covers 46 EMDEs across six regions, while the detailed WBES green module has data on 21 countries in ECA and six in MENA. The global and detailed green modules encompass 25,848 and 21,152 firms, respectively. Table 2.2 summarizes firm distribution across regions, while Appendix A provides details on distribution by country, sector, and size. Adaptation is not directly measured in the WBES green modules,[45] necessitating the use of proxies, based on evidence of strong correlation among different adaptation measures (Li 2025). WBES offers three resilience-enhancing measures: energy-efficiency management, heating/cooling improvements, and waste management practices. Energy-efficiency management has been used as a proxy for overall adaptation effort (Uji et al. 2024). Energy-efficiency measures are often associated with mitigation but also enhance resilience to climate impacts such as rising temperatures, shifting precipitation patterns, and extreme weather. These changes affect the reliability of energy demand and supply.[46] At the firm level, again despite strong mitigation co-benefits, the measure incorporates sufficient adaptation "content" to serve as a robust proxy; for example, energy efficiency helps MSMEs reduce their vulnerability to energy-price spikes and unreliable power grids.[47] Electricity use is nearly ubiquitous, and it may measure better adaptation tendencies for a wider range of sectors and enterprise sizes. The underlying assumption is that undertaking one adaptation measure likely signals broader efforts and/or demand for adaptation: scarce resources are focused on the most (cost-)effective adaptation strategy. For many MSMEs—where electricity costs form a significant portion of operating expenses and where they may pay higher energy prices per unit of production than larger firms—that strategy is energy-efficiency management.[48] In the global green module, the adoption of energy management measures to reduce emissions is designated as a proxy. The detailed green module offers a richer selection of proxies: (i) adoption of heating/cooling improvements, (ii) waste management practices, and (iii) energy-efficiency measures over the previous three years. Improvements in heating and cooling systems are a key adaptation strategy to address rising temperatures and more frequent extreme heat events (IFC and UNEP 2024). Efficient building energy management (such as smart cooling) reduces strain on the grid, helping prevent power outages during extreme heatwaves. Energy efficiency is the only relevant measure in the global green module; despite strong mitigation co-benefits, we use it because it incorporates sufficient adaptation elements—enhanced resilience against climate impacts—to serve as a proxy. Waste management practices, including recycling, support adaptation by improving environmental health and resource efficiency. They are also essential for advancing circular economy objectives (Kirchherr et al. 2023; Aryee et al. 2024). While waste management can help reduce methane emissions and enable energy recovery, its primary impact is to lower firm-level vulnerability to energy-price spikes and unreliable power grids.[49] The detailed green module offers stronger proxies—heating/cooling and waste management also address both the causes and consequences of climate change, but with more "adaptation content." Heating/cooling strengthens supply-chain resilience and reduces dependence on expensive raw materials, can create new business lines, and can help avoid waste regulation penalties.[50]

Table 2.2A: Firm distribution by region, size, and sector, global green module, 2021–2024

Region	Countries	Firms	Micro	Small	Medium	Large	Manu-facturing	Retail	Other services
Africa	15	5,149	1,613	2,448	851	237	1,770	853	2,526
East Asia and Pacific	9	7,231	2,335	2,944	1,553	399	2,997	818	3,416
Europe and Central Asia	8	3,611	773	1,551	1,059	228	1,646	535	1,430
Latin America and Caribbean	7	4,845	1,022	2,152	1,391	280	2,035	784	2,026
Middle East and North Africa	3	1,977	534	1,050	312	81	818	178	981
South Asia	4	3,035	675	1,336	812	212	1,677	398	960
Total	**46**	**25,848**	**6,952**	**11,481**	**5,978**	**1,437**	**10,943**	**3,566**	**11,339**

Table 2.2B: Firm distribution by region, size, and sector, ECA/MENA detailed green module, 2018–2020

Region	Countries	Firms	Micro	Small	Medium	Large	Manu-facturing	Retail	Other services
Europe and Central Asia	21	14,868	3,471	6,453	3,881	1,063	8,677	2,246	3,945
Middle East and North Africa	6	6,284	1,658	2,857	1,334	435	3,508	374	2,402
Total	**27**	**21,152**	**5,129**	**9,310**	**5,215**	**1,498**	**12,185**	**2,620**	**6,347**

Table 2.3A: Descriptive statistics, global green module, 2021–2024

	Micro	Small	Medium and large
Climate variables	**Mean (%)**	**Mean (%)**	**Mean (%)**
Experienced damage of physical assets due to extreme weather (last FY)	8.4	11.5	12.9
Monitored own carbon dioxide emissions (last 3 years)	7.7	11.8	0.2
Adopted energy management measures to reduce emissions (last 3 years)	22.9	29.8	0.5
Total observations	**6,952**	**11,481**	**7,415**

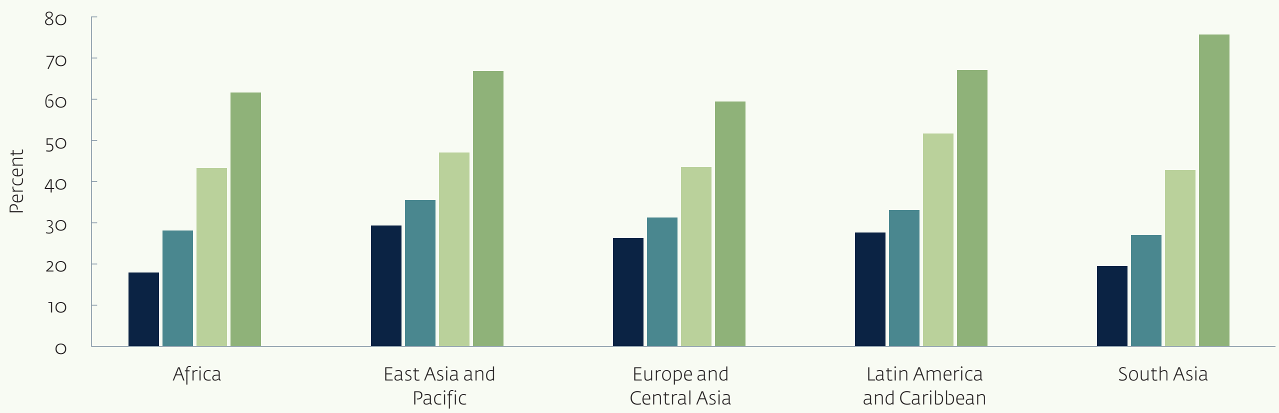
Table 2.3B: Descriptive statistics, detailed green module, 2018–2020, ECA and MENA

	Micro	Small	Medium and large
Climate variables	**Mean (%)**	**Mean (%)**	**Mean (%)**
Strategic objectives mention environmental or climate change issues (last FY)	7.1	11.9	21.9
Has a manager responsible for environmental or climate issues (last FY)	2.9	5.8	14.9
Experienced monetary losses due to extreme weather events (last 3 years)	6.8	8.6	11.3
Experienced monetary losses from pollution (last 3 years)	2.0	2.3	2.8
Monitored energy consumption (last 3 years)	41.5	49.1	57.6
Set targets on energy consumption (last 3 years)	15.2	20.3	29.2
Adopted heating and cooling improvements (last 3 years)	25.4	32.5	46.0
Adopted waste minimization, recycling, and waste management (last 3 years)	19.9	30.5	42.2
Adopted energy-efficiency measures (last 3 years)	19.3	25.7	35.7
Used energy from own renewable sources (last FY)	1.9	3.0	6.4

Figure 2.1: Firm adoption of adaptation measures by region and size

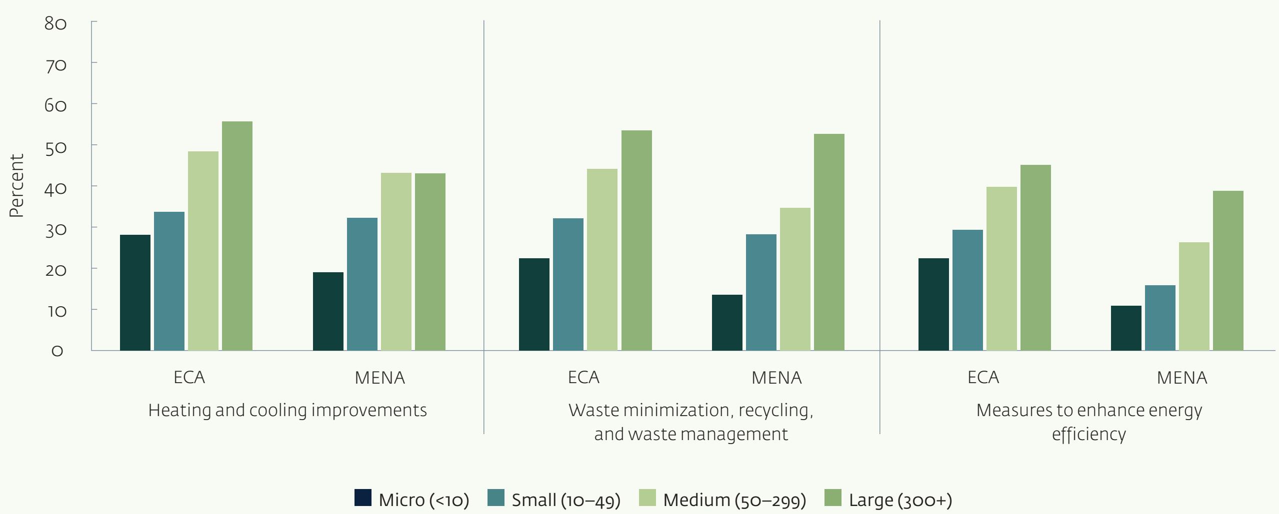
Panel A: Global green module, 2021–2024

Percentage of firms that adopted energy management measures over the last three years



Panel B: Detailed green module, 2018–2020, ECA and MENA

Percentage of firms that adopted these measures over the last three years



SOURCE: WBES and authors' calculations.

NOTE: The results account for the survey structure of the dataset by applying appropriate weights to calculate country-level averages. For regional averages, each country is treated as one, ensuring that the results are not driven by larger countries, such as Türkiye. In Panel B, we exclude regional averages for MENA as there are only three countries in the sample.

2.11 An economically significant share of firms use various adaptation techniques such as energy-efficiency management, heating/cooling improvements, and waste management practices (Table 2.3). Globally, across developing countries from 2019 to 2024, 8.4 percent of micro firms and 11.5 percent of small firms experienced damage to physical assets due to extreme weather. Only 9.0 percent of MSMEs formally monitored their emissions levels (versus 24.5 percent for medium and large firms). The detailed module has similar figures. Adaptation-effort and demand measures are much higher, however: 22.9 percent of micro firms, 29.8 percent of small firms, and 45.4 percent of larger firms adopted energy management measures. The detailed module confirms these results across the three proxies: 19.3 percent of micro firms and 30.5 percent of small firms adopted energy-efficiency measures, 25.4 percent and 32.5 percent made heating/cooling improvements, and 19.9 percent and 30.5 percent adopted waste management measures over the three years preceding the survey. In Part 4, we examine the relationship between access to financing and the adoption of adaptation measures, assessing whether observed patterns align with our hypothesis that credit constraints and related market frictions may limit firms' ability to pursue first-best adaptation strategies.

2.12 The data show significant awareness and adoption of sustainability measures by MSMEs, contrary to implicit assumptions in the literature that little, if any, adaptation originates with the private sector in EMDEs. Moreover, the findings hold across different firm sizes, through to micro firms. For the variable on adoption of energy management measures as a proxy for adaptation, 71.0 percent of large firms and 53.6 percent of medium firms undertake adaptation actions in the global green module, compared with 30.1 percent for small firms and 20.9 percent for micro firms. The difference between large and small (as well as large and micro) is statistically significant at the 1 percent level ($t = 7.53$ for small versus large, and $t = 9.71$ for micro versus large). Panel A in Figure 2.1 illustrates that these results are maintained across all regions. Turning to the detailed green module, we can expand the set of proxies used and test their robustness. The results once again present a consistent pattern. Among medium firms in the sample, 39.7 percent, 33.2 percent, and 33.7 percent undertake energy, heating/cooling, and waste adaptation, respectively, compared with 29.4 percent, 25.2 percent, and 33.3 percent, respectively, for small firms (the figures for micro firms are 23.1 percent, 17.7 percent, and 27.1 percent, respectively). In ECA and MENA, 51.4 percent of small firms and 40.7 percent of micro firms undertake at least one of these adaptation measures (Panel B). The fact that MSME adaptation is widespread, heterogeneous, and often embedded in routine decisions raises a fundamental question of classification: which actions are most typical, and can they be systematically identified? We turn to this question in Part 3.

Roughly one in five micro firms and one in three small firms in developing countries verifiably undertake adaptation measures. Given data limitations, these numbers are likely a floor estimate.

PART 3

Classifying adaptation actions *and* their financing: An MSME-tailored typology

3.1 A review of notable taxonomies of adaptation finance and a proposed MSME adaptation and financing typology

3.1.1 Adaptation spans all sectors and every aspect of firm operations, and yet no uniform classification has emerged in the literature—a gap that continues to hinder analysis. In addition to being geography-specific, adaptation measures are richly diverse across sectors—for example, climate-resistant seeds (agriculture); cooling equipment, water management systems, and reflective windows (manufacturing); early warning systems, architectural design, technical assistance on smart agricultural techniques, and resilience intelligence (services); and energy efficiency and optimized water use (resource use). With such an abundance of adaptation actions, researchers and practitioners have not reached a consensus on how to categorize them. Numerous classifications exist; we review the most notable ones below (Table 3.1), and propose an MSME-tailored adaptation and financing typology.

Table 3.1: Notable adaptation typologies

Classification/compendium	Coverage of adaptation instances	Links adaptation to finance?	Relevant to MSMEs?
IFC Sustainable MSME Finance Reference Guide (2023a)	A typology of eligible mitigation and adaptation activities in agribusiness, textiles, tourism, other manufacturing, and other services.	Technical instructions to financial intermediaries on MSME climate finance.	Focused on MSMEs.
UNEP et al. (2016) overview of (private) finance instruments for adaptation	Matrix of adaptation measures, linked to specific case study examples, falls short of providing an evidence-based framework.	Exhaustive list of debt and equity instruments, with examples but no typology.	Not specifically tailored to MSMEs.
UNFCCC's Private Sector Initiative (started in 2012)	Over 100 self-reported case studies of private adaptation (global, across sectors).	Funding is part of some examples, but not systematically covered.	Multinationals; 13 cases involve MSMEs.
UNDRR Guide for Adaptation and Resilience Finance (2024)	A largely exhaustive list of investable adaptation activities.	Examples not analytically arranged into a typology.	Not specifically tailored to MSMEs.
NAP Global Network (2024)	–	Adaptation finance tools, with case study examples.	Geared to large firms or countries.
CRISP classification (2024)	Supply side of adaptation, encompasses both ex-ante and ex-post adaptation.	–	Limited activities relevant to MSMEs.
The Lightsmith Group Adaptations Solutions Taxonomy (2020)	Accelerator data on MSMEs in EMDEs offering adaptation solutions. Targets early-stage investors and specific geographies.	–	Focused exclusively on MSMEs.
Adaptation and Resilience Investors Collaborative (2024)	A framework to classify and measure impact of adaptation/ resilience investments.	–	Not specifically tailored to MSMEs.
CFI Green Inclusive Finance Framework (2023)	Links finance to climate risks (mitigation, adaptation, resilience, and transition).	Links financial products and services.	Focused on low-income households.
CIFAR Alliance (2024)	Examples of how different financial instruments can be applied to adaptation.	Yes.	Focused on low-income households.

SOURCE: Authors' compilation.
NOTE: The authors have compiled a detailed list of adaptation measures and a list of typical financing mechanisms on the basis of major existing typologies and tailored them to MSMEs. The data are available on request.

3.1.2 A taxonomy of clearly defined context-specific adaptation actions would enable reliable adaptation investment categories to be used in corporate reporting and enhance adaptation finance and risk management. Poor data and measurement have prevented research from directly documenting the extent of private investment in adaptation (CPI 2018). Several major attempts at a typology have been made. This report serves as a foundation for an MSME-specific typology developed jointly with CGAP and extends the IFC Sustainable MSME Finance Reference Guide, developed in 2023 and used to support financial intermediaries looking to expand MSME climate finance. The guide provides step-by-step technical instructions for lending practitioners and includes a typology of eligible climate activities (mitigation and adaptation) in five sectors—agribusiness, textiles, tourism, other manufacturing, and other services (Appendix B provides an overview of additional typologies). Hallegatte et al.'s (2021) Resilience Rating System assesses how economic actors—firms, households, or projects—perform under climate shocks rather than under normal conditions. It measures resilience as the ability to resist disruption, recover from shocks, and adapt over time. The Resilience Rating System distinguishes between resilience of the firm (internal capacity to withstand and recover) and resilience through the firm's product (the firm's external contribution to broader system resilience). The United Nations Environment Programme's (UNEP's) work provides further important classifications. UNEP et al. (2016) provide an overview of private finance instruments for adaptation, including an exhaustive list of debt and equity instruments and examples of how they have funded adaptation, but without a framework to assess the suitability of funding tools or to generalize beyond the examples. UNEP et al. (2016) also provide a matrix of adaptation measures linked to case study examples. UNEP's Adaptation Gap Report 2023 typifies blended financing approaches to crowd in private adaptation investment. The Center for Financial Inclusion developed a Green Inclusive Finance Framework that links financial products and services to climate risks, focused on vulnerable populations. The framework focuses on low-income households rather than MSMEs and is based on examples that cover mitigation, adaptation, resilience, and transition. Similarly, the CIFAR Alliance focuses on climate solutions for vulnerable populations and shares lessons and examples of how different financial instruments can be applied to adaptation for these populations, particularly through initiatives such as their "Co-Labs." The United Nations Framework Convention on Climate Change (UNFCCC) provides an online database of case studies featuring good practices and financially sustainable climate change adaptation activities by private companies (sometimes in partnership with nongovernmental organizations (NGOs) or the public sector) from a wide range of regions and sectors. While the benefit is a large set of examples (101 initiatives across sectors including water, food and agriculture, transport and infrastructure, and tourism), they are mostly of multinational firms, with limited activity in EMDEs or involving MSMEs.[51] This is the only large database of private sector engagement in adaptation and is frequently used in research (for example, Surminski 2013 and Pauw et al. 2015). The Guide for Adaptation and Resilience Finance, developed by UNDRR, Standard Chartered Bank, and KPMG International (2024), lists 100 investable adaptation activities. The list is detailed but not specific to MSMEs. Although these activities are not linked to financing or arranged in a typology, they were a departure point for this study's classification effort. The NAP Global Network inventory of adaptation finance mechanisms lists adaptation-specific financing (with case study examples where available), geared mostly to large companies or the country level, with few tools suited to MSMEs. The Climate Resilience Investments in Solutions Principles (CRISP) classification (GARI et al. 2024) focuses on the supply side of adaptation. It does not include financing instruments but encompasses both ex-ante and ex-post adaptation. It builds on the 2020 Adaptations Solutions Taxonomy produced by the Lightsmith Group, created around an accelerator program aimed at identifying MSMEs offering adaptation solutions in EMDEs and targeting early-stage investors and specific geographies. Another accelerator program is run by PlanAdapt, a global organization that also provides case studies of adaptation and financing based on practice and focused on MSMEs.

Other notable compendiums include the Gold Standard for the Global Goals, the Resilient Cities Catalyst Adaptation Framework, the European Commission's Corporate Sustainability Reporting Directive, the International Sustainability Standards Board, and the University of Oxford's Resilient Planet Finance Lab. Sustainable finance taxonomies, which list activities, assets, and projects that can be counted as adaptation, have expanded coverage to 24 countries (ICMA 2021), but vary in principles, sector coverage, and reference activities, potentially compromising the objective of clarifying what counts as "adaptation" (Martín et al. 2024). UNEP FI (2024) distinguishes between different types of adaptation financing, considering intent, timing, nature of adaptation, type of investment, target groups, project size and actors, and revenue streams (see also Watkiss et al. 2022 and Lim et al. 2006). CGAP (2022) provides a taxonomy of climate-responsive financial products identified through desk research. A niche taxonomy also worth mentioning is the Climate Bonds Resilience Taxonomy Methodology, which was developed by several multilateral development banks for financial intermediaries to expand their resilience lending via bonds.

Table 3.2: The MSME Adaptation Finance Typology

Adaptation cluster	Adaptation actions	Core finance instruments
Changes in business process/ operations resilience	• Cooling and cold storage upgrades. • Resilient transport and logistics. • Circularity (repair, reuse, refurbish, recycle). • Resilience intelligence/early warning. • Climate-smart agricultural processes.	*Match financing tenor to asset life and seasonality; combine credit with risk transfer where volatility is high:* • Pay-as-you-go (PAYG), subscription models, asset-as-a-service, leasing. • Credit lines, blended finance. • Guarantees, venture capital, fintech, peer-to-peer/digital marketplaces. • Working capital and term loans. • Equipment leasing, fintech, low-tech aggregation. • Value-chain financing/sustainable payable finance. • In-kind (nonfinancial) process adaptation. • Lines of credit, first-loss schemes, partial credit guarantees.
Product and input adaptation: Agriculture	Climate-smart seeds/inputs, irrigation, soil/water conservation, crop diversification.	*Link finance to production cycle; aggregate; anchor to commodity/input markets:* • Informal lending, rural microfinance agri-finance, leasing. • Inventory finance, warehouse-receipt finance, value-chain finance. • Fintech agri-input credits combined with other business credit, microinsurance, savings, and payment services. • Diversified income sources, crop diversification, asset sale. • Index, yield, and parametric insurance; meso-insurance for lenders.
Product and input adaptation: Manufacturing/ services	Manufacturing: Material substitution, supply-chain adjustments, circular inputs, climate-resilient products, resilient construction. Services: Disaster-resilient health services, drought-resistant hospitality, adapted retail inventory management, rural emergency response system services and capacity building.	*Match finance to business-model payback (for example, secondary markets); ease cash-flow timing; share risk:* • Supply-chain/accounts receivable finance, factoring, reverse factoring. • Product-leasing services. • Digital finance (e-commerce/gig economy, combined with digital business services). • Embedded finance. • Supply-chain/microfinance, merchant cash advances, fintech (for example, healthcare MSMEs).
Adaptation in resource use: Energy and water	Distributed generation and energy storage, localized emergency backup power, micro-hydro, rainwater harvesting, efficiency retrofits.	*Anchor to efficiency savings or service revenues; de-risk through blended or concessional support to crowd in private sector:* • Energy performance contracts, PAYG, receivables-based structures, factoring for off-grid systems. • Multi-party concessional and blended finance schemes, partnerships.

3.1.3 The proposed MSME Adaptation Finance Typology reviews specific adaptation actions and links them to funding mechanisms (Table 3.2). We cluster adaptation actions into three channels that recur across sectors: (i) adaptive changes in business processes and operations; (ii) adaptive changes in production inputs and outputs; and (iii) adaptive changes in resource use (energy and water). We use sector-specific examples where they sharpen intuition or where financing constraints and instruments differ materially by sector. In this classification, "inputs" include material products as well as services used in the production of goods and services, but exclude natural resources such as energy and water, which we treat separately.

3.1.4 It is important to distinguish between adaptation actions to "adopt resilience" (demand side) and to "sell resilience" (supply side). This distinction helps tailor the typology to MSMEs' dual role in adaptation markets. Where possible, we separate the deployment of adaptation technologies or products (such as installing cooling in a factory) from the production of adaptation technologies and products (such as manufacturing a cooling device). The two are linked through market size and demand, but the financing and policy problems differ: deployment ("resilience of the firm") is often an incremental cost within broader business investment, while production ("resilience through the firm") typically requires purpose-built risk capital and patient finance. MSMEs can be active on both the demand and supply sides of adaptation solutions (Table 3.3). For example, financing the deployment of cooling solutions in service firms or agriculture raises different questions than financing the growth of innovative MSMEs that design and supply sustainable cooling equipment.

3.1.5 The adaptation categories are derived from key drivers of firms' operational resilience:

- **Business process adaptation and financing by MSMEs** (covered in section 3.2). This category captures adaptation through changes in operational practices and business models (for example, crop rotation, managed grazing, and switching from owning equipment to cooling-as-a-service) and through the acquisition and use of new or improved technologies (such as drip irrigation, water-efficiency systems, and resilient storage). It includes both the assets and the services firms adopt. Logistics, transport, storage, cooling, and last-mile distribution appear repeatedly on both the demand and supply sides of MSME adaptation. Financing solutions therefore range from MSME-tailored asset finance (product leasing, buy-now-pay-later, lease-to-own, and sharing models) to working capital financing when these services are purchased as operating expenditures. Climate-smart agricultural processes—crop rotation, cover crops, reduced tillage, integrated pest management, managed grazing, and climate-smart processing—are often most feasible to finance within value chains (for example, supply-chain financing, factoring, reverse factoring, merchant-receivables financing, sustainable payable finance, and loans for sustainable agriculture).

Table 3.3: Example: Risks to an agri-MSME from flooding

	Examples: MSMEs on the demand side	Examples: MSMEs and others on the supply side
Business process/ operations resilience	Climate-resilient operations (crop rotation, cooling-as-a-service) or adopting technologies (drip irrigation or water-efficiency systems).	Technologies and know-how (sustainable cold chain, climate-smart transport and logistics, building insulation to improve energy efficiency, circularity within the value chain).
Products and (intermediate) inputs	Agriculture: New inputs (climate-smart fertilizer, crop protection chemicals), resilient outputs (early-maturing, heat- and drought-tolerant, or salinity-sturdy crops). Manufacturing: Reuse/refurbish materials or adapt new products such as two-wheel electric vehicles or remanufactured automotive parts. Services: Climate-adapted retail, tourism, hospitality.	Agriculture and manufacturing: New inputs and resilient outputs (same as on the demand side), climate-smart equipment, recyclable packaging, climate-proofing of assets and construction, ICT/data forecasting services, capacity building, new MSME financing (pay-as-you-go, insurance technology, embedded or aggregation financing).
Infrastructure services	Using diversified power source mix to reduce dependency on hydrological conditions or improved wastewater management.	Providing innovative, localized solutions or optimizing energy and water for themselves and their customers.

SOURCE: Authors' elaboration.

- **Product and input adaptation and financing by MSMEs in agriculture, manufacturing, construction, and services** (covered in sections 3.3–3.5). This category covers (i) MSMEs producing goods and delivering services that enable adaptation for others (for example, recyclable packaging, forecasting tools and advisory services, and climate-proofing services) and (ii) MSMEs adapting their own production by changing intermediate inputs (for example, drought-resistant seeds and climate-smart fertilizers). Inputs include goods and services, including workforce-relevant skills and knowledge. In agriculture, suitable tools for climate-smart inputs include inventory finance and bundled risk management (first-loss schemes, partial credit guarantees, crop insurance, weather-based/index/parametric insurance). In manufacturing, adaptation frequently involves circular inputs (reuse, refurbish, remanufacture) and climate-resilient products and equipment (including for health and other adaptation services). These activities are often financed through MSME-tailored working capital and trade finance—receivables finance, payables finance, asset-based lending, and supplier finance. For service-sector MSMEs (for example, those in tourism, retail, and information and communication technology (ICT), and climate-data services such as remote sensing and early warning systems), digital finance and platform-based aggregation can be effective given lower fixed assets and inventories, and have helped mainstream technological innovations at scale.

- **Resource use adaptation and financing by MSMEs** (covered in section 3.6). This category covers adaptation in the use of critical infrastructure services—especially water and electricity—where climate risks translate into outages, price volatility, and operational losses. It also includes MSME investments that improve efficiency, diversify energy sources, or secure water availability (for example, distributed generation and storage, localized backup power, rainwater harvesting, and optimized water use). Financing options commonly anchor repayments to efficiency savings or service revenues and include off-grid and pay-as-you-go (PAYG) schemes, receivables-based and factoring structures, and—where relevant—carbon markets-linked approaches with an aggregator.[52] Multi-party concessional and blended finance schemes have also been applied to crowd in private financing for MSME energy and water solutions at scale.

3.2 Business process adaptation and financing by MSMEs

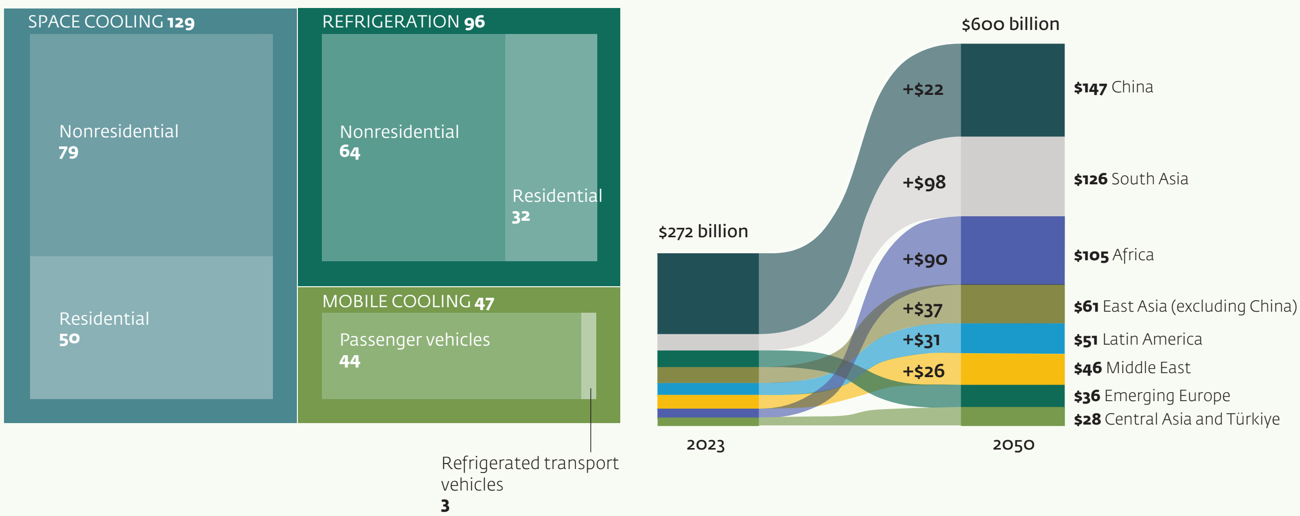
3.2.1 Firms can increase their resilience by adjusting their business models and operational processes. This first typology channel focuses on the operational side of adaptation—how MSMEs change "how they do business," either by adopting adaptation solutions as users or by providing adaptation solutions to others. Firms can be directly affected by climate (for example, through flooding or extreme heat) or indirectly affected (for instance, through worker health, higher insurance costs, reduced coverage, and supply disruptions). Typical MSME adaptations in production processes include upgrading or changing technologies, equipment, and machinery; reorganizing logistics and storage; and adopting information and planning tools. Many of these actions also yield immediate business benefits, facilitating the financing of adaptation. For example, water-saving measures can reduce operating costs while addressing scarcity, and building insulation can create a cost advantage where energy is a sizable share of total costs (UNEP 2016). The sections below examine cooling and cold chains (3.2.2–3.2.7), transport and logistics (3.2.8–3.2.12), circularity (3.2.13–3.2.19), air pollution (3.2.20–3.2.22), resilience intelligence (3.2.23–3.2.27), and climate-smart agricultural processes (3.2.28–3.2.32).

The MSME Adaptation Finance Typology is tailored to MSMEs, focused on specific actions, and explicitly links concrete adaptation measures to financing instruments suited to MSMEs' needs.

Cooling and cold-chain storage

3.2.2 The market for cooling solutions in developing economies is set to double in size from around $300 billion to $600 billion by 2050 (Figure 3.1). Business processes related to cooling and cold-chain storage apply to firms across all sectors and include sustainable cold-chain applications for agricultural produce (section 3.2.6.1), food and pharmaceuticals (3.2.6.2), and sustainable cooling/heating technologies for buildings and production processes (3.2.6.3–4). Demand for cooling is rising due to economic and population growth and expected temperature increases. Sustainable cooling includes active technologies (such as fans, air conditioning, and refrigeration equipment) and passive strategies such as insulation and reflective materials, and natural ventilation.[53] Passive designs make up 10 percent of the market and can decrease cooling loads by 24 percent by 2050 while increasing access to cooling for 3.5 billion people (UNEP 2023a). Scaling up sustainable cooling across developing countries could cut consumers' electricity bills by as much as $5.6 trillion over the next 25 years, reduce new investment needs by $1.8 trillion, and reduce cumulative spending on cooling equipment by around $800 billion (IFC and UNEP 2024).[54]

Figure 3.1: The cooling market in EMDEs was worth $272 billion in 2023 and is expected to double by 2050



SOURCE: IFC and UNEP 2024.

3.2.3 Financing constraints for cooling are higher in EMDEs and for MSMEs, and the financing gap for EMDEs is $400–$800 billion currently, not accounting for future increase in demand (IFC and UNEP 2024). The total cost of closing the residential space-cooling gap in EMDEs ranges from $7.8 billion to $372 billion in 2023, with fans costing about 50 times less than air conditioning (see section 3.2.5 for space cooling).[55] Closing the residential refrigeration gap in EMDEs would cost $172 billion for 2023, decreasing to $91 billion by 2050 due to increases in income per capita.[56] The space cooling and refrigeration gap for small and medium enterprises in EMDEs is $268 billion for 2023 and will be $179–$584 billion by 2050, depending on the evolution of access to financing.[57]

3.2.4 The size of the cooling industry suggests that there is finance available to pay for conventional cooling technologies, but the main barriers to mass adoption are affordability, risk management, and the uptake of new technologies (Nain and Bhasin 2022).

The financing mechanisms for deploying sustainable cooling include revolving funds, working capital loans, results-based finance, risk-sharing facilities, conventional equity, cooling bonds, and carbon offsets. Sustainability commitments from major cooling equipment manufacturers create opportunities for trade and supply-chain financing to support partners, suppliers, and customers in achieving more sustainable cooling solutions. Affordability is still a challenge, pending innovation in technology and business models. Limited infrastructure is another barrier, as 760 million people lacked access to electricity in 2022, 600 million in Africa alone (IEA 2023). In sectors such as residential construction, developers often lack incentives to prioritize sustainable cooling (Musić 2021). On the producer side, funding for more energy-efficient cooling can be hindered by nonfinancial barriers, such as verifying performance and reliability (especially for business models linking payment to savings), limited insurance coverage, and poor awareness of often complex government incentives.

3.2.5 Space cooling will account for 70 percent of cooling-related energy consumption by 2050 (UNEP 2023a). The biggest market segment of global cooling is the provision of space cooling to homes and commercial premises, and nonresidential refrigeration. Residential space cooling is experiencing the fastest growth, spurred by population growth and urbanization, as well as rising incomes and higher global temperatures. The SSA market is expected to multiply by a factor of seven by 2050, and South Asia will quadruple in size (IFC and UNEP 2024).

3.2.6 Cold-chain storage and cooling solutions are critical for EMDEs, especially at lower-income levels (ACES 2024). A cold chain is a logistics chain of activities involving post-harvest handling and storage, packaging, intermediate storage, and distribution of perishable products such as produce or pharmaceuticals (World Bank 2022a). Typically, a cold chain comprises packhouses or source points, a food-processing unit, refrigerated transport, cold storage, and ripening chambers. Refrigeration equipment at retail outlets and in households is also an important element. Market-based, privately funded provision of cold-chain solutions is growing (for example, cooling-as-a-service), as is private investment in district cooling through public-private partnerships. Subnational investments in cooling, especially at the city level, can considerably scale up the service provision.

3.2.6.1 Agribusiness cold-supply chains can improve produce quality, increase farmer returns, and minimize food loss, but they are seasonal and complex, making it hard to link financing to returns.[58] Chilling milk reduces food waste by up to 30 percent and minimizes food safety risks for consumers. In some environments, providing cooling to cattle can increase milk production by as much as 40 percent, lowering overall greenhouse gas emissions per unit of output. However, affordable financing options are limited for MSMEs, and costs are high (for example, upfront costs alone are \$100–\$300/m³ (GCA 2019); \$23–\$35/m³ for India). Investors and financial institutions may perceive the cold-chain sector in developing countries as high risk due to factors such as weak regulatory frameworks, inadequate infrastructure, and volatile market conditions. Aggregation of small producers can help, as can well-enforced efficiency standards and practices (such as minimum energy-performance standards, labeling, and certification).

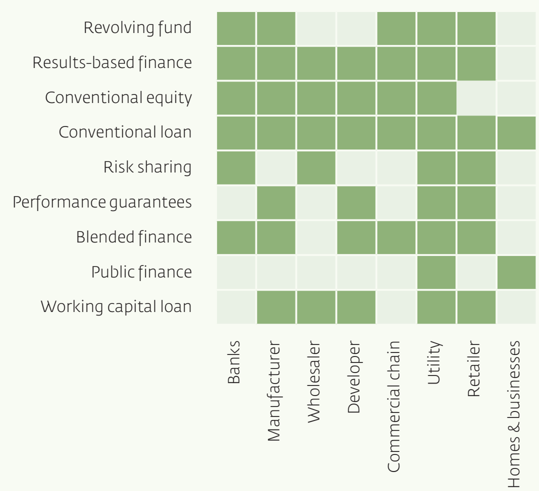
3.2.6.2 Pharmaceuticals: The vaccine cold chain maintains the quality of medication from manufacture to administration. This requires ensuring that a vaccine is packed, transported, and stored within recommended temperature ranges, up to and including the immunization session itself. The vaccine cold chain is a global network of cold rooms, freezers, refrigerators, cold boxes, and vaccine carriers that keep vaccines at the right temperature during each link on the long journey from the manufacturing line to the end delivery point. Public or blended financing for vaccine cold chains is justified by the health externality.

3.2.6.3 Manufacturing as a user and producer of cooling: Financing the development of supply chains linked to locally manufactured sustainable cooling equipment is critical for increasing the availability of proven technologies in EMDEs and integrating more MSMEs into production. Many developing countries are entirely dependent on imported (used) equipment, so it is important to leverage international cooling equipment manufacturers—and domestic manufacturers of cooling equipment, where they exist—to increase the supply of more sustainable cooling products. The financial needs of cooling equipment manufacturers include funding fixed assets (plant and equipment), working capital for higher-efficiency components, and equity for new ventures. Adequate risk management and strengthening local supply chains to involve domestic MSMEs in production, maintenance, and distribution can also help strengthen the supply of cooling equipment in EMDEs. In addition to producing cooling equipment, the manufacturing sector is also a user—and lack of cooling in manufacturing has been linked to lower productivity.

3.2.6.4 There is a strong business case for green buildings (IFC 2023a; Sustainable Hospitality Alliance and IFC 2020 for hotels; Musić 2021 for housing). However, the market has not taken off in most EMDEs (with the notable exception of some countries, such as India and Colombia, where it accounts for 25 percent of new construction). Yet the benefits are significant—passive cooling measures such as solar reflective roofs, glazing, insulation, and external shading reduce cooling demand by 24 percent and pay for themselves within five to nine years.[59] Some strategies such as reflective surfaces, shading, and reduced window areas, when combined, have payback periods between two and four years. In India, for example, the payback period for external reflective surfaces and shading systems is one to two years. In Vietnam, payback periods for solar reflective roofs and walls are three and four and a half years, respectively. Optimized window-to-wall ratios have a payback period of 1.8 years in Indonesia (IFC 2019).

3.2.7 New business models and financial instruments have helped promote sustainable cooling solutions in difficult-to-reach market segments (IFC and UNEP 2024; ESMAP 2024; Figure 3.2). These include PAYG systems, which allow users to pay for cooling in small amounts, and subscription models, in which consumers pay nothing upfront and are instead charged a monthly fee that covers both installation and maintenance. PAYG and regular asset financing have successfully brought cold storage equipment and cooling appliances such as fans within reach of rural users, usually linked to a distributed energy service company paid via mobile payment systems. Other business models to adopt sustainable cooling include on-bill financing,[60] cooling-as-a-service, dealer financing, leasing, and bulk procurement in the public sector. Revolving funds can be used to repeatedly fund cooling programs and are suitable for relatively small projects (for example, led by NGOs), a limited number of clients, and short, simple paybacks. Larger projects can use results-based finance to achieve development outcomes and accelerate innovation. Risk-sharing facilities help leverage modest investments more effectively and work best in markets with excess liquidity, where they can encourage entry into new market segments. Working capital loans finance the incremental costs of purchasing more efficient and more expensive components, as supply-side manufacturers and cooling-as-a-service companies scale up.[61] Enhancing innovation and risk management will require market-based and nonmarket incentives, with lower-income countries particularly needing concessionality (Cirera and Maloney 2017)[62] and rural areas requiring affordability and scaling.

Figure 3.2: Matching financing instruments to cooling market entities



SOURCE: IFC and UNEP 2024.

Transport and logistics

3.2.8 Climate change poses significant economic risks to the transport sector, including to MSMEs, through physical damage of key infrastructure. Climate change is likely to threaten transportation systems both temporarily through extreme weather events (Koks et al. 2019; Verschuur et al. 2023; Jaramillo et al. 2022) and permanently through gradual changes (Markolf et al. 2019). Direct estimated annual damage to transport assets ranges from $3.1 billion to $22 billion globally, with a mean estimate of about $14.6 billion per year (Koks et al. 2019). This damage will cause significant maintenance costs.[63] Climate change can increase road maintenance costs by up to 2.7 times compared to historical averages across Africa due to precipitation, flooding, and heat stress on pavements. This will raise operating costs for transport operators, including small logistics firms (CPI 2025). Climate change could raise bridge-related costs in flood-prone regions to between 1.5 and 7 times historic levels (CPI 2025), cutting into the profit margins of transport MSMEs that lack capital buffers. Besides physical damage to transport infrastructure, disruptions to transport services translate into wider economic losses for firms and households because transport is central to supplying goods and enabling access to markets. More than 80 percent of global trade in goods by volume is transported by sea, with ports serving as crucial links in production, distribution, and supply chains for low-cost transportation (Kuehne Climate Center 2025).

3.2.9 Climate-related impacts on the transport sector disrupt MSME operations and supply chains, with cascading effects across industries that rely on timely transport services. Temporary shutdowns of transport corridors due to storms result in delivery delays and less reliable transport services, raising operational costs for transport users and providers alike (UNECE 2020; Hallegatte et al. 2019; Koetse and Rietveld 2009; Verschuur et al. 2023; Wang et al. 2020). This can have cascading effects across industries that depend on reliable and timely transport services (Hallegatte et al. 2019; McKinnon 2024). In LMICs, while direct damages to sectors such as power and transport amount to roughly $18 billion per year, total losses including disruptions to households and businesses reach at least $390 billion annually (Hallegatte et al. 2019). Empirical studies indicate that transport MSMEs are particularly vulnerable to climate-related disruptions because they often operate with small fleets, limited storage options, few alternative suppliers, fragile logistics networks, and a heavy dependence on vulnerable infrastructure (Crick et al. 2018; Griese et al. 2021; Verschuur et al. 2023). Overall, climate change introduces both physical and systemic risks that threaten MSME transport operations and broader supply-chain performance.

Investing in resilient infrastructure pays off: UNECE (2020) estimates that every $1 spent on infrastructure resilience yields about $4 in benefits over an asset's life due to reduced disruptions and associated economic costs.

3.2.10 MSMEs in transport can pursue multiple adaptation strategies to enhance their operational resilience. Empirical evidence highlights that MSMEs can use their flexibility to reroute deliveries, adjust schedules, or diversify service areas in response to extreme weather (Aem-on et al. 2024; Griese et al. 2021). MSMEs can also implement redundancy measures, such as maintaining backup vehicles and using alternative transport routes and temporary storage facilities, to maintain business continuity during disruptions (Bak et al. 2020). Adoption of digital tools and visibility systems, including real-time fleet tracking and predictive weather monitoring, further supports operational adaptation (Aem-on et al. 2024; Wang et al. 2020). Moreover, MSMEs can partner with suppliers, clients, and local authorities to share resources, information, and logistics solutions, which improves both their resilience and efficiency (Bak et al. 2020; Crick et al. 2018). These strategies not only reduce their vulnerability but may also generate competitive advantages, such as reliability during extreme events and enhanced service reputation.

3.2.11 There are rich opportunities for adaptation in the logistics sector.[64] Adverse weather is a major cause of global supply-chain disruptions, which are rated second to cyberattacks as a threat to supply-chain resilience over the next five years (Business Continuity Institute 2023).[65] Economic losses to storage from floods increase threefold if power outage effects are included (Koks et al. 2019). Adaptation includes greener transport, resilient warehousing and packaging, supply-chain diversification, and technology-enabled optimization (McKinnon and Kreie 2010). While the logistics sector is driven by large shippers and third-party distributors, MSMEs can be part of their supply chains—for instance, for last-mile delivery.

3.2.12 A variety of financing instruments and support mechanisms may enable MSME adaptation in the transport and logistics sector. Empirical studies and case study evidence highlight the role of credit lines and concessional loans, often provided by development banks or climate finance institutions, to fund resilient fleet upgrades, warehouse retrofitting, and infrastructure improvements (Alam et al. 2022; Hallegatte et al. 2019). Insurance products, including parametric insurance and catastrophe coverage, help MSMEs transfer risk from extreme events, reducing the financial burden of operational disruptions (Verschuur et al. 2023; McKinnon 2024). Additionally, public and donor grants can support knowledge transfer, climate-proofing initiatives, and adoption of digital adaptation technologies (Tautiva et al. 2025). Conventional equity can fund projects such as transport control logistics to prevent post-harvest food loss. Innovative instruments, such as blended finance, combine public guarantees with private capital to reduce lending risks for small transport operators (Hallegatte et al. 2019). Finally, technical assistance programs and capacity-building initiatives complement financial tools by enabling MSMEs to identify cost-effective adaptation measures and integrate climate risk management into business planning (Crick et al. 2018; Aem-on et al. 2024).

Circularity

3.2.13 Circularity seeks to move from "take-make-waste" to "reuse-recycle-refurbish," minimizing the use of virgin materials. The circular economy is gaining prominence as a sustainable approach to economic development. For industry, circularity translates into a "5R" approach—reduce, reuse, recycle, recover, and repair; while for capital goods this becomes recondition and remanufacture; and for raw auxiliary materials—reuse (Putri et al. 2025). The vast majority of materials entering the economy are virgin (93.1 percent), with the share of secondary materials falling from 7.2 percent in 2023 to 6.9 percent in 2025 (Circle Economy and Deloitte 2025).[66] There is a wealth of recent research on the barriers and drivers shaping MSME participation in the circular economy (see Rizos et al. 2016; Mathivathanan et al. 2022; Despoudi et al. 2023; Palombi et al. 2024). Geissdoerfer et al. (2017) show that the circular economy can help MSMEs cut production costs, while Kirchherr et al. (2018) indicate that MSMEs can use the circular economy to create new products and services, access new markets, and improve the sustainability of supply chains.[67] There are many country-specific studies that examine the readiness of MSMEs to adopt circular economy practices and the factors that influence adoption (see Vedula et al. 2024 and Singh et al. 2018 for Indian manufacturing; Zuofa et al. 2023 for Nigeria; John et al. 2023 for construction; Almanza et al. 2023 for Colombian services; Chowdhury et al. 2022 for Vietnam; Ahmed et al. 2025 for Malaysia).

3.2.14 Transitioning to circular models can provide MSMEs with new market opportunities. Specifically, it can lead to a 28 percent reduction in global resource consumption by 2050 (UNEP 2017), increase resource productivity by up to 3 percent per year (Bassi and Dias 2019), create 6 million additional jobs globally by 2030 (ILO 2018), and unlock $4.5 trillion of value by 2030 (Accenture 2015).[68] Two types of adaptation via circularity improvements are worth noting. Circularity within the value chain (section 3.2.15) involves adjusting operations to acquire and use recycled materials or products. Waste management (sections 3.2.16–17) can maximize circularity within the firm and minimize negative effects on the environment and surrounding communities.

3.2.15 Circularity within the value chain can be supported by increased reuse of secondary materials, reduced use of inputs and production of waste, and increased recycling of virgin materials. Half of secondary materials are reused in construction (49.6 percent), and almost as much are reused from industrial waste (44 percent). A total of 82 percent of waste is collected, but only 27 percent is recycled. Recycling activities can involve new revenue opportunities for MSMEs.[69]

3.2.16 The global market for waste management is valued at $1.3 trillion (2022) and is expected to grow by 5.4 percent annually. The waste management industry is concentrated globally in a few multinationals but is diverse locally. In developing economies, local MSMEs, cooperatives, and informal operators manage large waste volumes outside formal markets. Formal collection covers less than half of total waste in Africa, with minimal rural coverage (Kaza et al. 2018). A significant amount of collection and recycling activities are semi-informal or informal. These operators rely on basic technologies but are highly skilled at identifying valuable materials and can be more efficient than formal systems (Oyinlola et al. 2022). Integrating them into formal systems while improving working conditions is essential for building circular plastic and recycling markets (Schröder 2019; Wilson et al. 2006).

3.2.17 Implementing waste reduction measures can reduce costs for MSMEs. Measures such as recycling, reusing, or repurposing waste generated during production processes can help MSMEs cut down on disposal expenses.[70] MSMEs produce over 70 percent of waste and emissions and hold vast recycling potential. Common waste types include metals, plastics, paper, textiles, wood, and chemicals. Around half of MSMEs undertake at least basic waste management practices (Derhab and Elkhwesky 2023). Circular economy opportunities for MSMEs include upstream measures such as pollution avoidance, design changes, resource-efficient production, and the substitution of secondary materials for primary resources (SEED 2021). MSMEs can reuse waste generated from their operations within their production processes to replace virgin raw materials. For example, construction and demolition waste can be repurposed as an alternative input material.

3.2.18 Limited access to finance—due to market imperfections and gaps or uncertainty in policy and regulation—remains a major barrier to MSMEs adopting circular models. Financial institutions consider the unpredictability of the circular economy business model as a significant obstacle to making investments (Mishra et al. 2025). Unpriced environmental and social externalities, imperfect capital markets, and information asymmetries reduce the relative profitability of circular activities. As a result, circular investments face lower returns or higher perceived risks compared to linear models. Informal MSMEs face even greater constraints. The absence of clear regulatory frameworks and policy uncertainty around new business models further constrain investment and scaling of circular practices, for example in India (Mishra et al. 2025).

3.2.19 Financing circular assets for MSMEs requires tailored instruments such as circular-economy-aligned loans, digital finance, equity, leasing, and risk mitigation tools. Leasing and performance-based models enable MSMEs to access machinery, vehicles, and production equipment without large upfront costs, aligning with "as-a-service" principles that promote product longevity and producer responsibility. Guarantees can mobilize private capital toward circularity by mitigating risk exposure. Public or development-backed guarantees protect lenders from loan defaults, thereby improving lending terms for circular enterprises. Partial guarantees retain incentives for due diligence while improving capital access for MSMEs lacking collateral. Equity and venture capital funds are emerging to support circular enterprises.[71] Similar impact-oriented vehicles can finance early-stage innovations in recycling, remanufacturing, and sustainable packaging.[72] Digital finance and financial technology (fintech) markets can complement traditional finance. Peer-to-peer lending, digital marketplaces for secondary materials, and data-driven supply-chain tools reduce costs, enhance traceability, and connect MSMEs to new markets. Fintech solutions can accelerate the adoption of circular business models (Siddik et al. 2023). Enabling frameworks such as clear national strategies, effective regulation, capacity building, and incentives for circular practices are essential to scale circular investment.

Air pollution

3.2.20 MSMEs face considerable economic costs from air pollution in both urban and rural contexts. Exposure to pollutants such as fine particulate matter (PM2.5) is linked to a range of health impacts as well as significant economic losses through reduced productivity, lower agricultural yields, damage to infrastructure and equipment, and increased healthcare costs, absenteeism, and worker turnover (OECD 2016; Chang et al. 2019). In India alone, lost economic output due to air-pollution-related morbidity and mortality was estimated at 1.4 percent of GDP in 2019 (equivalent to $36.8 billion), with even higher losses in some states (India State-Level Disease Burden Initiative Air Pollution Collaborators 2020). The use of crop burning there has been linked to lack of access to and financing for crop residue management machines (Jack et al. 2022). MSMEs are often located in densely populated urban settings with higher concentrations of pollutants[73] due to traffic, industrial emissions, construction, and energy use, but even rural MSMEs in EMDEs face significant air pollution exposure due to high baseline levels of PM2.5 (Figure 3.3). Higher temperatures and fires further worsen air quality. While air purification efforts on a macro scale are critical, here we focus on MSME-level adaptation. By adopting cleaner energy sources and efficiency improvements, MSMEs can reduce their exposure to air pollution while contributing to climate change mitigation. Actions to reduce air pollution include transitioning vehicles and manufacturing to renewable energy, incentivizing public transport and active mobility, carbon capture, dust control, waste reforms, limitations on crop burning and land-clearing burning, decarbonized crop and livestock inputs (for example, fertilizer management), and clean power. These actions need to be supported by policy measures in urban planning, construction, household efficiency, and air quality monitoring and enforcement.

3.2.21 Adaptation strategies are essential for MSMEs to protect worker health, maintain productivity, and reduce operational risks from poor air quality. Key adaptation measures include improving indoor air quality with proper ventilation by, for example, installing high-efficiency particulate air filters in workplaces, using portable air purifiers with multi-stage filtration systems, regularly cleaning ventilation ducts, and timeously replacing filters. Additional practical steps include adopting dust-control practices, enhancing workspace layout to minimize pollutant accumulation, and implementing

Figure 3.3: Population-weighted fine particulate matter concentrations for regional groupings, 2023–2024

SOURCE: WHO 2024.

employee awareness programs on minimizing exposure to air pollutants. However, evidence from Southeast Asia shows that awareness among workers, particularly younger and informal workers, of occupational air pollution risks and associated health impacts is generally low, reducing demand for protective measures. In contrast to other adaptations with immediate and visible monetary savings, this may lower the priority given to air quality measures among MSMEs (Slater et al. 2023).

3.2.22 Practical and low-cost adaptations allow MSMEs to reduce worker exposure to air pollutants even before investing in more expensive interventions. Low-resource and in-kind measures include wet cleaning instead of dry sweeping, optimizing workspace layouts, and employee awareness programs. Higher-cost measures, including upgrading ventilation systems, installing air-cleaning technologies, and deploying portable multi-stage purifiers, can be supported through private financing such as leasing, installment plans, or equipment loans. Service providers may offer bundled solutions for MSMEs covering installation, maintenance, and filter replacement. Public or community programs may provide temporary equipment loans, interest subventions, or subsidies to encourage adoption.

Resilience intelligence

3.2.23 Resilience intelligence comprises the protocols, business tools, and services to reduce climate risk. Examples include networking, information, remote sensors (for agriculture), weather forecasting, early warning systems, data analytics and technology to understand and forecast climate risks, contingency planning, supply-chain management, and climate-smart investing to build capacity to recover from climate disruptions. Climate risks arise due to uncertainty about their location, magnitude, and timing. They are modeled using backward-looking historical data, which makes it difficult for businesses to deal with future-oriented uncertainties (Okereke et al. 2012). Forecasting data tend to be more accurate in rich countries than in poor countries (Linsenmeier and Shrader 2023).

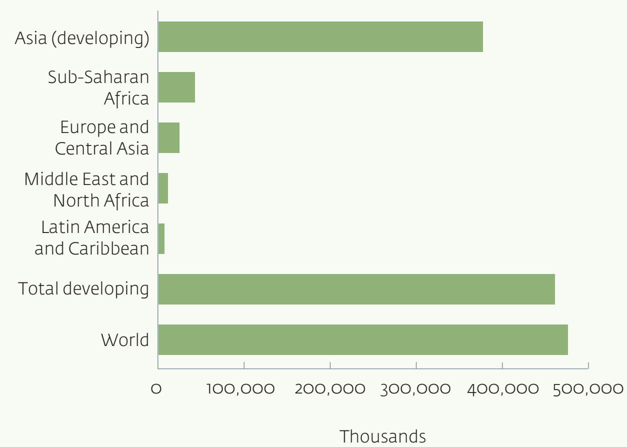
3.2.24 Limited access to resilience intelligence can lead MSMEs to make suboptimal adaptation decisions. MSMEs are highly vulnerable to climate impacts but have low awareness about climate risks. MSMEs may not perceive climate change to be a risk factor in line with, for example, financial instability. They have limited access to climate data specific to their sector and geography (AXA and UNEP 2015) and have limited capacity and resources to assess risk (Dougherty-Choux et al. 2015). Thus, MSMEs might make near-rational decisions that lower their resilience (Danielson and Scott 2006).

3.2.25 The delivery of weather and climate information (WCI) services to MSMEs may be significantly improved through private sector provision of tailor-made products, backed by regulatory solutions for equitable access. Relevant data and information tailored to MSME needs, contexts, and scale are likely not provided by national meteorological and hydrological services in developing countries. Private business models have been successful in delivering WCI services adapted to MSMEs' specific needs to fill specific gaps, sometimes in cooperation with national meteorological agencies.[74] However, private providers may focus on high-value clients and products, reducing the resources available to public agencies to invest in the infrastructure the sector depends on. To address this, business models are needed in which private operators help fund the observation infrastructure that underpins their products and services. Strong public-private coordination is crucial to avoid multiple, conflicting "early warnings" that can confuse users and undermine trust in the information.

3.2.26 WCI products and services carry net social and economic benefits. Accurate climate information products and forecasts can help with slow-onset hazards such as droughts, early warnings are critical for storms and floods, and accurate agrometeorological forecasts are increasingly important for farmers and their financiers (for example, for index-based crop insurance). The reduction in asset losses resulting from the use of WCI products largely justifies the costs of the required hardware and communication systems, while also generating wider social and economic benefits such as increased investment and improved access to credit for farmers (Andersson and Treich 2011; Hoedjes et al. 2018). Accurate, timely, and actionable WCI products provided to the public and private sector can increase the benefits from investments in WCI systems by an additional 6–10 percent (Hallegatte 2012). Benefit-cost ratios of investments in WCI systems in developing countries commonly range from 2:1 (WMO 2015) to as high as 36:1 (Hallegatte 2012). Accurate forecasts reduce adverse effects on revenue by 50 percent for small vendors to Ghana's largest mobile money provider (Annan et al. 2024). Private actors such as mobile telephone providers target WCI products at MSMEs by, for example, presenting public data in a user-friendly format or providing forecasts using their own equipment. Hoedjes et al. (2018) review several successful private WCI initiatives and find that rising climate risks, improved connectivity, and better education in EMDEs will drive demand for paid WCI services, especially from smallholder farmers. More recent research finds that the global benefits of providing universal access to early warning systems amount to $13 billion in prevented asset losses annually, with well-being gains equivalent to a $22 billion increase in income, compared to the global cost of providing such a service, roughly calculated at $1 billion annually (WMO 2024).[75] In related research, the economic value of enhancing multi-hazard early warning systems has a cost-benefit ratio of 1:9 (GCA 2019).[76] For agriculture, return on investment is estimated at between 1:24 and 1:47, with an increase in yield of 10–30 percent for smallholder farmers (Campbell et al. 2026).

3.2.27 WCI applications in agriculture, manufacturing, and services provide location-specific information on rain or heat, as well as produce price data by location, which allows supply, demand, and shortage/surplus forecasts to mitigate profitability risks. Seasonal forecasts help with decisions on seed variety and post-harvest risks. Medium-range forecasts help with timing decisions for sowing, planting, weeding, and harvesting. Advisories on pests, disease, and agrochemicals improve yields, prevent crop losses, and reduce farmers' climate footprint. Beyond crop production, timely, localized, reliable weather information and seasonal forecasts are highly valuable for others such as small-scale fishers (Snow et al. 2016). In manufacturing, WCI helps with supply-chain management and demand forecasting, especially for climate-sensitive products (such as bottled water, air conditioning, clothing, and soft drinks and beer). Services sectors where forecasts are important include tourism and transport (Stenek et al. 2013). Logistics companies optimize their distribution strategy using WCI for road conditions. Weather can affect energy costs, as an increasing share of power is being generated from wind, water, and solar. Across industries, it is critical for firms to be able to adapt quickly, based on weather forecasts (Mirasgedis et al. 2014).

Figure 3.4: Number of smallholder farms



SOURCE: Authors' calculations, based on Lowder, Skoet, and Raney 2016.

Climate-smart agricultural processes

3.2.28 Agricultural MSMEs in EMDEs are disproportionately affected by climate change and therefore have the greatest potential for resilience gains. CGAP (2013) estimates that there are 500 million smallholder farms in LMICs (Figure 3.4).[77] These farmers produce 35 percent of the world's food, including 80 percent of the food consumed in developing countries. They manage 12 percent of total agricultural land and dominate agri-food supply chains, providing 65 percent of food in South Asia and SSA (CPI 2022). Over 60 percent of working women in those two regions are involved in agriculture, with their activities often focused on low-paying or even unpaid labor-intensive tasks (ILO 2016). Adaptation is critical for preserving agricultural yields in the face of climate change. Extreme weather events have almost doubled in frequency over the past 40 years (UNDRR 2020), resulting in declining productivity for agricultural MSMEs, new pests and diseases, and volatility in prices and supply.[78]

3.2.29 Process adaptation in agriculture comprises changes in processes and adoption of technologies to increase crop yields and output efficiency in animal production, forestry, and fishing. Examples of process adaptation include diversifying crops; changes in resource management (reforestation, conservation farming, micro-irrigation); and livelihood diversification. Climate-smart agriculture can help agri-MSMEs improve their resilience through cultures, technologies, and practices (UNEP DTU 2017; Dougherty-Choux et al. 2016; UNEP DTU 2018). In the case of crop production, adaptation methods include modifying farming practices to improve soil and water management by, for example, using cover crops, drip irrigation,[79] and rotating crops.[80] For animal production, process adaptation includes changes in animal breeds, livestock and grazing management, and infrastructure (such as using mist cooling, sprinklers, and ventilation). For fisheries and forestry management, process adaptation includes creating biodiverse agroeconomic systems, improving water management and usage, shifting markets, reforesting, and reducing emissions from deforestation. These adaptation methods increase resilience beyond agriculture, livestock, forests, and fisheries into food processing, commodities, and fertilizers. In Ukraine, climate-smart fertilizer, no-till practices, and agricultural technology tools reduced emissions by 11 million metric tons per hectare of carbon dioxide equivalent, lowered costs, and generated revenues of $11 billion from a $1.7 billion investment (World Bank 2021a). Across subsectors, sustainable agriculture and land use encompass practices such as climate-smart processing, storage, logistics, transport, last-mile distribution, crop insurance, and technology (Appendix C).

3.2.30 Climate-smart agriculture is underfinanced and underutilized by agri-MSMEs, which form a larger share of enterprises in fragile, conflict-, and violence-affected (FCV) countries and those supported by IDA. MSMEs in agriculture tend to have higher risk profiles, more limited cash flows, and less suitable collateral than other sectors, which hinder their access to finance. Risk is augmented due to the seasonal nature of production, weather-related risks, pests and diseases, and the price volatility of agricultural commodities.[81] These risks have been increasing in recent years due to climate change and macro factors and are particularly high in IDA/FCV settings. Many agri-MSMEs have opaque financial and business records and can struggle to maintain consistent yields, quantify their inputs, and estimate a return on investment within a given margin. Financing in EMDEs is complicated by the disaggregation and heterogeneity of firms, as the agricultural sector largely involves subsistence or family-led operations with varying plot sizes, production capacities, resources, and levels of expertise, with a large informal portion and low population densities. Additionally, many firms are female-led (more than in other sectors), and female entrepreneurs often remain financially underserved. On the supply side, financiers (commercial banks more so than fintech lenders) face higher transaction costs in providing services to small, remote, and informal borrowers. Tailored products, backed by specialized staff, remain limited. In practice, these MSMEs rely more on internal and informal financing sources. Access to finance is further limited by underdeveloped infrastructure and immature markets in EMDEs.

3.2.31 Given the scarcity of long-term adaptation finance, MSMEs can fund climate-smart agricultural processes via innovative short-term finance. Agricultural MSMEs will often use many different lending approaches and credit lines at once, for example, by leasing movable assets (such as equipment) using an advance payment from an end-buyer higher up the value chain (IFC 2012). Lending systems in agriculture range from financing within loose or tight value chains, to direct financing of farmers, financing movable assets, and cooperative financing. Digital innovation lowers the cost of financial services targeting smaller enterprises. Promising new trends in digital finance technology can enable agri-MSMEs in IDA/FCV countries to overcome funding challenges. Low-tech aggregation of MSMEs to reduce costs also had favorable adaptation results (Caretta 2014).[82] Value-chain financing for climate adaptation is rising in MSME agri-finance (see section 3.3.13)—examples being sustainable payable finance and loans for sustainable agriculture. These solutions leverage the links between participants in a value chain, and their connections with lenders, to facilitate access to finance and encourage investments in processes, output, and machinery to reduce greenhouse gas emissions and improve climate resilience (World Bank 2024e).

3.2.32 Lines of credit, first-loss schemes, and partial credit guarantees have been used to manage risk and crowd in private finance. In EMDEs these tend to use blending mechanisms to incentivize financing to agri-MSMEs for investments in equipment, logistics, warehouses, irrigation systems, and climate technologies, but on conditions that require financial institutions to add their own funding. Box 3.1 presents some successful examples.

Box 3.1: Agribusiness process adaptation: Examples of innovative financing and risk management

Contingent products: In Bangladesh, BRAC offered farmers guaranteed access to emergency loans in the case of severe weather events, triggered automatically by climate index data. Unlike insurance, there was no upfront payment; farmers only paid if they borrowed after a flood. The added level of security gave farmers the confidence to invest in expanding their crop production despite climate risks. Most farmers suffered no flooding and never needed the credit but saw substantially higher yields (36 percent) and incomes as a result of the higher investment. Farmers who were hit by floods and used the line of credit were better able to cope and did not need to reduce household consumption as much (Lane 2024).

Embedded/integrated insurance: In India, SEWA developed a savings product that triggers automatic payouts linked to a heat index. It is targeted at informal workers such as street vendors, construction workers, and waste pickers. The approach has generated payouts for tens of thousands of low-income women when temperatures rise to dangerous levels, allowing them to stay home without worrying about lost income or exposing themselves to major health risks.

In Ghana, insurance reduced the rate of missed meals in climate-affected farming households by 8 percentage points.

Innovative financial services for value-chain adaptation: In India's turmeric value chain, solar-powered dryers and peelers reduce the physical burden of labor (mostly by women), improve labor efficiency, and strengthen climate and operational resilience. Blended finance can unlock access to such technologies at the last mile through instruments such as credit guarantees and outcome-based agreements, including social success notes, which provide better terms or partial repayment if measurable social goals are achieved.

Bundled products: In the Philippines, microfinance institutions that combined credit with training in disaster preparedness saw repayment rates remain stable even after severe typhoons.

In Peru, coffee farmers accessing credit tied to climate-adapted crop management reported higher productivity and were less likely to abandon farms during years of extreme weather. Inclusive finance can also enable access to green technologies at scale.

Pay-as-you-go financing models have allowed millions to acquire solar home systems, water heaters, and irrigation pumps, paying flexibly according to usage.

SOURCE: CGAP 2025.

3.3 Product and input adaptation and financing by MSMEs in agriculture

3.3.1 MSMEs can adapt by introducing climate-resilient products and inputs. In agriculture, this includes changes in input, feed, fertilizer, equipment, or infrastructure use. Sections 3.3.2–3 discuss crops, sections 3.3.4–5 focus on livestock, sections 3.3.6–14 discuss financing methods, sections 3.3.15–16 examine financial innovation, and sections 3.3.17–22 discuss risk management and aggregation. Section 3.4 covers manufacturing and construction, and section 3.5 covers services. Labor as an input is covered implicitly under various categories such as health, cooling, and air pollution, and explicitly under climate impact on productivity (section 2.6).

Box 3.2: Glossary: Crops and climate stresses

Crops

- ***Cereals***: Maize, rice, grain, wheat, millet, sorghum barley, and teff.
- ***Legumes***: Soybean, chickpea, cowpea, common bean, mung bean, and groundnut.
- ***Fruit and vegetables***: Tomato, eggplant, pepper, cocoa, mango, clover, garlic, mustard, pea, onion, saffron, green gram, and cola nut.
- ***Roots, tubers, and bananas***: Banana, plantain, yam, sweet potato, cassava, and potato.

Climate stresses

- ***Abiotic stresses***: Drought, heat, floods, salinity, shorter growing season, and climate-induced pests.
- ***General challenges***: Moisture retention in the soil, improved soil quality, and reduced erosion.

SOURCE: Acevedo et al. 2020.

Crop production: Costs and benefits of adaptation through product and input changes

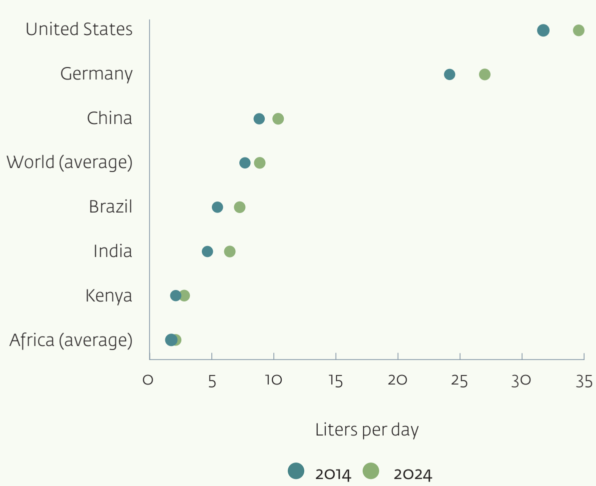
3.3.2 Climate change is expected to reduce yields of staple crops by up to 30 percent due to lower productivity and crop failure (Hultgren et al. 2025). There are 33 million farms in Africa (IFAD 2025). Climate-resistant crops are especially critical in semi-arid lands, which are home to 1 billion people (Gannon et al. 2020). Examples of climate-resilient crops are early-maturing cereals, heat-tolerant crops, drought-tolerant legumes or tubers, salinity-tolerant crops, and rice with submergence tolerance (Box 3.2). Adaptation is suboptimally low despite the benefits of farmers' increased resilience to climate change.

3.3.3 The benefits of adopting resilient seeds are estimated at \$1–\$2.1 billion between 2020 and 2050 (Cacho et al. 2020). Popular adaptations are changes in planting date, improved crop varieties, and land rotation, as well as modern hybrid and early-maturing seeds and conservation farming to maintain soil moisture. Sought-after traits of seeds are drought tolerance, water-use efficiency, and earlier maturity, typically used in conjunction with other climate-resilient technologies such as climate-smart agriculture, conservation agriculture, tree planting, modified planting dates, and irrigation (Acevedo et al. 2020). Based on 202 research papers, the authors identify adoption determinants to be access to seeds and fertilizers, extension services, farmer education, and climate awareness (for example, via social networks such as farmers' organizations or cooperatives). Farmers with access to credit, insurance, or remittances adopt more climate-resilient crop technologies, while credit-constrained farmers cultivate local varieties. There is a gender gap in climate-smart crop adoption (Fisher and Carr 2015).[83]

Adaptation in livestock agriculture

3.3.4 EMDEs lag developed countries in both productivity and climate friendliness in livestock agriculture. Milk is the highest-value agricultural commodity globally, accounting for 27 percent of livestock value add and 10 percent of agricultural output, with global demand growing by 1.2 percent per year (FAO 2016b). India has the world's largest cattle population, followed by Brazil and China. Milk yields in India improved from 3.8 to 5.3 liters a day between 2013 and 2022, compared with global yields of 6.4 to 7.4 liters a day. Yields in LICs are much lower, though they are also improving—from 1.6 to 2 liters a day in Africa (compared with 30 liters a day for commercial farmers in OECD countries)—mainly due to differences in feed and forage quality (Figure 3.5).[84] New technology has been improving yields. For example, the grass variety Brachiaria, adopted in South America in the 1970s and in Africa in the 2000s, has increased milk production by up to 40 percent and boosted the body weight of heifers by 50 percent (Njarui et al. 2016). Efficiency improvements are also helping reduce climate impacts.[85]

Figure 3.5: Average milk yield per cow



SOURCE: FAOSTAT 2025.

3.3.5 Livestock systems exhibit a higher adaptive capacity than crops. Potential changes in climate variability, extreme events, and mean climate trends affect various stages of the livestock supply chain. Direct impacts include reduced animal productivity, and compromised health and welfare.[86] The greatest indirect impact on the livestock supply chain can be expected through changes in feed resources due to shifts in temperature, precipitation, and atmospheric carbon dioxide levels. These changes will affect both the availability and nutritional quality of feed, exhibiting large regional variations in the magnitude and direction of impacts. On a global scale, increased climate variability is likely to yield overall negative impacts on feed quantity and quality (Godde et al. 2021), driven by changes in water availability and demand, as well as an increase in the frequency of floods and droughts.[87] Efforts to reduce the vulnerability of livestock systems to climate change are location-specific, rely on accurate impact projections, and consider the complex interactions and potential trade-offs affecting input and product prices at various spatial and temporal scales. Adaptation measures involve interventions in animal management, infrastructure, and resource use to address heat stress. For example, Africa's cattle possess genes conferring tolerance to heat and drought, resistance to diseases, and the capacity to combat inflammation and tick infestations (Kim et al. 2020).

Financial access mechanisms for product and input adaptation

3.3.6 EMDE smallholder farmers are arguably the largest group of financially underserved people in the world, with a $172 billion funding gap (Miller and Yoon 2020). Rural households' demand for agricultural and nonagricultural finance is estimated at $240 billion, while the current supply is only $68 billion (ISF Advisors 2019). IFC (2023b) estimates a financing gap of $117 billion for agricultural small and medium enterprises and smallholder farmers in SSA alone. The Mastercard Foundation finds total smallholder finance to be $50 billion per year ($14 billion from formal institutions, $17 billion from value-chain actors, and $25 billion from informal or community-based sources).

Miller and Yoon (2020) estimate that $30 billion is provided by value-chain actors, mostly focused on farmers growing cash crops, and $21 billion comes from formal financial institutions including state banks, microfinance institutions, commercial banks, social lenders, high-touch NGOs, and fintech/innovators. State banks provide $9 billion and are largely active in Asia. Microfinance institutions provide $3 billion, while impact-driven lenders provide $350 million, largely concentrated in Latin America and the Caribbean, with expanding operations in SSA. This is complemented by $17 billion from informal and community-based financial institutions, including loan associations and local money lenders. This leaves farmers with a financing gap of $86 billion for long-term and $66 billion for short-term agricultural finance globally. Insurance penetration is low (3 percent in SSA, 22 percent in South and Southeast Asia, and 33 percent in Latin America and the Caribbean).[88]

3.3.7 Access to credit is an important determinant of adaptation in crop production. Farmers in Zambia cited a lack of access to credit as a major deciding factor for their cropping choices, affecting production levels. In Malawi, the lack of access to credit is the largest barrier to livelihood diversification for small-scale tea farmers. Climate-smart agricultural inputs may be pricier, unavailable, or accompanied by limited information about their climate-smart qualities. Using combinations of improved inputs (fertilizers or hybrid seeds) is more effective than using single adaptations, but it is also more costly (Teklewold 2017).[89] Hybrid seeds cannot be recycled, which limits the seed available to households for replanting and creates a financial burden, as farmers must repurchase seeds at the start of each season. In addition, seeds suitable for early planting require large oxen to reduce ploughing time, resulting in extra costs for hiring cattle.

3.3.8 The livestock sector has strong co-benefits between adaptation and mitigation, which spurs innovative approaches to financing, including via carbon markets.[90] Land-use investments are an underdeveloped opportunity, with a $300–$400 billion annual gap (Lang et al. 2017). The increasing number of blended finance structures focused on sustainably intensifying cattle ranching and mitigating deforestation could be economically viable in Latin America and the Caribbean (World Bank 2020a). Index-based insurance has been successfully applied to livestock (section 3.3.21). Climate finance innovations are being adopted, such as the verified sourcing area approach piloted in Brazil to help small beef farmers optimize production, decrease land degradation, increase productivity, and grow their incomes (World Bank 2020a).

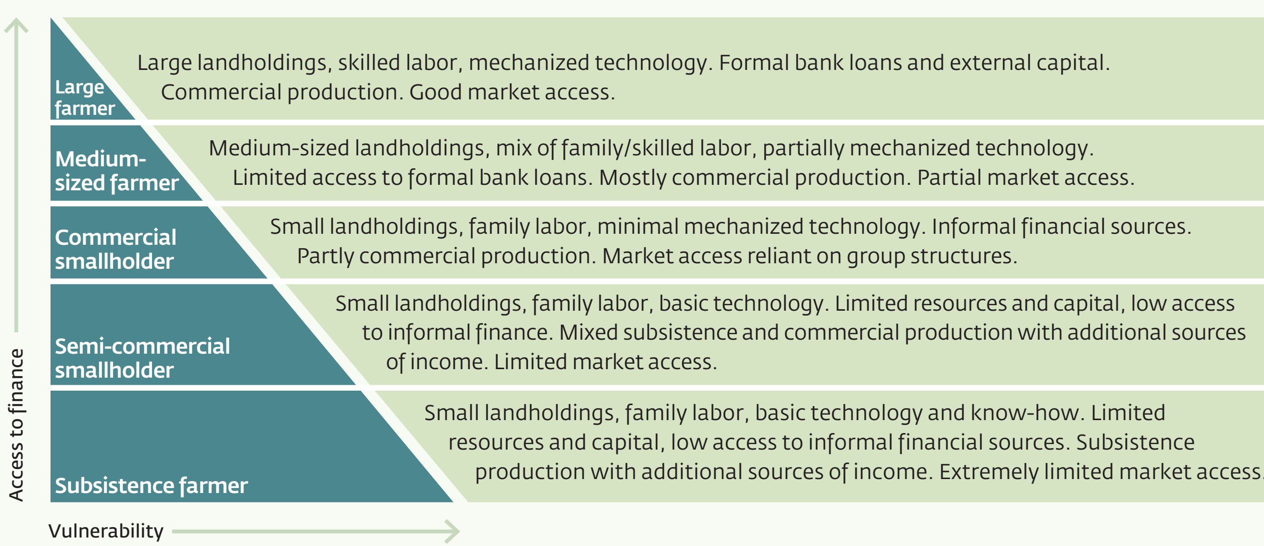
3.3.9 Challenges in smallholder finance exist on both the demand and supply sides. The provision of financial services to smallholders (credit, savings, insurance, and remittances) is still underdeveloped despite broad demand. Traditional financial services see farmers as too risky, costly to reach, opaque or informal, and having poorly defined property rights. Lending from formal financial institutions and value-chain actors remains limited to an estimated $31 billion in annual credit as of 2015, with estimated growth to $43 billion by 2020 (Colina et al. 2016). Other obstacles include lack of producer organizations and structured value chains, and limited capacity to repay loans due to uneven cash flow and low profitability of farming. There are also cultural barriers among farmers, many of whom are reluctant to take on loans or other financial exposure.[91]

3.3.10 Informal and social lending are the most likely source of financing for agricultural adaptation. About 60 percent of smallholder farmers are not commercial and not integrated into supply chains (about 300 million households or 1.5 billion people). They tend to rely on traditional crops and animals, with limited engagement in input, produce, and service markets, resulting in low productivity and high vulnerability to shocks. They typically have access to informal financial tools—borrowing from friends or family, informal groups or savings and credit associations, pawnshops, money guards, credit from a store or agent, saving at home, and borrowing from middlemen with in-kind repayment. Social networks can supply information and access in imperfect markets, enabling farmers to get inputs on schedule, and overcome credit constraints and shocks (Wossen et al. 2015 on Ethiopia). Commercial farmers have access to a wider range of financing tools, including crop storage as a form of savings (a main source to fund inputs, together with casual labor) and small loans from informal groups or social networks. Farmers who are not well integrated in value chains have access to an average of 12 financing tools, compared with 18 for integrated farmers, 99 percent of whom borrow from family and friends, agricultural commission agents, and local stores (Anderson and Ahmed 2016).

3.3.11 Among formal adaptation financing, microfinance remains more prominent than bank finance. To ensure the market is sustainable, microfinance providers assess payment ability from household cash flows; use character-based lending techniques and agricultural criteria; diversify their loan portfolios across regions, markets, crops, or livestock activities; limit their total exposure to agriculture and may use credit insurance; and train credit officers on agriculture. Rural microfinance institutions blend traditional microfinance, agricultural finance, and standard financial services such as leasing.

3.3.12 Access to value-chain finance and commercial bank finance is limited in EMDEs. Figure 3.6 provides a useful segmentation of the agricultural small and medium enterprise lending market. A small set of high-growth or high-margin outfits, such as agricultural technology firms, are attracting about $1–$2 billion per year in higher-risk venture debt and equity financing. A larger set of relatively mature, moderate growth firms are being served primarily by commercial banks (about $40 billion), nonbank financial institutions (about $6 billion), and impact funds (about $1–$3 billion) with debt finance. A range of lower-growth, less mature, and less profitable farms are funded by development banks and social lenders (about $4 billion each) through short-term trade finance and working capital loans (ISF Advisors 2022).

Figure 3.6: Farmer segmentation and access to finance



SOURCE: IFC 2012.

Table 3.4: Types of financing along the agricultural value chain

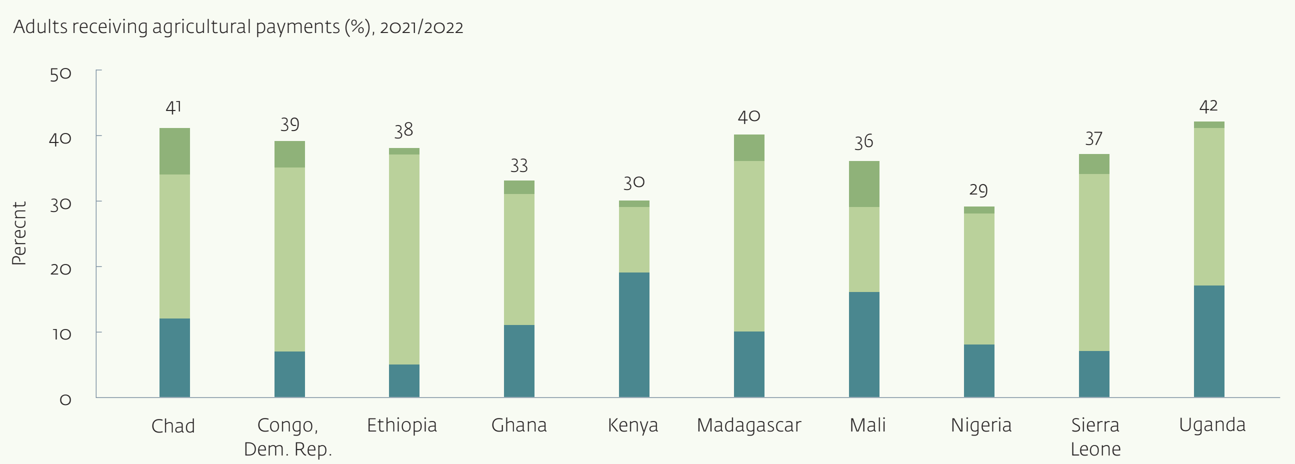
Overarching category	Financial service provider	Commercial smallholders in tight value chains	Commercial smallholders in loose value chains
Savings			
Regular expenses	Banks, credit unions, licensed deposit-taking microfinance institutions (MFIs).	Harvest savings account—depositing proceeds of sales for later, agreed use.	Harvest savings account—depositing proceeds of sales for later, agreed use.
Larger investments		Passbook savings account into which family members can deposit daily and weekly incomes from nonfarming activities.	Passbook savings account for daily/weekly deposits from nonfarming activities.
Emergencies		Passbook savings account.	Contractual, periodic savings from nonfarm activities, with programmed disbursements.
Credit			
Regular expenses	Input suppliers.	Supplies on credit if farmer has a long-standing relationship with an input supplier and is a steady producer, or a contract with a value-chain actor from whom they buy inputs and to whom they sell harvests.	Supplies on credit if farmer has a long-standing relationship with an input supplier and is a steady producer.
	Purchasing agents along the value chain.		Agricultural production loans—tied to cash-flow cycle, but maintaining general credit obligation for the household.
	Microlenders with specialized capacity, agricultural banks.	Agricultural production loans—tied to cash-flow cycle, but maintaining general credit obligation for the household.	Solidarity group or village banking type loan.
Larger investments	Microlenders and credit unions that can analyze individual credit risks.	Individual and solidarity group loans to farmers or family members engaged in productive off-farm activities.	Pawn-based loans for very short terms (commonly gold, other jewelry).
Emergencies	Microlenders and credit unions that can analyze individual credit risks.	Individual and solidarity group loans to farmers or family members engaged in productive off-farm activities.	Loans by groups made with internally funded short terms.
Transfers			
Regular expenses	Remittance companies, telecommunications companies.	Money transfer services, mobile money, conditional cash transfers.	Money transfer services, mobile money, conditional cash transfers.
Risk management			
Emergencies	MFIs.	Group-based life, funeral, and weather index insurance policies added to microcredit.	Group-based life and funeral insurance policies added to microcredit.
	MFIs, agricultural loan providers.	Group-based crop and livestock and weather index insurance policies added to agricultural loans.	

SOURCE: CGAP 2013.

3.3.13 Value-chain finance could help address financing needs for commercial smallholder farms. Agricultural value-chain finance can be classified by financial need addressed—for example, product financing (input supplier and trader credit, contract farming), receivables financing (factoring, forfaiting), physical asset collateralization (warehouse receipts), and risk mitigation products and financial enhancements (forward contracts). Agricultural value-chain finance funds the purchase of fertilizer and improved seed varieties, and facilitates the provision of agronomic advice, aggregation, efficiency improvements, and partnerships. The financing can be buyer-driven and producer-driven.[92] Commercial smallholders in loose (low-interdependence) value chains (about 165 million farmers) tend to focus on common, undifferentiated staple crops that are sold in a wide variety of markets and may use some form of value-chain finance such as warehouse receipts for large volumes. Contract farming is usually not feasible due to the risk of side-selling (CGAP 2013).[93] Commercial smallholders in tight value chains (about 35 million farmers) usually grow high-value crops and use structured value-chain-finance approaches focused on a single crop. Contract farming has positive spillover effects on other agricultural activities as well as drawbacks: a funding bundle with hard-to-value individual components (inputs, transportation, and credit), uneven power between buyers and farmers, and nonpayment risk in force majeure circumstances. Table 3.4 lists the financial products available to smallholders in value chains, including supplier credit, agricultural production loans, and social loans, as well as microlenders and pawn-based lenders for farmers in loose value chains. Commitment savings accounts can complement farmer financing, while mobile phones can lower financing costs.

3.3.14 In lower-income regions, underdeveloped payments markets and the prevalence of cash transactions can impede agricultural value-chain finance (Figure 3.7). One in three adults in SSA sells agricultural goods, and nearly three-quarters of payments are made in cash, via relatively informal, local markets. In contrast, globally, agricultural payments are declining as the sector shrinks—only 14 percent of adults in LMICs received agriculture-related payments in 2024, down from 25 percent in 2014 (Global Findex Database 2025). Only an estimated 20 percent of SSA farmers participate in formal value chains (CGAP 2013). There is significant variation even within SSA: in the Democratic Republic of Congo, 81 percent of agricultural income earners are paid only in cash, 27 percent of adults have accounts, and 39 percent of adults receive agricultural payments. In Kenya, about 80 percent of adults have bank accounts, and wholesalers have invested in digitalizing payments within their supply chains, so that by 2021, 63 percent of agricultural payments were made digitally. Innovators have started using digital payments to farmers (World Bank 2020b).

Figure 3.7: In SSA, most agricultural payments are still made in cash, but this share is decreasing over time



SOURCE: Global Findex Database 2021; World Bank Group 2020.

The potential for innovative financial mechanisms

3.3.15 Digital finance is capable of scaling up service to farmers, leapfrogging EMDEs' sustainable agricultural development. Fintech has the potential to tailor its offerings to the demands of different farmer groups, and offer products beyond input credit, such as other business credit, insurance savings, and payment services. Evidence on fintech-enhanced agricultural initiatives in 17 SSA countries shows that smallholder farmers are accessing fintech financial products to adopt sustainable agriculture and improve efficiency (Mapanje et al. 2023). In SSA, 40 out of 45 countries have adopted digital credit, crowdfunding, and peer-to-peer lending, which have lowered transaction costs and improved transparency and security for rural households (Sy et al. 2019). Digital microinsurance is also lowering premiums with index-based insurance services.[94] Evidence from China shows that digital finance improved resilience (Liu and Li 2025). Electronic transactions services such as digital payment platforms can further boost resilience (Singh et al. 2023) by connecting famers to value chains and helping with information or extension services. Services such as sustainable agronomic practices, pest and disease control, weather, and input and output price can be delivered to farmers' mobile phones.

3.3.16 Beyond digital finance, big data and technology such as artificial intelligence and blockchain can promote resilience financing. The disruption in existing business models is driven by new forms of intermediation and collection, use, and analysis of massive amounts of agricultural data. Digitalization enables smallholder farmers to make more informed and timely product-to-market decisions, while improving access to credit and microinsurance. Market information is improved, digitized agricultural data create network effects that drive scale, markets become more efficient and transparent, and transaction costs decrease. Digital technologies have made the sharing economy possible, so farmers can efficiently access mechanized tools to improve crop yields. Taken together, the sharing economy, digitization, and artificial intelligence connect farmers directly with markets, service providers, and aggregators, thereby shortening the value chain and increasing profitability (Ordu et al. 2021). Precision farming, equipment leasing, service provision, and e-commerce also create quality jobs. Emerging evidence from Asia (FAO 2016a) and Africa (Kim at al. 2020) suggests that digital technology holds promise to enhance smallholders' productivity and incomes by increasing on-farm and off-farm efficiency, enhancing traceability, reducing vulnerability to counterfeit products, and improving farmers' access to output, input, and financial markets.[95] Big data, artificial intelligence, machine learning, blockchain, the internet of things, and agri-food 4.0 helped optimize India's agricultural supply chain (Nayal et al. 2021). IFC (2023b) presents a suite of successful agribusiness finance business-to-consumer and business-to-business instruments.

Risk management and insurance

3.3.17 Smallholders have a wide range of risk management strategies. Farmers typically have multiple household income sources, including agricultural income, casual labor, self-employment, resources received, and regular employment.[96] Agricultural production income is markedly more volatile than other sources of income (in Pakistan, for example, it is 458 percent more volatile). Less commercialized smallholders experience more production-related shocks, such as bad weather or pests, while more commercialized households face greater market-related shocks, such as fluctuations in input and crop prices. Anderson and Ahmed (2016) distinguish between traditional risk management, which may entail income loss and discourage investment and technology adoption, and formal instruments such as insurance, which may be unaffordable.

3.3.18 Traditional risk management mechanisms such as crop rotation and income source diversification are accessible and well used but provide imperfect risk protection. Crop diversification, such as planting several crops or keeping livestock, can stabilize income and protect against price risk, but lowers yields and economies of scale compared to specializing in a single crop. Intercropping—growing two crops on the same plot (for example, maize and beans)—can limit the transmission of pests or disease, reduce erosion, shade new growth, and control weeds.[97] Staggered planting and harvesting protect against drought, flooding, or pests. Other risk management techniques rely on agricultural training and information, price information, machinery, and the use of fertilizer and pest control.[98] Farmers can manage price fluctuations by ensuring access to price information and storing surplus production, but warehousing involves fees and transport costs, and the need to meet quality standards (and can be a source of credit).[99] A frequently used risk mitigation technique is income source diversification and nonfarm employment.[100] However, in the case of climate, it is highly likely that agricultural and nonfarm revenues are correlated. Farmers use cash and in-kind contributions from family and friends to cope with shocks, as well as selling assets such as livestock, building materials, (bricks, gravel), firewood, and manure.[101]

3.3.19 Formal risk management tools include savings and insurance, with insurance serving as a critical complement to short-term crop finance for MSMEs. Insurance supports access to credit (Carter, Galarza, and Boucher 2007), boosts technology adoption (Carter, Cheng, and Sarris 2016), and increases productive investment (Jensen and Barrett 2017). Insurance can drive adaptation, provided it is integrated into a broader risk-reduction strategy (Box 3.3). In agriculture, insurance can help manage production risk, market risk, institutional risk, personal risk, and financial risk (Komarek et al. 2020).[102] Insurance is increasingly recognized as an effective complement to post-disaster payments in addressing the costs of climate risks. Providing insurance coverage to large firms and wealthier households enables governments to direct scarce public resources toward post-disaster support for poorer people and smaller firms (Hallegatte 2014). Natural disasters can dramatically undermine the ability of financial intermediaries to lend after an event, curtailing access to finance for farmers, increasing the cost of the disaster, and delaying recovery. Moreover, the risk of natural disasters discourages investment in vulnerable regions and economic sectors and slows economic development. Financial risk transfer mechanisms such as insurance can help maintain lending following a climate disaster event. More generally, agricultural insurance can reduce systemic weather-related risks for lenders, such as floods and droughts that disrupt a large number of farms in the same geographic location, and can have a cascading effect in rural communities and other parts of the food value chain. Managing disaster-related credit risk may be done more effectively through insurance products for financial intermediaries, rather than directly to households (Collier 2013).

Box 3.3: Example: Microcredit with insurance

Kore W provides natural disaster insurance to small-scale entrepreneurs in Haiti who borrow from the microfinance provider Fonkoze. Coverage is mandatory, with a premium of 3 percent of the loan and a $125 indemnity payout, full loan balance reimbursement, and the right to a new loan. Fonkoze is, in turn, covered by MiCRO, which is backed by local and international insurers and development finance institutions.

SOURCE: UNEP DTU 2018.

3.3.20 The use of insurance to protect against climate and disaster risks in developing countries remains very low, and very few insurance instruments directly target MSMEs. ClimateWise (2011) documents only 123 existing insurance schemes in middle- and lower-income countries. In Indonesia, only 4 percent of MSMEs use natural catastrophe insurance (Mardanugraha 2016). Few MSMEs were insured during the 2010 floods in Pakistan (Asgary et al. 2012). There is a limited number of meso-level climate insurance products, which are targeted at "risk aggregators," including professional associations, NGOs, mutuals, community associations, and cooperatives (Schaefer and Waters 2016). Insurance can create moral hazard and reduce incentives for direct risk reductions (Tanner et al. 2015).

Due to low penetration, there is limited evidence on direct links between climate insurance and adaptive behaviors by MSMEs in EMDEs. Both demand and supply challenges limit climate insurance, such as lack of MSME-tailored products, high costs, and low take-up. Crop and livestock insurance markets frequently suffer from imperfections, which result in slow or unresponsive claim payouts, and in some cases, regulatory distortions. Issues with product design and implementation can weaken the beneficial effect of agricultural insurance on the credit constraint problem (Meyer et al. 2017). Few private insurers have the required distribution networks in rural areas of developing countries, so to reach MSMEs, they often work through an intermediary with an existing network (such as a microfinance institution, supermarket, bank, input dealer, agro-processor, or NGO), or they work with groups of MSMEs (for example, using mobile phone and mobile banking technologies to collect premiums and make payouts in a timely and cost-effective manner). MSMEs themselves may distribute climate risk insurance products on behalf of micro-insurers through their shops (for example, "banking correspondents" in Brazil and India).

3.3.21 The range of agri-insurance products has been growing, including weather index, area yield, and parametric insurance targeted at producers; meso-insurance to protect the agricultural portfolio of lenders; and contingent credit instruments, which provide finance to agri-MSMEs in the case of a predefined production shock akin to insurance.[103] Index insurance holds considerable promise for microfinance institutions as protection against a surge in nonperforming loans following systemic weather-based shocks (Miranda 2011). Indexed insurance and risk transfer for residual risk require investment on many fronts, including in data collection, weather stations, research, training, start-up support, and likely ongoing support. Furthermore, the private insurance sector has become active in providing reinsurance to underwrite some of the tail-end risks of agricultural insurance portfolios.

3.3.22 Aggregation can help MSMEs access adaptation finance and reach MSMEs with services such as capacity building, information sharing, and technology propagation. Adaptation financing for MSMEs can be predicated on the availability of appropriate delivery systems (aggregators). Aggregators collect premiums and make payouts in a timely and cost-effective manner through intermediaries with an existing network (for example, a microfinance institution, supermarket, bank, input dealer, agro-processor, producer organization, cooperative, or NGO), or digital tools such as mobile phone and mobile banking technologies. Aggregation can help MSMEs invest in adaptation by improving efficiency, resource use, and productivity through access to climate-smart inputs, information, data, technologies, and know-how, and in many instances also storage, cooling and other infrastructure that can help reduce costs. Rural and marginalized MSMEs can have a better chance of obtaining information about and access to relevant climate-smart solutions and related financing when participating in some form of aggregation. Transaction costs for financing and loan supervision, coordination costs, and some risks can be reduced through working with organized groups, especially at the micro and small enterprise level. MSMEs that are integrated across value chains and in commercial market systems can also benefit from lower transaction costs and economies of scale for obtaining inputs, marketing services, and financial services, thus improving competitiveness (G20 2017). Furthermore, organized groups such as producer organizations, cooperatives, and microfinance networks can be essential for capacity development to meet standards and adopt new technologies needed for smallholders' competitiveness (for example, microfinance has been successfully used to mainstream technology adoption in the water sector) (UNEP DTU 2017). Aggregators play a convening role in building awareness of the risks and implications of climate change and in advocating for necessary changes. However, in many developing countries there are relatively few well-organized groups (World Bank 2010).

3.4 Product and input adaptation and financing by MSMEs in manufacturing

3.4.1 Manufacturing and construction MSMEs sustain considerable costs from both extreme climate events and slow-onset effects. The average cyclone in India reduces manufacturing firms' sales by 3.1 percent and destroys 2.2 percent of fixed assets; however, firms are able to recover within one year. Less productive firms experience larger decreases in sales (Pelli et al. 2023). Rentschler et al. (2021) estimate that a single flood destroyed $7.8 million worth of buildings, machines, and inventory in Tanzania. Indian metalworking and textile MSMEs experience direct heat and flood impacts on their buildings and manufacturing processes, as well as indirect impacts on their supply chains and markets—for example, due to rising energy and raw material prices (Bollinger et al. 2012). Heat and floods damage manufacturing assets and lower workers' productivity. Adaptation in manufacturing (and services—see section 3.5) may be less extensively documented than agriculture as it is done as part of business as usual, reporting on adaptation may impose additional costs, or MSMEs choose to rely on community-level protection, individual property-level protection, or risk insurance (Wedawatta and Ingirige 2012). Nevertheless, extensive adaptation has been the norm. The costs and benefits of adaptation for manufacturing have not been well estimated due to the limited coverage of firms in the adaptation literature. Rexer and Sharma (2024) calculate an offset of 46 percent of climate losses when firms use effective adaptation strategies.

3.4.2 For MSMEs in manufacturing and construction, adaptation includes designing climate-resilient products, intermediary goods, and inputs (raw materials, labor, technology, information/forecasts). This includes offering new adaptation tools or parts, products, or equipment for climate adaptation services such as health, or climate-proofing assets (Figure 3.8). MSMEs can adapt by using more sustainable materials, improving resource efficiency, and designing resilient and repairable products. MSMEs can also modify their assets to withstand climate impacts by, for example, elevating machinery in flood-prone areas or installing weather-resistant roofing. Adaptive practices in manufacturing can help create innovative and differentiated products, enhancing market competitiveness and attracting environmentally conscious customers.

3.4.3 Climate-adaptation-friendly materials, tools, parts, and products can reduce costs and attract new business opportunities for manufacturing and construction MSMEs. Circular models in the automotive industry have a potential value in 2030 of $475–$810 billion in current prices, and circular models of appliances and machinery have a potential value in 2030 of $305–$525 billion (UNDESA 2020). LMICs are better than advanced countries at using resources efficiently, as they have lower consumption levels, lower levels of waste, higher recycling rates, and a productive informal reuse and repair sector (Webster 2023); however, they tend to have lower energy and material efficiency. The sectors with the largest recycling potential comprise textiles, construction, automotive, logistics, and furniture.[104] By designing durable products that use materials frugally and in an environmentally friendly way, businesses can extend the lifespan of their products, reducing the need

Figure 3.8: Adaptation in manufacturing

for frequent replacements (Babbitt et al. 2018). Extended product lifespans, repairability, and recyclability can reduce MSMEs' costs (Blomsma et al. 2019). Designing products for easy disassembly and using recycled or refurbished materials allow MSMEs to recover valuable materials, reducing the need to procure raw materials (for example, a packaging company creating recyclable packaging materials that can be collected and reused in the manufacturing process; or a clothing manufacturer sourcing pre-consumer textile waste from other industries and using it to create new garments) (Cavalieri et al. 2021).

3.4.4 Adaptation can involve variation in location and suppliers, collaboration within the supply chain, nonmonetary or in-kind adaptation, or optimization of energy and water use. MSMEs can adapt by relocating operations and diversifying supply chains toward suppliers from locations less susceptible to weather extremes, reducing dependence on single suppliers.[105] In-kind adaptation may be a first-resort strategy for resource-constrained MSMEs. Solutions include, for example, moving inventory to a higher floor prior to an expected flood or adjusting operating hours on hot days. Examples of measures to optimize water and energy use include producing clean drinking water (for example, via small-scale, simple solar-powered desalination systems), providing fire security measures, or producing and running cooling systems (for chemicals, medications, data centers, server farms).[106] MSMEs can also offer energy storage solutions such as off-grid energy use (renewables, batteries, generators, nonrenewables) or emergency on-site backup power (generator, battery storage, combined heat and power with fuel storage) (UNDRR 2024).

3.4.5 Adaptation in construction frequently involves climate-proofing private dwellings, factory buildings, and machinery. Construction is one of the most MSME-heavy sectors (UNEP DTU 2018). To green buildings, MSMEs can use climate-resilient building materials/insulation, install green roofs to reduce urban heat island effects, and introduce green spaces or walls and green or water retention gardens. Heating and cooling demand can be reduced by painting buildings white or adding trees or vegetation to streets. MSMEs can enhance resilience by strengthening buildings and plants, elevating critical equipment, safe-proofing electrical equipment before floods, and improving drainage systems (UNDRR 2024). The key obstacle to construction-related adaptation is the lack of worker skills in resilience and energy efficiency due to limited formal training, as workers tend to learn on the job.

3.4.6 Like agriculture, manufacturing MSME financing is rarely earmarked for adaptation in EMDEs. Adaptation strategies are conducted in the course of regular business, provided they are financially sustainable. UNEP (2016) confirms that private adaptation investments are typically financed using the same instruments as traditional business investments. Explicit adaptation financing can be given to MSMEs within the supply chain, or within a multi-party concessional finance framework (as with agriculture). The adaptation financing products offered by private financial institutions and investors—such as banks, pension funds, insurance companies, or impact investors—are often ill-suited to MSMEs or require aggregators. Tailoring financial products to MSME needs (Appendix D) can shift offerings toward more efficient, data-, and technology-enabled short-term finance (for example, various forms of working capital such as inventory finance, secured revolving lines of credit, merchant-receivables financing), or alternatively toward short-term finance solutions for asset finance (such as product leasing). Digital finance has lowered costs and improved data across financial products. Outcomes improve if adaptation finance is bundled with nonfinancial services, for example, credit ratings that take climate risk into account (Adelphi 2019). In Africa, start-ups serving MSMEs use innovative tools such as predictive supply-chain analytics, alternative credit scoring, and buy-now-pay-later financing products to break down some of the traditional barriers faced by micro retailers to build and operate their businesses.

3.4.7 Adaptation financing is sometimes available to MSMEs within the value chain (supply-chain or accounts receivable financing, factoring, and reverse factoring). Most of the finance sources flowing to MSMEs are in the form of value-chain finance, either internally between buyers, traders, and sellers or from financial institutions to one or more of the most secure value-chain enterprises or companies, which in turn can help supply financing, often in kind, to their suppliers or buyers.[107] This type of financing is tied to the value-chain commodity or product and is generally short term, requiring traditional sources of MSME finance to be adapted or combined to support climate adaptation investments. Using value-chain finance for adaptation relies on larger firms investing in their own adaptation and carrying their value-chain MSMEs as well, opening up new opportunities, for example, by stimulating demand for adaptation products and services (Frei-Oldenburg et al. 2018). Large companies also have a significant role to play in supporting suppliers and smaller companies in dealing with climate impacts, including by managing value chains and providing risk data to reduce uncertainties.

3.4.8 Product leasing services comprise buy-now-pay-later, lease-to-own schemes, MSME-tailored equipment financing, and asset-sharing models among MSMEs. On the supply side, MSMEs can adopt business models where they lease or share their products instead of selling them outright (Andrea et al. 2020). This allows them to retain ownership of the products and generate recurring revenue through leasing fees or subscription-based models. For instance, a fashion brand can offer clothing rental services, allowing customers to rent garments for a specific period instead of buying them. Additionally, MSMEs can use adaptation to attract partnerships with sustainability-focused organizations and investors who prioritize companies with sustainable practices, as they are seen as less risky and more likely to achieve long-term financial success.

3.4.9 Digital finance. Digitizing the MSME ecosystem through e-commerce, the gig economy, and digital business services has reshaped the MSME landscape and enabled new growth opportunities. Digitally enabled solutions such as digitalization of business processes, digital credit scoring, and risk assessment using alternative data have lowered costs, enhanced information, and advanced MSME access to financial services. Platforms have appeared in most big EMDEs, including e-commerce platforms that lend along their supply chains and crowdfunding platforms. Insurance technology provides MSME insurance, including against natural disasters, and digital banking (fintech) provides MSME credit and savings services. There are also digitally enabled versions of existing financing products and services, which provide various options such as factoring, reverse factoring, supply-chain/accounts receivable financing, secured revolving lines of credit, and merchant-receivables financing. Unlike traditional banks, which rely solely on credit scores, peer-to-peer and marketplace lending platforms use a range of data points, including education, academic transcripts, labor profiles, bill-payment histories, tax returns, historical bank statements, and employment history, to make underwriting decisions. By linking their accounting software or business bank account directly to the platform, MSMEs can also increase data accessibility, and the efficiency of risk assessments and loan application processes.

3.4.10 Embedded finance involves integrating financial services within nonfinancial platforms or applications to expand access to financial products and services for MSMEs. Embedded finance providers leverage digitalization to integrate financial services into their existing offerings. Many providers initially focus on digital commerce or payments facilitation and later expand into lending. Embedded finance providers include companies from the mobility, agriculture, manufacturing, services, supply-chain, and e-commerce sectors. They use transaction-driven business intelligence to offer financial services.

3.5 Product and input adaptation and financing by MSMEs in services

3.5.1 Climate adaptation is relevant for many service and trade MSMEs, including those in the health services supply chain, climate-adapted services such as tourism and hospitality, retail, ICT, and data services. Climate adaptation capacity-building services involve building the business case, assessing risks, developing response plans, learning about climate-smart tools and hi-tech and low-tech adaptation mechanisms, training farmers, and educating stakeholders on important climate topics such as stormwater or flood management systems. Other climate adaptation services include repair and remanufacture services and transport and logistics. MSMEs could also subcontract services to local and other government adaptation projects, such as building dikes or drainage systems for flood management, preventing pollutant runoff, raising road levels, building land-use buffers or sea walls, and conserving wetlands and reefs.

3.5.2 Health services and products are both MSME-dominated and climate-sensitive. Climate change will lead to increased ill-health, particularly in low-income developing countries (IPCC 2023).[108] This increases demand for healthcare services and basic public health measures, such as clean water and sanitation, vaccination and child health services, and disaster preparedness (IPCC 2014). The most common types of health service providers are MSMEs, including medical professionals, clinics, and diagnostic facilities (IFC 2016d). An increasing number of MSMEs are joining the pharmaceutical supply chain, producing specialized products for larger pharmaceutical companies. Adapting health systems to climate change can involve practical options that build on existing knowledge as well as innovative approaches that require new skills. For example, the advent of handheld diagnostic devices and video-mediated consultations is expanding the prospects for telemedicine and making it easier for isolated communities to connect to the global health infrastructure (World Bank 2010). Activities suited to MSME capacity include resilient public hospital infrastructure, health surveillance technologies to identify and pre-empt natural-hazard-driven disease patterns, disaster-specific health information management systems (including inventory management), and virtual healthcare and digital health technologies activated in disaster situations. The benefits of healthcare adaptation have been well estimated in selected subsectors such as vector/waterborne diseases and extreme heat. They include $2–$4 billion in direct additional costs for surveillance and facility resilience (World Bank 2024c) and $21 trillion in potential avoided costs by 2050, or about 1.3 percent of GDP (Alcayna and O'Donnell 2022).

3.5.3 Climate-adapted services such as tourism and hospitality are also offered by many MSMEs (for example, services incorporating drought-resistant meals into menus). The tourism and hospitality MSMEs are highly dependent on the weather. The strong seasonality element of the sector affects MSMEs' ability to absorb costs, but they are also more flexible than large firms to respond to changes more quickly (UNEP DTU 2018). MSMEs in the tourism and hospitality sector lack access to capital and resources and operate with marginal profits, so they have limited cash reserves to respond to and recover from a disaster. They also tend to be housed in nonengineered buildings and often have insufficient capacity to devise and execute a disaster management plan. They are susceptible to mechanical failures, employee absences, utility supply disruptions, telecommunications breakdowns, and property destruction. For tourism, adaptation benefits have been calculated mainly in the areas of small states and coastal tourism. For small states, the benefits are 3.5 to 15.7 times larger than costs and can cut GDP damage by over 50 percent, while for coastal tourism, the benefit-cost ratio is 5.6 to 6.5, even under conservative calculation assumptions (Saghir and Ijjasz-Vasquez 2025).[109]

3.5.4 Resilient retail centers are able to withstand extreme heat, heavy rainfall, and flooding. Retail MSMEs adapt through inventory management—stocking goods with greater climate resilience or innovating their product offerings. They can also remain updated on climate trends to predict potential shifts in customer demand. Small and micro retailers should protect their physical assets by elevating inventory storage or installing flood barriers.[110] Similarly to MSMEs in manufacturing, they can explore alternative suppliers and transportation options to minimize disruptions during extreme weather. Finally, customer engagement and product innovation might involve climate-conscious marketing (sustainable product options, highlighting climate-related benefits), product adaptation (new or modified products to better suit changing climate conditions), and community outreach to raise customers' awareness of adaptation.

3.5.5 ICT and data services are another sector heavily populated by MSMEs with significant potential to support adaptation. MSMEs could specialize in providing emergency response system services and capacity building, connectivity for disaster risk areas, critical systems backup, and ICT infrastructure resilience. In terms of data services, MSMEs could provide forecasting, climate modeling and monitoring for parameters such as air quality or fire monitoring and equipment such as high-definition cameras, and early warning systems. MSMEs could assist capacity-constrained local governments with early warning systems in their local communities (Zommers 2012) by, for example, collecting data. The ICT sector in particular can deploy systems to collect and model climate information (satellite imagery, geographic information systems' risk modeling, post-disaster evaluation), take early warning measures (for example, integrated or multi-hazard early warning systems), and provide real-time risk communications on weather and disasters tailored for smartphone and mobile phone markets (GEF and IFC 2012).

3.5.6 Service-sector MSMEs face severely limited adaptation finance sources and rely on their supply chain or community and microfinance organizations. Financing tools tailored to MSME adaptation needs such as supplier finance, various forms of working capital, and digital finance would be the most appropriate for the services sector, which is light on fixed assets and inventory. In the tourism industry, MSMEs can use climate adaptation know-how and funding from multinationals. Another option is merchant-receivables financing (also known as merchant cash advances)—short-term financing that uses MSME retailers' acceptance of payment card transactions as collateral.[111] Innovative finance can reduce lending costs to MSMEs and scale up. Fintech systems can be used to measure the historical performance of MSMEs' payment receivables and monitor daily collections. They also provide alerts in case of discrepancies between expected and actual electronic sales, allowing a lender to adjust advances, fees, and retention of funds based on an MSME's actual cash flow (World Bank and IFC 2022). Fintech has been successfully used to finance health MSMEs. In 2023, climate tech start-ups received about one-third of start-up funding in Africa, raising $1.04 billion, marking a threefold increase from that raised in 2019 (CPI 2024a). Digitizing retail MSME ecosystems as well as relevant financing products and services can improve access to finance and lower costs. Embedded finance is another high-potential source of funding.

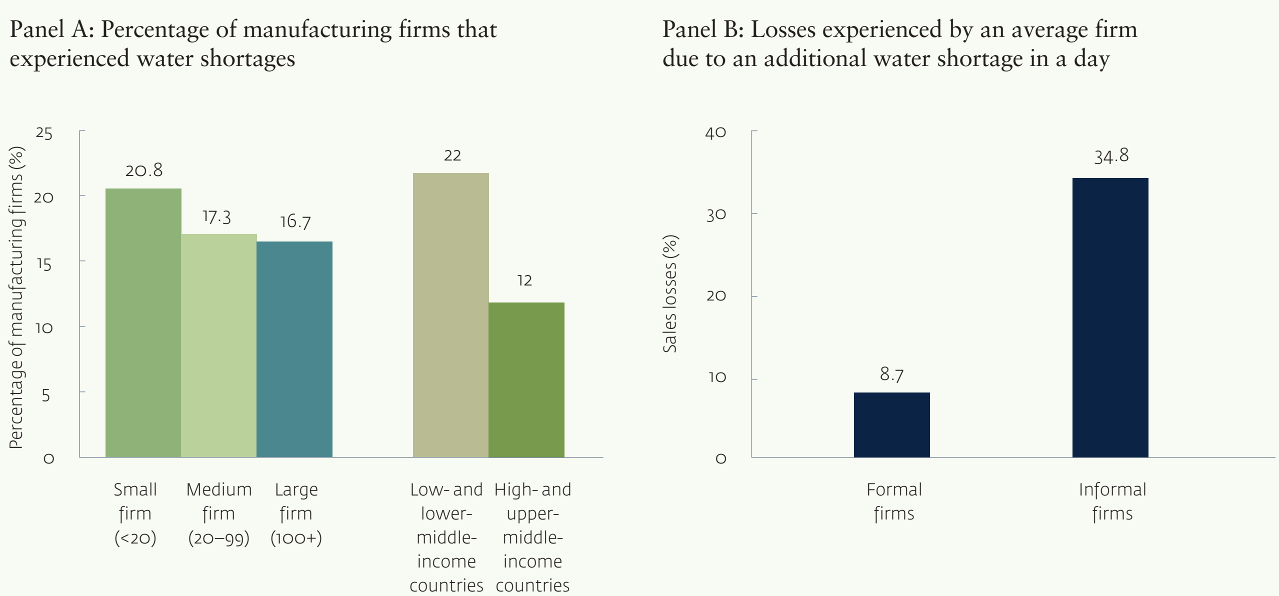
3.6 Resource use adaptation and financing by MSMEs

Energy and water risks and MSME adaptation strategies

3.6.1 Climate risks threaten the reliability of water and energy infrastructure, which directly affects MSMEs as users and possibly as providers as well. MSMEs face disruptions and higher costs as infrastructure is exposed to climate hazards such as flooding, wildfires, hurricanes, and heat. Water scarcity and extreme heat can result in water supply rationing, while utilities in flood-prone areas may suffer from water infrastructure damage and saltwater intrusion, reducing their efficiency and resilience. High temperatures can overload power plants due to increased air conditioning demands, and power systems may become less productive under extreme heat, affecting other sectors. In African countries, electricity supplies are threatened by increased variability and uncertainty in hydropower generation, particularly during severe droughts. Extreme weather events such as storms and heatwaves can further disrupt electricity networks and grids. Disruptions to energy, water, and transport infrastructure have serious economic implications and carry major economic costs for MSMEs. Based on microdata on about 143,000 firms in 137 LMICs, utilization losses from power, water, and transport disruptions are estimated at $151 billion a year; sales losses from electricity outages amount to $82 billion a year; and additional costs stem from self-generating electricity ($65 billion a year) (Hallegatte et al. 2019a). Hardy and McCasland (2019) find that frequent power outages disproportionately reduce the profitability and productivity of single-person firms, with each additional blackout day in a week lowering weekly revenues by 10 percent and weekly profits by 13 percent. Damania et al. (2017) find that smaller firms and those in low- or lower-middle-income countries are more exposed to water shortages, with 20.8 percent of small manufacturing firms reporting shortages compared with 16.7 percent of large firms (Figure 3.9). Similarly, 22 percent of firms in low- and lower-middle-income countries reported shortages compared with 12 percent in high- and upper-middle-income countries. Each additional water outage in a month causes an 8.7 percent reduction in sales for formal firms, with informal firms, which fall within the MSME category, losing as much as 34.8 percent. Abeberese, Ackah, and Asuming (2021) show that the productivity of small and medium enterprises in Ghana's manufacturing sector decreases by about 10 percent due to roughly 10 outages per month. The adaptation costs in the infrastructure sector as a whole are estimated at $11–$65 billion for LMICs alone, with the benefit-cost ratio ranging from 2:1 to 4:1 (Nicolas et al. 2019).

3.6.2 MSMEs can adapt to risks to energy infrastructure through distributed generation and energy storage solutions, such as off-grid energy use (renewables, batteries, generators) and localized emergency backup power during grid outages. Installing rooftop solar, efficient cooktops, energy-saving lighting and appliances, and other low-tech innovations adapted to local needs and resources can enhance resilience. Renewable energy sources, such as wind and solar, contribute to both mitigation and resilience. As energy use increases and extreme weather events threaten supply, MSMEs can benefit from investing in alternative energy sources that are often less costly in the long run. In agriculture, renewable energy technologies can provide a reliable supply of energy and be cost-effective. For instance, solar pumping irrigation systems can be more economical than diesel pumps even in the first year of operation. Smallholders are also adopting solar dryers

Figure 3.9: Water shortages, firm size, and development



SOURCE: World Bank 2017.

and cooling for storage, solar lighting for livestock security, biogas digesters for cooking and fertilizer, and briquettes made from crop residues for heating and processing. Other solutions, such as building insulation and reflective roofing, can help MSMEs gain a cost advantage, as energy consumption can account for 25–50 percent of their total business costs (Business Energy Index 2013). Simplified monitoring tools, training programs, and access to finance can help MSMEs overcome upfront costs and build energy resilience. Evidence from Ghana highlights both the range and the limits of current adaptation strategies. Abeberese, Ackah and Asuming (2021) find that MSMEs in Ghana rely on measures such as shifting production to less electricity-intensive products, rescheduling operations, switching processes, or using generators. Although about 27 percent of firms use generators, this strategy is ineffective for MSMEs in reducing productivity losses, in contrast to larger firms that can spread the fixed costs.

3.6.3 Given water-scarcity risks, businesses are adopting water-efficient solutions to build resilience, reduce costs, and enhance competitiveness. Water stress poses risks of water supply disruption and increased water prices. MSME adaptation measures include enhanced water management (water recycling, watershed and aquifer management, rainwater harvesting and storage, and employee training on sustainable water use) and integrating water-efficient processes and technologies (new types of metering, water resource monitoring equipment, leak detection equipment, automated water and pressure control systems, wastewater treatment, loss reduction, recycling, and desalination). For instance, in Niger, small businesses can access piped water through smart meters and mobile PAYG billing (Cariolle and Carroll 2020). In Nepal, smallholder farmers and MSMEs adapt to variable water access and energy needs through PAYG microgrids and solar-powered pumps (GSMA 2022).

3.6.4 While many infrastructure services are publicly owned, the private sector, including MSMEs, also plays a role in driving adaptation and resilience. Certain infrastructure-related adaptation needs are highly context dependent and can create opportunities for MSME participation. For example, enhancing urban climate resilience and implementing solar-powered water management tools create opportunities for MSMEs to provide innovative, localized solutions, optimizing energy and water for themselves and their customers. As climate change increases global demand for resilience solutions, the market for climate-resilient products and services is expected to grow (UNEP DTU 2018). This includes new metrics, stress tests, climate-resilient materials, risk-sharing mechanisms, and flood maps. MSMEs can strengthen climate resilience by developing technologies and systems that improve water and energy efficiency. Energy efficiency is positively associated with firm performance in LMICs (Gutiérrez and Teshima 2018 for Mexico; Adhvaryu et al. 2020 for India; Zhang et al. 2008 for China), with payback periods for energy investments in manufacturing of 0.9–2.9 years (Alcorta et al. 2014). Examples include solar-powered desalination, decentralized water treatment, and clean drinking water solutions. MSMEs can also provide tools and services for water management in agriculture and manufacturing, such as efficient irrigation, rainwater harvesting, and water-saving plumbing fixtures. In addition, MSMEs can supply flood-resistant building materials, sanitation solutions such as improved latrines, and water purification technologies such as filtration systems. In developing countries, Khattri, Parameshwar, and Pellech (2010) suggest that the private sector can significantly support social adaptation and build resilience to climate change in urban areas, including through water management and off-grid energy solutions. Several examples illustrate these contributions. In India, Sarvajal empowers microentrepreneurs to run decentralized reverse osmosis water treatment plants. Franchisees contribute modest start-up capital and share in the revenue, providing safe drinking water to over 60,000 people while generating local livelihoods (Macomber and Sinha 2011). JanaJal, also in India, uses a PAYG "water on wheels" model to deliver affordable, safe drinking water to urban households through micro firms that manage mobile water distribution. In Egypt, KarmSolar designs and operates solar-powered desalination units that combine clean energy with water access in off-grid areas. In Senegal, informal vendors respond to flooding by selling sand and debris to raise household foundations, an adaptive practice rooted in the informal economy (WRI 2013).

Financing mechanisms for MSME adaptation of resource use

3.6.5 New financing models, such as energy performance contracts, PAYG, receivables-based financing, and factoring for off-grid systems, can help MSMEs spread adaptation costs over time. For example, PAYG solar has been successful in providing energy access in SSA, and PAYG models have been applied to water solutions in countries such as Niger and India. In India, companies such as Bepure and Claro Energy use PAYG models to provide water purifiers for urban users and solar-powered irrigation via e-rickshaws to reduce energy costs (GSMA 2022). Integrating digital data solutions into PAYG systems enhances transparency, accountability, and user engagement. With real-time monitoring, service issues can be identified more quickly, and corrupt adjustments become visible to all stakeholders (Mahendra et al. 2021). In Niger, the deployment of digital PAYG for water services led to higher revenues, greater public trust, and savings for consumers (White and Morais 2020). Carbon markets-based funding with an aggregator can also support adaptation projects. For instance, funding solar water pumps in Kenya using carbon revenues can reduce pump costs by a projected 25–40 percent and reach farmers at lower prices (see Box 3.4 for examples in agriculture and manufacturing). Aggregators can facilitate water adaptation projects, such as offering credit to implement water-saving technologies in Jamaica (UNEP DTU 2018).

3.6.6 Multi-party concessional and blended finance schemes leverage public funding, such as grants, guarantees, or first-loss capital, to mobilize private sector investments. In energy and water, market-based solutions may fail due to economies of scale and financing barriers. Commercial banks may view energy MSMEs as high risk due to long supply chains and slower payback periods, but microfinance institutions and private specialized lenders can offer more flexible financing suited to these MSMEs (Haselip et al. 2014). Concessional solutions can help lower the cost of capital and reduce risks, making investments more attractive to private financiers and well suited to climate-resilient energy and water infrastructure.

Box 3.4: Carbon markets-based multi-party concessional and blended financing schemes for MSMEs

Most outfits that link MSMEs to carbon credits focus on pure mitigation, but the approach can be used to raise funds by mitigation for adaptation. One example is combining carbon sequestration with improvements in water quality. MSMEs in Ethiopia and farmers in South Africa earn carbon credits via regenerative agricultural practices (for example, reducing nitrogen use per hectare and tilling) and renewable agriculture, which represent a combination of mitigation and adaptation. In Nigeria, green energy companies earn carbon credits by supplying solar solutions to their clients. Voluntary carbon markets, which offer the most immediate opportunities in EMDEs, were valued at an estimated $723 million in 2023 (Donofrio et al. 2023), and compliance markets at $949 billion in 2023, with the European Union's Emissions Trading System accounting for the majority (Twidale 2024). The growing convergence between voluntary and compliance markets will increasingly open new opportunities in EMDEs.

SOURCE: Authors' elaboration; CGAP 2024a.

3.6.7 While private capital and MSME participation are essential, adaptation in infrastructure also requires substantial public investment and policy leadership. National governments, supported by development partners, can invest in resilient transport, electricity, communication, sanitation, and water systems as part of larger national adaptation plans, ensuring MSMEs are not excluded from benefits. This can be done by prioritizing MSMEs in national adaptation plans, using public-private partnerships that include them, offering targeted financing, and designing projects that allow smaller firms to participate. For example, procurement can be structured to simplify contracts, break large projects into smaller lots, and require cost data disclosure, increasing the number of bidders and allowing MSMEs to compete alongside larger firms. Public investment in physical and market infrastructure encourages further adaptation by supporting diversification, economic growth, sustainability, trade, and the attraction of additional foreign investment. Improved infrastructure, including water and electricity, facilitates MSME growth and supports their investment in adaptation (Dougherty-Choux et al. 2015). Through public-private partnerships, governments can partner with communities and small vendors to create or co-produce new, hybrid formal-informal models of service delivery. For instance, in Hubli-Dharwad, India, the utility has contracted private vendors to install kiosks in urban areas with no piped connections or clean water supply nearby. The kiosks draw and filter water from reservoirs, improving water quality so that it is suitable for drinking (Devadiga 2020). In Ouagadougou, Burkina Faso, the utility cooperates with small entrepreneurs to resell water at controlled prices to residents of informal settlements (Heymans et al. 2016).

PART 4

Funding adaptation

Financing constraints and funding instruments for MSME adaptation

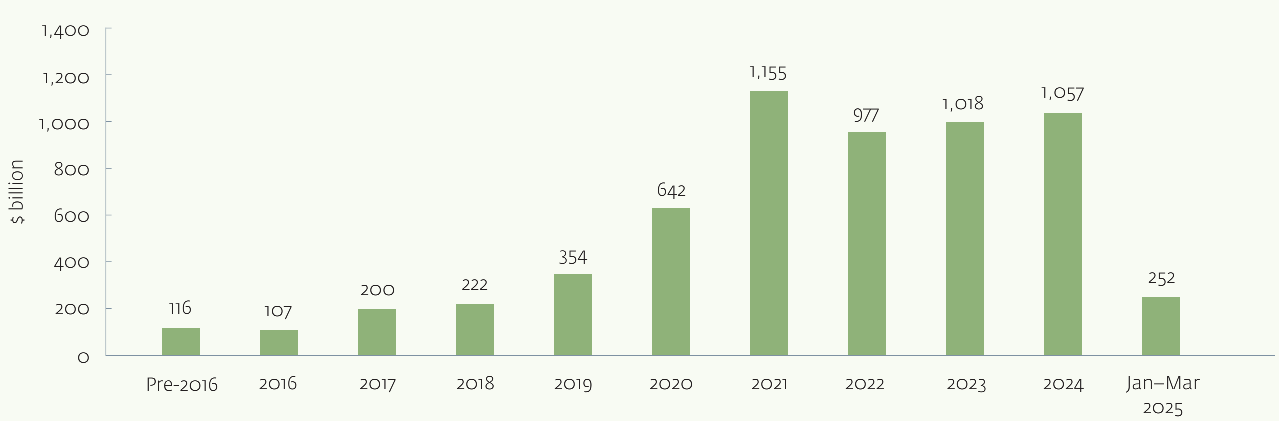
4.1 Most financing available to MSMEs in EMDEs is short term, and adaptation finance is even more limited. To our knowledge, there are no formal estimates of MSME funding for adaptation. Looking at overall funding to MSMEs in EMDEs, there is a formal financing gap equivalent to 19 percent of GDP, with informal MSMEs adding another 8 percentage points of GDP to the gap (IFC 2026c). The financing constraints are especially dire in LICs: MSMEs in LICs fund nearly 85 percent of their financing needs from their own savings, while 5.64 percent comes from short-term supplier finance and 5.16 percent from banks, some of which may provide long-term financing (Nenova, forthcoming).

Africa is home to about 11 percent of the world's MSMEs, yet accounts for 40 percent of those that are financially constrained. The agriculture and traditional services sectors, which account for most of the economic activity in EMDEs (at 23 percent and 67 percent in SSA, respectively), run mostly on working capital with very little capital expenditure. Post-pandemic and recent financial tightening have widened the financing gap of MSMEs in LICs, almost entirely on the short-term tenor side (IFC 2024). MSMEs often lack resources for ex-ante adaptation as well as ex-post financing in case climate risks materialize. Their access to adaptation finance is more limited than that of larger firms, especially to formal and bank funds, as commercial banks shy away from the small scale and higher risk involved. Instead, MSMEs' adaptation financing may come from value chains' trickle-down support, social networks, and microfinance institutions, which themselves struggle with climate risks (Stein et al. 2013).[112] The bulk of private adaptation finance, however, is long-term funding such as catastrophe, green, climate, resilience, asset-backed, or thematic bonds (Global Center on Adaptation 2020; see Figure 4.1).[113] For the remainder of this report, we turn our attention to markets funding adaptation and show that finance is a binding constraint.

4.2 Higher climate risks dampen both access to and the cost of finance, which in turn negatively impact adaptation; the effect is more pronounced for MSMEs in EMDEs (Burgess et al. 2017; Rajan and Ramcharan 2023; Riley 2018; Jack and Suri 2014). McDermott et al. (2014) find that countries with low levels of financial sector development and credit constraints on adaptation have persistent negative effects on economic growth over the medium term. This dampening effect is stronger for adaptation than for mitigation (De Haas et al. 2024; Van Reenen and Keiller 2024). Furthermore, climate vulnerability drives up the debt cost and lowers access to debt financing even at higher interest rates, especially for smaller firms and in high-risk sectors and countries (Cevik and Miryugin 2022).[114] Investors price in climate risk (Kling et al. 2018; Ginglinger and Moreau 2019; Li et al. 2020; Giglio et al. 2021).[115] Increased climate uncertainty raises price volatility in climate-sensitive markets such as agriculture and energy (Fleming et al. 2006; Taghizadeh-Hesary et al. 2019 for agriculture), which can deter investments and increase resource requirements for risk management. Small firms face disproportionate financing challenges, particularly in developing countries and especially when seeking funding for higher-risk

Figure 4.1: Global sustainable debt market growth

Global labeled sustainable bond annual issuance, $ billion



SOURCE: World Bank based on Environmental Finance Data (2025).

climate-related investments (Grover and Imbruno 2020). Financial barriers are aggravated by climate-related financial regulation, which can raise lending costs to the exclusion of borrowers that are smaller, lower income, or subject to higher climate risks (CGAP 2024c). Differences in wealth and income play a large role in determining adaptive responses to climate change and the resulting welfare effects (Carleton et al. 2022). Fried (2024) finds that income heterogeneity can increase the aggregate welfare losses caused by climate change fourfold. Adaptation is less accessible for credit-constrained households (Van der Straten 2024), even with green incentives for supplier firms (Berkouwer and Dean 2022). Tight credit explains around 60 percent of the recent slowdown in the rise of green patenting (Aghion et al. 2024).

4.3 Financial market constraints in LMICs limit adaptation,[116] as do missing markets for risk (section 4.6).[117] Didier (2024) finds that limited access to finance is a primary barrier to flood adaptation for 43 percent of small and medium enterprises and 34 percent of large businesses that consider floods a recurring risk—10 percentage points more than the second-most cited barrier, namely, lack of awareness and knowledge. Businesses with limited access to finance have three times greater revenue losses associated with floods. Insurance is used by 88 percent of large firms and 36 percent of small firms that have not experienced flooding; these figures increase to 100 percent for large firms and 81 percent for small firms hit by floods (Didier 2024). Insurance payouts are a primary source of funding for reconstruction for 37 percent of small and medium enterprises and 24 percent of large businesses.[118] In Mexico, extreme temperature shocks increase the delinquency rate by 0.17 percentage points, with agriculture experiencing particularly negative effects. Indirect impacts from agriculture affect sectors that rely on local demand such as services and retail (Aguilar-Gomez et al. 2024), while more integrated markets experience less pronounced climate-related fluctuations. Miguel et al. (2022) find that banks accounting for environmental risks in capital assessments in Brazil did not impact overall lending because firms with higher environmental risks simply started borrowing from smaller lenders. Collier and Babich (2019) find that community lenders in LMICs reduce credit supply after natural disasters due to capital constraints rather than lower expected returns on loans, suggesting that lenders may have already priced in climate risk; and that lender-level insurance can prevent such capital constraints (Collier 2020). Firms can also adapt to climate change by altering their financial decisions—globally, firms facing higher climate risk hold more cash, less short-term debt, and more long-term debt than those facing low climate risk (Huang et al. 2018). Chinese firms attempt to buffer climate impacts by increasing debt and reducing liquidity (Elliott et al. 2019).

Box 4.1: Enhancing carbon project finance

Credit and savings products can enable MSMEs to participate in carbon projects by helping to spread the cost of adopting green technologies and practices over time. Digital payments can improve the transparency and efficiency of benefit-sharing models, increasing inclusivity and providing more information on the carbon revenues that project participants receive. Informal financial services can help MSMEs adapt and diversify, helping them to transition away from unsustainable practices while protecting and even improving their incomes. Important financial service innovations include digital payment-enabled benefit-sharing models, leveraging carbon projects to support loan underwriting, and carbon savings accounts. Women-centric financial services can equip women to participate in carbon projects and take advantage of benefit sharing to improve their lives and livelihoods.

SOURCE: Based on CGAP 2024a, 2024d.

4.4 While case studies show the feasibility of funding MSME adaptation, scaled-up finance attempts have only recently emerged, and very few have been successful in LICs. Anecdotal evidence shows that short-term finance has been repurposed by MSMEs to fund adaptation in the usual course of business: credit (especially working capital) and savings products, financing along the value chain, various short-term versions of asset finance, digital finance products, sustainable and carbon-related financing (see Box 4.1 for a carbon credit example), and microfinance (for examples of MSME adaptation in EMDEs, see CGAP 2024b; WRI 2013; CGAP 2025c). Farmers in Ghana who used informal credit were less likely to sell important assets during climate shocks, recovering faster and improving their resilience by about 12 percent (Batung et al. 2022). Kenyan households with savings were more likely to adopt climate-smart farming practices than those without savings and used more than one climate-smart technology (Gikonyo et al. 2022). Tailored MSME funding has become possible through innovative microfinance and digital products, such as embedded insurance, early warning, bundled products with customer service, adaptation asset finance, contingent savings or lines of credit, and mobile layaway or smart agri-input payments by installments. However, commercial banks have not scaled such adaptation-specific finance tools. Asset-as-a-service models are likely to facilitate higher resilience and higher energy efficiency, especially in sectors such as cooling and resource use. Leveraging digital platforms and integrating climate and biodiversity risks into credit decisions have opened new funding opportunities, enabling more informed decision-making and improving resilience outcomes.[119] An untapped ecosystem of investors, regulators, and financial institutions has evolved over the past decades to deliver large-scale funding in small-ticket financing (while managing risk) to their existing long-term customers in climate-vulnerable communities (CGAP 2024d). Large-scale climate disruptions leave little choice but to build MSMEs' resilience to ensure countries' overall economic prospects (IFC and UNEP 2024). Private finance can help scale climate adaptation and resilience efforts, from directly investing in adaptation-focused MSMEs to developing microfinance and sustainability-linked loans and deploying innovative mechanisms such as weather index insurance, as well as leveraging blended finance models and de-risking investments. To see the financially promising MSME "bottom-up" adaptation that defies the efforts of private finance and policy makers alike, better data and measurement and more success stories are needed, leveraging risk management and, where appropriate, concessional funding.

4.5 Newer financial technologies (such as mobile money and satellite-based index insurance) facilitate adaptation. Examining the role of credit market failures in limiting adaptation, Lane (2024) finds that guaranteed credit to farmers encourages more adaptation and farmers are less severely affected by floods, and that this type of emergency loan is profitable for the microfinance institution. Contingent loans improve adaptation (Collier et al. 2024), as do better-functioning markets of land, labor, or other inputs (Jones et al. 2022 on the decision to adopt irrigation). Gormsen et al. (2023) find that the perceived capital cost of green firms is significantly lower than that of brown firms after 2016, due to firms' perception that they can easily raise capital for green projects, so they are willing to invest at a lower return for greener projects.

4.6 Climate insurance plays a key role in pricing adaptation, incentivizing proactive risk management, and driving risk management standards. Insurance use and support have gained much attention in the context of adaptation (Linnerooth-Bayer and Mechler 2006).[120] Disasters can cause spatially concentrated loan defaults in the absence of insurance (Collier and Babich 2019; Collier 2020), while the resulting reduction in credit supply can further delay the recovery of affected firms (Del Ninno et al. 2003). Indeed, microfinance institutions often limit the share of agricultural loans in their portfolio in case widespread weather impacts cause their clients to default (Christen and Pearce 2005), and insurance markets in India have been moving away from covering extreme climate events (Cole et al. 2024).[121] Barriers to MSME climate adaptation insurance in EMDEs include underdeveloped financial and insurance markets, as well as (i) differences in the perception of risks and lack of data, including from insufficient hydromet observation systems; (ii) liquidity constraints; and (iii) the presence of other types of risks that may be more prevalent in developing countries (Grover and Kahn 2024). Most insurance research in LICs is focused on weather index insurance for smallholder farmers, as they are particularly exposed to risks from extreme weather (for example, Cole et al. 2017; Hill et al. 2019; Greatrex et al. 2015; Kraehnert et al. 2021).[122] Insured farmers cultivate more land and are more likely to invest in seeds and fertilizers and adopt innovations such as improved seeds or irrigation systems, boosting yields and incomes while fostering resilience (CGAP 2025b). Janzen and Carter (2019) find that insured farmers in Kenya are 96 percentage points less likely to sell assets during droughts than uninsured households, providing liquidity and avoiding asset fire sales. Hill et al. (2019) find that index insurance improves adaptation, which is also confirmed by Janzen and Carter (2019), who show that microinsurance lowers the need for costly "self-insurance" using personal assets. Stoeffer et al. (2022) find that index insurance positively affects agricultural investment after a shock through actions such as replacing damaged inventory and replanting fields. Insurance with quick payouts can also help households recover. However, unreliable insurance payoffs can undermine trust, and moral hazard can introduce perverse incentives, lowering the need to adapt given the protection from insurance—this is confirmed by evidence from the United States (though not for EMDEs) (Javeline et al. 2021). Digitalization can enhance insurance markets by leveraging information and data, expanding digital financial inclusion, reducing transaction costs by using universal IDs, and developing data platforms for weather and climate trends, hazards data, satellite data on crop health, and cross-validation with local information.

4.7 Under specific conditions, market failures call for the use of concessional or blended finance to manage risk. De-risking is essential for scaling up climate finance, usually with concessional elements due to the gap between the social and private benefits of adaptation.[123] IFC's DFI Enhanced Blended Concessional Finance Principles for Private Sector Projects suggest that blended finance is most effective when it minimizes concessionality, targets market failures to avoid crowding out private finance, and generates transparent results. Some research argues for concessionality for countries with credit markets that offer high interest rates or transaction costs, as adaptation benefits can outweigh the subsidy cost (Lane 2024).[124] Bhandari et al. (2022) find that targeted subsidies for technology to use groundwater more efficiently in Bangladeshi villages reduce electricity used for pumping by 38 percent, but only when targeted to water sellers, while subsidizing technology to individual farmers has much smaller effects. CGAP (2025e) argues that, together, social protection and financial services can enhance climate outcomes for beneficiaries.[125] A strong argument also exists for blended funding for infrastructure projects (proactive resilience design is cheaper than retrofitting) to leverage private adaptation investments, especially in emerging markets (World Bank Group 2022a). Elements of concessional funding in climate and energy start-ups achieve a greater rate of financial success than purely private investment (Kennedy et al. 2024; Hatashima and Demberel 2020). Blended finance for adaptation secured $7.5 billion between 2013 and 2023 (compared with $64.2 billion for mitigation and $18.5 billion for hybrid transactions addressing both mitigation and adaptation) (Convergence 2023).[126] A total of 60 percent of blended finance deals are in the agriculture sector (UNEP 2025).

Evidence of adaptation finance decisions based on WBES data

4.8 The WBES data confirm the literature findings on credit constraints in EMDEs, particularly for MSMEs. We use the WBES data to assess whether credit constraints limit firms' ability to pursue adaptation strategies. Table 4.1 presents summary statistics of the financial data. Although a high share of MSMEs are banked (84.2 percent of micro firms and 90.5 percent of small firms), only 19.3 percent of micro firms and 29.9 percent of small firms have access to working capital from a bank.

Trade credit is available to 20.7 percent of micro firms and 21.9 percent of small firms. The detailed module results are slightly higher, perhaps because they focus on regions with relatively more middle-income countries. Access to bank-provided working capital is 23.2 percent for micro firms and 33 percent for small firms, while access to trade credit is 21.7 percent and 24.1 percent, respectively.

4.9 Financing constraints significantly affect firms' ability to adapt to climate change. Figure 4.2 shows that firms using external sources of working capital finance, such as banks or trade credit, tend to have higher adoption rates for adaptation than those that do not. The bars in the figure represent country-averaged adoption rates, weighted by survey weights within each country and then averaged equally across countries to avoid results being driven by larger economies. Panel A shows the results at the global level across the entire sample. Firms using bank financing for working capital have an average adoption rate roughly 8 percentage points higher than nonusers; for trade credit, the gap is about 5 percentage points. These differences are statistically significant. In the full global sample,

Table 4.1A: Descriptive statistics, global green module, 2021–2024

	Micro	Small	Medium and large
Financing variables	**Mean (%)**	**Mean (%)**	**Mean (%)**
Fully credit constrained	20.1	14.7	8.3
Partially credit constrained	18.6	17.8	14.1
Credit unconstrained	61.4	67.5	77.6
Has a checking or savings account	84.2	90.5	92.8
Has a bank loan/line of credit	24.4	35.5	46.2
Uses banks to finance working capital	19.3	29.9	37.0
Uses supplier/customer credit to finance working capital	20.7	21.9	23.3
Total observations	**6,952**	**11,481**	**7,415**

Table 4.1B: Descriptive statistics, detailed green module, 2018–2020, ECA and MENA

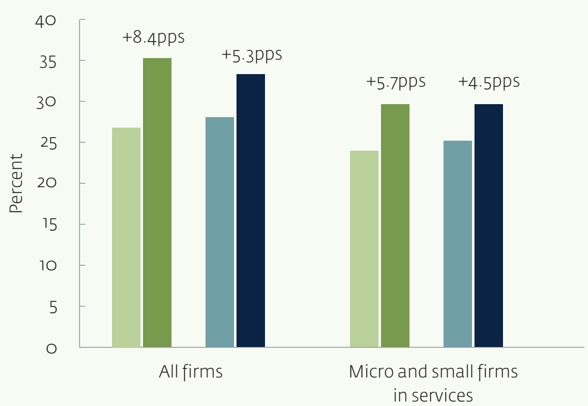
	Micro	Small	Medium and large
Financing variables	**Mean (%)**	**Mean (%)**	**Mean (%)**
Fully credit constrained	15.1	11.8	9.0
Partially credit constrained	17.2	16.5	12.8
Credit unconstrained	67.8	71.8	78.2
Has a checking or savings account	88.9	93.0	95.5
Has a bank loan/line of credit	24.3	33.6	46.9
Uses banks to finance working capital	23.3	33.0	41.6
Total observations	**5,129**	**9,310**	**6,713**

the ordinary least squares t-statistics are 3.73 for bank financing and 3.20 for trade credit, both significant at the 1 percent level. To check for robustness and ensure that larger firms are not driving the result, we re-test this for micro and small firms only. The difference remains statistically significant: at the 1 percent level, $t = 4.78$ for bank financing, and at the 5 percent level, $t = 2.62$ for trade credit financing. Finally, we abstract from sectoral effects by isolating micro and small firms in services only. This provides a lower bound to the adaptation financing effect, as those firms have fewer assets and are thus the most credit constrained and the least able to adapt. The differences remain statistically significant (at the 1 percent level, $t = 4.45$ for bank financing and $t = 2.78$ for trade credit financing). Panels B and C present these results for the three adaptation proxy measures available for ECA and MENA in the detailed green module, and the results stay the same. Firms that use banks to finance working capital have a higher adoption rate of adaptation measures, with increases ranging from 3 to 8 percentage points. These results suggest that limited access to finance may constrain smaller firms' ability to implement adaptation measures.

Figure 4.2: Firm adoption of adaptation measures by financing for working capital

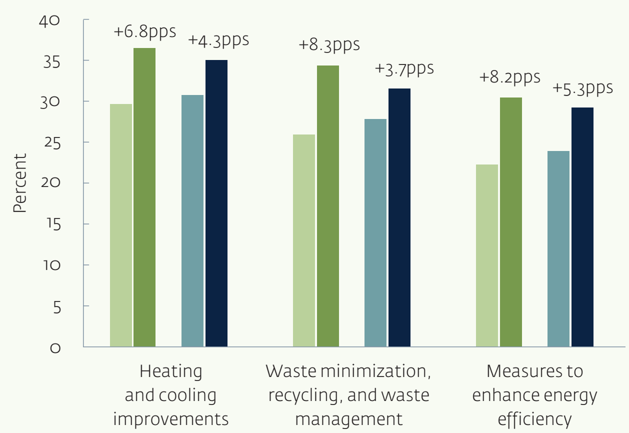
Panel A: Global green module, 2021–2024

Percentage of firms that adopted energy management measures (last three years)



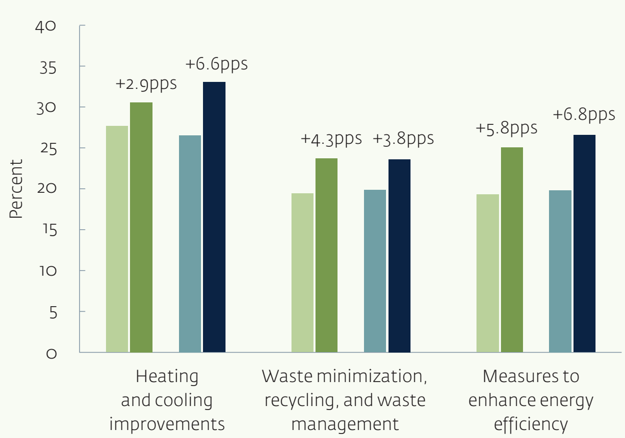
Panel B: Detailed green module, 2018–2020, ECA and MENA, all firms

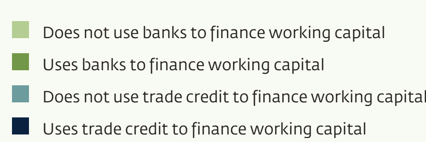
Percentage of firms that adopted these measures over the last three years



Panel C: Detailed green module, 2018–2020, ECA and MENA, micro and small firms only

Percentage of firms that adopted these measures (last three years)—micro and small firms in services





SOURCE: WBES and authors' calculations.
NOTE: The results account for the survey structure of the dataset by applying appropriate weights to calculate country-level averages. For regional averages, each country is treated as one, ensuring that the results are not driven by larger countries, such as Türkiye.

4.10 The regression results suggest that adaptation decisions at the firm level are related to financial access. We run probit regressions of the firm-level adaptation investment decision across four progressively richer specifications, adding firm characteristics, climate and country controls, a finance environment control, and region and sector fixed effects. All regressions use survey weights. Standard errors are clustered at the country level throughout. The progressively augmented specification structures are in Appendix E. Using bank financing increases the latent propensity to undertake adaptation by 0.43 standard deviations in the global sample and by 0.30 standard deviations in the ECA-MENA sample. For firms using trade finance, the figures are 0.36 for the global sample and 0.53 for the ECA-MENA sample. All results are statistically significant. The results for bank financing are stable across all specifications and both samples (tables 4.2 to 4.5). Trade credit shows large and significant marginal effects across all specifications. We further explore possible transmission channels through which finance influences the decision to adapt, including capacity and know-how, climate risks, liquidity, and the quality of regulation and institutions.

4.11 Capacity and know-how affect MSME adaptation decisions to some extent, but not for common, deeply familiar choices—such as electricity use—underpinned by years of experience and condensed wisdom. To explore transmission channels, it helps to treat climate adaptation as a specific form of high-risk, long-term innovation that is uniquely sensitive to finance. Adaptation may be stymied by MSME capacity and know-how (Howell 2017). Adding a proxy of the firm's "sophistication" (firm age, number of employees, foreign ownership dummy, exporter dummy, manager's years of experience in the sector) may explain away the finance effect. Looking at specification 2, we see that the significance of the finance variable is preserved across all regressions, including with the relatively less rich global data. Firm capacity is a very important determinant for adaptation—the magnitude of the coefficient halves in the global sample (the effect is much weaker in the ECA-MENA sample).[127] Adaptation choices in MSMEs, at least for common basics such as electricity, heating and cooling use, and waste, are not driven by limited capacity. This conflicts with established literature findings. More research is needed to understand the disconnect, but one possible reason could be that adaptation is an abstract concept, as are risks, expected benefits, and pricing. In contrast, years of experience with basics such as electricity use have condensed complex wisdom to a few easy-to-apply rules taught since childhood.

4.12 While some adaptation measures are used to manage climate risks, this is not the case for most firms—this channel is stronger in middle-income countries and for firms with access to bank finance. Adaptation may serve as a risk management mechanism to avoid losses rather than generate new revenue (Tian and Wang 2014). If this is the case, we should expect firms in countries exposed to greater climate risks to adopt more adaptation measures. When including climate exposure data (following Grover and Kahn 2024 and Huppertz 2025), the finance coefficient remains significant across specifications, dropping more in the bank-finance specification (Table 4.2), with the strongest effect in the ECA-MENA middle-income country specification (Table 4.3). In those cases, finance acts as more of a buffer against climate risks.

4.13 There is evidence that adaptation is prevented by tight liquidity among firms that use trade finance for working capital but not among those with access to banks. If this is the case, adding a proxy for the firm's financing constraints would eliminate the coefficient significance of the financing variable (see Hall and Lerner 2010). Specification 3 controls for firm-level perceptions of finance obstacles, as well as for the broader credit supply environment in the country. We see that bank finance remains significant, while trade credit disappears. More research is needed to substantiate this, but there may be distinct groups of firms with access to bank finance versus trade credit (comparing specification 3 in tables 4.2 and 4.4). Existing evidence confirms this dichotomy (Demirgüç-Kunt and Maksimovic 2002; Fisman and Love 2003). While firms with access to bank credit may not make adaptation decisions based on liquidity constraints, firms lacking bank access may use trade finance as a last resort (Kuntchev et al. 2012).

Table 4.2: Probit estimates—global sample, bank financing for working capital

Dependent variable: Energy management measures adopted

	(1) No controls	(2) Firm capacity	(3) +Climate risks	(4) +Liquidity	(5) +Institutions
Uses bank financing for working capital (dummy)	0.429*** (0.102)	0.257*** (0.069)	0.215*** (0.055)	0.179*** (0.063)	0.128** (0.065)
Firm capacity	No	Yes	Yes	Yes	Yes
Climate risks	No	No	Yes	Yes	Yes
Liquidity	No	No	No	Yes	Yes
Institutions	No	No	No	No	Yes
Observations	**21,716**	**20,492**	**19,189**	**18,926**	**18,926**

NOTE: Standard errors in parentheses.
Clustered standard errors at country level.
Firm controls: Log age, log employees, foreign ownership, exporter status, log manager experience.
Climate controls: ND-GAIN vulnerability index (standardized), ERA5 three-year temperature anomaly (standardized).
Country controls: Log GDP per capita.
Finance instruments: Finance obstacle dummy, leave-one-out country finance constraint.
* p<0.10, ** p<0.05, *** p<0.01.

Table 4.3: Probit estimates—ECA-MENA sample, bank financing for working capital

Dependent variable: Adoption of any adaptation measure (1 if yes, 0 otherwise)

	(1) No controls	(2) Firm capacity	(3) +Climate risks	(4) +Liquidity	(5) +Institutions
Uses bank financing for working capital (dummy)	0.303*** (0.115)	0.330*** (0.108)	0.203*** (0.056)	0.210*** (0.048)	0.198*** (0.042)
Firm capacity	No	Yes	Yes	Yes	Yes
Climate risks	No	No	Yes	Yes	Yes
Liquidity	No	No	No	Yes	Yes
Institutions	No	No	No	No	Yes
Observations	**19,055**	**18,239**	**17,675**	**17,348**	**17,348**

NOTE: Standard errors in parentheses.
Clustered standard errors at country level.
Firm controls: Log age, log employees, foreign ownership, exporter status, log manager experience.
Climate controls: Firm-level weather shock dummy (WBES), ND-GAIN vulnerability index (standardized), ERA5 three-year temperature anomaly (standardized).
Country controls: Log GDP per capita.
Finance instruments: Finance obstacle dummy, leave-one-out country finance constraint.
* p<0.10, ** p<0.05, *** p<0.01.

Table 4.4: Probit estimates—global sample, trade credit financing for working capital

Dependent variable: Energy management measures adopted

	(1) No controls	(2) Firm capacity	(3) +Climate risks	(4) +Liquidity	(5) +Institutions
Uses trade credit for working capital (dummy)	0.362***	0.153*	0.095	-0.019	-0.061
	(0.109)	(0.083)	(0.093)	(0.108)	(0.097)
Firm capacity	No	Yes	Yes	Yes	Yes
Climate risks	No	No	Yes	Yes	Yes
Liquidity	No	No	No	Yes	Yes
Institutions	No	No	No	No	Yes
Observations	**21,761**	**20,535**	**19,189**	**18,926**	**18,926**

NOTE: Standard errors in parentheses.
Clustered standard errors at country level.
Controls as listed in Table 4.2 notes above.
* p<0.10, ** p<0.05, *** p<0.01.

Table 4.5: Probit estimates—ECA-MENA sample, trade credit financing for working capital

Dependent variable: Adoption of any adaptation measure (1 if yes, 0 otherwise)

	(1) No controls	(2) Firm capacity	(3) +Climate risks	(4) +Liquidity	(5) +Institutions
Uses trade credit for working capital (dummy)	0.531***	0.449***	0.448***	0.453***	0.466***
	(0.143)	(0.117)	(0.109)	(0.109)	(0.108)
Firm capacity	No	Yes	Yes	Yes	Yes
Climate risks	No	No	Yes	Yes	Yes
Liquidity	No	No	No	Yes	Yes
Institutions	No	No	No	No	Yes
Observations	**19,094**	**18,275**	**17,706**	**17,379**	**17,379**

NOTE: Standard errors in parentheses.
Clustered standard errors at country level.
Controls as listed in Table 4.3 notes above.
* p<0.10, ** p<0.05, *** p<0.01.

4.14 The level of development of the financial system and the quality of institutions or the enabling regulations matter. In specification 3, we test how the relationship between adaptation and finance changes based on a country's level of financial development. The results are as expected: the less developed or more constrained a financial system is, the more important finance becomes for adaptation. In specification 4, we look at the role of country-, region-, and sector-specific characteristics, and we interpret that through a regulatory/institutional development lens. In related work, we look at the following alternative transmission channels: sectoral distinctions (for example, do low-capital expenditure sectors finance adaptation differently? Is there an agri-specific effect?); capital deepening as adaptation (do firms adapt more through equipment and machinery investment?); disentangling skills (firm size vs. managerial capacity), cross-border adaptation learning (via exports or foreign ownership), scale effects (interacting finance and firm size to disentangle big and small firms—does adaptation finance simply allow the firm to get bigger, and bigger firms to adapt better? In other words, is finance more effective for small firms due to relieving a bottleneck or large firms who generate economies of scale?), and financing tenor (does the tenor of financing matter—is adaptation solely a long-term story?). This ongoing research is not presented here due to its limited relevance to MSMEs and data constraints, but it is of interest when including all firms in the analysis.

Predictive effects and conclusion

4.15 Adaptation measures and associated financing have focused predominantly on large public climate investments, creating a blind spot for MSME activity. MSMEs—which employ the majority of workers in EMDEs—are adapting silently and incrementally, often using internal resources or informal finance. Using global WBES climate data, the empirical results reveal that adaptation among MSMEs is far more prevalent than commonly measured, with a lower bound of roughly one-third—and likely close to half—of MSMEs engaging in some form of adaptation. Yet financing remains a binding constraint to scaling adaptation further, which is of vital importance for economic resilience across EMDEs—countries exposed to relatively higher climate risks and adaptation costs than developed countries.

4.16 Standard metrics miss this activity because adaptation is specific to each country and geography, and difficult to standardize, measure, and classify. We offer a practical MSME Adaptation Finance Typology that maps specific adaptation actions to financing mechanisms and illustrate it with research evidence and examples from adaptation finance practitioners. This typology serves as an operational tool for banks, development finance institutions, policy makers, and MSME support organizations to identify adaptation demand and design fit-for-purpose finance products.

4.17 The adaptation imperative will only strengthen; forecasts of the economic impacts of climate effects point to stronger and more urgent needs. Studies either adjust for expected adaptation or compute the implied adaptation gap, as discussed further below. GDP impact is most frequently the focus, but other aspects such as health, agricultural yields, and firm outcomes are also studied. For example, the short-term impact on GDP growth is 0.1 percentage points for disasters in the 75th percentile of severity, 0.46 percentage points for those in the 95th percentile, and 6.9 percentage points for disasters in the 99th percentile (Felbermayr and Groeschl 2014). Hsiang and Jina (2014) find small but persistent long-run growth losses from climate, which accumulate: a 90th percentile event reduces per capita incomes by 7.4 percent two decades later, effectively undoing 3.7 years of average development. Dellink et al. (2019) examine climate damages to 2060 in a multi-region, multi-sector dynamic computable general equilibrium, including changes in crop yields and fisheries catches, loss of land and capital, labor productivity and health changes, changes in tourism flows, and changes in energy demand for cooling and heating. Global annual GDP losses rise twice as fast as global economic activity, to 1–3.3 percent by 2060, with labor productivity and agriculture having the largest negative economic consequences; damages are especially large in Africa and Asia. This is confirmed by ILO (2019), which finds that Southern Asia and Western Africa are projected to experience the largest productivity losses, estimated at 4.8 percent and 4.6 percent, respectively, by 2030, which correspond to about 40 million and 9 million full-time jobs, respectively. Productivity declines from extreme heat stress alone will cause the loss of 80 million jobs globally by 2030 (ILO 2019). For a hot/dry climate scenario in 2050, labor productivity losses from heat stress in services, industry, and agriculture are estimated at –4.1, –6.0, and –8.5 percent, respectively, in lower-income countries; at –5.3, –6.5, and –9.2 percent in lower-middle-income countries; and at –2.5, –3.9, and –6.8 percent in upper-middle-income countries (World Bank Group 2025). Carleton and Hsiang (2016) compute that future warming slows global economic growth rates by about 0.28 percentage points per year, with an additional $9.7 trillion in present-value losses due to cyclones.[128] They find that in Africa, crop yields are likely to decline by 17–22 percent for maize, sorghum, millet, and groundnuts by 2050. If better water management policies are not implemented, GDP losses in regions such as India, China, Central Asia, and much of Africa could range from 6 percent to 12 percent by 2050 (GCA 2019). Transport effects are significant as well: heat alone will account for about 92 percent of total hazard damage in Europe's transport sector by 2080, largely because roads are built for cooler times (Forzieri et al. 2018). By 2035, the average listed infrastructure and transportation company is projected to incur fixed-asset losses of $50–$53 million annually due to climate hazards (roughly 7 percent of earnings), with figures rising further by 2055 (Kuehne Climate Center 2025). At the firm level, Huppertz (2025) estimates the impact of climate change on Zambian firms' sales under three different climate change scenarios, using predictions from 27 different climate models for each scenario. Under a severe climate change scenario, the average Zambian firm faces an almost 19 percent decrease in sales by the 2080s. Even under a mild scenario, sales would drop by almost 9 percent.[129]

4.18 Predictive data are of specific interest to measure the effect of future adaptation. Extensive adaptation of infrastructure, operations, and service provisions will be crucial to mitigate climate impacts. However, Burke and Emerick (2016) show that longer-run adaptations mitigate less than half—and more likely none—of the large negative short-run impacts of extreme heat on productivity. Carleton and Hsiang (2016) find that effective adaptation to temperature at the macro level is limited, and once temperatures exceed the optimum, each 1°C increase reduces economic production by roughly 1–1.7 percent. Hultgren et al. (2025) estimate the impact of global producer adaptations for six staple crops spanning 12,658 regions (or two-thirds of global crop calories). Global production declines by the equivalent of 4.4 percent of recommended consumption for every 1°C increase in temperature. Adaptation and income growth are projected to alleviate 23 percent of these global losses by 2050 and 34 percent by the end of the century (or 6 percent and 12 percent, respectively, in a moderate-emissions scenario), but substantial residual losses remain for all staples except rice. Worst-case-scenario models (without adaptation) estimate that global agricultural productivity may decrease by 17 percent by 2050 and by as much as 50 percent in Africa (World Bank 2024a). While impacts on GDP, social outcomes, and conflict are predicted to cause the greatest damage to the global poor, global impacts on crops in low-income regions are somewhat moderated because losses are concentrated in today's breadbasket regions, which have favorable climates but limited adaptation. These studies show that current adaptation technology is inadequate to address most climate change impacts.

4.19 Forecasts of climate effects on employment show significant impacts on hours worked and productivity, while migration only provides imperfect adaptation. Carleton and Hsiang (2016) conclude that heat stress can lower work intensity, reduce cognitive performance, and voluntarily shorten work hours in affected sectors such as construction and agriculture.[130] By 2030, a global temperature rise of 1.5°C could lead to a 2.2–3.8 percent loss in worldwide working hours due to high temperatures, equivalent to 80–136 million full-time jobs (ILO 2019; compared with 1.4 percent in 1995 or 35 million jobs).[131] The number of hours worked in industries highly exposed to climatic conditions, including agriculture, construction, mining, and manufacturing, will decline by an hour on days when temperatures exceed 29°C (ILO 2019). Future global economic heat-related productivity losses are estimated to be in the range of 0.4–2.9 percent of global GDP in 2100 after accounting for adaptation (Zhao et al. 2021).[132] Heat also lowers labor productivity through direct impacts on worker capacity and indirect changes in time use—for example, lower cognitive performance among workers in Indonesia (Masuda et al. 2020), needing 44 percent more breaks (Masuda et al. 2021), and spending less time working in China (Garg et al. 2020) and across LMICs (LoPalo 2023). Dunne et al. (2013) estimate that by 2050, labor productivity could decrease by up to 80 percent in the hottest months globally and that up to 40 percent of daylight hours could be too hot to work in some tropical and subtropical latitudes. In addition to heat, extreme variations in precipitation and increasingly severe natural disasters could impact labor productivity. Market frictions may limit the adaptive potential of migration (Goicoechea and Lang 2023): the temperature-migration link only holds for out-migration from countries that are the most dependent on agriculture (Cai et al. 2016). The link also holds in middle-income countries, while in LICs temperature shocks reduce the likelihood of migration (Cattaneo and Peri 2016).[133]

4.20 Implications for action.

For banks and development finance institutions: The findings on prevalence and financing constraints suggest significant unfulfilled demand for adaptation finance products. The MSME Adaptation Finance Typology (Part 3) identifies specific adaptation actions and their corresponding financing needs, enabling product design and portfolio targeting.

For policy makers: The data show that MSME adaptation is market driven and occurring at scale, but policy can accelerate it by (i) strengthening enabling frameworks for adaptation finance (credit bureaus, collateral registries, payment infrastructure); (ii) de-risking through first-loss guarantees and public-private partnerships; and (iii) improving climate information and early warning systems so firms can make informed decisions on adaptation investments.

For MSME support organizations (NGOs, business associations, extension services): Coupling technical assistance with finance access dramatically improves adaptation outcomes. Bundled offerings—combining advice on adaptation options with links to credit, insurance, and grant funding—outperform finance-only or technical-assistance-only approaches.

Appendixes, notes, *and* bibliography

Appendix A: WBES data description

Table A.1: WBES firm distribution by country

Panel A: Detailed green module, 2018–2020, ECA and MENA

Country/region	Firms	Micro	Small	Medium	Large	Manu-facturing	Retail	Other services
Europe and Central Asia	**14,868**	**3,471**	**6,453**	**3,881**	**1,063**	**8,677**	**2,246**	**3,945**
Albania (2019)	377	102	139	118	18	146	77	154
Armenia (2020)	546	155	230	132	29	275	129	142
Azerbaijan (2019)	225	59	100	52	14	53	58	114
Belarus (2018)	600	130	221	179	70	330	123	147
Bosnia and Herzegovina (2019)	362	76	147	108	31	134	93	135
Bulgaria (2019)	772	175	334	215	48	428	138	206
Georgia (2019)	581	129	299	121	32	205	114	262
Kazakhstan (2019)	1,446	384	656	332	74	926	180	340
Kosovo (2019)	271	55	122	43	51	148		123
Kyrgyz Republic (2019)	360	61	183	88	28	147	93	120
Moldova (2019)	360	87	150	98	25	138	100	122
Montenegro (2019)	150	49	46	48	7	65		85
North Macedonia (2019)	360	77	151	111	21	133	112	115
Poland (2019)	1,369	404	534	323	108	1,004	110	255
Romania (2019)	814	173	371	214	56	518	128	168
Russian Federation (2019)	1,323	227	573	408	115	889	151	283
Serbia (2019)	361	71	143	110	37	127	104	130
Tajikistan (2019)	352	84	166	80	22	160	73	119
Türkiye (2019)	1,663	379	720	467	97	1,065	222	376
Ukraine (2019)	1,337	257	617	370	93	945	115	277
Uzbekistan (2019)	1,239	337	551	264	87	841	126	272
Middle East and North Africa	**6,284**	**1,658**	**2,857**	**1,334**	**435**	**3,508**	**374**	**2,402**
Egypt, Arab Rep. (2020)	3,075	836	1,496	512	231	1,992		1,083
Jordan (2019)	601	208	272	85	36	291	84	226
Lebanon (2019)	532	169	228	126	9	268		264
Morocco (2019)	1,096	214	443	323	116	463	189	444
Tunisia (2020)	615	115	247	221	32	365		250
West Bank and Gaza (2019)	365	116	171	67	11	129	101	135
Total	**21,152**	**5,129**	**9,310**	**5,215**	**1,498**	**12,185**	**2,620**	**6,347**

Table A.1: WBES firm distribution by country

Panel B: Global green module, 2021–2024

Country/region	Firms	Micro	Small	Medium	Large	Manu-facturing	Retail	Other services
Africa	**5,149**	**1,613**	**2,448**	**851**	**237**	**1,770**	**853**	**2,526**
Botswana (2023)	622	192	317	100	13	163	159	300
Central African Republic (2023)	151	38	97	16		32		119
Chad (2023)	164	74	73	16	1	81		83
Congo, Rep. (2024)	365	152	125	67	21	104	94	167
Côte d'Ivoire (2023)	649	156	330	120	43	273	142	234
Gambia, The (2023)	162	62	81	19		76		86
Ghana (2023)	713	170	396	128	19	232	121	360
Lesotho (2023)	150	58	58	18	16	57		93
Madagascar (2022)	402	187	131	63	21	126	89	187
Mauritius (2023)	353	63	200	64	26	116	74	163
Rwanda (2023)	358	96	156	79	27	132	75	151
Seychelles (2023)	103	35	52	13	3	27		76
Sierra Leone (2023)	209	105	89	15		101		108
Tanzania (2023)	600	174	290	103	33	196	99	305
Togo (2023)	148	51	53	30	14	54		94
East Asia and Pacific	**7,231**	**2,335**	**2,944**	**1,553**	**399**	**2,997**	**818**	**3,416**
Cambodia (2023)	519	180	171	87	81	264	94	161
Hong Kong SAR, China (2023)	598	204	306	79	9	92		506
Indonesia (2023)	2,955	1,155	1,109	588	103	1,385	488	1,082
Philippines (2023)	1,002	233	401	294	74	430	140	432
Samoa (2023)	157	81	67	8	1	45		112
Singapore (2023)	623	146	311	151	15	122		501
Timor-Leste (2021)	238	115	94	28	1	82		156
Vanuatu (2023)	111	48	52	11		11		100
Vietnam (2023)	1,028	173	433	307	115	566	96	366
Europe and Central Asia	**3,611**	**773**	**1,551**	**1,059**	**228**	**1,646**	**535**	**1,430**
Bosnia and Herzegovina (2023)	351	81	131	106	33	131	90	130
Bulgaria (2023)	710	136	272	259	43	376	86	248
Georgia (2023)	592	127	299	128	38	226	116	250
Kyrgyz Republic (2023)	354	65	189	88	12	155	34	165
Moldova (2024)	152	37	47	55	13	76		76
Montenegro (2023)	151	46	56	42	7	69		82
North Macedonia (2023)	354	69	139	117	29	120	98	136
Romania (2023)	947	212	418	264	53	493	111	343

Table A.1: WBES firm distribution by country

Panel B: Global green module, 2021–2024

Country/region	Firms	Micro	Small	Medium	Large	Manu-facturing	Retail	Other services
Latin America and Caribbean	**4,845**	**1,022**	**2,152**	**1,391**	**280**	**2,035**	**784**	**2,026**
Barbados (2023)	153	45	77	29	2	63		90
Colombia (2023)	919	215	431	215	58	294	168	457
Costa Rica (2023)	357	79	155	105	18	113	72	172
El Salvador (2023)	729	190	338	152	49	339	130	260
Mexico (2023)	1,322	228	532	502	60	669	171	482
Paraguay (2023)	378	79	156	118	25	107	87	184
Peru (2023)	987	186	463	270	68	450	156	381
Middle East and North Africa	**1,977**	**534**	**1,050**	**312**	**81**	**818**	**178**	**981**
Iraq (2022)	1,019	356	573	58	32	375		644
Morocco (2023)	598	64	313	182	39	310	84	204
West Bank and Gaza (2023)	360	114	164	72	10	133	94	133
South Asia	**3,035**	**675**	**1,336**	**812**	**212**	**1,677**	**398**	**960**
Bangladesh (2022)	998	206	489	201	102	544	130	324
Bhutan (2024)	155	52	74	25	4	69		86
Nepal (2023)	582	194	253	114	21	215	87	280
Pakistan (2022)	1,300	223	520	472	85	849	181	270
Total	**25,848**	**6,952**	**11,481**	**5,978**	**1,437**	**10,943**	**3,566**	**11,339**

Table A.2: WBES firm distribution by sector

Panel A: Detailed green module, 2018–2020, ECA and MENA

Sector	Europe and Central Asia	Middle East and North Africa
C. Manufacturing	8,549	3,490
E. Water supply; sewerage, waste management, and remediation activities	66	7
F. Construction	1,050	513
G. Wholesale and retail trade; repair of motor vehicles and motorcycles	3,744	1,390
H. Transportation and storage	481	241
I. Accommodation and food service activities	595	442
J–S. Other services	383	201

Panel B: Global green module, 2021–2024

Sector	Africa	East Asia and Pacific	Europe and Central Asia	Latin America and Caribbean	Middle East and North Africa	South Asia
C. Manufacturing	1,767	2,986	1,646	2,035	816	1,677
F. Construction	320	571	417	494	239	43
G. Wholesale and retail trade; repair of motor vehicles and motorcycles	1,714	1,878	960	1,385	480	637
H. Transportation and storage	198	248	191	173	75	45
I. Accommodation and food service activities	898	918	235	595	263	541
J–S. Other services	252	630	162	163	104	92

Appendix B: Notable existing typologies of MSME climate-smart products and inputs

IFC's Sustainable MSME Finance Reference Guide supports financial intermediaries with MSME climate finance by providing step-by-step technical instructions and a typology of eligible climate activities (mitigation and adaptation) in five sectors: agribusiness, textiles, tourism, other manufacturing, and other services. Another important classification is found in UNEP's Demystifying Adaptation Finance for the Private Sector, which contains an exhaustive list of debt and equity instruments, linking them where available with examples of how they have funded adaptation. The report also provides a matrix of adaptation measures, linked to case studies, but falls short of analyzing the suitability of funding tools for adaptation or providing evidence beyond the examples. The UNFCCC's Private Sector Initiative provides an online database of over 100 self-reported case studies of adaptation activities by private companies from around the world and a wide range of sectors, including water, food and agriculture, transport and infrastructure, and tourism. While this is a rare large database of private sector engagement in adaptation and is frequently used in research (for example, Surminski 2013; Pauw et al. 2015), the case studies focus mostly on multinational firms, with relatively poor representation of EMDEs and MSMEs. The UNDRR Guide for Adaptation and Resilience Finance provides a largely comprehensive list of investable adaptation activities, though it is not specifically tailored to MSMEs. However, it falls short of linking these activities to financing or organizing them into a typology.

Other notable compendiums include the NAP Global Network inventory of adaptation finance mechanisms, which lists adaptation-specific financing (with case study examples where available), geared mostly to large companies or to countries, with little MSME-suited content, as well as the Climate Resilience Investments in Solutions Principles (CRISP) classification, which focuses exclusively on the supply side of adaptation and stops short of including appropriate financing instruments, but does encompass both ex-ante and ex-post adaptation. The CRISP classification itself builds on the 2020 Adaptations Solutions Taxonomy produced by the Lightsmith Group, created around an accelerator program aimed at identifying MSMEs offering adaptation solutions in EMDEs. By design, it targets early-stage investors and specific geographies. The Adaptation and Resilience Investors Collaborative, an international partnership of development finance organizations, has also developed a framework for classification and impact measurement of adaptation and resilience investments, without a link to financing. The Center for Financial Inclusion developed a Green Inclusive Finance Framework that links financial products and services to climate risks (mitigation, adaptation, resilience, and transition), focused on low-income households rather than MSMEs. The focus of the Climate Innovation for Adaptation and Resilience (CIFAR) Alliance is similar, but rather than presenting a structured framework, CIFAR shares lessons and examples of how different financial instruments can be applied to adaptation for these populations, particularly through initiatives such as its "Co-Labs." A niche taxonomy also worth mentioning is the Climate Bonds Resilience Taxonomy Methodology, which was developed by several multilateral development banks for financial intermediaries to expand their resilience lending by issuing bonds.

Appendix C: Climate-smart agricultural processes and inputs

- ***Climate-resilient crops***: Enhanced or drought-resistant seeds, research and development on new varieties, fewer water-intensive crops.
- ***Crop rotation***: Changes in inputs to maintain soil health and diversity.
- ***No-till agriculture***: Reducing or eliminating tillage can help minimize soil erosion and maintain soil health.
- ***Vertical farming***: Yields of up to 240 times higher, using 98 percent less water and 99 percent less land.
- ***Cover crops***: Cover crops such as clover can help prevent soil erosion and replenish nutrients.
- ***Diversification***: Diversifying along the value chain reduces risk (for example, improving transport, storage, and marketing along the supply chain can reduce post-harvest losses and greenhouse gas emissions).
- ***Climate-smart fertilizer***: Crop protection chemicals.
- ***Integrated pest management***: Using strategies such as biological control, crop rotation, and chemical controls to manage pests and diseases.
- ***Agroforestry***: Integrating trees into agricultural landscapes on the edges of or between fields, afforestation and reforestation including restoring drylands, seagrasses and kelp conservation (replanting), nature-based flooding solutions including mangrove conservation and replanting, planting of water reclamation plants in water-stressed areas, coastal restoration, reforestation of flood and drought-prone areas.
- ***Managed grazing***: Moving livestock to different pastures so they can graze on different plants.
- ***Climate-resilient livestock infrastructure***: For example, temperature regulation technology such as cooling sheds, and emergency shelters.
- ***Climate-smart sustainable fisheries management***: Biodiverse agroeconomic systems, aquatic food systems.
- ***Climate-smart irrigation***: Water conservation (drip irrigation, more efficient irrigation—pressurized irrigation technologies, reusing treated wastewater from food production), water storage (groundwater storage, rainwater harvesting, low-tech solutions such as water catchment), pollution prevention (flood-proof pit latrines, water purification), solar water pumps, solar water harvesting, water delivery.
- ***Agricultural technology, data tools, and planning***: ICT to promote awareness, service support, and delivery (Farmerline in Ghana provides personalized voice alerts that communicate critical information on price, weather, and farming techniques; direct access support lines for advice; and data collection).

Appendix D: Asset- and trade-based financing tools for MSMEs

Financing based on accounts payable

- Reverse factoring
- Buyer-centric financing or approved-payables finance
- Dynamic discounting
- Purchase order financing
- Merchant cash advances
- Vendor credit
- Selling goods on installments
- Distributor finance or channel financing

Financing based on accounts receivable

- Factoring
- Discounting
- Invoice financing
- Invoice factoring
- Receivables purchase
- Forfaiting
- Customer advances
- Revenue-based financing
- Monthly recurring revenue line of credit
- Loan advances against receivables

Other financing mechanisms

- Pre-shipment finance
- Other inventory finance (refinancing by specialized provider, refinancing by means of purchase of receivables, and refinancing by means of credit line)
- Inventory repurchase or buy-back agreement
- Toll manufacturing finance
- Overdrafts
- Cash-flow loans
- Working capital revolvers
- Unsecured short-term debt that firms issue

Related/derivative methods of financing

- Asset-based financing
- Documentary trade finance
- Payments and foreign exchange

Appendix E: Robustness specifications

Several biases may affect the analysis. First, cross-country comparability is challenging because climate impacts are highly regional, and sometimes country-specific, and some areas are significantly more exposed to climate risks than others. With a cross-country sample such as WBES, regional climate effects may be obscured. To control for this, climate exposure data were used as a robustness check (following Grover and Kahn 2024 and Huppertz 2025). Berkeley Earth provides global historical climate data on temperature trends. Its datasets combine land-based stations, ocean records, and satellite observations. As an additional check, the IMF-adapted Notre Dame Global Adaptation Initiative (ND-GAIN) Index was incorporated as a country-level control for vulnerability and adaptive capacity, helping account for cross-national differences in baseline resilience to climate risks.

The ND-GAIN index is a country-level indicator of vulnerability to climate change and readiness to improve resilience. The index captures two dimensions: (i) vulnerability, assessing exposure, sensitivity, and adaptive capacity across sectors such as food, water, health, ecosystem services, human habitat, and infrastructure; and (ii) readiness, which measures a country's ability to leverage investments and convert them to adaptation actions through three components: economic, governance, and social readiness.

Second, sample size constraints could lead to the under-representation of micro and small enterprises, as larger firms tend to be overrepresented in WBES (Cirera et al. 2020). This could result in large firms disproportionately influencing the observed effects. To mitigate this, the analysis controls for firm size.

Third, sectoral biases may arise due to differences in exposure to climate risks across industries. To address this, the study isolates firms at the two-digit Standard Industrial Classification sector level.

Finally, there is a timing bias in the absence of time-series data. Some variation exists between the detailed WBES module (pre-COVID-19) and the global module (post-COVID-19). The lack of a time-series dataset remains a significant limitation.

All probit regressions use the following progressively augmented specification structure:

- ***No controls***.
- ***Firm capacity controls***: Log firm age, log number of employees, a foreign ownership dummy, an exporter dummy, and the log of the top manager's years of experience in the sector.
- ***Climate risk controls***: This specification adds the standardized ND-GAIN country vulnerability index (capturing structural climate exposure), the standardized ERA5 three-year temperature anomaly (capturing recent local climate variation), and log GDP per capita (capturing income-related adaptation capacity). For the ECA-MENA sample, this specification also includes climate_shock, a dummy equal to 1 if the firm reported losses from extreme weather events in the prior three years.
- ***Liquidity controls***: Two variables are added to address the concern that financing access and adaptation propensity may share common unobserved determinants. The first is fin_obstacles, a firm-level dummy equal to 1 if the firm rates access to finance as a major or very severe obstacle to its operations. The second is loofin_obstacle, the leave-one-out country average of fin_obstacle, computed as the country aggregate minus the firm's own response, divided by the number of remaining firms. This leave-one-out variable captures the broader credit supply environment in the country, independent of the individual firm's own circumstances, and approximates the approach of using average peer-firm financial constraints as a proxy for exogenous credit conditions.
- ***Quality of institutions and regulation controls***: Region and sector fixed effects (global sample) or country and sector fixed effects (ECA-MENA sample).

Notes

1 World Bank (2024b, 2025). The cost of natural disasters for International Development Association countries was 1.3 percent, compared with 0.3 percent for other EMDEs over 2011–2022 (World Bank 2024d).

2 We take adaptation to mean "the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities" (IPCC 2014). Resilience is "the capacity of a system—natural, social, or economic—to absorb, recover from, and adapt to shocks while maintaining essential functions" (IPCC 2023). However, to date there is no consensus on a strict definition of adaptation.

3 We follow the Climate Resilience Classification Framework proposed in UNDRR (2023), which provides a standardized list of climate change impacts. This list includes the direct effects of extreme temperatures (*heat and cold*); floods, droughts, and fires (*wet and dry*); wind and sand storms (*wind*); heavy snow and avalanches as well as glaciers and lake, river, and sea ice (*snow and ice*); air pollution, carbon dioxide, or radiation at surface; effects related to sea levels (*coastal*); ocean temperatures and acidity (*open ocean*); indirect effects related to changes in terrestrial, freshwater, and ocean ecosystems (*impact on ecosystems*); and effects on human economic activities, health, and infrastructure (*impacts on human systems*).

4 People exposed to climate hazards with a propensity to be adversely affected or unable to cope (World Bank Group Scorecard 2026; IPCC 2023).

5 These estimates, which are from the latest World Bank Climate Change and Development Report Summary Report, assume current policies.

6 These impacts have been modeled via quantitative general equilibrium models (Bilal and Rossi-Hansberg 2023; Desmet and Rossi-Hansberg 2024) or integrated assessment models and process-based models (Diaz and Moore 2017; Martinich and Crimmins 2019). In part due to data and modeling limitations, the literature has yet to converge on benefit estimates (for example, Docquier et al. 2019; Laborde and Gouel 2019; Rossi-Hansberg et al. 2021 on trade and migration).

7 The literature also looks at how cash transfers moderate the effects of weather shocks on outcomes, including educational and labor market outcomes in Mexico (Adhvaryu et al. 2024); consumption and food security in Zambia (Asfaw et al. 2017); savings, asset accumulation, and income smoothing in rural Niger (Premand and Stoeffler 2022) and Nicaragua (Macours et al. 2022); and violence in Indonesia (Christian et al. 2019).

8 In 10 particularly afflicted countries, it was more than half the population; 80 percent of these countries are in Africa.

9 This study is focused on ex-ante adaptation finance, as rebuilding efforts are likely to rely on humanitarian aid rather than private sector investment.

10 Such studies use variations of (i) prices of ex-ante or ex-post adaptation technologies (for example, Aker and Jack 2023; Björkman-Nyqvist et al. 2023); (ii) income (for example, Macours et al. 2022; Premand and Stoeffler 2022); or (iii) frictions and constraints in the adaptation decision environment to assess their impact on climate damages and on specific adaptive actions, behaviors, or investments (for example, Shrader et al. 2023, and many cited in this section).

11 The size advantage dissipates over time (Grover and Kahn 2024).

12 Over 60 percent of the businesses cited direct loss of inventories and about 50 percent of affected businesses mentioned nonstructural building damages. Half of small and medium enterprises had equipment damage due to floods, compared with 34 percent of large businesses, and 27 percent cited vehicle damage, compared with 17 percent of large businesses. In terms of indirect losses, 63 percent of small and medium enterprises experienced flood impacts on their customers, compared with 44 percent of large businesses. Supply-chain disruptions affected more than half of all businesses, and over two-thirds of small firms.

13 Lui et al. (2023) find that heat lowers agricultural productivity, which in turn reduces demand for nonagricultural goods, services, and labor. Somanathan et al. (2021) argue that heat primarily reduces the output elasticity of labor, rather than affecting capital or other inputs.

14 Indirect effects (through infrastructure systems such as electricity and transport, supply chains, and workers) are more prevalent and sizable than direct on-site damages. Rentschler et al. estimate that supply-chain multipliers are responsible for 30–50 percent of all flood-related delivery delays.

15 Agarwal et al. (2025) find a drop of 12.4 percent in sales on US data following hurricanes. The impact was sector-specific. Hotels and gas stations were more resilient than restaurants, retail, and home-improvement stores. Independent stores are more vulnerable than chains.

16 But not always: for example, the benefits of air conditioning in MSME offices pay off quickly and yet there is underinvestment.

17 Management's effect on energy intensity varies with factor costs. Better managed firms conserve in the face of high prices but intensify use if prices are lower. For manufacturing in Eastern Europe, the negative correlation between management practices and energy (expenditure) intensity is much higher in magnitude when energy prices are low (subsidized) than when they are high (Schweiger and Stepanov 2019).

18 For example, Nath (2023) finds that if the poorest quartile of countries went to OECD levels of trade openness, climate-related productivity shocks would be reduced by 70 percent. Infrastructure affects market competition and hence adaptation (see Brooks and Donovan 2020 for Rwanda; Barwick et al. 2022 for China; Balboni et al. 2023 for Pakistan; and Kochhar and Song 2023 for India). Chakravorty et al. (2023) show that the use of fixed fees rather than marginal prices affects the adoption of a water-saving technology in Bangladesh.

19 More research is needed on how firms form expectations. Kala (2017) models expectations formation among farmers, but much less is known about firms more broadly. Firms may learn from investors, whose changing valuations shape incentives, or from lenders, who may alter the cost of debt in response to climate risks (Goicoechea and Lang 2023). However, these signals are likely to be less accessible to small and medium enterprises, particularly in LMICs.

20 Burlig et al. (2024) combine variation in weather forecasts with careful measurement of farmer beliefs and find that more accurate information changes farmers' investment decisions. Consistent with a Bayesian updating model, that the direction of these changes depends on farmers' prior beliefs. Similarly, Kala (2017) shows that farmers respond to greater uncertainty in their environment by modifying their predictions to be robust to such uncertainty.

[21] More research is needed on the ability of firms to accurately evaluate climate risks. Two studies that document ex-ante adjustments to weather shocks and associated costs are Letta et al. (2022), who show that grain traders in India raise prices well in advance of the harvest in response to negative weather forecasts, and Balboni et al. (2023), who show that Pakistan firms relocate to less flood-prone areas to reduce climate risk.

[22] Ninety-two percent of MSMEs in Africa are informal, the highest share among all regions. Women make up a significant portion of the agricultural workforce and play a vital role in forest management (Wedeman and Petruney 2019).

[23] For example, Cambio Score is an open-source, data-driven framework that quantifies climate change impacts for MSMEs in EMDEs, reducing information costs and tailoring the data to the specific MSME and its country context. UNEP DTU (2018) presents a case study where Cambio Score successfully identifies and prioritizes areas of vulnerability and means of climate change readiness for a medical-supply MSME in Bangladesh.

[24] UNEP (2023b) estimates are $140–$446 billion per year for all developing countries this decade.

[25] For example, water efficiency can reduce costs and increase resilience to water scarcity, and drip irrigation can generate positive financial returns. Every $1 spent on coastal protection avoids $14 in damages (UNEP 2025). Access to healthcare services can moderate the mortality-heat relationship (see Cohen and Dechezleprêtre 2022 for Mexico; Björkman Nyqvist et al. 2023 for Uganda). Climate-adapted agricultural technologies such as new seed varieties can improve household welfare (Emerick et al. 2016; Aker and Jack 2023).

[26] Bankable projects in upfront adaptation as distinct from public investments or adaptation needs.

[27] Examples include building materials (Franco and Hanna Collado 2016), new agricultural systems, community resilience building, and products linked to carbon markets (such as solar panels, drip irrigation, resistant seeds, and electric vehicles) where MSMEs can participate in the supply chain or as end users. Other MSME-specific products with market-based promise are embedded/integrated insurance (Sirtaine and Wattez-Richard 2024), early warning, bundled products with customer service such as biodigester asset finance (Highet et al. 2024), pay-as-you-go solar (Lighting Global/ESMAP et al. 2022), a mobile layaway product to pay in installments for climate-smart agricultural inputs, and farmer training (CGAP 2024b). Contingent savings/lines of credit ("insurance without premiums") resulted in farmers investing 18 percent more in land, and a 19 percent increase in output in flooded locations (Lane 2024).

[28] Studies from Sri Lanka, South Africa, and Vietnam show that MSMEs are concerned with cultivating positive community relationships. In this sense, they can also have a social "license to operate" when it comes to adaptation. For example, MSMEs can educate households on actions they can take and items they can purchase to increase their resilience to extreme weather and climate events.

[29] See also Syafri et al. (2021) for Indonesia; Chege and Wang (2020) for Kenya; Bacinello et al. (2019) for Brazil; Qiu et al. (2020) for China; Asif et al. (2021) for Pakistan; and Suat and San (2019) for Malaysia.

[30] MSMEs account for over 95 percent of all firms, contribute up to 40 percent of GDP, and generate seven out of 10 formal jobs in EMDEs (Nenova 2026).

[31] IDFC (2021) estimates adaptation at 21.1 percent in its sample of climate finance from national development finance institutions in 2020 (with mitigation at 78.9 percent).

[32] CPI (2022) has private adaptation finance at $0.5 billion each by institutional investors and private enterprises, with smaller firms glaringly omitted. The OECD (2023) estimates private finance for adaptation at $1.2 billion per year in 2016–2021, with 30 percent going to industry, mining, and construction; 16 percent to energy; 13 percent to water and sanitation; 11 percent to agriculture, forestry, and fishing; and 8 percent to banking and financial services (significantly different from the sectoral distribution of public adaptation finance). Multilateral development banks mobilized 55 percent of private adaptation finance; bilateral provider countries 30 percent, and multilateral climate funds 15 percent. Investment was done directly (44 percent) and through guarantees (17 percent), syndicated loans (15 percent), simple co-financing (13 percent), shares in collective investment vehicles (8 percent), and credit lines (3 percent). A quarter of private finance mobilized for adaptation went to LICs, 24 percent to LMICs, 20 percent to upper-middle-income countries, and 13 percent to high-income countries. Private investment in adaptation generates positive financial returns in banking and financial services, energy generation (OECD 2023), agriculture (World Bank 2019), and water use (Oehling et al. 2025), but even in these sectors financial returns are typically lower than economic returns.

[33] Specifically, the private sector adaptation investment flows are tracked at about $5 billion per year, with a potential of $50 billion per year. UNEP (2025) estimates adaptation costs of $310–$365 billion per year, primarily considering activities that involve adaptation actions typically funded by the public sector or by a mix of the public and private sectors. UNEP (2025) estimates do not include the costs of adaptation activities funded by the private sector. UNEP does not count private adaptation investments for which financial support has not been requested in national adaptation plans or nationally determined contributions, such as climate-proofing private sector assets, but estimates those indicatively at more than $250 billion per year for EMDEs by 2035 (UNEP 2025).

[34] The World Bank (2025) finds that income growth plays a larger role in building resilience than climate adaptation itself: 79 percent of the reduction in climate-related mortality is attributed to rising incomes, compared with 21 percent attributable to adapting to climate change.

[35] Catastrophe bonds have also been found to be highly effective in mitigating the welfare effects of hurricanes but are not readily available to all vulnerable nations (Borensztein et al. 2017; Mallucci 2022; Phan and Schwartzman 2024). A more detailed discussion can be found in Carleton et al. (2025).

[36] Financial market participants value climate risk information: a 1 percent improvement in climate forecasts reduces firms' exposure to a one standard deviation shock by $18 billion and induces traders to spend an additional $2 million hedging the outlook's news (Lemoine and Kapnick 2024). Schlenker and Taylor (2021) compare the prices of US financial derivatives, whose payouts are based on future weather outcomes, to climate model predictions and observed weather data, and find that derivative prices respond both to short-term weather forecasts and longer-term warming trends.

[37] While mapping trends in adaptation finance over time is difficult due to changing methods, UNEP (2025) highlights that the adaptation finance gap is not narrowing. UNEP (2016) estimated the gap at 7–13 times current finance flows, while UNEP (2023b) placed it at 10–18 times. The gap changed little between the 2023 and 2024 Adaptation Gap Reports, despite international public adaptation finance flows rising from $21 billion in 2021 to $27.5 billion in 2022.

[38] Bareille and Chakir (2023) find that adaptation by French farmers offsets one-quarter to two-thirds of the negative agronomic impacts of future warming on crop yields.

[39] Within sectors, firms diversify sourcing locations in India (Castro-Vincenzi et al. 2024), where suppliers exposed to climate risk charge lower prices, and Pakistan (Balboni et al. 2023), where flood-affected firms are more likely to relocate and diversify their suppliers to less flood-prone regions.

[40] Spatial adaptation—relocating the business, trade, knowledge spillovers, and migration—is found to have net positive effects if unrestricted; imposing restrictions on migration raises the welfare costs of warming temperatures by 1.7 percent globally (Desmet and Rossi-Hansberg 2024). For EMDEs, there is a 3 percent increase in output per capita when skilled and unskilled migration is allowed (Shayegh 2017) (8 percent for Africa (Conte 2023)) and 6 percent under a broader set of climate shocks (Burzynski et al. 2022).

[41] The economy-wide impact is 2.5 percent of GDP loss from services compared to 0.1 percent from agriculture. Cyclone damage is similar for services and agriculture (Hsiang 2010).

[42] At 33–34°C, labor productivity can decrease by up to 50 percent in physically demanding jobs. Sahu et al. (2013) find that Indian rice harvesters collected 5 percent fewer rice bundles for every 1°C increase above 26°C.

[43] WBES is a nationally representative firm-level survey with data on various business environment aspects, including access to finance, corruption, infrastructure, and firm performance. WBES has a series of limitations on data representation and comparability (Appendix E), but it remains the most detailed source of cross-country firm-level data available. Industry classifications are too broad—for example, manufacturing and services are at the two-digit level in select countries, and agriculture is not covered (the survey does stratify across location, industry, and firm size). The smaller sample size in many countries can introduce biases and overrepresent large firms. Differences in survey design compromise strict comparability across countries and years.

[44] The short and detailed green module questionnaires are available at https://www.enterprisesurveys.org/en/enterprisesurveys.

[45] WBES also has limitations in how it measures adaptation, for the reasons discussed above—poor data, lack of a clear definition given the context-specific nature of adaptation, limited private reporting, and unreliable adaptation investment categories (CPI 2018). Future research could expand the number of country-specific climate surveys and incorporate more adaptation-focused detail. More research is also needed on how MSME adaptation is funded and how much innovation is associated with MSME adaptation and its funding.

[46] These climate impacts also have implications for water use, given the close links between energy and water systems.

[47] Energy management systems can shift some operations to periods of lower electricity demand or draw on backup renewable energy when the main grid fails, making them a key adaptation to more frequent severe weather events. Implementing on-site renewable energy and storage reduces reliance on central power lines, which are vulnerable to climate events.

[48] Reaching 35–50 percent of overall production costs in India (OECD 2022), and 25–50 percent globally (Business Energy Index 2013). Small and medium enterprises spent considerably more than larger firms in 10 of 17 manufacturing sectors (in food, leather, and electronics manufacturing, energy costs per dollar of output were more than double in small and medium enterprises than in larger entities). This is also true in 26 of the 31 commercial sectors, where the median small and medium enterprise energy cost per sales ratio was 2.7 times greater than the ratio for larger firms (see Bollman 2008, who focuses on data for the United States in 2002).

[49] Sustainable waste practices shift from a "take-make-dispose" model to a circular economy. The circular economy contributes to resource security by recycling, making supply chains more resilient to climate-driven disruptions in mining or agriculture. Proper waste collection also prevents clogging of urban drainage, which is a major cause of flash floods.

[50] Heating and cooling reduce energy demand, but more importantly, improve insulation; act as a shield against extreme heatwaves and cold snaps, protecting health and productivity; and reduce peak energy demand, contributing to grid stability.

[51] The PSI database consists of open self-submitted business cases.

[52] Carbon market-based funding schemes have been shown to work as an MSME financing source for reforestation or wetland restoration via agroforestry aggregators, for manufacturing of stoves, and for solar water pumps, for example.

[53] Other examples include planting trees for shade, painting roofs white, and using natural ventilation.

[54] By increasing the use of passive strategies and the penetration of higher-efficiency equipment for active cooling, cooling energy consumption in EMDEs could be reduced by 42 percent (6,530 TWh to 3,780 TWh by 2050). The use of passive strategies alone would avoid $4.6 trillion of consumer costs by 2050 (half from lower electricity consumption and half from lower spending on active cooling equipment) (IFC and UNEP 2024).

[55] Using fans, the gap is $3.9 billion in SSA, $2.8 billion in South Asia (SAR), and $100–$500 million per year in MENA and Latin America and the Caribbean (LAC). For air conditioning, the gap is $117 billion in SAR, $92 billion in SSA, and $85 billion in East Asia and Pacific (EAP) ($30 billion for China), $25–$35 billion in LAC and MENA, and less than $15 billion in ECA. By 2050, increased incomes due to economic growth will reduce the gap to below $20 billion (and eliminate it in China by 2040), except in SSA where the gap will balloon to $126 billion in 2050 as increased affordability fails to keep pace with the higher demand (IFC and UNEP 2024).

[56] This gap is around $65 billion in SAR and SSA, $5–$15 billion in EAP, MENA, and LAC in 2023, and expected to close in China and ECA by 2025. By 2050, the SSA gap is projected at $77 billion (vs. $14 billion total for all other regions) (IFC and UNEP 2024).

[57] China accounts for 69 percent of the total cost ($186 billion), followed by EAP, SAR, and ECA with a gap of $15–$25 billion.

[58] Cold-chain processes comprise packhouse processing, rural cold storage, transport, off-grid renewable energy, and cold storage at destination (IFC and UNEP 2024; ESMAP 2024 on off-grid).

[59] Higher savings are possible: for example, offices in the Philippines: 43 percent, Ivorian shopping centers: 29 percent, Nigerian data centers: 35 percent, and homes in Mexico: 40 percent (IFC and UNEP 2024).

[60] On-bill financing allows users to pay for energy-efficient appliances over time, linked to utility bills and service. On-wage financing is linked to salaries.

[61] Other instruments could include cooling bonds (sustainable bonds focused on cooling projects), or carbon-offset payments for any cooling-related energy-efficiency improvements (such as reductions in refrigerant use) (Michaelowa et al. 2021).

[62] Closing the financing gap and promoting high-risk capital requires harmonized regulations, market incentives, and collaboration between governments, research institutions, manufacturers, development finance institutions, and venture capital funds (IEA 2020).

[63] Yesudian and Dawson (2021) find that 269 airports are currently at risk of coastal flooding. A temperature increase of 2°C in line with the Paris Agreement will cause 100 airports to remain below the mean sea level and 364 airports to face the risk of flooding. Estimated annual damage expressed as a share of annual global maintenance needs is 0.2–1.5 percent, although in some lower-income economies estimated annual damage can reach 0.5–1 percent of GDP annually, on par with national transport budgets (Koks et al. 2019). Africa could face road repair and maintenance costs of $183.6 billion by 2100 due to damage from rising temperatures and changing precipitation patterns (Chinowsky et al. 2013).

[64] Logistics activities include transportation, warehouse management, packaging, order processing, handling, customs clearance, customer services, information management, demand forecasting, after-sales service, factory-warehouse location selection, purchasing, and waste parts management.

[65] Within many supply chains, freight transport is the activity most susceptible to weather-induced disruption. Warehouses are also among the most climate-vulnerable commercial buildings: in England, 9,897 warehouses were in the highest flood risk category (chance greater than 1 in 30), compared with 8,480 retail buildings, 5,504 office buildings, and 2,951 buildings for industry (Foulkes et al. 2023). Logistics facilities are less resilient than manufacturing assets (McKinsey Global Institute 2020), yet adaptation opportunities in logistics have been under-researched (Goldstein et al. 2019; Franz et al. 2020).

[66] This number would increase to 25 percent if all waste currently not being recycled were to be recycled without reducing overall material use. Global extraction of virgin materials has more than tripled in the last 50 years and is set to rise by a further 60 percent by 2060.

[67] More recently, Vásquez et al. (2024) compute the circularity gains from a small coffee and pig farm in Colombia: 86 percent reduction in water consumption in the coffee-pulping stage, 100 percent use of pig-raising waste for biogas generation, and 100 percent use of solid waste from coffee processing for biofertilizer.

[68] Ninety-five percent of plastic packaging material, valued at $80–$120 billion annually, is lost to the economy after a single use (WEF and Ellen MacArthur Foundation 2016). Negative externalities of plastic waste cost $40 billion per year (UNEP 2014). The circular economy can reduce the annual volume of plastics entering our oceans by 80 percent, reduce greenhouse gas emissions by 25 percent, generate savings of $200 billion per year, and create 0.7 million net additional jobs (Ellen MacArthur Foundation 2025).

[69] Examples include fixing/refurbishing electronics and outdated furniture; upcycling textile and other waste into fashion accessories; remanufacturing automotive components or industrial machines; refurbishing used vehicles; small repair shops; moped/bicycle repair; recovering used carpets; recycled wastepaper/packaging; product repair and take-back programs for textiles, electronics, and furniture; appliance rental platforms; reuse of construction material; waste pickers and informal e-waste processing; composting; waste-based fertilizer; and carbon-negative building material (Kaswan et al. 2023; Mishra et al. 2025; online sources).

[70] For example, a food-processing firm implementing a waste management system that composts food waste or uses it for animal feed (Spaltini et al. 2021).

[71] Examples include Circularity Capital's $78 million private equity fund for European MSMEs, the European Union's BlueInvest Fund for blue economy start-ups, and hybrid funds such as the Moringa Partnership Fund for agroforestry in Latin America and Africa.

[72] Examples include the Plastics Fund I, Blue Oceans Partners, and Closed Loop Ventures.

[73] In India, 49 percent of MSMEs are in urban areas and 51 percent in rural areas (India, Ministry of MSMEs 2024).

[74] The public sector is also addressing MSMEs' limited resources for risk assessments, with assistance from donors, NGOs, and international organizations, by disseminating information on climate risks and impacts (for example, rainfall information for farmers in Chiredzi, Zimbabwe; UNDP 2014).

[75] The underlying assumption is that advanced warnings could reduce asset losses from storms, floods, and tsunamis by an average of up to 20 percent.

[76] GCA (2019) also reports that an investment of $800 million in such systems in developing countries could prevent annual losses of between $3 billion and $16 billion. Providing just 24 hours' notice of an impending storm or heatwave can reduce potential damage by 30 percent.

[77] This corresponds to 2.5 billion people in smallholder households. Smallholder farms are defined as having less than two hectares of land.

[78] By 2050, this is expected to result in price increases of 32–37 percent for rice, 52–55 percent for maize, 94–111 percent for wheat, and 11–14 percent for soybeans (Rice and Vos 2024). Increased temperatures across Central America play a major role in devastating outbreaks of coffee leaf rust, which led to the loss of over 500,000 coffee-related jobs and $1 billion in revenue in 2013–2014.

[79] Other examples include changing planting dates, planting in new locations, intercropping, dry planting, cooling roots, and vertical farming.

80 As well as contour ploughing, bud maintenance, barrier crops, water catchment and harvesting, water efficiency, agroforestry, changing the crop mix, integrated pest controls, and tilling practices.

81 These risks are transmitted through entire agricultural value chains, including producers, warehousing, processing, trading, transport, and packaging. This higher level of risk of agri-MSMEs is compounded by the fact that agricultural assets, including lands and agricultural produce, are more difficult to collateralize due to limited enforceability and traditional land-tenure systems. Formal lenders, especially commercial banks, are usually reluctant to lend to agri-MSMEs, and tend to focus on more mature, less risky, and larger borrowers (World Bank 2024e).

82 Where microloans to women in Kenya were combined with training in small business administration and agroforestry. Coulibaly et al. (2015) emphasize the need for clearer ex-ante communication of climate change threats (for example, crop failure in Malawi). Dougherty-Choux et al. (2015) point out the need for an affordability assessment (for example, drip irrigation and granaries were unaffordable to MSMEs without finance in Namibia).

83 Lower adoption of drought-tolerant maize by women in Uganda is mainly due to poor resource access (land, agricultural information, and credit). Access to credit is 48 percent for men-headed households and 47 percent for women-headed households, but only 34 percent for wives in spousal-couple households.

84 Productivity gains can be had from selective breeding and improved husbandry. Simply reducing the number of cows improves the quantity of feed and care for each cow. The private company iCow relies on big data to improve productivity in Tanzania by 50 percent.

85 Cattle are responsible for 7 percent of manmade greenhouse gas emissions. Ethiopia, home to the largest livestock population in Africa, halved the carbon footprint per kilogram of milk produced while boosting participating farmers' incomes by 100 percent (World Bank 2023) by introducing dairy service hubs (joint milking, collection, and cooling, and access to inputs, services, and training), embedded extension services for climate-smart processes (helping reduce grazing during the dry period, install biogas digesters to convert manure into fuel, replace bulls and nonproductive cows, rear young stock, and invest in better veterinary care), and fodder service centers (offering, at commercial scale, better feed that increases milk production and lowers methane emissions, resulting in healthier land that is less stressed by grazing).

86 Livestock health may suffer from changes in behavior, alterations in physiology and immune system depression, and shifts in other variables such as pathogen ecology and spread; feed quality, availability, and affordability; and water quality and availability.

87 For example, prolonged dry seasons may reduce forage quality, growth, and biodiversity, while floods could alter the root structure and leaf growth rate. Pasture composition may be affected by shifting seasonal patterns and changes in the optimal growth rate and water availability.

88 In contrast, payments and savings markets are growing. In SSA, 30 percent of rural adults used digital payments in 2017, up from 24 percent three years earlier. Adults with mobile money accounts increased from 11 percent to 20 percent, with wide variation across countries (79 percent in Kenya vs. 22 percent in Nigeria). In East Asia, digital payments are used by 55 percent of rural adults (up from 32 percent). In South Asia, use rose from 15 percent to more than 25 percent; and in Latin America and the Caribbean, use rose from 32 percent to more than 42 percent. The use of savings accounts has also increased in rural areas, encouraged by a wave of digital wallets: between 2011 and 2017, use increased from 19 percent to 30 percent in SSA, from 50 percent to 68 percent in South and Southeast Asia, and from 34 percent to 50 percent in Latin America and the Caribbean.

89 In areas of greater rainfall variability, farmers are less likely to use fertilizer, either alone or in combination with improved seed varieties. However, they may adopt fertilizer and improved seeds when combined with agricultural water management. Although each of these three practices individually improves yields, their combined effect is greater. Simulation results suggest that rising temperatures and decreased precipitation in future decades will increase the likelihood of farmers adopting a combination of practices instead of only one.

90 Examples of co-benefits are reduced carbon emissions, increased production efficiency, better animal feed digestibility and nutritional levels, using methane from manure for fuel, a lower number of unproductive animals in the herd, energy-efficient equipment, and efficient land management.

91 In Pakistan, smallholders shied away from warehouse receipts (Pakistan Microfinance Network 2019).

92 In buyer-driven models such as contract farming, finance is used by the buyers to commit producers to sell to them under specific conditions. Contract farming can increase both farmers' and sponsors' income but has a mixed impact on smallholder farmers: it can lower transaction costs, increase efficiency, and enhance farm profitability and welfare, but many are skeptical about its impact on inequality, dependency, and division of risk. In producer-driven models, farmer associations provide smallholder farmers with finance, marketing, technical assistance, and inputs. See Villalba et al. (2023) for a detailed discussion.

93 Farmers might agree to sell to one buyer but later switch, needing cash quickly. Side-selling is much less likely for specialized crops.

94 Savings products are provided by mobile network operators or linked to mobile money services, allowing farmers to deposit and save their money for an established goal such as the next planting season at a lower cost (farmers can also use remittance products and commitment savings accounts). Remittance products are linked digitally and directly to farmers' savings accounts, and they allow funds to be saved for later uses, rather than to be cashed out immediately. Commitment savings accounts freeze farmers' funds until there is a particular need that has to be financed on a particular date (for example, seasonal purchasing of seeds). They keep funds safe, secure, and away from family or community pressures.

95 As of 2024, 53.7 percent of Kenyans own mobile phones (Kenya National Bureau of Statistics), and their credit histories are accessible. This allows agricultural technology firms to offer farmers embedded mobile payment and credit plans, bundling agricultural, advisory, and extension services, and input supply with finance, credit, and payments for market access through mobile devices. Agricultural technology funding in SSA increased steadily from $13 million in 2017 to $95 million in 2021. Kenya and Nigeria attracted $638 million and $410 million in start-up funding in 2024, respectively, followed by South Africa ($394 million), Ghana ($68 million), and Tanzania ($53 million) (Giacomelli and Bayen 2025). Digital agricultural technology formed 25 percent of start-up funding in 2024 (Briter Intelligence 2024).

[96] Sources of cash income are agricultural production (49 percent in Pakistan and 39 percent in Tanzania), casual labor (14 percent and 19 percent, often related to agriculture), and off-farm sources such as managing a small business (9 percent and 15 percent), receiving remittances (8 percent and 11 percent), or engaging in regular or waged employment (7 percent and 10 percent). While a relatively small proportion of smallholder farmers' cash income comes from agriculture, consumption in kind raises it from 26 percent to 46 percent in Tanzania and from 42 percent to 53 percent in Pakistan (Anderson and Ahmed 2016).

[97] On average, farmers grow 3.6 crops in Tanzania, 4.3 crops in Pakistan, and 6.3 crops in Mozambique. In Mozambique, 87 percent use intercropping (Anderson and Ahmed 2016).

[98] Training was accessed by 13 percent of farmers in Tanzania, 75 percent in Pakistan, and 16 percent in Mozambique. In Tanzania, 78 percent used fertilizer and 23 percent insecticide; almost everyone used these in Pakistan, while only a few farmers did so in Mozambique. Mechanization: 94 percent in Pakistan and 2 percent in Mozambique (Anderson and Ahmed 2016).

[99] Price information was available to 84 percent of farmers in Pakistan and 46 percent of farmers in Tanzania, but the price was revealed only once the farmer had reached the market, after incurring transportation costs (Anderson and Ahmed 2016).

[100] The median nonagricultural cash income was 93 percent in Mozambique, 74 percent in Tanzania, and 58 percent in Pakistan (Anderson and Ahmed 2016).

[101] Asset sales were utilized by 55 percent of farmers in Tanzania, 72 percent of farmers in Pakistan, and 0 percent of farmers in Mozambique. Livestock sales are limited by mortality/loss, fire sale prices, and asset indivisibility.

[102] The paper identifies 3,283 peer-reviewed studies that address one or more of the five major types of risk in agriculture over 1974–2019.

[103] Specifically, insurance indexed to, for example, rainfall, temperature, El Niño, satellite-measured vegetation indices, area yields, and livestock mortality rates avoids many issues of conventional insurance such as moral hazard and is cheaper to administer as its terms are not individually tailored but require a strong correlation between the indemnities provided and actual losses incurred. Other sources of risk management are mostly public or concessional. For example, guarantee funds for climate risk adaptation have found it necessary to have some level of subsidy due to the nature of the investment (IFC partial credit guarantee for "Commercializing Energy-Efficiency Finance," newer first-loss instruments).

[104] MSMEs can create goods that last longer and require fewer repairs or replacements. For example, a furniture manufacturer uses high-quality materials and sturdy construction techniques (Jaeger and Upadhyay 2020). As another example, a smartphone manufacturer designs devices with modular components that can be easily replaced or repaired instead of replacing the entire device (Diaz Lopez et al. 2019). The secondhand market for two- and three-wheelers, parts, and recycled batteries has a high share of MSMEs in developing countries. These MSMEs sometimes also participate in the downstream end of automotive supply chains to recycle and reuse parts.

[105] As well as benefit from other climate adaptation measures along their supply chains such as closed-loop supply chains, which can reduce dependence on scarce resources and mitigate supply-chain disruptions, contributing to greater stability and enhanced resilience (Acerebi and Taisch 2020).

[106] For example, ambient air cooling, liquid cooling, use of artificial intelligence to optimize cooling efficiency, resized cooling units, dry cooling systems, air conditioning in areas prone to high heat stress, closed-loop water cooling systems, and alternative cooling technologies.

[107] Working capital finance (conventional banking and lines of credit, microfinance or credit union finance, value-chain or trade finance, digital and mobile finance) is available to well-established MSMEs with conventional collateral, MSMEs with regular cash flows that need short-term financing, and MSMEs in organized, competitive value-chain relationships. Short-term microfinance and money transfers are an emerging option for MSMEs in some areas.

[108] In addition to the risk of immediate death as a result of fires, climate impacts such as intense heatwaves can result in reduced food production (leading to the likelihood of undernutrition), reduced labor productivity or higher unemployment for vulnerable populations, and food, water, and vector-borne diseases.

[109] For the Belize Barrier Reef, the benefit-cost ratio of ecosystem services, carbon storage, sequestration from mangroves, and beneficiaries' future income is between 1.08 and 4.34 within 10 years, and between 1.89 and 8.34 for a 20-year project horizon (Global Center on Adaptation 2025).

[110] Further options include using flood-resistant building materials, efficient cooling systems, reflective roofing, and shading for outdoor displays; improving energy efficiency; saving water; and harvesting rainwater.

[111] Credit payments, debit card payments, or e-money (including mobile money) receivables are deposited into a controlled account, which is provided as collateral, and the amortized portion of the loan is paid directly from this account via a daily percentage of credit card deposits.

[112] Microfinance struggles with assessing climate risk, costly heat maps, and a lack of short-term climate data (matching 6–12-month loan terms).

[113] One innovative example is IFC's MSME Natural Catastrophe Facility, a new product being piloted in Ghana before a global rollout. The facility triggers a stand-still in IFC's financing terms to financial intermediaries in case of predefined natural catastrophes and requires the intermediaries to pass that stand-still through to their MSME clients to create economic resilience in response to extreme weather events. Other examples include private equity and venture capital, project finance, mezzanine instruments, insurance-linked securities, and risk mitigation instruments (for example, climate insurance and public-private partnerships). See also UNEP (2016) for an overview of the typical private financial instruments for adaptation.

[114] Using 3.3 million firms from 24 EMDEs, 1997–2019. In the United States, the effect is 4.2 basis points for municipal bonds (Jiang et al. 2019) and 7 basis points for corporate bonds (Allman 2021).

[115] This incentivizes firm adaptation, albeit information is incorporated inefficiently (Xu et al. 2022).

[116] Leitold et al. (2021) for Vietnam; Crick et al. (2018) for Kenya and Senegal.

[117] More research is needed on the climate impact on asset class performance, rates of capital depreciation, and the implications for firm adaptation strategies, as well as on lender pricing of credit for adaptation and other distinct lending barriers (Goicoechea and Lang 2023).

[118] About 40 percent of banks do not provide any emergency support to businesses, and about 20 percent of banks have no adaptation financing products. Over 75 percent of banks consider microbusiness coverage "poor," with 17 percent of flood-affected businesses receiving insurance refusals, and 32 percent of small and medium enterprises (27 percent of large businesses) required to retrofit premises to obtain insurance (Didier 2024).

[119] Funds that aim to drive private sector investment in climate adaptation and resilience include the Climate Resilience and Adaptation Finance and Technology-transfer facility (CRAFT) Fund (Tall et al. 2021 examine outcomes), the Catalyst Fund, the Kuali Fund, the GAIA Fund, the Adaptation SME Accelerator Project, UNEP's Microfinance for Ecosystem-based Adaptation, and Mastercard's Climate Smart Innovation Hub.

[120] Insurance can support by sharing risk information, integrating approaches to risk reduction and financial resilience, and sharing risks among private insurers and the state. Public intervention can also improve risk market infrastructure, including data systems, risk models, and legal frameworks.

[121] The World Bank (2010) argues that, unchecked, climate change could make many climate risks uninsurable or the premiums unaffordable, hence major climate risks are not widely covered by insurance, particularly in EMDEs. Insurance is appropriate when impacts are random and rare—it is not viable if the climate is trending in a predictable fashion (toward hotter or drier conditions). Insurability requires the ability to identify and quantify the likelihood of an event and the associated losses to set premiums and to diversify risk among individuals or collectives. Financial sustainability also requires reasonably low transaction costs.

[122] At the other extreme is evidence showing that weather-based derivatives are an effective tool for large utilities and energy companies to hedge against weather risk (for example, Matsumoto and Yamada 2021).

[123] As well as any economy-wide impacts from cost savings and climate damage reduction.

[124] Even in the absence of market failures, some argue for concessional funding on equity grounds (Callahan and Mankin 2022; Okereke and Coventry 2016; Rode et al. 2022).

[125] For example, India's PMFBY, which subsidized crop insurance for 57 million farmers, or Brazil's PRONAF, which channels credit through public and cooperative banks at scale to enable farmers to invest in resilient agricultural practices, such as adopting drought-resistant crops and sustainable irrigation systems.

[126] Blended finance usually employs bonds and notes (which can take the form of privately placed securities or public issuances), facilities such as private equity funds and funds of funds structured with concessional capital in the stack, as well as specific projects.

[127] This could be interpreted as larger effects in lower-income countries, but more research is needed to tease out the nuance.

[128] Temperature and tropical cyclones reduce global economic growth by roughly 0.25 percentage points and 1.3 percentage points per year, respectively (for example, 13 percent of infant mortality in the Philippines is due to tropical cyclones). They also find that violence rises by roughly 11 percent per standard deviation in temperature, with temperatures contributing to 29 percent of civil conflicts in SSA. Globally, El Niño-Southern Oscillation events have elevated civil conflict rates by 21 percent.

[129] The analysis uses NASA data to capture future climate predictions and a causal forest algorithm, which performs well and provides reliable inference even with a large selection of explanatory variables to optimize for out-of-sample performance. Adaptation to climate change is incorporated by including long-term means and variances of all weather variables (the causal forests approach solves the high dimensionality challenge of weather data using conventional approaches—for example, linear regression).

[130] While individuals are each affected modestly, at scale this generates substantive aggregate impacts on output and growth. Labor productivity losses might be exacerbated by market reactions that reduce the intensity of labor used in economic activities and slow downstream production.

[131] Country-specific studies confirm this: high temperatures are strongly associated with migration (Mueller, Gray, and Kosec 2014 for Pakistan; Thiede, Gray, and Mueller 2016 for South America; and Mueller, Sheriff, Dou, and Gray 2020 for Eastern Africa). High temperatures reduce both agricultural and nonagricultural labor in Mexico and increase rural to urban migration and migration to the United States (Jessoe et al. 2018); extreme rainfall has similar effects in Colombia (Otero-Cortés and Bohorquez-Penuela 2020). In India, off-farm employment increases after groundwater depletion in areas with a more robust manufacturing sector (Blakeslee et al. 2020). Branco and Féres (2020) also find that droughts tend to increase the labor supply of rural households in nonagricultural sectors in Brazil. The capacity of the manufacturing sector to absorb agricultural workers critically determines the severity of economic losses from temperature shocks (Colmer 2021 for India; Albert et al. 2021 for Brazil). Albert et al. (2021) find a strong migration response to dryness (a municipality at the 90th percentile of dryness loses 1.8 percent of its population), less if it is financially integrated.

[132] This varies by standardized climate scenarios ("Representative Concentration Pathways"): 0.4 percent for RCP 2.6 (the "peak-and-decline" scenario with very stringent mitigation, limited warming below 2°C, and radiative forcing of 2.6 W/m²) to 2.9 percent for RCP 8.5 (the "worst-case" scenario of 8.5 W/m²).

[133] Little is known about adaptation strategies to climate-induced labor availability. There is some evidence of firms relocating to address labor availability swings (Jin et al. 2021), but this evidence comes from US data rather than from EMDEs, where migration costs and administrative barriers to migration are higher. A lack of geographically varied data limits the ability to assess differences in migration demand, potential destinations, firm relocation costs, and cost differences across urban areas (Goicoechea and Lang 2023).

Bibliography

Abajian, A., C. Cole, B. K. Jack, K. C. Meng, and M. Visser. 2024. "Dodging Day Zero: Drought, Adaptation, and Inequality in Cape Town." Working paper.

Abajian, A. C., T. Carleton, K. C. Meng, and O. Deschenes. 2023. "The Climate Adaptation Feedback." Working paper.

Abeberese, Ama Baafra, Charles Godfred Ackah, and Patrick Opoku Asuming. 2021. "Productivity Losses and Firm Responses to Electricity Shortages: Evidence from Ghana." *The World Bank Economic Review* 35 (1): 1–18.

Accenture. 2015. *Waste to Wealth: The Circular Economy Advantage*, by Peter Lacy and Jakob Rutqvist. 1st ed. English: Palgrave Macmillan.

Acerbi, Federica, and Marco Taisch. 2020. "A Literature Review on Circular Economy Adoption in the Manufacturing Sector." *Journal of Cleaner Production* 273: 123086.

ACES (Africa Centre of Excellence for Sustainable Cooling and Cold Chain). 2024. "ACES Report."

Acevedo, M., K. Pixley, N. Zinyengere, S. Meng, H. Tufan, K. Cichy, L. Bizikova, K. Isaacs, K. Ghezzi-Kopel, and J. Porciello. 2020. "A Scoping Review of Adoption of Climate-Resilient Crops by Small-Scale Producers in Low- and Middle-Income Countries." *Nature Plants* 6: 1231–1241.

Addoum, J. M., D. T. Ng, and A. Ortiz-Bobea. 2021. "Temperature Shocks and Industry Earnings News." SSRN.

Adelphi. 2019. "Financing Adaptation to Climate Change – an Introduction," by Helen Burmeister, Annica Cochu, Tobias Hausotter, and Cosima Stahr.

Adhvaryu, A., N. Kala, and A. Nyshadham. 2020. "The Light and the Heat: Productivity Co-benefits of Energy-Saving Technology." *The Review of Economics and Statistics* 102 (4): 779–792.

Adom, P. K., and S. Amoani. 2021. "The Role of Climate Adaptation Readiness in Economic Growth and Climate Change Relationship: An Analysis of the Output/Income and Productivity/Institution Channels." *Journal of Environmental Management* 293: 112923.

Aem-on, K., S. Setamanit, A. Chandrachai, and S. Sinthupinyo. 2024. "Empowering Supply Chain Resilience in High-Growth of Small and Medium Enterprises (SMEs) through the Integration of the SCOR Model Paradigm." *TEM Journal* 13 (2): 1331–1344.

AFI (Alliance for Financial Inclusion). 2019. "SME Finance Guideline Note." AFI SME Finance Working Group, Guideline Note No. 36.

Afridi, F., K. Mahajan, and N. Sangwan. 2022. "The Gendered Effects of Droughts: Production Shocks and Labor Response in Agriculture." *Labour Economics*.

Aghion, P., A. Bergeaud, M. de Ridder, and J. van Reenen. 2024. "Lost in Transition: Financial Barriers to Green Growth." INSEAD Working Paper No. 2024/16/EPS.

Aguilar-Gomez, S., E. Gutierrez, D. Heres, D. Jaume, and M. Tobal. 2024. "Thermal Stress and Financial Distress: Extreme Temperatures and Firms Loan Defaults in Mexico." *Journal of Development Economics* 168: 103246.

Ahmed, S., N. Ahsan, S. Alam, and H. Kokash. 2025. "Advancing Circular Economy Implementation in Malaysian SMEs: The Role of Financial Resources, Operational Alignment, and Absorptive Capacity." *Circular Economy and Sustainability* 5: 2843–2871.

AIDR (Australian Institute for Disaster Resilience) and Queensland Government. 2023. *Resilience Valuation Initiative Case Study: Queensland Reconstruction Authority Cost-Benefit Analysis*.

Aker, J. C., and B. K. Jack. 2023. "Harvesting the Rain: The Adoption of Environmental Technologies in the Sahel." *The Review of Economics and Statistics*, 1–52.

Alam, A., A. Du, M. Rahman, H. Yazdifar, and K. Abbasi. 2022. "SMEs Respond to Climate Change: Evidence from Developing Countries." *Technological Forecasting and Social Change* 185.

Albert, C., P. Bustos, and J. Ponticelli. 2021. "The Effects of Climate Change on Labor and Capital Reallocation." Technical report, National Bureau of Economic Research.

Alcayna, T., and D. O'Donnell. 2022. "How Much Global Climate Adaptation Finance Is Targeting the Health Sector?" *European Journal of Public Health* 32.

Alcorta, Ludovico, Morgan Bazilian, Giuseppe de Simone, and Ascha Pedersen. 2014. "Return on Investment from Industrial Energy Efficiency: Evidence from Developing Countries." *Energy Efficiency* 7: 43–53.

Allman, E. 2021. "Pricing Climate Change Risk in Corporate Bonds." SSRN.

Almanza, C., M. Ramirez, M. Angulo, M. Gómez-Gaicedo, and A. Suárez. 2023. "Factors for the Implementation of the Circular Economy in Big Data Environments in Service Companies in Post Pandemic Times of COVID-19: The Case of Colombia." *Frontiers in Big Data* 6.

Al-Mashat, R. A., M. Jeuland, J. Puri, P. A. Vieira, M. Aboulatta, S. Ahmad, J.-Z. Chowdhury, A. Diaz-Herrera, M. Elsharief, F. Farghal, J. Phillips, N. Tawfik, L. Teji, and D. von Glahn. 2024. "Resilience Monetization and Credits Initiative: A Background Paper." NI WP 24-02, James E. Rogers Energy Access Project, Nicholas Institute for Energy, Environment & Sustainability, Duke University, Durham, NC.

Anderson, J., and W. Ahmed. 2016. "Smallholder Diaries: Building the Evidence Base with Farming Families in Mozambique, Tanzania and Pakistan." Perspectives No. 2, CGAP.

Anderson, V., and G. Boocock. 2002. "Small Firms and Internationalization: Learning to Manage and Managing to Learn." *Human Resource Management Journal* 12: 5–24.

Andersson, H., and N. Treich. 2011. "The Value of a Statistical Life: Problems and Prospects." In *Handbook in Transport Economics*, edited by A. de Palma, R. Lindsey, E. Quinet, and R. Vickerman, 396–424. Cheltenham, UK: Edward Elgar.

Andrea, U., R. Paolo, S. Claudio, C. Davide, and T. Sergio. 2020. "Circular Business Models in the European Manufacturing Industry: A Multiple Case Study Analysis." *Journal of Cleaner Production* 274: 122964.

Annan, F., E. Klobodu, J. Shrader, and S. Basuroy. 2024. "Competition Constrains Adaptation to Climate Shocks." SSRN. https://jeffreyshrader.com/papers/competition_adaptation.pdf.

Aragon, F. M., F. Oteiza, and J. P. Rud. 2021. "Climate Change and Agriculture: Subsistence Farmers' Response to Extreme Heat." *American Economic Journal: Economic Policy* 13 (1): 1–35.

Aryee, Raphael, and Wisdom Kanda. 2024. "A Strategic Framework for Analysing the Effects of Circular Economy Practices on Firm Performance." *Journal of Cleaner Production* 476: 143753.

Asgary, A., M. Imtiaz Anjum, and N. Azimi. 2012. "Disaster Recovery and Business Continuity after the 2010 Flood in Pakistan: Case of Small Business." *International Journal of Disaster Risk Reduction*.

Asif, M., M. Asad, M. Kashif, and M. Abrar ul Haq. 2021. "Knowledge Exploitation and Knowledge Exploration for Sustainable Performance of SMEs." In *Proceedings of the Third International Sustainability and Resilience Conference: Climate Change*, 29–34.

Atela, J., K. E. Gannon, and F. Crick. 2018. "Climate Change Adaptation among Female-Led Micro, Small, and Medium Enterprises in Semiarid Areas: A Case Study from Kenya." In *Handbook of Climate Change Resilience*, edited by W. Leal Filho, 1–18. Cham: Springer.

Auffhammer, M. 2022. "Climate Adaptive Response Estimation: Short and Long Run Impacts of Climate Change on Residential Electricity and Natural Gas Consumption." *Journal of Environmental Economics and Management* 114: 102669.

Averchenkova, A., F. Crick, A. Kocornik-Mina, H. Leck, and S. Surminski. 2016. "Multinational and Large National Corporations and Climate Adaptation: Are We Asking the Right Questions? A Review of Current Knowledge and a New Research Perspective." *WIREs Interdisciplinary Reviews: Climate Change* 7 (4): 517–536. doi:10.1002/wcc.402.

AXA and UNEP (United Nations Environment Programme). 2015. "Business Unusual: Why the Climate Is Changing the Rules for Our Cities and SMEs."

Babbitt, C. W., G. Gaustad, A. Fisher, W. Q. Chen, and G. Liu. 2018. "Closing the Loop on Circular Economy Research: From Theory to Practice and Back Again." *Resources, Conservation and Recycling* 135: 1–2.

Bacinello, E., G. Tontini, and A. Alberton. 2019. "Influence of Maturity on Corporate Social Responsibility and Sustainable Innovation in Business Performance." *Corporate Social Responsibility and Environmental Management* 27 (2): 749–759.

Bak, O., S. Shaw, C. Colicchia, and V. Kumar. 2023. "A Systematic Literature Review of Supply Chain Resilience in Small–Medium Enterprises (SMEs): A Call for Further Research." *IEEE Transactions on Engineering Management* 70 (1): 328–341.

Bakkensen, L., and L. Barrage. 2018. "Climate Shocks, Cyclones, and Economic Growth: Bridging the Micro-Macro Gap." Technical report, National Bureau of Economic Research.

Balboni, C., J. Boehm, and M. Waseem. 2023. "Firm Adaptation in Production Networks: Evidence from Extreme Weather Events in Pakistan." Structural Transformation and Economic Growth CEPR Working Paper.

Bannock, G. 2015. *The Economics and Management of Small Business: An International Perspective*. London: Taylor & Francis Routledge.

Bansal, R., D. Kiku, and M. Ochoa. 2016. "Price of Long-Run Temperature Shifts in Capital Markets." Technical report, National Bureau of Economic Research.

Bareille, F., and R. Chakir. 2023. "Structural Identification of Weather Impacts on Crop Yields: Disentangling Agronomic from Adaptation Effects." *American Journal of Agricultural Economics* 106 (3): 989–1019.

Bari, M., and S. Dessus. 2022. "Adapting to Natural Disasters in Africa: What's in It for the Private Sector?" Working paper, IFC.

Barwick, P. J., D. Donaldson, S. Li, Y. Lin, and D. Rao. 2022. "Improved Transportation Networks Facilitate Adaptation to Pollution and Temperature Extremes."

BASE (Basel Agency for Sustainable Energy) and U4E (United for Efficiency). 2023. "Using Finance to Accelerate Adoption of More Energy Efficient and Climate Friendly Appliances." October 3, 2023.

Basker, E., and J. Miranda. 2018. "Taken by Storm: Business Financing and Survival in the Aftermath of Hurricane Katrina." *Journal of Economic Geography* 18 (6): 1285–1313.

Bassi, F., and J. G. Dias. 2019. "The Use of Circular Economy Practices in SMEs across the EU." *Resources, Conservation and Recycling* 146: 523–533.

Bassi, V., M. E. Kahn, N. Lozano Gracia, T. Porzio, and J. Sorin. 2021. "Pollution in Ugandan Cities: Do Managers Avoid It or Adapt in Place?" SSRN.

Bassi, Vittorio, Matthew E. Kahn, Tommaso Porzio, and Elena Spadini. 2024. "Perception of Environmental Risks and Challenges to Adaptation among Ugandan SMEs: Insights from a New Survey." Background paper, *Rethinking Resilience: Adapting to a Changing Climate*, World Bank, Washington, DC.

Batung, E., K. Mohammed, M. Kansanga, H. Nyantakyi-Frimpong, and I. Luginaah. 2022. "Credit Access and Perceived Climate Change Resilience of Smallholder Farmers in Semi-arid Northern Ghana." *Environment, Development, and Sustainability* 25 (1): 1–30.

Bento, A. M., N. Miller, M. Mookerjee, and E. Severnini. 2023. "A Unifying Approach to Measuring Climate Change Impacts and Adaptation." *Journal of Environmental Economics and Management* 121: 102843.

Berg, Claudia N., L. Bettarelli, D. Furceri, M. Ganslmeier, A. Grover, M. E. Lang, and M. T. Schiffbauer. 2025. "Firm-Level Climate Change Adaptation: Micro Evidence from 134 Nations." Policy Research Working Paper 11081, World Bank.

Berkouwer, S., and J. Dean. 2022. "Credit, Attention, and Externalities in the Adoption of Energy Efficient Technologies by Low-Income Households." *American Economic Review* 112 (10): 3291–3330.

Berry, S. 2020. "The Forest Stewards Guild's HEPA Filter Loan Program." Fire Adapted Communities Learning Network.

Bhandari, H., U. Chakravorty, K. Emerick, and M. A. Habib. 2022. "Targeted Subsidies for Water Conservation in Smallholder Agriculture." Working paper.

Bijnens, G., S. Anyfantaki, A. Colciago, J. de Mulder, E. Falck, V. Labhard, P. Lopez-Garcia, N. Lourenço, J. Meriküll, M. Parker, O. Röhe, J. Schroth, P. Schulte, and J. Strobel. 2024. "The Impact of Climate Change and Policies on Productivity." European Central Bank Occasional Paper Series No. 340.

Bilal, A., and E. Rossi-Hansberg. 2023. "The Importance of Anticipating Climate Change." VoxEU.org, July 24, 2023. https://cepr.org/voxeu/columns/importance-anticipating-climate-change.

Birkie, S. E., P. Trucco, and P. F. Campos. 2017. "Effectiveness of Resilience Capabilities in Mitigating Disruptions: Leveraging on Supply Chain Structural Complexity." *Supply Chain Management: An International Journal*.

Björkman Nyqvist, M., T. von Carnap, A. Guariso, and J. Svensson. 2023. "Weather Shocks, Child Mortality, and Adaptation: Experimental Evidence from Uganda." medRxiv.

Blakeslee, D., R. Fishman, and V. Srinivasan. 2020. "Way down in the Hole: Adaptation to Long-Term Water Loss in Rural India." *American Economic Review* 110 (1): 200–224.

Blomsma, F., M. Pieroni, M. Kravchenko, D. C. A. Pigosso, J. Hildenbrand, A. R. Kristinsdottir, E. Kristoffersen, S. Shahbazi, K. D. Nielsen, A.-K. Jönbrink, J. Li, C. Wiik, and T. C. McAloone. 2019. "Developing a Circular Strategies Framework for Manufacturing Companies to Support Circular Economy-Oriented Innovation." *Journal of Cleaner Production* 241: 118271.

Bobonis, Gustavo J., Paul J. Gertler, Marco Gonzalez-Navarro, and Simeon Nichter. 2022. "Vulnerability and Clientelism." *American Economic Review* 112 (11): 3627–3659.

Bohorquez-Penuela, C., and A. Otero-Cortes. 2020. "Blame It on the Rain: The Effects of Weather Shocks on Formal Rural Employment in Colombia." Documentos de trabajo sobre economía regional y urbana 292, Banco de la República de Colombia.

Bollinger, K., H. Mewes, A. Janssen, and C. Strasser. 2012. *Facing the Impacts of Climate Change: Indian MSMEs and Adaptation*. New Delhi: GIZ.

Bollman. 2008. "Characterization and Analysis of Small Business Energy Costs." Durham, NC, SBA Office of Advocacy.

Borensztein, E., E. Cavallo, and O. Jeanne. 2017. "The Welfare Gains from Macro-insurance against Natural Disasters." *Journal of Development Economics* 124: 142–156.

Boucher, S. R., M. R. Carter, J. E. Flatnes, T. J. Lybbert, J. G. Malacarne, P. P. Mareyna, and L. A. Paul. 2024. "Bundling Genetic and Financial Technologies for More Resilient and Productive Small-Scale Farmers in Africa." *The Economic Journal* 134: 2321–2350.

Branco, D., and J. Féres. 2021. "Weather Shocks and Labor Allocation: Evidence from Rural Brazil." *American Journal of Agricultural Economics* 103 (4): 1359–1377.

Bret, Lauriane, Maxime Dussud, Lucas Metral, Anne-Laure Ladier, and Lorraine Trilling. 2021. "Towards a Model Assessing Supply Chain Resilience Strategies." *Procedia CIRP* 103: 14–19.

Briter Intelligence. 2024. *State of AgTech Investment in Africa* 2024.

Brookings Institution. 2021. "Global Economic Impacts of Climate Shocks, Climate Policy and Changes in Climate Risk Assessment." Climate and Energy Economics Discussion Paper.

Brooks, W., and K. Donovan. 2020. "Eliminating Uncertainty in Market Access: The Impact of New Bridges in Rural Nicaragua." *Econometrica* 88 (5): 1965–1997.

Brucal, Arlan, and Antoine Dechezleprêtre. 2021. "Assessing the Impact of Energy Prices on Plant-Level Environmental and Economic Performance: Evidence from Indonesian Manufacturers." OECD, Paris.

Brucal, Arlan, and Shilpita Mathews. 2021. "Market Entry, Survival, and Exit of Firms in the Aftermath of Natural Hazard-Related Disasters." ERIA Discussion Paper Series No. 414, Economic Research Institute for ASEAN and East Asia, Jakarta.

Burgess, R., O. Deschenes, D. Donaldson, and M. Greenstone. 2017. "Weather, Climate Change and Death in India." Working paper, London School of Economics, London, UK.

Burke, M., and K. Emerick. 2016. "Adaptation to Climate Change: Evidence from US Agriculture." *American Economic Journal: Economic Policy* 8 (3): 106–140.

Burke, M., S. M. Hsiang, and E. Miguel. 2015. "Global Non-linear Effect of Temperature on Economic Production." *Nature* 527 (7577): 235–239.

Burke, M., and V. Tanutama. 2019. "Climatic Constraints on Aggregate Economic Output." NBER Working Paper 25779, National Bureau of Economic Research, Cambridge, MA.

Burlig, F., A. Jina, E. M. Kelley, G. Lane, and H. Sahai. 2024. "Long-Range Forecasts as Climate Adaptation: Experimental Evidence from Developing-Country Agriculture." NBER Working Paper 32173, National Bureau of Economic Research, Cambridge, MA.

Burzyński, Michal, Christoph Deuster, Frédéric Docquier, and Jaime de Melo. 2022. "Climate Change, Inequality, and Human Migration." *Journal of the European Economic Association* 20 (3): 1145–1197.

Business Continuity Institute. 2023. *BCI Horizon Scan Report 2023*. Reading, UK: Business Continuity Institute.

Cacho, Oscar J., Jonathan Moss, Philip K. Thornton, Mario Herrero, Ben Henderson, Benjamin L. Bodirsky, Florian Humpenöder, Alexander Popp, and Leslie Lipper. 2020. "The Value of Climate-Resilient Seeds for Smallholder Adaptation in Sub-Saharan Africa." *Climatic Change* 162 (3): 1213–1229.

Caggese, A., A. Chiavari, S. Goraya, and C. Villegas-Sanchez. 2025. "Climate Change, Firms, and Aggregate Productivity." CEPR Discussion Papers 19164.

Cai, R., S. Feng, M. Oppenheimer, and M. Pytlikova. 2016. "Climate Variability and International Migration: The Importance of the Agricultural Linkage." *Journal of Environmental Economics and Management* 79: 135–151.

Callahan, C., and J. Mankin. 2022. "National Attribution of Historical Climate Damages." *Climatic Change* 172 (3): 40.

Campbell, A., N. Spencer, and E. Strobl. 2021. "Sea Level Rise under Climate Change: Implications for Beach Tourism in the Caribbean."

Campbell, Bruce M., Aniruddha Ghosh, Ousmane Ndiaye, Arame Tall, and Robert Zougmoré. 2026. "Food Security: A Practical Roadmap for Scaling Digital Climate Advisory Services in Africa." Adaptation Insights 03. Rotterdam: Global Center on Adaptation.

Cantelmo, A., G. Melina, and C. Papageorgiou. 2023. "Macroeconomic Outcomes in Disaster-Prone Countries." *Journal of Development Economics* 161: 103037.

Caretta, M. A. 2014. "Situated Knowledge in Cross-Cultural, Cross-Language Research: A Collaborative Reflexive Analysis of Researcher, Assistant and Participant Subjectivities." *Qualitative Research* 15 (4): 489–505.

Cariolle, J., and D. A. Carroll. 2020. "Digital Technologies for Small and Medium Enterprises and Jobs."

Carleton, T., E. Duflo, K. Jack, and G. Zappalà. 2025. "The Economics of Climate Adaptation: From Academic Insights to Effective Policy." VoxEU.org, April 15, 2025. https://cepr.org/voxeu/columns/economics-climate-adaptation-academic-insights-effective-policy.

Carleton, T., A. Jina, M. Delgado, M. Greenstone, T. Houser, S. Hsiang, A. Hultgren, R. E. Kopp, K. E. McCusker, and I. Nath. 2022. "Valuing the Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits." *The Quarterly Journal of Economics* 137 (4): 2037–2105.

Carleton, T. A., and S. M. Hsiang. 2016. "Social and Economic Impacts of Climate." *Science* 353: 6304.

Carter, M., L. Cheng, and A. Sarris. 2016. "Where and How Index Insurance Can Boost the Adoption of Improved Agricultural Technologies." *Journal of Development Economics* 118 (C): 59–71.

Carter, Michael, Francisco Galarza Arellano, and Stephen Boucher. 2007. "Underwriting Area-Based Yield Insurance to Crowd-In Credit Supply and Demand." Working paper.

Caselli, G., and C. Figueira. 2020. "The Impact of Climate Risks on the Insurance and Banking Industries." In *Sustainability and Financial Risks*, 31–62. Springer.

Castro-Vincenzi, J. 2024. "Climate Hazards and Resilience in the Global Car Industry." Working paper.

Castro-Vincenzi, J., G. Khanna, N. Morales, and N. Pandalai-Nayar. 2024. "Weathering the Storm: Supply Chains and Climate Risk." NBER Working Paper 32218, National Bureau of Economic Research, Cambridge, MA.

Cattaneo, Cristina, and Giovanni Peri. 2016. "The Migration Response to Increasing Temperatures." *Journal of Development Economics* 122: 127–146.

Cavalieri, A., J. Reis, and M. Amorim. 2021. "Circular Economy and Internet of Things: Mapping Science of Case Studies in Manufacturing Industry." *Sustainability* 13: 3299.

Cevik, S., and F. Miryugin. 2022. "Rogue Waves: Climate Change and Firm Performance." *Comparative Economic Studies*, 1–31.

Cevik, V. A. 2024. "Impacts of Climate Change on Logistics and Supply Chains." *Afet ve Risk Dergisi*.

CGAP (Consultative Group to Assist the Poor). 2013. "Segmentation of Smallholder Households: Meeting the Range of Financial Needs in Agricultural Families," by R. Peck Christen and J. Anderson. Focus Note 85, Washington, DC.

CGAP. 2022. "CGAP Strengthening Climate Resilience & Adaptation through Financial Services."

CGAP. 2024a. "A Green Future for All: How Financial Services Can Build More Inclusive Carbon Markets," by M. Mattern, E. Kiamba, and B. Gordon.

CGAP. 2024b. "8 Billion Reasons: Inclusive Finance as a Catalyst for Climate Action," by P. Zetterli, M. Mattern, and J. Swanborough.

CGAP. 2024c. "Exclusion Risks in Climate-Related Financial Regulation: An Analytical Framework," by Denise Dias, Majorie Chalwe-Mulenga, Tatiana Reyes Chamas, and Tatiana Alonso. Working paper.

CGAP. 2024d. "Charting the Path to Belém: Inclusive Finance Is the Key to Climate Action," by Sophie Sirtaine. Blog, November 25, 2024.

CGAP. 2025a. "New Data Show the Key Role of Inclusive Finance in Climate Adaptation," by P. Zetterli.

CGAP. 2025b. "The Evidence of Credit and Insurance's Role in Tackling Climate Change," by Karina Broens Nielsen and Peter Zetterli. Blog, February 20, 2025.

CGAP. 2025c. "Inclusive Finance Can Deliver Climate Funding into the Hands of People Who Need It Most," by Peter Zetterli, Gaia Larsen, and Edward Davey. Blog, January 23, 2025.

CGAP. 2025d. "Strengthening Financial Systems for Climate Adaptation," by S. Baur-Yazbeck and H. Miller. Working paper.

CGAP. 2025e. "Social Protection + Financial Inclusion = A Path to Climate Resilience," by Joep Roest. Blog, January 29, 2025.

CGAP. 2025f. "Climate Change Is Undermining Financial Inclusion for the Poor," by P. Zetterli, and S. Notta.

Chakravorty, Ujjayant, Manzoor H. Dar, and Kyle Emerick. 2023. "Inefficient Water Pricing and Incentives for Conservation." *American Economic Journal: Applied Economics* 15 (1): 319–350.

Chambwera, M., G. Heal, C. Dubeux, S. Hallegatte, L. Leclerc, A. Markandya, B. A. McCarl, R. Mechler, and J. E. Neumann. 2014. "Economics of Adaptation." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. New York: Cambridge University Press.

Chang, T. Y., J. Graff Zivin, T. Gross, and M. Neidell. 2019. "The Effect of Pollution on Worker Productivity." *American Economic Journal: Applied Economics*.

Chege, M., and D. Wang. 2020. "The Influence of Technology Innovation on SME Performance through Environmental Sustainability Practices in Kenya." *Technology in Society* 60: 101210.

Chen, S., and B. Gong. 2021. "Response and Adaptation of Agriculture to Climate Change: Evidence from China." *Journal of Development Economics*.

Chinowsky, P., J. Helman, S. Gulati, J. Neumann, and J. Martinich. 2019. "Impacts of Climate Change on Operation of the US Rail Network." *Transport Policy* 75: 183–191.

Chinowsky, P. S., J. C. Price, and J. E. Neumann. 2013. "Assessment of Climate Change Adaptation Costs for the U.S. Road Network." *Global Environmental Change* 23 (4): 764–773.

Chowdhury, S., et al. 2022. "Impact of Organisational Factors on the Circular Economy Practices and Sustainable Performance of Small and Medium-Sized Enterprises in Vietnam." *Journal of Business Research* 147: 362–378.

Christen, R. P., and D. Pearce. 2005. *Managing Risks and Designing Products for Agricultural Microfinance: Features of an Emerging Model*. Washington, DC: CGAP; Rome: IFAD.

Christian, C., L. Hensel, and C. Roth. 2019. "Income Shocks and Suicides: Causal Evidence from Indonesia." *The Review of Economics and Statistics* 101 (5): 905–920.

Ciani, A., F. M. D'Arcangelo, M. London, and E. Zaurino. Forthcoming. "Adapting Supply Chains: The Role of Climate Shocks." Unpublished manuscript.

Ci-Dev. 2024. "Rwanda: Rural Electrification and Clean and Improved Cooking."

CIF (Climate Investment Funds). 2016. "Private Sector Investment in Climate Adaptation in Developing Countries: Landscape, Lessons Learned and Future Opportunities."

Circle Economy and Deloitte. 2025. *The Global Circularity Gap Report 2025*. Circle Economy Foundation.

Cirera, X., and W. Maloney. 2017. *The Innovation Paradox: Developing-Country Capabilities and the Unrealized Promise of Technological Catch-Up*. Washington, DC: World Bank.

Cirera, X., and S. Muzi. 2020. "Measuring Innovation Using Firm-Level Surveys: Evidence from Developing Countries." *Research Policy* 49 (3): 103912.

CLASP (Collaborative Labeling and Appliance Standards Program). 2023. "Pathways to Prevent Dumping of Climate Harming Room Air Conditioners in Southeast Asia."

Climate Change Committee. 2021. "Independent Assessment of UK Climate Risk: Advice to Government for the UK's Third Climate Change Risk Assessment (CCRA3)."

ClimateWise. 2011. *ClimateWise Compendium of Disaster Risk Transfer Initiatives in the Developing World*. London: ClimateWise, University of Cambridge Programme for Sustainability Leadership.

Coalition for Climate Resilient Investment. 2021. *The Physical Climate Risk Assessment Methodology (PCRAM): Guidelines for Integrating Physical Climate Risks in Infrastructure Investment Appraisal*.

Cohen, François, and Antoine Dechezleprêtre. 2022. "Mortality, Temperature, and Public Health Provision: Evidence from Mexico." *American Economic Journal: Economic Policy* 14 (2): 161–192.

Cole, Shawn, Xavier Giné, and James Vickery. 2017. "How Does Risk Management Influence Production Decisions? Evidence from a Field Experiment." *The Review of Financial Studies* 30: 1935–1970.

Cole, Shawn, Xavier Giné, and James Vickery. 2024. "Designing Index Insurance: Evidence from a Field Experiment." Background paper, *Rethinking Resilience: Adapting to a Changing Climate*, World Bank, Washington, DC.

Cole, Shawn, Daniel Stein, and Jeremy Tobacman. 2014. "Dynamics of Demand for Index Insurance: Evidence from a Long-Run Field Experiment." *American Economic Review* 104 (5): 284–290.

Colina, C., L. Goldman, M. Tsan, R. Dogandjieva, S. Daga, and V. Woolworth. 2016. *Inflection Point: Unlocking Growth in the Era of Farmer Finance*. Initiative for Smallholder Finance and the Rural and Agricultural Finance Learning Lab.

Collier, B. 2013. "Financial Inclusion and Natural Disasters." Doctoral dissertation.

Collier, B. L. 2020. "Strengthening Local Credit Markets through Lender-Level Index Insurance." *Journal of Risk and Insurance* 87 (2): 319–349.

Collier, B. L., and V. O. Babich. 2019. "Financing Recovery after Disasters: Explaining Community Credit Market Responses to Severe Events." *Journal of Risk and Insurance* 86 (2): 479–520.

Collier, B. L., S. T. Howell, and L. Rendell. 2024. "After the Storm: How Emergency Liquidity Helps Small Businesses following Natural Disasters." NBER Working Paper 32326, National Bureau of Economic Research, Cambridge, MA.

Colmer, J. 2021. "Temperature, Labor Reallocation, and Industrial Production: Evidence from India." *American Economic Journal: Applied Economics* 13 (4): 101–124.

Conte, B. 2023. "Climate Change and Migration: The Case of Africa." CESifo Working Papers 9948, CESifo.

Convergence. 2023. *State of Blended Finance* 2023.

Costinot, A., D. Donaldson, and C. Smith. 2016. "Evolving Comparative Advantage and the Impact of Climate Change in Agricultural Markets: Evidence from 1.7 Million Fields around the World." *Journal of Political Economy* 124 (1): 205–248.

Cotula, L., and S. Vermeulen. 2010. "Making the Most of Agricultural Investment: A Survey of Business Models That Provide Opportunities for Smallholders." International Institute for Environment and Development.

Coulibaly, Y. J., G. A. Gbetibouo, G. Kundhlande, G. W. Sileshi, and T. L. Beedy. 2015. "Responding to Crop Failure: Understanding Farmers' Coping Strategies in Southern Malawi." *Sustainability* 7: 1–17.

CPI (Climate Policy Initiative). 2018. *Understanding and Increasing Finance for Climate Adaptation in Developing Countries*, by Valerio Micale, Bella Tonkonogy, and Federico Mazza.

CPI. 2022. *Global Landscape of Climate Finance: A Decade of Data*.

CPI. 2024a. *Landscape of Climate Finance in Africa*.

CPI. 2024b. *Tracking and Mobilizing Private Sector Climate Adaptation Finance*.

CPI. 2025. *Global Landscape of Climate Finance 2024: Insights for COP29*.

Crick, C., M. Diop, M. Sow, B. Diouf, B. Diouf, J. Muhwanga, and M. Dajani. 2016. "Enabling Private Sector Adaptation in Developing Countries and Their Semi-arid Regions: Case Studies of Senegal and Kenya." Grantham Research Institute on Climate Change and the Environment Working Paper No. 258.

Crick, Florence, Shaikh M. S. U. Eskander, Sam Fankhauser, and Mamadou Diop. 2018. "How Do African SMEs Respond to Climate Risks? Evidence from Kenya and Senegal." *World Development* 108: 157–168.

Cuaresma, C., J. Hlouskova, and M. Obersteiner. 2008. "Natural Disasters as Creative Destruction? Evidence from Developing Countries." *Economic Inquiry* 46: 214–226.

Cuvellier Giacomelli, Max, and Maxime Bayen. 2026. *Africa: The Big Deal*. Accessed May 17, 2026.

Damania, Richard, Sébastien Desbureaux, Marie Hyland, Asif Islam, Scott Moore, Aude-Sophie Rodella, Jason Russ, and Eline Wijnen. 2017. *Uncharted Waters: The New Economics of Water Scarcity and Variability*. Washington, DC: World Bank.

D'Amour, Christopher Bren, Leonie Wenz, Matthias Kalkuhl, Jan Christoph Steckel, and Felix Creutzig. 2016. "Teleconnected Food Supply Shocks." *Environmental Research Letters* 11: 035007.

Danielson, Morris G., and Jonathan A. Scott. 2006. "The Capital Budgeting Decisions of Small Businesses." *Journal of Applied Finance* 16 (2): 45–56.

De Haas, R., R. Martin, M. Muuls, and H. Schweiger. 2024. "Managerial and Financial Barriers to the Green Transition." *Management Science*.

Dell, M., B. F. Jones, and B. A. Olken. 2012. "Temperature Shocks and Economic Growth: Evidence from the Last Half Century." *American Economic Journal: Macroeconomics* 4 (3): 66–95.

Dellink, R., E. Lanzi, and J. Chateau. 2019. "The Sectoral and Regional Economic Consequences of Climate Change to 2060." *Environmental and Resource Economics* 72 (2): 309–363.

Del Ninno, C., P. A. Dorosh, and L. C. Smith. 2003. "Public Policy, Markets and Household Coping Strategies in Bangladesh: Avoiding a Food Security Crisis following the 1998 Floods." *World Development* 31 (7): 1221–1238.

Demirgüç-Kunt, A., and V. Maksimovic. 2002. "Firms as Financial Intermediaries: Evidence from Trade Credit Data." World Bank Policy Research Working Paper 2696.

Derhab, N., and Z. Elkhwesky. 2023. "A Systematic and Critical Review of Waste Management in Micro, Small and Medium-Sized Enterprises: Future Directions for Theory and Practice." *Environmental Science and Pollution Research* 30: 13920–13944.

Deschênes, Olivier, and Michael Greenstone. 2011. "Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US." *American Economic Journal: Applied Economics* 3 (4): 152–185.

Desmet, K., and E. Rossi-Hansberg. 2024. "Climate Change Economics over Time and Space." *Annual Review of Economics* 16: 271–304.

Despoudi, S., U. Sivarajah, K. Spanaki, V. Charles, and V. Durai. 2025. "Industry 4.0 and Circular Economy for Emerging Markets: Evidence from Small and Medium-Sized Enterprises (SMEs) in the Indian Food Sector." *Annals of Operations Research* 350: 453–491.

Devadiga, Asavari. 2020. "'Water When You Need It': Drawing Lessons from Practices in Hubli-Dharwad, India." *Environment and Urbanization* 32 (2): 331–348.

Diaz, D., and F. Moore. 2017. "Quantifying the Economic Risks of Climate Change." *Nature Climate Change* 7 (11): 774–782.

Diaz Lopez, F. J., T. Bastein, and A. Tukker. 2019. "Business Model Innovation for Resource-Efficiency, Circularity and Cleaner Production: What 143 Cases Tell Us." *Ecological Economics* 155: 20–35.

Didier, T. 2024. "Managing Flood Risks: Leveraging Finance for Business Resilience in Malaysia." World Bank and Bank Negara Malaysia.

Docquier, F., J. de Melo, C. Deuster, and M. Burzyński. 2019. "Climate Migration Frightens… Climate Poverty Is Frightening!" VoxEU.org, December 10, 2019.

Donofrio, Stephen, Alex Procton, Ciro Calderon, and Laura Weatherer. 2023. "State of the Voluntary Carbon Markets 2023." Forest Trends' Ecosystem Marketplace.

Dougherty-Choux, L., P. Terpstra, S. Kammila, and P. Kurukulasuriya. 2015. *Adapting from the Ground Up*. Washington, DC: World Resources Institute.

Downing, T. E. 2012. "Views of the Frontiers in Climate Change Adaptation Economics." *WIREs Climate Change* 3 (2): 161–170. doi:10.1002/ wcc.157.

Druce, L., U. Moslener, C. Gruening, P. Pauw, and R. Connell. 2016. "Demystifying Adaptation Finance for the Private Sector." UNEP and GIZ.

Dunne, John P., Ronald J. Stouffer, and Jasmin G. John. 2013. "Reductions in Labour Capacity from Heat Stress under Climate Warming." *Nature Climate Change* 3: 563–566.

Du Puy, T., and J. G. Shrader. 2024. "Costs of Climate Adaptation: Evidence from French Agriculture." Working paper.

Ellen MacArthur Foundation. 2025. "Plastics." www.ellenmacarthurfoundation.org/topics/plastics/overview.

Elliott, Robert J. R., Yi Liu, Eric Strobl, and Meng Tong. 2019. "Estimating the Direct and Indirect Impact of Typhoons on Plant Performance: Evidence from Chinese Manufacturers." *Journal of Environmental Economics and Management* 98: 102252.

Emerick, K., A. de Janvry, E. Sadoulet, and M. H. Dar. 2016. "Technological Innovations, Downside Risk, and the Modernization of Agriculture." *American Economic Review* 106 (6): 1537–1561.

ESMAP (Energy Sector Management Assistance Program). 2024. "Sustainable Cooling in Off Grid Areas: The Nexus between Access to Energy and Cooling." ESMAP Paper, World Bank, Washington, DC.

Falchetta, G., E. de Cian, I. Sue Wing, and D. Carr. 2024. "Global Projections of Heat Exposure of Older Adults." *Nature Communications* 15: 3678.

FAO (Food and Agriculture Organization of the United Nations). 2016a. *E-agriculture Strategy Guide: Piloted in Asia-Pacific Countries*. FAO and ITU.

FAO. 2016b. "The Global Dairy Sector: Facts." Note.

FAO. 2019. *The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction*. Rome: FAO.

FAO. 2023. "New FAO Report Maps Pathways towards Lower Livestock Emissions." Press release.

FAO and AFRACA (African Rural and Agricultural Credit Association). 2021. *Agricultural Value Chain Finance Innovations and Lessons: Case Studies in Africa*. 2nd ed. Rome: FAO.

FAO, IFAD (International Fund for Agricultural Development), UNICEF (United Nations Children's Fund), WFP (World Food Programme), and WHO (World Health Organization). 2022. *The State of Food Security and Nutrition in the World 2022: Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable*. Rome: FAO.

Felbermayr, Gabriel, and Jasmin Gröschl. 2014. "Naturally Negative: The Growth Effects of Natural Disasters." *Journal of Development Economics* 111: 92–106.

Feriga, Moustafa, Nancy Lozano Gracia, and Pieter Serneels. 2025. "The Impact of Climate Change on Work: Lessons for Developing Countries." *The World Bank Research Observer* 40 (1): 104–146.

Ffoulkes, C., B. Hockridge, H. Oliver, and L. Palmer. 2023. *Research to Update Indicators Which Monitor Progress in Adaptation in England*. Climate Change Committee: Oxford, UK.

Fisher, M., and E. R. Carr. 2015. "The Influence of Gendered Roles and Responsibilities on the Adoption of Technologies That Mitigate Drought Risk: The Case of Drought-Tolerant Maize Seed in Eastern Uganda." *Global Environmental Change* 35: 82–92.

Fisman, R., and I. Love. 2003. "Trade Credit, Financial Intermediary Development, and Industry Growth." *The Journal of Finance* 58 (1): 353–374.

Fleming, J., C. Kirby, and B. Ostdiek. 2006. "Information, Trading, and Volatility: Evidence from Weather-Sensitive Markets." *The Journal of Finance* 61 (6): 2899–2930.

Forzieri, G., A. Bianchi, F. B. Silva, M. A. Marin Herrera, A. Leblois, C. Lavalle, J. C. J. H. Aerts, and L. Feyen. 2018. "Escalating Impacts of Climate Extremes on Critical Infrastructures in Europe." *Global Environmental Change* 48: 97–107.

Fowlie, M., M. Greenstone, and C. Wolfram. 2018. "Do Energy Efficiency Investments Deliver? Evidence from the Weatherization Assistance Program." *Quarterly Journal of Economics* 133 (3): 1597–1644.

Franco, C., and J. Hanna Collado. 2016. "Strengthening Climate Resilience of Small and Medium Enterprises (SMEs): Practitioners' Dialogue on Climate Investments." GIZ.

Franz, M., F. Bücken, K. P. Schumacher, and K. M. Griese. 2020. "Sustainability Transition and Climate Change Adaption of Logistics." In *The Palgrave Encyclopedia of Urban and Regional Futures*, 1–8. Springer International Publishing.

Frei-Oldenburg, A., J. Wohlgemuth, S. M. von Stieglitz, C. Stahr, and F. Eisinger. 2018. "Climate Expert: A Bottom-Up Approach to SME Resilience to Climate Change." In *Private-Sector Action in Adaptation: Perspectives on the Role of Micro, Small and Medium Size Enterprises*, edited by C. Schaer and N. D. Kuruppu. UNEP DTU Partnership.

Fried, S. 2024. "A Macro Study of the Unequal Effects of Climate Change." Working paper.

G20. 2017. "Climate Smart Financing for Rural MSMEs: Enabling Policy Frameworks."

G20 Global Partnership for Financial Inclusion. 2023. "Innovations in Financial Services for Micro, Small and Medium-Sized Enterprises."

Gannon, Kate Elizabeth, Florence Crick, Joanes Atela, Zhanna Babagaliyeva, Samavia Batool, Claire Bedelian, Elizabeth Carabine, Declan Conway, Mamadou Diop, and Sam Fankhauser. 2020. "Private Adaptation in Semi-arid Lands: A Tailored Approach to 'Leave No One Behind'." *Global Sustainability* 3: e6.

Garg, Teevrat, Matthew Gibson, and Fanglin Sun. 2020. "Extreme Temperatures and Time Use in China." *Journal of Economic Behavior & Organization* 180: 309–324.

GARI (Global Adaptation & Resilience Investment). 2024. "The Unavoidable Opportunity: Investing in the Growing Market for Climate Resilience Solutions." Discussion paper, New York.

Gasbarro, F., F. Rizzi, and M. Frey. 2016. "Adaptation Measures of Energy and Utility Companies to Cope with Water Scarcity Induced by Climate Change." *Business Strategy and the Environment* 25 (1): 54–72.

GCA (Global Commission on Adaptation). 2019. *Adapt Now: A Global Call for Leadership on Climate Resilience*. Global Center on Adaptation and World Resources Institute.

GCA. 2024. *State and Trends in Climate Adaptation Finance 2024*. Global Center on Adaptation and World Resources Institute.

Gechter, M., and N. Kala. 2025. "Firm Presence, Pollution, and Agglomeration: Evidence from a Randomized Environmental Place-Based Policy." NBER Working Paper 33707.

GEF (Global Environment Facility) and IFC (International Finance Corporation). 2012. "Private Sector Engagement in Climate Change Adaptation: Prepared by the GEF Secretariat in Collaboration with the International Finance Corporation." GEF/LDCF. SCCF.12/Inf.06.

Geissdoerfer, M., P. Savaget, and S. Evans. 2017. "The Cambridge Business Model Innovation Process." *Procedia Manufacturing* 8: 262–269.

GIC and Bain. 2025. *Sizing the Inevitable Investment Opportunity: Climate Adaptation*, by D. R. Wong and K. B. Kim. Singapore.

Giglio, Stefano, Bryan Kelly, and Johannes Stroebel. 2021. "Climate Finance." *Annual Review of Financial Economics* 13: 15–36.

Gikonyo, N. W., J. R. Busienei, J. K. Gathiaka, and G. N. Karuku. 2022. "Analysis of Household Savings and Adoption of Climate Smart Agricultural Technologies: Evidence from Smallholder Farmers in Nyando Basin, Kenya." *Heliyon* 8 (6).

Gine, X., R. M. Townsend, and J. Vickery. 2015. "Forecasting When It Matters: Evidence from Semi-arid India." Working paper.

Ginglinger, E., and Q. Moreau. 2019. "Climate Risk and Capital Structure." Université Paris Dauphine Research Paper 3327185.

Global Center on Adaptation. 2020. "What Are Resilience Bonds and How Can They Protect Us against Climate Crises?"

Global Center on Adaptation. 2021. "Economics and Finance: Macroeconomics and Climate Adaptation." In *State and Trends in Adaptation Report: How Adaptation Can Make Africa Safer, Greener and More Prosperous in a Warming World*.

Global Center on Adaptation. 2025. "How SIDS Can Leverage Their Natural Assets to Enhance Climate Resilience," by Chandrahas Choudhury. November 13, 2025.

Godde, C. M., D. Mason-D'Croz, D. E. Mayberry, P. K. Thornton, and M. Herrero. 2021. "Impacts of Climate Change on the Livestock Food Supply Chain: A Review of the Evidence." *Global Food Security* 28: 100488.

Godinho, Catrina. 2022. "What Do We Know About the Employment Impacts of Climate Policies? A Review of the Ex Post Literature." *WIREs Climate Change* 13 (6): e794.

Goicoechea, A., and M. Lang. 2023. "Firms and Climate Change in Low- and Middle-Income Countries." World Bank Policy Research Working Paper 10644.

Goldstein, A., W. R. Turner, J. Gladstone, and D. G. Hole. 2019. "The Private Sector's Climate Change Risk and Adaptation Blind Spots." *Nature Climate Change* 9 (1): 18–25.

Gormsen, Niels Joachim, Kilian Huber, and Sangmin Oh. 2023. "Climate Capitalists." Fama-Miller Working Paper.

Gouda, S. K., and H. Saranga. 2018. "Sustainable Supply Chains for Supply Chain Sustainability: Impact of Sustainability Efforts on Supply Chain Risk." *International Journal of Production Research* 56 (17): 5820–5835.

Gouel, C., and D. Laborde. 2021. "The Crucial Role of Domestic and International Market-Mediated Adaptation to Climate Change." *Journal of Environmental Economics and Management* 106: 102408.

Graff Zivin, J., S. M. Hsiang, and M. Neidell. 2018. "Temperature and Human Capital in the Short and Long Run." *Journal of the Association of Environmental and Resource Economists* 5 (1): 77–105.

Greatrex, H., J. Hansen, S. Garvin, R. Diro, S. Blakeley, M. le Guen, K. Rao, and D. Osgood. 2015. "Scaling Up Index Insurance for Smallholder Farmers: Recent Evidence and Insights (CCAFS Report No. 14)." CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Griese, H., R. Hagedorn, and D. Rübbelke. 2021. "Private Adaptation to Climate Change: Evidence from Transport and Logistics Firms." *Climate Policy* 21 (6): 805–819.

Grover, A., and M. Imbruno. 2020. "Using Experimental Evidence to Inform Firm Support Programs in Developing Countries." Technical Report 9461, World Bank.

Grover, A., and M. Kahn. 2024. "Firm Adaptation to Climate Change." NBER Working Paper 32848.

GSMA. 2022. "Pay-as-You-Go Utilities: Innovations and Opportunities in Asia."

GSMA. 2023. "Digitalising Innovative Finance: Emerging Instruments for Early-Stage Innovators in Low- and Middle-Income Countries."

Gutiérrez, Emilio, and Kensuke Teshima. 2018. "Abatement Expenditures, Technology Choice, and Environmental Performance: Evidence from Firm Responses to Import Competition in Mexico." *Journal of Development Economics* 133: 264–274.

Hall, B. H., and J. Lerner. 2009. "The Financing of R&D and Innovation." NBER Working Paper 15325.

Hallegatte, S. 2012. "A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation." Policy Research Working Paper 6058. doi:10.1596/1813-9450-6058.

Hallegatte, S. 2014. "Economic Resilience: Definition and Measurement." Policy Research Working Paper, World Bank, Washington, DC.

Hallegatte, S., M. Bangalore, L. Bonzanigo, M. Fay, T. Kane, U. Narloch, J. Rozenberg, D. Treguer, and A. Vogt-Schilb. 2016. *Shock Waves: Managing the Impacts of Climate Change on Poverty*. Climate Change and Development Series. Washington, DC: World Bank.

Hallegatte, S., and P. Dumas. 2009. "Can Natural Disasters Have Positive Consequences? Investigating the Role of Embodied Technical Change." *Ecological Economics* 68 (3): 777–786.

Hallegatte, S., J. Rentschler, and J. Rozenberg. 2019. *Lifelines: The Resilient Infrastructure Opportunity*. World Bank.

Hallegatte, S., and J. Rozenberg. 2017. "Climate Change through a Poverty Lens." *Nature Climate Change* 7 (4): 250–256.

Hardy, Morgan, and Jamie McCasland. 2023. "Lights Off, Lights On: The Effects of Electricity Shortages on Small Firms." *The World Bank Economic Review* 37 (3): 445–465.

Haselip, James, Gordon Mackenzie, and Fatma Denton. 2014. "Financing Energy SMEs in Ghana and Senegal: Outcomes, Barriers and Prospects." *Energy Policy* 65: 369–376.

Hatashima, H., and U. Demberel. 2020. "What Is Blended Finance, and How Can It Help Deliver Successful High-Impact, High-Risk Projects?" World Bank Group, Independent Evaluation Group, January 27, 2020.

Henderson, J., C. Rodgers, R. Jones, J. Smith, K. Strzepek, and J. Martinich. 2015. "Economic Impacts of Climate Change on Water Resources in the Coterminous United States." *Mitigation and Adaptation Strategies for Global Change* 20 (1): 135–157.

Heymans, Chris, Rolfe Eberhard, David Ehrhardt, and Shannon Riley. 2016. *Providing Water to Poor People in African Cities Effectively: Lessons from Utility Reforms*. Water and Sanitation Program Report. Washington, DC: World Bank Group.

Highet, C., L. Datwani, A. Sulakhe, and V. Reddy. 2024. "Customer Focus Brings Green Technology to Rural Women in India." CGAP (blog), September 3, 2024.

Hill, R. V., N. Kumar, N. Magnan, S. Makhija, F. de Nicola, D. J. Spielman, and P. S. Ward. 2019. "Ex Ante and Ex Post Effects of Hybrid Index Insurance in Bangladesh." *Journal of Development Economics* 136: 1–17.

Hoedjes, J., A. Miller, and J. Usher. 2018. "Climate Information for Climate Change Adaptation." In *Private-Sector Action in Adaptation: Perspectives on the Role of Micro, Small and Medium Size Enterprises*, edited by C. Schaer, and N. D. Kuruppu. UNEP DTU Partnership.

Hoffmann, V. H., D. C. Sprengel, A. Ziegler, M. Kolb, and B. Abegg. 2009. "Determinants of Corporate Adaptation to Climate Change in Winter Tourism: An Econometric Analysis." *Global Environmental Change* 19 (2): 256–264.

Hogan, D., and W. Schlenker. 2024. "Empirical Approaches to Climate Change Impact Quantification." *Handbook of the Economics of Climate Change* 1 (1): 53–111.

Hoogendoorn, Gijsbert, and Jennifer M. Fitchett. 2018. "Tourism and Climate Change: A Review of Threats and Adaptation Strategies for Africa." *Current Issues in Tourism* 21 (7): 742–759.

Hottenrott, H., S. Rexhauser, and R. Veugelers. 2016. "Organisational Change and the Productivity Effects of Green Technology Adoption." *Resource and Energy Economics* 43: 172–194.

Howell, S. T. 2017. "Financing Innovation: Evidence from R&D Grants." *American Economic Review* 107 (4): 1136–1164.

Hsiang, S. M. 2010. "Temperatures and Cyclones Strongly Associated with Economic Production in the Caribbean and Central America." *Proceedings of the National Academy of Sciences* 107 (35): 15367–15372.

Hsiang, S. M., and A. S. Jina. 2014. "The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth: Evidence from 6,700 Cyclones." Technical report, National Bureau of Economic Research.

Hu, H., T. Lei, J. Hu, S. Zhang, and P. Kavan. 2018. "Disaster-Mitigating and General Innovative Responses to Climate Disasters: Evidence from Modern and Historical China." *International Journal of Disaster Risk Reduction* 28: 664–673.

Huang, H. H., J. Kerstein, and C. Wang. 2018. "The Impact of Climate Risk on Firm Performance and Financing Choices: An International Comparison." *Journal of International Business Studies* 49 (5): 633–656.

Huang, K., H. Zhao, J. Huang, J. Wang, and C. Findlay. 2020. "The Impact of Climate Change on the Labor Allocation: Empirical Evidence from China." *Journal of Environmental Economics and Management*.

Hugon, A., and K. Law. 2019. "Impact of Climate Change on Firm Earnings: Evidence from Temperature Anomalies." SSRN.

Hultgren, A., T. Carleton, M. Delgado, D. R. Gergel, M. Greenstone, T. Houser, S. Hsiang, A. Jina, R. E. Kopp, S. B. Malevich, K. E. McCusker, T. Mayer, I. Nath, J. Rising, A. Rode, and J. Yuan. 2025. "Impacts of Climate Change on Global Agriculture Accounting for Adaptation." *Nature* 642: 644–652.

Huppertz, M. 2025. "Sacking the Sales Staff: Weather Shocks to Labor Productivity, Complementary Input Adjustments, and Their Climate Policy Implications." Job Market Paper.

ICMA (International Capital Markets Association). 2021. *Overview and Recommendations for Sustainable Finance Taxonomies*. Zurich.

IDFC (International Development Finance Club). 2021. *IDFC Green Finance Mapping Report 2021*. Prepared with the support of the Climate Policy Initiative and Trinomics. Paris: IDFC Secretariat.

IEA (International Energy Agency). 2016. *Energy Technology Perspectives 2016: Towards Sustainable Urban Energy Systems*. Paris: IEA and OECD.

IEA. 2018. "Air Conditioning Use Emerges as One of the Key Drivers of Global Electricity-Demand Growth." Press release, May 15, 2018.

IEA. 2020. "Financing Energy Efficiency: Recent Developments in Policy and Practice," IEA, Paris.

IEA. 2023. "Access to Electricity Improves Slightly in 2023, but Still Far from the Pace Needed to Meet SDG7." IEA, Paris.

IFAD (International Fund for Agricultural Development). 2025. "Change Starts Here: Small Farmers with a Big Message for the World."

IFC (International Finance Corporation). 2011. "Climate Risk and Business: Ports—Terminal Marítimo Muelles el Bosque, Cartagena, Colombia. Executive Summary," by V. Stenek, J.-C. Amado, R. Connell, O. Palin, S. Wright, B. Pope, J. Hunter, J. McGregor, W. Morgan, B. Stanley, R. Washington, D. Liveman, H. Sherwin, P. Kapelus, C. Andrade, and J. D. Pabon.

IFC. 2012. *Innovative Agricultural SME Financing Models*. Washington, DC: IFC.

IFC. 2013. *Enabling Environment for Private Sector Adaptation: An Index Assessment Framework*.

IFC. 2016a. "Innovative Insurance to Manage Climate Risks," by A. Miller and S. Swann. EM Compass Note 9.

IFC. 2016b. "Insurance Options for Addressing Climate Change," by A. Miller and S. Swann. EM Compass Note 13.

IFC. 2016c. "MSME Finance Gap: An Updated Estimation and Evolution of the Micro, Small and Medium Enterprises (MSME) Gap in Emerging and Developing Markets."

IFC. 2016d. "Opportunities and Trends in Investing in the Health Sector."

IFC. 2019. "Measuring What Matters: Benefits of Green Building in Indonesia."

IFC. 2023a. *Building Green: Sustainable Construction in Emerging Markets*. Washington, DC: IFC.

IFC. 2023b. *Scaling Up Farmer Financing through AgTechs in Sub-Saharan Africa*.

IFC. 2023c. *2022 Implementation Progress Report: Canada-IFC Blended Climate Finance Program*. Washington, DC: IFC.

IFC. 2023d. *2022 Annual Report: IFC-Canada Climate Change Program*. Washington, DC: IFC.

IFC. 2026. *IFC Approach and Framework for Regenerative Agriculture: Investments and Advisory Engagements*.

IFC and SME Finance Forum. 2024. *MSME Finance Gap: Updated Estimation and Evolution*. World Bank Group.

IFC and UNEP (United Nations Environment Programme). 2024. *Cooler Finance: Mobilizing Investment for the Developing World's Sustainable Cooling Needs*. Washington, DC: IFC.

ILO (International Labour Organization). 2018. *World Employment and Social Outlook 2018: Greening with Jobs*.

ILO. 2019. *Working on a Warmer Planet: The Impact of Heat Stress on Labor Productivity and Decent Work*.

IMF (International Monetary Fund). 2023. "The Macroeconomic Returns of Investment in Resilience to Natural Disasters under Climate Change: A DSGE Approach," by E. F. Corugedo, A. Gonzalez, A. Guerson, and M. A. D. Guerson. IMF Working Papers 23/138.

IMF. 2024. "Unlocking Adaptation Finance in Emerging Market and Developing Economies," by D. Gautam, E. Gratcheva, F. M. Natalucci, and A. Prasad. Staff Climate Note 2024/007, Washington, DC, IMF.

India, Ministry of Micro, Small and Medium Enterprises. 2024. *Annual Report 2023–24*.

India State-Level Disease Burden Initiative Air Pollution Collaborators. 2020. "Health and Economic Impact of Air Pollution in the States of India: The Global Burden of Disease Study 2019." *The Lancet Planetary Health*.

Ingirige, B., K. Jones, and D. Proverbs. 2008. "Investigating SME Resilience and Their Adaptive Capacities to Extreme Weather Events: A Literature Review and Synthesis." In *Proceedings of the Conference on Building Education and Research (BEAR 2008)*. Kandalama, Sri Lanka.

Ingirige, B., and G. Wedawatta. 2016. "A Conceptual Framework for Understanding Resilience of Construction SMEs to Extreme Weather Events." *Built Environment Project and Asset Management* 6 (4): 428–443.

Institute for Public Policy Research. 2016. *Known Unknowns: The Hidden Threats That Climate Risks Pose to British Prosperity*. 2nd ed.

Intellecap. 2010. *Opportunities for Private Sector Engagement in Urban Climate Change Resilience Building*.

IPCC (Intergovernmental Panel on Climate Change). 2014. "AR5 Synthesis Report: Climate Change 2014."

IPCC. 2023. "AR6 Synthesis Report: Climate Change 2023."

ISF Advisors. 2019. *Pathways to Prosperity: 2019 Rural and Agricultural Finance State of the Sector Report*.

ISF Advisors. 2022. "The State of the Agri-SME Sector – Bridging the Finance Gap."

Ishtiaque, A., T. J. Krupnik, V. Krishna, M. N. Uddin, J. P. Aryal, A. K. Srivastava, S. Kumar, M. F. Shahzad, R. Bhatt, M. Gardezi, C. S. Bahinipati, S. B. Nazu, R. Ghimire, A. R. Anik, T. B. Sapkota, M. Ghosh, R. Subedi, A. Sardar, K. M. Z. Uddin, A. Khatri-Chhetri, M. S. Rahman, B. Singh, and M. Jain. 2024. "Overcoming Barriers to Climate-Smart Agriculture in South Asia." *Nature Climate Change*.

Jack, B., S. Jayachandran, N. Kala, and R. Pande. 2022. "Money (Not) to Burn: Payments for Ecosystem Services to Reduce Crop Residue Burning." NBER Working Paper 30690.

Jack, William, and Tavneet Suri. 2014. "Risk Sharing and Transactions Costs: Evidence from Kenya's Mobile Money Revolution." *American Economic Review* 104 (1).

Jaeger, B., and A. Upadhyay. 2020. "Understanding Barriers to Circular Economy: Cases from the Manufacturing Industry." *Journal of Enterprise Information Management* 33 (4): 729–745.

Jagnani, M., C. B. Barrett, Y. Liu, and L. You. 2021. "Within-Season Producer Response to Warmer Temperatures: Defensive Investments by Kenyan Farmers." *The Economic Journal* 131 (633): 392–419.

Janzen, S. A., and M. R. Carter. 2019. "After the Drought: The Impact of Microinsurance on Consumption Smoothing and Asset Protection." *American Journal of Agricultural Economics* 101 (3): 651–671.

Jaramillo, P., W. M. Griffin, and J. J. McCarthy. 2022. "Climate Change Impacts on Transportation Systems and Infrastructure: A Systematic Review." *Climatic Change* 171 (3–4): 29.

Javeline, Debra, Tracy Kijewski-Correa, and Angela Chesler. 2022. "Do Perverse Insurance Incentives Encourage Coastal Vulnerability?" *Natural Hazards Review* 23 (1).

Jensen, N., and C. Barrett. 2017. "Agricultural Index Insurance for Development." *Applied Economic Perspectives and Policy* 39: 199–219.

Jessoe, K., D. T. Manning, and J. E. Taylor. 2018. "Climate Change and Labour Allocation in Rural Mexico: Evidence from Annual Fluctuations in Weather." *The Economic Journal* 128 (608): 230–261.

Jiang, F., C. W. Li, and Y. Qian. 2019. "Can Firms Run Away from Climate-Change Risk? Evidence from the Pricing of Bank Loans." Unpublished manuscript.

Jin, Zuben, Frank Weikai Li, Yupeng Lin, and Zilong Zhang. 2021. "Do Firms Adapt to Rising Temperatures? Evidence from Establishment-Level Data."

John, I., S. Adekunle, and C. Aigbavboa. 2023. "Adoption of Circular Economy by Construction Industry SMEs: Organisational Growth Transition Study." *Sustainability* 15 (7): 5929.

Jones, Benjamin F., and Benjamin A. Olken. 2010. "Climate Shocks and Exports." *American Economic Review: Papers & Proceedings* 100: 454–459.

Jones, M., F. Kondylis, J. Loeser, and J. Magruder. 2022. "Factor Market Failures and the Adoption of Irrigation in Rwanda." *American Economic Review* 112 (7): 2316–2352.

Kahn, M. E., K. Mohaddes, R. N. C. Ng, M. H. Pesaran, M. Raissi, and J.-C. Yang. 2021. "Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis." *Energy Economics* 104: 105624.

Kala, N. 2017. "Learning, Adaptation, and Climate Uncertainty: Evidence from Indian Agriculture." Working paper.

Kalkuhl, M., and L. Wenz, 2020. "The Impact of Climate Conditions on Economic Production. Evidence from a Global Panel of Regions." *Journal of Environmental Economics and Management* 103: 102360.

Karplus, Valerie J., and Arti Grover. 2021. "Coping with COVID-19: Does Management Make Firms More Resilient?" Policy Research Working Paper 9514.

Kaswan, M. S., D. B. Sabale, and R. Rathi. 2023. "Integrating Circular Economy Aspects with Manufacturing Planning: An MSME Perspective." *E3S Web of Conferences* 453: 01007.

Kato, H., and T. Okubo. 2018. "The Impact of a Natural Disaster on Foreign Direct Investment and Vertical Linkages." SSRN.

Kaza, Silpa, Lisa Yao, Perinaz Bhada-Tata, and Frank van Woerden. 2018. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Urban Development Series. Washington, DC: World Bank.

Kennedy, K. M., M. R. Edwards, C. Doblinger, Z. H. Thomas, M. A. Borrero, E. D. Williams, N. E. Hultman, and K. Surana. 2024. "The Effects of Corporate Investment and Public Grants on Climate and Energy Startup Outcomes." *Nature Energy* 9.

Khanna, G., W. Liang, A. M. Mobarak, and R. Song. 2021. "The Productivity Consequences of Pollution-Induced Migration in China." Technical report, National Bureau of Economic Research.

Khattri, Alok, Deepa Parameshwar, and Sabine Pellech. 2010. *Opportunities for Private Sector Engagement in Urban Climate Change Resilience Building*. Bangkok, Thailand: Intellecap, Asian Cities Climate Change Resilience Network, and the Rockefeller Foundation.

Kim, J., P. Shah, J. Gaskell, A. Prasann, and A. Luthra. 2020. *Scaling Up Disruptive Agricultural Technologies in Africa*. Washington, DC: World Bank.

Kirchherr, J., Laura Piscicelli, Ruben Bour, Erica Kostense-Smit, Jennifer Muller, Anne Huibrechtse-Truijens, and Marko Hekkert. 2018. "Barriers to the Circular Economy: Evidence From the European Union (EU)." *Ecological Economics* 150: 264–272.

Kirchherr, Julian, Nan-Hua Nadja Yang, Frederik Schulze-Spüntrup, Maarten J. Heerink, and Kris Hartley. 2023. "Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions." *Resources, Conservation and Recycling* 194: 107001.

Kling, Gerhard, Yuen C. Lo, Victor Murinde, and Ulrich Volz. 2018. "Climate Vulnerability and the Cost of Debt."

Kochhar, R., and R. Song. 2023. "Does Market Power in India's Agricultural Markets Hinder Farmer Climate Change Adaptation?" Working paper.

Koetse, M. J., and P. Rietveld. 2009. "The Impact of Climate Change and Weather on Transport: An Overview of Empirical Findings." *Transportation Research Part D: Transport and Environment* 14 (3): 205–221.

Koks, E., R. Pant, S. Thacker, and J. W. Hall. 2019. "Understanding Business Disruption and Economic Losses Due to Electricity Failures and Flooding." *International Journal of Disaster Risk Science* 10 (4): 421–438.

Kolstad, C. D., and F. C. Moore. 2020. "Estimating the Economic Impacts of Climate Change Using Weather Observations." *Review of Environmental Economics and Policy*.

Komarek, A. M., A. D. Pinto, and V. H. Smith. 2020. "A Review of Types of Risks in Agriculture: What We Know and What We Need to Know." *Agricultural Systems* 178: 102738.

KPMG. 2024. "Climate Risk in Financial Statements. Handbook." US GAAP.

Kraehnert, Kati, Daniel Osberghaus, Christian Hott, Lemlem Teklegiorgis Habtemariam, Frank Wätzold, Lutz Philip Hecker, and Svenja Fluhrer. 2021. "Insurance against Extreme Weather Events: An Overview." *Review of Economics* 72: 71–95.

Kuehne Climate Center. 2025. *Logistics in a +2°C World: A Call for Shippers and Logistics Service Providers to Accelerate Efforts to Strengthen the Climate-Resilience of Global Supply Chains*. Hamburg.

Kuntchev, V., R. Ramalho, J. Rodríguez-Meza, and J. S. Yang. 2012. "What Firms Face Intense Credit Constraints? Evidence from World Bank Enterprise Surveys." World Bank Policy Research Working Paper 6212.

Kuruppu, N., P. Mukheibir, and J. Murta. 2015. "Ensuring Small Business Continuity under a Changing Climate: The Role of Adaptive Capacity." In *Applied Studies in Climate Adaptation: Australian Experiences*, edited by J. P. Palutikof, S. L. Boulter, J. Barnett, and D. Rissik. Oxford: Wiley.

Laborde, D., and C. Gouel. 2019. "The Role of Trade in Adaptation to Climate Change." VoxEU.org, February 6, 2019.

Lane, G. 2024. "Adapting to Climate Risk with Guaranteed Credit: Evidence from Bangladesh." *Econometrica* 92 (2): 355–386.

Lang, K., A. Rodinciuc, and J. Humphrey. 2017. *Impact Investing in Sustainable Food and Agriculture across Asset Classes: Financing Resilient Value Chains through Total Portfolio Activation*. Portland: Trillium Invest.

Le, T., and M. Ikram. 2022. "Do Sustainability Innovation and Firm Competitiveness Help Improve Firm Performance? Evidence from the SME Sector in Vietnam." *Sustainable Production and Consumption* 29: 588–599.

Leapfrog, CGAP, and Temasek. 2023. "Investor Roadmap for Inclusive Green Growth."

Leitold, Roxana, Matthias Garschagen, Van Tran, and Javier Revilla Diez. 2021. "Flood Risk Reduction and Climate Change Adaptation of Manufacturing Firms: Global Knowledge Gaps and Lessons from Ho Chi Minh City." *International Journal of Disaster Risk Reduction* 61: 102351.

Lemoine, D. 2021. "Estimating the Economic Impact of Climate Change from Weather Variation." VoxEU.org, July 9, 2021.

Lemoine, D., and S. Kapnick. 2024. "Financial Markets Value Skillful Forecasts of Seasonal Climate." *Nature Communications* 15 (1): 1–10.

Letta, Marco, Pierluigi Montalbano, and Guillaume Pierre. 2022. "Weather Shocks, Traders' Expectations, and Food Prices." *American Journal of Agricultural Economics* 104 (3): 1100–1119.

Li, Chengzheng, Xunyong Xiang, and Haiying Gu. 2015. "Climate Shocks and International Trade: Evidence from China." *Economics Letters* 135: 55–57.

Li, F. W., Y. Lin, Z. Jin, and Z. Zhang. 2020. "Do Firms Adapt to Climate Change? Evidence from Establishment-Level Data." Research Collection Lee Kong Chian School of Business.

Li, X. 2025. "Physical Climate Change Exposure and Firms' Adaptation Strategy." *Strategic Management Journal* 46 (3): 750–789.

Lighting Global/ESMAP, GOGLA, Efficiency for Access, and Open Capital Advisors. 2022. *Off-Grid Solar Market Trends Report 2022: Outlook*. Washington, DC: World Bank.

Lim, Bo, Ian Burton, Elizabeth Malone, and Saleemul Huq. 2006. *Adaptation Policy Frameworks for Climate Change: Developing Strategies and Measures*. Cambridge University Press.

Lin, C., T. Schmid, and M. S. Weisbach. 2019. "Climate Change, Operating Flexibility and Corporate Investment Decisions." NBER Working Paper 26441.

Linnenluecke, M. K., A. Stathakis, and A. Griffiths. 2011. "Firm Relocation as Adaptive Response to Climate Change and Weather Extremes." *Global Environmental Change* 21 (1): 123–133.

Linnerooth-Bayer, J., and R. Mechler. 2006. "Insurance for Assisting Adaptation to Climate Change in Developing Countries: A Proposed Strategy." *Climate Policy* 6: 621–636.

Linsenmeier, Manuel, and Jeffrey G. Shrader. 2023. "Global Inequalities in Weather Forecasts." SocArXiv Working Paper 7e2jf, Center for Open Science.

Liu, M., Y. Shamdasani, and V. Taraz. 2023. "Climate Change and Labor Reallocation: Evidence from Six Decades of the Indian Census." *American Economic Journal: Economic Policy* 15: 395–423.

LoPalo, Melissa. 2023. "Temperature, Worker Productivity, and Adaptation: Evidence from Survey Data Production." *American Economic Journal: Applied Economics* 15: 192–229.

Lowder, Sarah K., Jakob Skoet, and Terri Raney. 2016. "The Number, Size, and Distribution of Farms, Smallholder Farms, and Family Farms Worldwide." *World Development* 87: 16–29.

Machiels, T., V. Srivastava, S. Whittaker, M. Carreira Silva, A. Jaunet, S. Porko Beugnet, and S. Simonet. 2024. *Adaptation Investment Landscape: Deliverable 1.1.* CLIMATEFIT.

Macomber, J. D., and M. Sinha. 2011. "Sarvajal: Water for All." Harvard Business School Case 211-028. Revised September 2013.

Macours, K., P. Premand, and R. Vakis. 2022. "Transfers, Diversification and Household Risk Strategies: Can Productive Safety Nets Help Households Manage Climatic Variability?" *Economic Journal* 132 (647): 2438–2470.

Mahadevan, M., and A. Shenoy. 2023. "The Political Consequences of Resource Scarcity: Targeted Spending in a Water-Stressed Democracy." *Journal of Public Economics* 220: 104842.

Mahendra, A., R. King, J. Du, A. Dasgupta, V. A. Beard, A. Kallergis, and K. Schalch. 2021. "Seven Transformations for More Equitable and Sustainable Cities." World Resources Report, *Towards a More Equal City*. Washington, DC: World Resources Institute.

Mallucci, E. 2022. "Natural Disasters, Climate Change, and Sovereign Risk." *Journal of International Economics* 139: 103672.

Mapanje, O., S. Karuaihe, C. Machethe, and M. Amis. 2023. "Financing Sustainable Agriculture in Sub-Saharan Africa: A Review of the Role of Financial Technologies." *Sustainability* 15 (5): 4587.

Mardanugraha, E. 2016. "Disaster-Resilience of Small and Medium Enterprises (SMEs) in Indonesia: Survey Results and Policy Environment." 2016 Asian Business Forum.

Markolf, S. A., C. Hoehne, A. Fraser, K. Peterson, A. de la Fuente, and M. Sullivan. 2019. "Transportation Resilience to Climate Change and Extreme Weather Events: A Synthesis of Key Impacts and Adaptation Strategies." *Transport Policy* 75: 1–13.

Martín, R. S., N. Ranger, and K. England. 2024. "The (In)Coherence of Adaptation Taxonomies."

Martinich, J., and A. Crimmins. 2019. "Climate Damages and Adaptation Potential across Diverse Sectors of the United States." *Nature Climate Change* 9 (5): 397–404.

Marto, R., C. Papageorgiou, and V. Klyuev. 2018. "Building Resilience to Natural Disasters: An Application to Small Developing States." *Journal of Development Economics* 135: 574–586.

Massetti, E., and R. Mendelsohn. 2018. "Measuring Climate Adaptation: Methods and Evidence." *Review of Environmental Economics and Policy* 12 (2): 324–341.

Masuda, Yuta J., Teevrat Garg, Ike Anggraeni, Kristie Ebi, Jennifer Krenz, Edward T. Game, Nicholas H. Wolff, and June T. Spector. 2021. "Warming from Tropical Deforestation Reduces Worker Productivity in Rural Communities." *Nature Communications* 12: 1601.

Masuda, Yuta J., Teevrat Garg, Ike Anggraeni, Nicholas H. Wolff, Kristie Ebi, Edward T. Game, Jennifer Krenz, and June T. Spector. 2020. "Heat Exposure from Tropical Deforestation Decreases Cognitive Performance of Rural Workers: An Experimental Study." *Environmental Research Letters* 15: 124015.

Mathivanathan, D., et al. 2022. "Drivers of Circular Economy for Small and Medium Enterprises: Case Study on the Indian State of Tamil Nadu." *Journal of Business Research* 149: 997–1015.

Matsumoto, Takuji, and Yuji Yamada. 2021. "Simultaneous Hedging Strategy for Price and Volume Risks in Electricity Businesses Using Energy and Weather Derivatives." *Energy Economics* 95: 105101.

McDermott, T. K., F. Barry, and R. S. Tol. 2014. "Disasters and Development: Natural Disasters, Credit Constraints, and Economic Growth." *Oxford Economic Papers* 66 (3): 750–773.

McKinnon, A. 2024. "Logistics and Climate: An Assessment of Logistics' Multiple Roles in the Climate Crisis." *International Journal of Logistics Research and Applications* 27 (12).

McKinnon, A. C., and A. Kreie. 2010. "Adaptive Logistics: Preparing Logistics Systems for Climate Change." In *Proceedings of the 15th Annual Logistics Research Network Conference*. Leeds: Logistics Research Network.

McKinsey Global Institute. 2020. *Climate Risk and Response: Physical Hazards and Socioeconomic Impacts*. New York: McKinsey & Company.

Melvin, A. M., P. Larsen, B. Boehlert, J. E. Neumann, P. Chinowsky, X. Espinet, J. Martinich, M. S. Baumann, L. Rennels, A. Bothner, D. J. Nicolsky, and S. S. Marchenko. 2017. "Climate Change Damages to Alaska Public Infrastructure and the Economics of Proactive Adaptation." *Proceedings of the National Academy of Sciences* 114 (2): E122–E131.

Mendelsohn, R. 2012. "The Economics of Adaptation to Climate Change in Developing Countries." *Climate Change Economics* 3 (2): 1–21.

Meyer, Richard, Peter Hazell, and Panos Varangis. 2017. *Unlocking Smallholder Credit: Does Credit-Linked Agricultural Insurance Work?* Washington, DC: IFC and ILO.

Miao, Q., and D. Popp. 2014. "Necessity as the Mother of Invention: Innovative Responses to Natural Disasters." *Journal of Environmental Economics and Management* 68 (2): 280–295.

Michaelowa, A., K. Michaelowa, I. Shishlov, and D. Brescia. 2021. "Catalyzing Private and Public Action for Climate Change Mitigation: The World Bank's Role in International Carbon Markets." *Climate Policy* 21 (1): 120–132.

Miguel, Faruk, Alvaro Pedraza, and Claudia Ruiz-Ortega. 2022. "Climate Change Regulations: Bank Lending and Real Effects."

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-Being: Synthesis Report*. Washington, DC: World Resources Institute.

Miller, C., and C. Yoon. 2020. "Fostering Smallholder Investment and Innovation through Inclusive Financial Services." *Enterprise Development and Microfinance* 31 (1): 28–42.

Miranda, M., and C. Gonzalez-Vega. 2011. "Systemic Risk, Index Insurance, and Optimal Management of Agricultural Loan Portfolios in Developing Countries." *American Journal of Agricultural Economics* 93 (2).

Mirasgedis, S., E. Georgopoulou, Y. Sarafidis, K. Papagiannaki, and D. P. Lalas. 2014. "The Impact of Climate Change on the Pattern of Demand for Bottled Water and Non-alcoholic Beverages." *Business Strategy and the Environment* 23: 272–288.

Mishra, S., D. Sahoo, and S. Mohapatra. 2024. "Circular Economy Adoption in MSMEs: Unveiling Enablers and Barriers." MPRA Paper No. 124196.

Mueller, V., C. Gray, and K. Kosec. 2014. "Heat Stress Increases Long-Term Human Migration in Rural Pakistan." *Nature Climate Change* 4 (3): 182–185.

Mueller, V., G. Sheriff, X. Dou, and C. Gray. 2020. "Temporary Migration and Climate Variation in Eastern Africa." *World Development* 126: 04704.

Muis, S., B. Guneralp, B. Jongman, J. C. J. H. Aerts, and P. J. Ward. 2015. "Flood Risk and Adaptation Strategies under Climate Change and Urban Expansion: A Probabilistic Analysis Using Global Data." *Science of the Total Environment* 538: 445–457.

Musić, R. 2021. "Building the Business Case for Green Affordable Housing." *Enterprise Development and Microfinance*.

Nain, A., and S. Bhasin. 2022. *Making Sustainable Cooling in India Affordable: A Study of Financing and Cooperation Models*. New Delhi: Council on Energy, Environment and Water.

Nath, I. 2020. "The Food Problem and the Aggregate Productivity Consequences of Climate Change." NBER Working Paper 27297.

Nath, I. 2023. "Climate Change, the Food Problem, and the Challenge of Adaptation through Sectoral Reallocation." Working paper.

Nath, I. B., V. A. Ramey, and P. J. Klenow. 2024. "How Much Will Global Warming Cool Global Growth?" Technical Report w32761, National Bureau of Economic Research.

Nayal, K., R. Raut, M. Queiroz, V. Yadav, and B. Narkhede. 2021. "Are Artificial Intelligence and Machine Learning Suitable to Tackle the COVID-19 Impacts? An Agriculture Supply Chain Perspective." *International Journal of Logistics Management*.

Nenova, Tatiana. 2026. "Système D – a Fresh Look at Micro and Informal Firms and Farms." Mimeo, World Bank Group, Washington, DC.

Nenova, Tatiana. Forthcoming. "Beyond Traditional Banking: Non-banking and Non-financial Credit Provision in Lower-Income Countries." *Emerging Market Insights*. Washington, DC: IFC.

Neumann, J. E., J. Price, P. Chinowsky, L. Wright, L. Ludwig, R. Streeter, R. Jones, J. B. Smith, W. Perkins, L. Jantarasami, and J. Martinich. 2015. "Climate Change Risks to US Infrastructure: Impacts on Roads, Bridges, Coastal Development, and Urban Drainage." *Climatic Change* 131 (1): 97–109.

Nguyen, V., and N. Vu. 2022. "Corporate Environmental Responsibility and Innovation: Empirical Evidence from Vietnam." *International Journal of Emerging Markets*.

Nicolas, Claire, Stephane Hallegatte, Charles Fox, Julie Rozenberg, and Jun Rentschler. 2019. "Strengthening New Infrastructure Assets: A Cost-Benefit Analysis." Policy Research Working Paper 8896.

Nielsen. 2018. *Sustainable Shoppers Buy the Change They Wish to See in the World*. New York: The Nielsen Company.

Njarui, D. M. G., E. M. Gichangi, S. R. Ghimire, and R. W. Muinga, eds. 2016. "Climate Smart Brachiaria Grasses for Improving Livestock Production in East Africa: Kenya Experience." In *Proceedings of a Workshop, Naivasha, Kenya, 14–15 September 2016*. Nairobi, Kenya: Kenya Agricultural and Livestock Research Organization.

OECD (Organization for Economic Co-operation and Development). 2015. *Climate Change Risks and Adaptation: Linking Policy and Economics*. Paris: OECD Publishing.

OECD. 2016. *The Economic Consequences of Outdoor Air Pollution*. Paris: OECD Publishing.

OECD. 2021. "No Net Zero without SMEs." OECD SME and Entrepreneurship Papers 30.

OECD. 2023. *Scaling Up Adaptation Finance in Developing Countries: Challenges and Opportunities for International Providers*. Green Finance and Investment. Paris: OECD Publishing.

OECD. 2024. "Feeling the Heat: Working under Increasing Temperatures." OECD Publishing, Paris.

Oehling, D., G. Fischer, D. Sivaprasad, T. Nanji, V. Shandal, B. Sheridan, H. L. Chua, F. Zimmermann, J. Teo, M. Teo, and H. Lim. 2025. *The Private Equity Opportunity in Climate Adaptation and Resilience*.

Okereke, C., and P. Coventry. 2016. "Climate Justice and the International Regime: Before, During, and After Paris." WIREs *Climate Change* 7 (6): 834–851.

Okereke, C., B. Wittneben, and F. Bowen. 2012. "Climate Change: Challenging Business, Transforming Politics." *Business & Society* 51 (1): 7–30.

Okoya, Silifat Abimbola, Muyiwa Oyinlola, Patrick Schröder, Seun Kolade, and Soroush Abolfathi. 2023. "Enhancing Decentralised Recycling Solutions with Digital Technologies." In *Digital Innovations for a Circular Plastic Economy in Africa*, edited by Muyiwa Oyinlola and Seun Kolade, 208–221. London: Routledge.

Okubo, T., and E. Strobl. 2021. "Natural Disasters, Firm Survival, and Growth: Evidence from the Ise Bay Typhoon, Japan." *Journal of Regional Science*.

Ordu, A. U., L. Cooley, and L. Goh. 2021. "Digital Technology and African Smallholder Agriculture: Implications for Public Policy." Brookings, August 16, 2021.

Ortiz-Bobea, A. 2021. "The Empirical Analysis of Climate Change Impacts and Adaptation in Agriculture." In *Handbook of Agricultural Economics*, edited by C. B. Barrett and D. R. Just, 3981–4073.

Pakistan Microfinance Network. 2019. "Warehouse Receipt Financing: Tackling the Financial Needs of Smallholder Farmers in Pakistan."

Palombi, G., V. Schiaroli, L. Fraccascia, and F. Nonino. 2024. "Identifying Barriers and Good Practices for Implementing Circular Economy Principles in Small and Medium Enterprises." *Business Strategy and the Environment* 33 (7): 6773–6794.

Pankratz, N., R. Bauer, and J. Derwall. 2019. "Climate Change, Firm Performance, and Investor Surprises."

Pankratz, N. M. C., and C. M. Schiller. 2024. "Climate Change and Adaptation in Global Supply-Chain Networks." *The Review of Financial Studies* 37 (6): 1729–1777.

Parsons, Luke A., David Shindell, Michelle Tigchelaar, Yuta J. Masuda, Jung-Eun Choi, and June T. Spector. 2022. "Global Labor Loss Due to Humid Heat Exposure Underestimated." *Environmental Research Letters* 17 (1): 014050.

Patel, D. 2024. "Learning About a Warming World: Attention and Adaptation in Agriculture." Working paper.

Pauw, W. Pieter. 2017. "Mobilising Private Adaptation Finance: Developed Country Perspectives." *International Environmental Agreements: Politics, Law and Economics* 17 (1): 55–71.

Pauw, W. Pieter, Pieter Buunder, Harro van Asselt, and Richard J. T. Klein. 2015. "Private Finance for Adaptation: Do Private Realities Meet Public Expectations?" *Climatic Change* 134 (4): 489–503.

Pelli, Martino, and Jeanne Tschopp. 2017. "Comparative Advantage, Capital Destruction, and Hurricanes." *Journal of International Economics* 108: 315–337.

Pelli, Martino, Jeanne Tschopp, Natalia Bezmaternykh, and Kodjovi M. Eklou. 2023. "In the Eye of the Storm: Firms and Capital Destruction in India." *Journal of Urban Economics* 134: 103529.

Phan, T., and F. Schwartzman. 2024. "Climate Defaults and Financial Adaptation." *European Economic Review* 170: 104866.

PlanAdapt. n.d. "Enhancing the Potential of Micro, Small and Medium Enterprises to Innovate and Provide Products and Services That Have Positive Adaptation and Resilience Outcomes."

Ponticelli, Jacopo, Qiping Xu, and Stefan Zeume. 2023. "Temperature and Local Industry Concentration." NBER Working Paper 31533.

Premand, P., and Q. Stoeffler. 2022. "Cash Transfers, Climatic Shocks and Resilience in the Sahel." *Journal of Environmental Economics and Management* 116: 102744.

Price, J. C., L. Wright, C. Fant, and K. M. Strzepek. 2016. "Calibrated Methodology for Assessing Climate Change Adaptation Costs for Urban Drainage Systems." *Urban Water Journal* 13 (4): 331–344.

Putri, E., C. Wongloucha, A. Plando, and B. Putra. 2025. "The Development of MSMEs Based on a Circular Economic Management System." Conference paper.

Qiu, L., X. Jie, Y. Wang, and M. Zhao. 2020. "Green Product Innovation, Green Dynamic Capability, and Competitive Advantage: Evidence from Chinese Manufacturing Enterprises." *Corporate Social Responsibility and Environmental Management* 27: 146–165.

Rajan, R., and R. Ramcharan. 2023. "Finance and Climate Resilience: Evidence from the Long 1950s US Drought." NBER Working Paper 31356.

Rentschler, Jun, Johannes Braese, Nick Jones, and Paolo Avner. 2019. "Three Feet Under: Urban Jobs, Connectivity, and Infrastructure." World Bank Policy Research Working Paper 8920, World Bank, Washington, DC.

Rentschler, Jun, Ella Kim, Stephan Thies, Sophie de Vries Robbe, Alvina Erman, and Stéphane Hallegatte. 2021. "Floods and Their Impacts on Firms: Evidence from Tanzania." Policy Research Working Papers, World Bank.

Rexer, Jonah, and Siddharth Sharma. 2024. "Climate Change Adaptation: What Does the Evidence Say?" Policy Research Working Paper 10729, World Bank.

Rice, B., and R. Vos. 2024. "Who's Afraid of High Fertilizer Prices?" IFPRI (blog), March 21, 2024.

Riley, E. 2018. "Mobile Money and Risk Sharing against Village Shocks." *Journal of Development Economics* 135: 43–58.

Rizos, V., et al. 2016. "Implementation of Circular Economy Business Models by Small and Medium-Sized Enterprises (SMEs): Barriers and Enablers." *Sustainability* 8 (11): 1212.

Rode, A., R. E. Baker, T. Carleton, A. D'Agostino, M. Delgado, T. Foreman, D. R. Gergel, M. Greenstone, T. Houser, S. Hsiang, A. Hultgren, A. Jina, R. E. Kopp, S. B. Malevich, K. McCusker, I. Nath, M. Pecenco, J. Rising, and J. Yuan. 2022. "Labor Disutility in a Warmer World: The Impact of Climate Change on the Global Workforce." Working paper.

Rode, A., T. Carleton, M. Delgado, M. Greenstone, T. Houser, S. Hsiang, A. Hultgren, A. Jina, R. E. Kopp, K. E. McCusker, and I. Nath. 2021. "Estimating a Social Cost of Carbon for Global Energy Consumption." *Nature* 598 (7880): 308–314.

Romanello, M., C. di Napoli, C. Green, H. Kennard, P. Lampard, D. Scamman, et al. 2023. "The 2023 Report of the Lancet Countdown on Health and Climate Change: The Imperative for a Health-Centered Response in a World Facing Irreversible Harms." *The Lancet* 402 (10419).

Rosenbusch, N., J. Brinckmann, and A. Bausch. 2011. "Is Innovation Always Beneficial? A Meta-Analysis of the Relationship between Innovation and Performance in SMEs." *Journal of Business Venturing* 26: 441–457.

Rosenzweig, M., and C. R. Udry. 2013. "Forecasting Profitability." NBER Working Paper 19334, National Bureau of Economic Research, Cambridge, MA.

Rossi-Hansberg, E., K. Desmet, D. K. Nagy, and B. Conte. 2021. "Trade to Adapt: Changing Specialisation to Cope with Climate Change." VoxEU.org, May 4, 2021.

RWE Npower plc. 2013. "Business Energy Index 2013."

Saghir, Jamal, and Ede Jorge Ijjasz-Vasquez. 2025. "Small Costs for Large Gains: Climate Resilience in Small Island Developing States." The Payne Institute for Public Policy, Colorado School of Mines, October 13, 2025.

Sahu, S., M. Sett, and T. Kjellstrom. 2013. "Heat Exposure, Cardiovascular Stress and Work Productivity in Rice Harvesters in India: Implications for a Climate Change Future." *Industrial Health* 51 (4): 424–431.

S&P. 2024. "Global Corporate Sustainability Assessment."

Sawhney, Swati, Salome Wanjiku Kimani, and Alexander Giorgios Sotiriou. 2025. "Diverse Paths: Finance for Women's Nano and Micro Enterprises." Focus Note, CGAP, Washington, DC.

Schaefer, L., and E. Waters. 2016. "Climate Risk Insurance for the Poor and Vulnerable: How to Effectively Implement the Pro-poor Focus of InsuResilience." Munich Climate Risk Insurance Alternative.

Schlenker, W., M. J. Roberts, and D. B. Lobell. 2013. "US Maize Adaptability." *Nature Climate Change* 3 (8): 690–691.

Schlenker, W., and C. A. Taylor. 2021. "Market Expectations of a Warming Climate." *Journal of Financial Economics* 142 (2): 627–640.

Schröder, Patrick. 2019. "Promoting a Just Transition to an Inclusive Circular Economy." Research paper, Chatham House, London.

Schweiger, H., and A. Stepanov. 2019. "Energy Subsidies, Energy Intensity and Management Practices." SSRN.

Serafeim, G. 2014. "Turning a Profit while Doing Good: Aligning Sustainability with Corporate Performance." Brookings Institution.

Shayegh, S. 2017. "Outward Migration May Alter Population Dynamics and Income Inequality." *Nature Climate Change* 7 (11): 828–832.

Shilpi, F., and C. Berg. 2024. "Climate Resilience of Farmers in Nigeria." World Bank working paper.

Shilpi, F., M. Kahn, and C. Berg. 2025. *Rethinking Resilience: Adapting to a Changing Climate*. Policy research report. Washington, DC: World Bank.

Shrader, J. G. 2023. "Improving Climate Damage Estimates by Accounting for Adaptation." Working paper.

Shrader, J. G., L. Bakkensen, and D. Lemoine. 2023. "Fatal Errors: The Mortality Value of Accurate Weather Forecasts." NBER Working Paper 31361.

Siddik, A. B., L. Yong, and M. N. Rahman. 2023. "The Role of Fintech in Circular Economy Practices to Improve Sustainability Performance: A Two-Staged SEM-ANN Approach." *Environmental Science and Pollution Research* 30: 107465–107486.

Signé, L. 2024. "Health Care in Africa: Emerging Technologies at Play." Brookings.

Simavi, Sevi, Clare Manuel, and Mark Blackden. 2010. *Gender Dimensions of Investment Climate Reform: A Guide for Policy Makers and Practitioners*. Washington, DC: World Bank.

Singh, M., A. Chakraborty, and M. Roy. 2018. "Developing an Extended Theory of Planned Behavior Model to Explore Circular Economy Readiness in Manufacturing MSMEs, India." *Resources, Conservation and Recycling* 135: 313–322.

Singh, Neeraj, Avinash Kumar, and Kushankur Dey. 2023. "Unlocking the Potential of Knowledge Economy for Rural Resilience: The Role of Digital Platforms." *Journal of Rural Studies* 101: 103053.

Sirtaine, S., and G. Wattez-Richard. 2024. "From Protection to Resilience: Rethinking Insurance for All." CGAP (blog), November 21, 2024.

Slater, J., D. Archer, C. O'Neill, J. Yi-Chen Han, and F. Vanhuyse. 2023. "Air Pollution and the World of Work in Southeast Asia: Findings from Regional Case Studies." SEI Brief, Stockholm Environment Institute.

Smith, P., and J. E. Olesen. 2010. "Synergies between the Mitigation of, and Adaptation to, Climate Change in Agriculture." *The Journal of Agricultural Science* 148 (5): 543–552.

Snow, J. T., B. Biagini, G. Benchwick, G. George, J. Hoedjes, A. Miller, and J. Usher. 2016. *A New Vision for Weather and Climate Services in Africa*. New York: UNDP.

Somanathan, E., R. Somanathan, A. Sudarshan, and M. Tewari. 2021. "The Impact of Temperature on Productivity and Labor Supply: Evidence from Indian Manufacturing." *Journal of Political Economy* 129 (6): 1797–1827.

Spaltini, M., A. Poletti, F. Acerbi, and M. Taisch. 2021. "A Quantitative Framework for Industry 4.0 Enabled Circular Economy." *Procedia CIRP* 98: 115–120.

Stein, Peer, Oya Pinar Ardic, and Martin Hommes. 2013. *Closing the Credit Gap for Formal and Informal Micro, Small, and Medium Enterprises*. Washington, DC: World Bank Group.

Stenek, Vladimir, Jean-Christophe Amado, and Richenda Greenall. 2013. *Enabling Environment for Private Sector Adaptation: An Index Assessment Framework*. Washington, DC: IFC.

Stoeffler, Quentin, Michael Carter, Catherine Guirkinger, and Wouter Gelade. 2022. "The Spillover Impact of Index Insurance on Agricultural Investment by Cotton Farmers in Burkina Faso." *The World Bank Economic Review* 36 (1): 114–140.

Stoll, P. P., W. P. Pauw, F. Tohme, and C. Grüning. 2021. "Mobilizing Private Adaptation Finance: Lessons Learned from the Green Climate Fund." *Climatic Change* 167: 45.

Strategic Investment Research Unit. 2022. "Strengthening of Pharmaceutical Industry (SPI) Scheme for MSMEs." Invest India, July 29, 2022.

Suat, L., and O. San. 2019. "Corporate Environmental Management: Eco-efficiency and Economics Benefits among Manufacturers Certified with EMS14001 in Malaysia." *International Journal of Recent Technology and Engineering* 7 (6): 873–886.

Surminski, Swenja. 2013. "Private-Sector Adaptation to Climate Risk." *Nature Climate Change* 3 (11): 943–945.

Sustainable Hospitality Alliance and IFC. 2020. "The Business Case for Sustainable Hotels."

Sy, Amadou, Rodolfo Maino, Massimiliano Appendino, Hector Perez-Saiz, and Piyusha Sharma. 2019. *FinTech in Sub-Saharan African Countries: A Game Changer?* Washington, DC: IMF.

Syafri, W., H. Prabowo, A. Sofyan, and U. Muafi. 2021. "The Impact of Workplace Green Behavior and Green Innovation on Green Performance of SMEs: A Case Study in Indonesia." *Journal of Asian Finance, Economics and Business* 8 (5): 365–374.

Taghizadeh-Hesary, F., E. Rasoulinezhad, and N. Yoshino. 2019. "Energy and Food Security: Linkages through Price Volatility." *Energy Policy* 128: 796–806.

Tall, A., S. Lynagh, C. Blanco Vecchi, P. Bardouille, F. Montoya Pino, E. Shabahat, V. Stenek, F. Stewart, S. Power, C. Paladines, P. Neves, and L. Harrison. 2021. *Enabling Private Investment in Climate Adaptation and Resilience: Current Status, Barriers to Investment and Blueprint for Action*.

Tambet, H., and Y. Stopnitzky. 2021. "Climate Adaptation and Conservation Agriculture among Peruvian Farmers." *American Journal of Agricultural Economics* 103 (3): 900–922.

Tanner, T., S. Surminski, E. Wilkinson, R. Reid, J. Rentschler, and S. Rajput. 2015. *The Triple Dividend of Resilience: Realising Development Goals through the Multiple Benefits of Disaster Risk Management*. London: Overseas Development Institute, World Bank.

Taraz, V. 2017. "Adaptation to Climate Change: Historical Evidence from the Indian Monsoon." *Environment and Development Economics* 22 (5): 517–545.

Tautiva, J., R. Pant, and J. W. Hall. 2025. "Climate Risk and Adaptation Options for Transport Infrastructure in Emerging Economies." *Transportation Research Part A: Policy and Practice*.

Teklewold, Hailemariam, Alemu Mekonnen, Gunnar Kohlin, and Salvatore di Falco. 2017. "Does Adoption of Multiple Climate-Smart Practices Improve Farmers' Climate Resilience? Empirical Evidence from the Nile Basin of Ethiopia." *Climate Change Economics* 8 (1).

Terpstra, P., P. McGray, and A. Ofstedahl. 2013. "Adapting to Climate Change: The Private Sector's Role."

Terpstra, P., and A. Ofstedahl. 2013. "Micro, Small, and Medium Enterprises: Key Players in Climate Adaptation." World Resources Institute (blog), December 4, 2013.

Thiede, B., C. Gray, and V. Mueller. 2016. "Climate Variability and Inter-provincial Migration in South America, 1970–2011." *Global Environmental Change* 41: 228–240.

Tian, Xuan, and Tracy Yue Wang. 2014. "Tolerance for Failure and Corporate Innovation." *The Review of Financial Studies* 27 (1): 211–255.

Tokui, Joji, Kazuyasu Kawasaki, and Miyagawa Tsutomu. 2017. "The Economic Impact of Supply Chain Disruptions from the Great East-Japan Earthquake." *Japan and the World Economy* 41.

Twidale, Susanna. 2024. "Global Carbon Markets Value Hit Record $949 Bln Last Year." *Reuters*.

Uji, A., J. Song, N. Dolšak, and A. Prakash. 2024. "Willingness to Incur Private Costs for Climate Adaptation? Public Support for Undergrounding Electricity Transmission Lines in California." *Energy Policy* 191: 114182.

UNDESA (United Nations Department of Economic and Social Affairs). 2020. "Micro-, Small, and Medium-Sized Enterprises (MSMEs) and Their Role in Achieving the Sustainable Development Goals."

UNDP (United Nations Development Programme). 2014. "Adaptation Learning Mechanism, Building Climate Resilient Rural Communities in Zimbabwe."

UNDP. 2015. "Adapting from the Ground Up: Enabling Small Businesses in Developing Countries to Adapt to Climate Change."

UNDRR (United Nations Office for Disaster Risk Reduction). 2020. "The Human Cost of Disasters: An Overview of the Last 20 Years (2000–2019)."

UNDRR. 2024. *Guide for Adaptation and Resilience Finance*.

UNECE (United Nations Economic Commission for Europe). 2020. *Climate Change Impacts and Adaptation for Transport Networks and Nodes*.

UNEP (United Nations Environment Programme). 2014. *Valuing Plastic: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry*.

UNEP. 2016. *Demystifying Adaptation Finance for the Private Sector*.

UNEP. 2017. *Resource Efficiency: Potential and Economic Implications*. A report of the International Resource Panel.

UNEP. 2023a. *Global Cooling Watch 2023: Keeping It Chill: How to Meet Cooling Demands while Cutting Emissions*.

UNEP. 2024a. *Food Waste Index Report 2024: Think Eat Save: Tracking Progress to Halve Global Food Waste*.

UNEP. 2023b, 2024b, 2025. *Adaptation Gap Report*. New York: UNEP.

UNEP DTU. 2017. *Climate Change Adaptation Technologies for Water: A Practitioner's Guide to Adaptation Technologies for Increased Water Sector Resilience*, by M. Bertule, L. Appelquist, J. Spensley, S. Trærup, and P. Naswa. UNEP DTU Partnership.

UNEP DTU. 2018. *Private-Sector Action in Adaptation: Perspectives on the Role of Micro, Small and Medium Size Enterprises*, edited by C. Schaer and N. D. Kuruppu. UNEP DTU Partnership.

UNEP and GCA. 2019. *Driving Finance Today for the Climate Resilient Society of Tomorrow*, by Alan Miller and Stacy Swann.

UNEP, SWITCH Africa Green, and European Union. 2022. "Assessment of Green Financing Mechanisms for MSMEs in Africa."

UNEP FI (United Nations Environment Programme Finance Initiative). 2024. "Assessing Adaptation & Resilience Impact in Private Investments: A Measurement Framework for Investors." Working paper, Adaptation and Resilience Investors Collaborative.

UNFCCC (United Nations Framework Convention on Climate Change). 2007. *Investment and Financial Flows to Address Climate Change*. Bonn: UNFCCC Secretariat.

UNFCCC. 2022. *Information Paper on Linkages between Mitigation and Adaptation*. Bonn: UNFCCC Secretariat.

UNFCCC. 2023. "Mapping Study on Capacity-Building Needs of MSMEs to Engage in Climate Action in the Southeast Asia Region." Executive summary.

UN-Habitat. 2024. *World Cities Report 2024: Cities and Climate Action*.

UNSGSA (United Nations Secretary-General's Special Advocate for Financial Health). 2023. *Green Finance: A Policy and Advocacy Approach*. Inclusive Green Finance Working Group, United Nations Secretary-General's Special Advocate for Inclusive Finance for Development.

Van der Straten, Y. 2024. "Flooded House or Underwater Mortgage? The Implications of Climate Change and Adaptation on Housing, Income, and Wealth." Working paper.

Van Reenen, J., and A. N. Keiller. 2024. "Disaster Management." Technical Report w32595, National Bureau of Economic Research.

Varangis, Panos. 2025. "Can Warehouse Receipts Unlock Farmer Finance?" *Private Sector Development* (blog), January 29, 2025.

Vásquez, P., V. Gallego, and J. Soto. 2024. "Transforming MSMEs towards Circularity: An Attainable Challenge with the Appropriate Technologies and Approaches." *Environment Systems and Decisions* 44: 624–644.

Vedula, B., S. Nudurupati, M. Kondala, and R. Pappu. 2024. "Adoption of Circular Economy: A Case Study of SMEs in Visakhapatnam, India." *Journal of the Institution of Engineers (India): Series C*.

Venturini, A. 2022. "Climate Change, Risk Factors and Stock Returns: A Review of the Literature." *International Review of Financial Analysis* 79: 101934.

Verschuur, J., E. E. Koks, and J. W. Hall. 2023. "Global Economic Impacts of Climate Change-Induced Disruptions to Transport Networks." *Nature Climate Change* 13 (3): 240–247.

Villalba, Roberto, Terese E. Venus, and Johannes Sauer. 2023. "The Ecosystem Approach to Agricultural Value Chain Finance: A Framework for Rural Credit." *World Development* 164: 106177.

Vu, Tam B., and Ilan Noy. 2018. "Natural Disasters and Firms in Vietnam." *Pacific Economic Review* 23: 426–452.

Waldron, Dan. 2023. "How Carbon Credits Are Driving Down the Costs of Climate-Friendly Goods in Africa." ImpactAlpha.

Walji, David. 2023. "BII, Shell Foundation, and SunCulture Pilot Innovative Carbon Financing to Accelerate Access to Solar Irrigation Systems for Kenyan Farmers."

Wang, T., Z. Qu, Z. Yang, T. Nichol, G. Clarke, and Y. Ge. 2020. "Climate Change Research on Transportation Systems: Climate Risks, Adaptation, and Planning." *Transportation Research Part D: Transport and Environment* 88: 102553.

Watkiss, Paul. 2022. "The Costs of Adaptation, and the Economic Costs and Benefits of Adaptation in the UK." Policy paper.

Watkiss, Paul, and Kit England. 2025. *Adaptation Finance and the Private Sector: Opportunities and Challenges for Developing Countries*.

Webster, M. 2023. "The Circular Economy in Low- and Middle-Income Countries – a Tool for Sustainable Development?" In vol. 51 of *The Circular Economy: Meeting Sustainable Development Goals*, edited by S. K. Ghosh and G. Eduljee, 65–91. Royal Society of Chemistry.

Wedawatta, G., and B. Ingirige. 2012. "Resilience and Adaptation of Small and Medium-Sized Enterprises to Flood Risk." *Disaster Prevention and Management: An International Journal* 21 (4): 474–488.

WEF (World Economic Forum) and Ellen MacArthur Foundation. 2016. *The New Plastics Economy: Rethinking the Future of Plastics*. Geneva: World Economic Forum.

Weinhofer, G., and T. Busch. 2013. "Corporate Strategies for Managing Climate Risks." *Business Strategy and the Environment* 22 (2): 121–144.

White, George, and Catarina Bandeira Morais. 2020. *Scaling Digital PAYG Water Services: Lessons from CityTaps in Niamey, Niger*. London: GSMA Mobile for Development Utilities.

Wilson, David C., Costas A. Velis, and Christopher R. Cheeseman. 2006. "Role of Informal Sector Recycling in Waste Management in Developing Countries." *Habitat International* 30 (4): 797–808.

Wise, R., J. Marinopoulos, D. O'Connell, N. Mesic, G. Tieman, R. Gorddard, J. Chan, D. Flett, A. Lee, P. Box, S. Meharg, and A. Helfgott. 2022. *Guidance for Applying the Enabling Resilience Investment Framework: Building National Capability or Enabling Resilience Investment*. Australia: CSIRO.

WMO (World Meteorological Organization). 2015. "Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services." WMO No. 1153.

World Bank. 2010. *World Development Report 2010: Development and Climate Change*. Washington, DC.

World Bank. 2017. *Uncharted Waters: The New Economics of Water Scarcity and Variability*. Washington, DC.

World Bank. 2019a. *Economics of Climate-Smart Agriculture: Considerations for Economic and Financial Analyses of Climate-Smart Agriculture Projects*. Washington, DC.

World Bank. 2019b. *Lifelines: The Resilient Infrastructure Opportunity*. Sustainable Infrastructure Series. Washington, DC: World Bank.

World Bank. 2020a. *Opportunities for Climate Finance in the Livestock Sector.* Washington, DC.

World Bank. 2020b. *Digitization of Agribusiness Payments in Africa: Building a Ramp for Farmers' Financial Inclusion and Participation in a Digital Economy*. Washington, DC.

World Bank. 2021a. *Creating Markets in Ukraine: Country Private Sector Diagnostic*. Washington, DC.

World Bank. 2021b. *Cold Road to Paris: Mapping Pathways toward Sustainable Cooling for Resilient People and Economies by 2050*. Washington, DC: World Bank.

World Bank. 2021c. *360° Resilience: A Guide to Prepare the Caribbean for a New Generation of Shocks*.

World Bank. 2022a. *Practical Guide on Sustainable Cold Chain*. Ozone Operations Resource Group.

World Bank. 2022b. *Guidelines for Integrating Climate Change Mitigation and Adaptation in Public Credit Guarantee Schemes for Small and Medium Enterprises*.

World Bank. 2023. "Green Milk? Sounds Good to Ethiopia's Dairy Industry," by Nigel Ross Hughes. *Africa Can End Poverty* (blog), July 31, 2023.

World Bank. 2024a. *Rising to the Challenge: Success Stories and Strategies for Achieving Climate Adaptation and Resilience*.

World Bank. 2024b. *People in a Changing Climate: From Vulnerability to Action: Insights from World Bank Group Country Climate and Development Reports Covering 72 Economies*.

World Bank. 2024c. *The Cost of Inaction: Quantifying the Impact of Climate Change on Health in Low- and Middle-Income Countries*.

World Bank. 2024d. *The Great Reversal: Prospects, Risks, and Policies in International Development Association Countries*.

World Bank. 2024e. *Boosting SME Finance for Growth: The Case for More Effective Support Policies*, by A. Carvajal and T. Didier.

World Bank. 2025. *Rethinking Resilience*. Policy research report.

World Bank and IFC. 2021. *Enabling Private Investment in Climate Adaptation and Resilience: Current Status, Barriers to Investment and Blueprint for Action*.

World Bank and IFC. 2022. *Fintech and SME Finance: Expanding Responsible Access*.

World Bank Group. 2020. *Digitization of Agribusiness Payments in Africa: Building a Ramp for Farmers' Financial Inclusion and Participation in a Digital Economy*. World Bank: Washington, DC.

World Bank Group. 2022a. *Unlocking Private Investment in Climate Adaptation and Resilience*.

World Bank Group. 2022b. *Climate and Development: An Agenda for Action*. Washington, DC: World Bank Group.

World Bank Group. 2025. *Jobs in a Changing Climate: Insights from World Bank Group Country Climate and Development Reports Covering 93 Economies*. Washington, DC: World Bank.

Wossen, T., T. Berger, and S. di Falco. 2015. "Social Capital, Risk Preference and Adoption of Improved Farm Land Management Practices in Ethiopia." *Agricultural Economics* 46 (1): 81–97.

WRI (World Resources Institute). 2013. "Micro, Small, and Medium Enterprises: Key Players in Climate Adaptation."

Wright, L., P. Chinowsky, K. Strzepek, R. Jones, R. Streeter, J. B. Smith, J.-M. Mayotte, A. Powell, L. Jantarasami, and W. Perkins. 2012. "Estimated Effects of Climate Change on Flood Vulnerability of U.S. Bridges." *Mitigation and Adaptation Strategies for Global Change* 17 (8): 939–955.

Xu, Jiangmin, Cheng Sun, and Yihui You. 2022. "Physical Climate Change Exposure and Stock Returns."

Yesudian, A., and R. J. Dawson. 2021. "Global Climate Risk to Transport Infrastructure: A Multi-hazard Assessment." *Environmental Research Letters* 16 (9): 094006.

Zappala, G. 2024. "Adapting to Climate Change Accounting for Individual Beliefs." *Journal of Development Economics* 169: 103289.

Zhang, Jianling, and Guoshun Wang. 2008. "Energy Saving Technologies and Productive Efficiency in the Chinese Iron and Steel Sector." *Energy* 33: 525–537.

Zhang, P., O. Deschenes, K. Meng, and J. Zhang. 2018. "Temperature Effects on Productivity and Factor Reallocation: Evidence from a Half Million Chinese Manufacturing Plants." *Journal of Environmental Economics and Management* 88: 1–17.

Zhao, M., J. K. W. Lee, T. Kjellstrom, and W. Cai. 2021. "Assessment of the Economic Impact of Heat-Related Labor Productivity Loss: A Systematic Review." *Climatic Change* 167: 22.

Zilberman, D., J. Zhao, and A. Heiman. 2012. "Adoption Versus Adaptation, with Emphasis on Climate Change." *Annual Review of Resource Economics* 4 (1): 27–53.

Zommers, Z. 2012. "Climate Early Warning System Feasibility Report: Early Warning Systems and Hazard Protection." UNEP.

Zuofa, T., E. Ochieng, and I. Ode-Ichakpa. 2023. "An Evaluation of Determinants Influencing the Adoption of Circular Economy Principles in Nigerian Construction SMEs." *Building Research and Information* 51 (1).

IFC International Finance Corporation WORLD BANK GROUP