Technological Diffusion and Global Convergence

The Circulation of Innovation from Advanced to Developing Economies

Abstract

Technological innovation is no longer the sole domain of a few advanced economies—it is diffusing globally at unprecedented speed. This paper examines how breakthroughs in automation, artificial intelligence (AI), financial technology (fintech), healthcare, energy, agriculture, and digital infrastructure are spreading from technology leaders to developing economies, and how this diffusion is driving economic convergence. We draw on diffusion theory and case studies (with an emphasis on African economies) to illustrate "leapfrogging" in action, where latecomer nations bypass traditional development stages by adopting cutting-edge solutions. We find that global technology circulation, enabled by falling costs and intensified knowledge flows, is reshaping productivity and living standards at scale. In many developing regions, access to mobile connectivity, renewable energy, digital finance, and AI-powered services has expanded dramatically, boosting growth and lifting millions from poverty. However, we also discuss challenges—such as digital divides and capacity gaps—that affect how quickly and equitably these benefits are realized. The 21st century, we argue, will be defined not only by the emergence of new technologies, but by how swiftly and inclusively they diffuse across the world.

Introduction

Technological progress has historically been uneven, with advanced nations dominating innovation while poorer countries lagged behind. Between 1995 and 2014, five countries (the United States, Japan, Germany, France, and the UK) accounted for about **75% of the global stock of patented innovations** [1]. This concentration of know-how meant that the diffusion of knowledge and technology across borders was crucial for sharing growth potential. Indeed, technology transfer has long been seen as a key mechanism for improving incomes and living standards worldwide [2]. Classic economic growth models suggest that as technologies spread and countries adopt more efficient production methods, **poorer economies can "catch up"** with richer ones – a process known as **economic convergence**.

In recent decades, the landscape of innovation and diffusion has begun to change markedly. Several emerging economies have rapidly increased their innovation capacity. Notably, **China and South Korea have become major sources of innovation**, now ranking among the top global contributors in R&D spending and patenting [3]. China's annual R&D expenditures, for example, are **second only to the United States** [3]. At the same time, globalization and digital connectivity have intensified international knowledge flows. Ideas, information, and expertise now cross borders more readily through trade, foreign investment, diaspora networks, and the internet. As a result, many developing countries can access and implement new technologies faster than ever before.

This paper explores how the **global diffusion of technology** is enabling a broad-based rise in living standards and a convergence in economic outcomes. We adopt both a theoretical and empirical lens. First, we review **diffusion theory** and the concept of **technological leapfrogging**

– when late adopters skip directly to newer technologies, bypassing intermediate stages of development. Next, we examine key **drivers of global technology circulation**, such as declining costs of innovation, international trade and investment, and collaborative initiatives. We then present a series of **sectoral case studies** – spanning digital infrastructure, fintech, energy, healthcare, agriculture, and AI-powered automation – to illustrate how innovations optimized in advanced contexts are being adapted and deployed in developing regions. Throughout, we place a particular emphasis on Africa, a continent where the challenges are stark but leapfrogging opportunities are immense. Finally, we consider the **economic impacts** of these diffusion trends, including evidence of productivity gains and poverty reduction, and discuss the remaining **barriers** to equitable diffusion (such as digital divides and skills gaps). We conclude with reflections on policy implications: how the global community can foster faster and fairer spread of crucial technologies to ensure that the prosperity gains of the 21st century are widely shared.

Theoretical Framework: Diffusion, Leapfrogging, and Convergence

Diffusion of Innovation. The spread of new technologies typically follows an S-shaped adoption curve as innovations gradually move from early adopters to the majority. Classic diffusion theory (Rogers, 1962) outlines how information flows, peer effects, and perceived benefits drive this process within societies. At the international level, **technology diffusion refers to the transfer of know-how across countries**, allowing followers to learn from leaders. In the past, such transfers often occurred slowly, impeded by limited connectivity and capacity. Today, however, the acceleration of communication and globalization has steeply increased the pace of diffusion. Studies have found that **cross-border knowledge flows have become significantly more globalized since the 1990s**, aided by the dramatic expansion of trade, foreign direct investment (FDI), and the internet [4][5]. Patent citation data show that the share of knowledge originating in leading economies (e.g. G5 nations) that diffuses to emerging markets has **risen steadily over the past two decades** [6]. In contrast, knowledge flows from leaders to other advanced economies have been relatively flat, suggesting that emerging markets are catching up by absorbing foreign innovations [6].

Leapfrogging and Creative Destruction. A related concept is *technological leapfrogging*, wherein latecomer countries skip over outdated technologies and adopt newer, more efficient ones. Leapfrogging is facilitated by the lack of entrenched legacy systems in developing contexts – there is often less "path dependence" holding back change [7]. Historically, leapfrogging has accompanied many transformative inventions: the printing press quickly displaced hand-copied manuscripts; cars replaced horse-drawn carriages; the mobile phone rendered extensive landline networks unnecessary. In Africa, for example, very few countries ever achieved widespread

fixed-line telephone penetration, but **mobile telephony leapfrogged that stage entirely** – today, even remote villages connect via cellular networks [8]. Leapfrogging is essentially a process of **creative destruction**, where new technologies render older infrastructure obsolete for late adopters[9]. This can enable faster developmental progress because countries can "sweep aside" older, less efficient modes and go straight to state-of-the-art solutions[9]. The 21st century's rapid innovation cycles have made such opportunities even more pronounced, as each technological generation builds on the last at **exponential rates of improvement**[10]. Crucially, while much cutting-edge R&D still occurs in high-income countries, the **uptake and social impact of new technologies are often seen most dramatically in developing countries**, where they address unmet needs [11].

Global Convergence. Economic convergence refers to the tendency of poorer economies to grow faster than richer ones, narrowing the income gap, especially when they can adopt existing technologies. Widespread diffusion of industrial and digital innovations should, in theory, promote convergence by enabling late-developing nations to dramatically improve productivity without "reinventing the wheel." Empirical evidence suggests this is happening in certain dimensions. **International technology diffusion has made a meaningful contribution to income convergence** for many emerging markets [12]. Research by the IMF found that between 2004 and 2014, **knowledge flows from G5 technology leaders contributed about 0.7 percentage points to annual labor productivity growth** in the average emerging economy sector – roughly **40% of observed productivity growth** in that period [13]. These gains from foreign technology have accelerated over time as globalization deepened [14]. Moreover, there is strong convergence in terms of **technology use for consumption**: many consumer technologies (mobile phones, appliances, internet access, etc.) have rapidly proliferated across developing

countries, leading to improvements in quality of life even where income convergence is slower [15]. In fact, global gaps in basic living standards (health, communications, access to knowledge) have shrunk more than income gaps in recent decades, partly due to fast diffusion of key consumer technologies [15].

At the same time, convergence is **neither automatic nor universal**. Diffusion patterns vary by sector and geography. Frontier production technologies (e.g. advanced manufacturing equipment, robotics) still see **slower and more partial adoption in low-income settings** compared to consumer tech [16]. Some countries remain excluded due to conflict, poor governance, or lack of human capital, raising concerns of a "digital divide" where those without access fall further behind. Thus, while the overall trend is toward greater global technological inclusivity, ensuring that diffusion is *equitable* – both across and within countries – remains a critical challenge. The next sections discuss what drives successful diffusion and provide concrete examples of how technological optimization is spreading worldwide, with attention to both the opportunities realized and the obstacles encountered.

Drivers of Global Technological Diffusion

A combination of economic, technological, and policy factors underlie the recent acceleration in global technology diffusion:

- **Globalization of Trade and Investment:** The expansion of international trade and foreign investment since the late 20th century has been a powerful conduit for technology transfer. Multinational corporations bring new production techniques to developing countries, and imported capital goods often embody advanced technologies. Empirical studies highlight trade and FDI as key channels of diffusion [17]. For instance, as China integrated into world trade, developing countries could import ever-cheaper high-tech equipment (like affordable smartphones or solar panels) that were previously out of reach. Additionally, emerging economies like China themselves became exporters of technology – e.g. **Chinese firms supply competitively priced telecom equipment and infrastructure across Africa**, lowering the cost of connectivity [18][19]. The rise of global value chains means know-how flows more freely across borders within production networks.

- **Knowledge and Information Flows:** The communications revolution has vastly increased the speed at which information spreads. The internet, satellite TV, social media, and open-access scientific knowledge all allow **instant sharing of ideas and practices worldwide**. A researcher in Nairobi or Dhaka can read the latest AI research, and an entrepreneur in Lagos can watch online tutorials or collaborate remotely with peers abroad. Patent citation analyses confirm that emerging market inventors are citing foreign patents much more frequently now than in the 1990s, indicating greater absorption of

global knowledge [20][21]. Notably, by the 2010s, **China and South Korea had become deeply integrated into global knowledge networks**, both using and contributing to the stock of technical knowledge through patent citations [22]. The diffusion of tacit knowledge has also improved through diaspora networks and return migrants transferring skills, as well as international education and training programs.

- **Falling Costs of Technology:** A critical driver has been the dramatic decline in costs for many technologies, making them affordable in lower-income markets. For example, the cost of computing power and digital storage has plummeted exponentially (often cited under "Moore's Law"), enabling even inexpensive smartphones to have capabilities that supercomputers lacked a few decades ago. The price of renewable energy technologies has also fallen sharply – solar photovoltaic module costs dropped around 85% in the 2010–2020 decade, and battery costs fell about 80%, greatly enhancing the viability of off-grid power in poor communities [23]. As innovations mature, economies of scale in production (often driven by manufacturing in emerging Asia) push prices down. This **"optimization" and commoditization of tech** means cutting-edge solutions (from gene-sequencing to drones) eventually become cheap enough to deploy in developing countries at scale. *Technological optimization is rapidly dispersing across the world*, as the prompt noted, because what was once expensive and scarce is becoming cheaper, faster, and more accessible.

- **Rise of New Innovators:** The geography of innovation itself is broadening. Beyond the traditional triad of North America, Western Europe, and Japan, we now see significant R&D activity in countries like China, India, South Korea, Israel, Brazil, and others. This matters because innovations arising in emerging economies may be especially suited (in

cost or design) to other developing contexts. For instance, **frugal innovations** – cost-effective solutions developed in resource-constrained settings (like inexpensive medical devices or ultra-compact cars from India) – can diffuse to other low-income markets more readily than high-end products from the West. Additionally, competition from emerging market firms can spur Western companies to create more affordable offerings. The net effect is a richer global ecosystem of innovation where ideas flow south-south and not just north-south. The IMF finds that **competition from emerging markets has a positive effect on innovation globally**: exposure to imports from China, for example, nudged European firms to innovate more [24]. In summary, developing countries are not only passive receivers of technology but increasingly active players in generating and adapting innovation.

- **Policy and Institutional Factors:** Many governments and international institutions have recognized the importance of closing technology gaps. Investments in education and technical skills help developing nations absorb new tools (for example, China's massive expansion of tertiary education has enhanced its capacity to harness foreign R&D [25][26]). Policies that encourage connectivity (such as liberalizing telecom sectors, or subsidizing rural internet) directly facilitate diffusion. Conversely, restrictive policies (e.g. heavy import tariffs on tech or excessive IP enforcement without local capacity-building) can slow diffusion. International aid and development programs have also pivoted toward tech – from programs distributing tablets in schools, to financing for renewable energy projects, to initiatives like the World Bank's support for tech incubators in Africa. The global community's emphasis on the **UN Sustainable Development Goals** has highlighted technology's role, fostering collaborations to spread

health, agricultural, and clean energy innovations. However, geopolitical factors can intervene as well: for instance, export controls on advanced semiconductors imposed by some countries might limit diffusion of cutting-edge AI hardware to certain regions [27][28]. Overall, sound policies at both national and international levels are essential to maximize the beneficial spread of innovation.

Impacts on Emerging Economies and Global Convergence

Growing evidence indicates that rapid technology diffusion is having transformative impacts on developing economies. One clear outcome is **faster productivity growth** in many follower countries as they adopt more efficient methods. For example, the research cited earlier showed that foreign knowledge flows have significantly boosted patenting and total factor productivity in emerging markets [21]. In fact, **foreign R&D has often contributed more to innovation output in emerging economies than domestic R&D** in recent years [29][13]. By leveraging ideas from abroad, countries can accelerate their development timeline.

This has translated, in several cases, into **income growth and poverty reduction**. New technologies reduce the cost of essentials – consider how cheaper renewable energy or generic medications lower household expenditure – and open new earning opportunities – for instance, via digital platforms or improved crop yields. A broad indicator of convergence is the narrowing gap in quality of life measures. Charles Kenny and colleagues find "considerably stronger global convergence in quality of life than in income," driven largely by the diffusion of **consumption technologies** such as mobile phones, sanitation, and modern energy[16]. People across the world are more connected and have better access to information and services than ever before, even if income inequality persists. As one World Bank commentary put it, **technology diffusion to emerging markets lifts global living standards** by sharing growth potential [30].

Crucially, the positive impacts extend beyond the recipient countries. **Global innovation itself benefits** from a wider circle of contributors. As emerging economies build innovation capacity, they add to the global stock of knowledge and often tackle problems (diseases, climate adaptation, etc.) that might be under-addressed by rich-country R&D. There is also evidence that

competition from emerging-market firms can induce incumbent firms in advanced economies to step up their innovation game, potentially boosting overall productivity [24]. In other words, diffusion and convergence need not be zero-sum; they can raise the innovation tide for all.

However, the impacts are not uniformly positive for everyone, which is why **equitable diffusion** is a central concern. Not all countries are catching up; some fragile states or marginalized regions remain on the periphery of the tech revolution. Within countries, there are divides – urban vs rural, educated vs less-educated – that determine who can benefit from new tools. For instance, even as mobile internet spreads in Africa, **about 710 million Africans still do not use the internet despite living in areas that have mobile broadband coverage** [31]. Often the poorest or those lacking skills are the last to benefit, which can initially widen inequality before eventually narrowing it. Automation and AI also pose a double-edged sword: while they promise leaps in productivity (and indeed, developing countries are **rapidly growing their use of industrial robots and AI applications** as we discuss later), they could displace certain low-skill jobs and require workers to up-skill or shift sectors. Thus, maximizing the gains from diffusion requires complementary investments (in education, social protection, infrastructure) to ensure broad-based participation in the tech-enabled economy.

Overall, the evidence supports an optimistic view that **global convergence is underway in many aspects of technology and development** – billions gaining access to modern tools, and many developing economies growing faster than advanced ones. Yet it also underscores that *how quickly and equitably* innovations spread will determine whether we truly witness a convergence that includes all of humanity, or whether pockets of exclusion and divergence persist. The

following section delves into concrete examples across key sectors to illustrate these dynamics in action.

Sectoral Pathways of Technological Leapfrogging

To ground the discussion, we now turn to several key sectors where innovation diffusion is visibly transforming developing economies. In each case, we highlight how advanced technologies are being adopted or adapted in lower-income contexts (often leapfrogging older approaches), and the impacts on development outcomes. The focus is global, but with emphasis on African experiences as representative of leapfrogging potential.

Digital Connectivity and Infrastructure

Perhaps the most fundamental leap in recent decades has been in digital connectivity. The spread of **mobile telecommunication networks** in the developing world has connected a previously unconnected majority. Many low-income countries skipped the era of copper landlines entirely – the cost of stringing landlines to every village was prohibitive and slow – and instead **"moved straight to mass mobile phone use" [32]**. Cellular towers now dot the landscapes of Africa and South Asia, reaching rural areas that never had telephone service before. As a result, basic voice communication became available to billions of people in just a couple of decades. By the 2010s, mobile phones were nearly ubiquitous even in very poor communities; by 2019, **Africa had about 444 million unique mobile subscribers and many times more SIM connections** (since individuals often have multiple SIMs) [33]. This has been a leapfrogging success comparable to the introduction of railways or roads in earlier eras in terms of its societal impact.

More recently, the emphasis has shifted to **internet connectivity** – specifically mobile broadband (3G, 4G and now 5G) – as the next leapfrogging frontier. Here too, progress is significant. As of 2025, **3G networks reach roughly 77% of Africa's population and 4G coverage reaches about 44%** [34]. Mobile internet users on the continent jumped from about

25% of the population in 2019 to **38% in 2024** [35], representing hundreds of millions of new internet users in a short span. While this still lags the global average (~68% internet usage), the growth rates are steep. Affordable smartphones (often Android devices costing <$50) and cheaper data plans have enabled many to come online for the first time. For example, Chinese telecom giants like Huawei and Transsion (maker of Tecno phones) have offered low-cost network equipment and handsets tailored to African markets, helping drive adoption [18][19]. There is even evidence of unconventional leapfrogging: in Somalia, lack of a strong central government didn't stop telecom operators from building extensive mobile networks – some analysts note that **parts of Somalia have better mobile coverage than rural England**, as private providers innovated unencumbered by legacy regulations [36].

Digital infrastructure leapfrogging also involves **new technologies for hard-to-reach areas**, like satellite internet. Initiatives such as SpaceX's *Starlink* constellation are now active in over a dozen African countries, delivering broadband to remote locations without terrestrial networks [37]. This could further bridge the rural-urban divide. Additionally, massive undersea fiber-optic cables (e.g., the 2Africa cable) encircling the continent and cross-border terrestrial fiber networks are coming online, increasing bandwidth and reducing costs. Government and private sector partnerships, often supported by development agencies, have launched programs to connect schools and community centers. For instance, in 2021 **Airtel Africa and UNICEF announced a $57 million initiative to provide free digital learning by connecting schools to the internet across 13 countries** [38]. Similarly, Safaricom in Kenya partnered with Nokia and the government to **connect schools in rural areas via 4G fixed wireless solutions** [39].

The impact of digital connectivity is difficult to overstate. It underpins many of the other advances discussed in this paper – from finance to health to agriculture. Mobile and internet

access serve as *the gateway to modern economic life*. Studies link internet expansion to higher GDP growth and new job creation (through the app economy, online work, etc.). Importantly, **connectivity reduces information asymmetries**, allowing farmers to check crop prices, students to access educational content, and citizens to engage with government services. For example, during the COVID-19 pandemic, countries with better internet could switch to remote work or e-learning more effectively, avoiding some losses. African telecom operators zero-rated (made free) certain educational and health sites to enable access for the poorest users [40][41]. These measures highlight how technology diffusion, if paired with inclusive policies, can mitigate crises and improve resilience.

That said, **challenges remain in closing the digital divide**. As noted, nearly 60% of sub-Saharan Africans are still offline [42], largely due to a *usage gap* – i.e. the infrastructure exists for many, but they cannot or do not use it. Barriers include affordability (devices and data costs), digital literacy, and electricity access for charging devices. For instance, a recent report estimated 710 million Africans live under a mobile broadband signal but aren't internet users [31]. Efforts to address these gaps include low-cost smartphone financing, digital skills training, and off-grid energy solutions (like solar phone chargers). Moreover, the next generation of network (5G) is just starting in Africa (only ~1.2% 5G access as of 2025) [43], which could widen gaps if not managed, though projections suggest 5G will expand to 17% penetration by 2030 in Africa [44]. In summary, the spread of digital connectivity is a prime example of technological diffusion driving convergence in access to information. The task ahead is to push it to the last mile and ensure everyone can partake in the digital economy.

Fintech and Financial Inclusion

Growth of active mobile money accounts worldwide by region (2010–2023). Sub-Saharan Africa (blue area) accounts for more than half of the global mobile money user base [45]. The number of active mobile money accounts globally surged from **13 million in 2010 to over 640 million by 2023**, with Sub-Saharan Africa's share exceeding 330 million accounts [46]. This reflects the rapid diffusion of fintech innovations in developing regions.

One of the most celebrated leapfrogging success stories is the rise of **mobile money** and digital finance in the developing world. In regions where traditional banking was inaccessible to large segments of the population, mobile network operators and fintech startups introduced services that allow people to **store, send, and receive money using basic mobile phones**. The pioneer was *M-Pesa* in Kenya (launched 2007), which quickly became a primary means of financial transaction for Kenyans who had never held a bank account. Since then, the model has proliferated: there are now more than **640 million mobile money accounts worldwide**, over half of them in Africa [46][45]. In Sub-Saharan Africa, the share of adults with a mobile money account jumped from just 12% in 2014 to **33% by 2021** [47]. This digital financial inclusion has nearly **tripled the overall rate of formal account ownership** in the region (from about one-third of adults to over one-half) within a decade, almost entirely thanks to mobile money rather than traditional banks [48].

Mobile money allows users to deposit cash with local agents (kiosks), convert it to digital credits, and make transfers or payments via SMS or app. The **infrastructure leapfrogged** the need for brick-and-mortar bank branches or ATMs. In many African cities and villages today, one sees ubiquitous **mobile money kiosks** with signage from providers like MTN Mobile

Money, Airtel Money, or Orange Money, serving as micro-bank branches for the unbanked. **Africa leads the world in digital financial innovation adoption** – a fact noted by analysts who observe that African countries are ahead in areas like person-to-person payments and agent banking[49]. For example, by 2023 **more people in Sub-Saharan Africa receive wages or remittances through mobile phones than through traditional bank accounts** [50].

The developmental impacts of this fintech diffusion are significant. **Financial inclusion** is linked to poverty reduction and economic empowerment. A well-known study in *Science* found that the expansion of M-Pesa in Kenya directly **lifted about 194,000 households (2% of Kenyan households) out of extreme poverty** by enabling them to save, invest, and better withstand shocks [51][52]. Mobile money services facilitate safer and quicker transfers, which is life-changing for rural families receiving urban remittances, or for small businesses paying suppliers. They also provide a secure place to store money, reducing the risks of theft or loss associated with cash. Over time, mobile money users have leveraged these tools to start businesses or migrate for better jobs, knowing they can send money home easily [53][54]. In rural Mozambique, for instance, introduction of mobile money spurred labor migration to cities, leading to higher incomes as people found non-farm employment [53].

Beyond basic transfers, fintech innovation in developing economies has expanded into **credit, savings, and insurance** via digital platforms. AI-driven credit scoring using mobile phone data now allows lenders to offer micro-loans to individuals with no credit history. In Kenya, platforms like M-Shwari and Tala have extended credit to millions based on mobile usage patterns. **Digital savings groups** and wallet-based interest accounts encourage saving small amounts. Farmers can buy micro-insurance for their crops or livestock, paying premiums and

receiving payouts through mobile money. All these services help smooth incomes and reduce vulnerability to shocks.

Notably, **mobile money has particularly benefited women and rural populations**, who traditionally were most excluded from finance. By lowering barriers (no need to travel to a bank or meet paperwork requirements), it gave women more financial autonomy. Studies have credited M-Pesa with increasing women's savings and even enabling some women to shift from subsistence farming to business occupations [51]. In many African countries today, the gender gap in financial access is closing thanks to mobile accounts.

Fintech diffusion is not limited to person-to-person transfers. Governments are also leveraging it for efficiency and inclusion. Social cash transfers and government subsidies are increasingly delivered via mobile wallets, ensuring the money reaches the intended recipients directly. This reduces leakage and corruption. During the pandemic, countries like Togo rapidly rolled out mobile cash assistance to citizens using digital platforms (the "Novissi" program). Furthermore, the ease of digital payments has catalyzed e-commerce and the gig economy in places like Nigeria and India, where youth can sell products or services online and get paid through mobile-linked accounts.

For all its success, challenges remain in the fintech space. Consumer protection and digital literacy need strengthening, as many new users may fall prey to fraud or misunderstand fees. The regulatory environment must balance innovation with financial stability – e.g., mobile money operators need sound regulation to prevent money laundering or system failures. Interoperability between different providers is also crucial so that the digital financial ecosystem doesn't fragment into silos. African central banks have been working on **real-time payment switches** to connect mobile money with bank systems and fintechs. Another frontier is integrating fintech

with formal banking and global financial systems, so that, for example, mobile wallet holders can easily receive international remittances or pay online for global services.

In sum, the diffusion of fintech exemplifies how developing countries can leapfrog to **modern, inclusive financial systems** without retracing the steps advanced economies took (e.g., building dense branch networks). By reducing transaction costs and expanding financial access, these innovations are enabling more inclusive economic activity and upward mobility. The "cashless" or "cash-lite" economy emerging in parts of Africa and South Asia was scarcely imaginable two decades ago, but today it is a cornerstone of convergence in opportunities.

Energy and Electrification

Access to affordable and reliable energy is a cornerstone of development. Historically, most wealthy countries achieved near-universal electrification through centralized grids powered by fossil fuels (coal, gas, oil) or large hydropower. But this model has struggled to reach many rural and remote parts of the developing world; today, about **600 million Africans (and many in South Asia) still lack basic access to electricity** [55]. The traditional path of extending national grids to every last mile is extremely costly and slow, often running into tens of billions of dollars needed in infrastructure investment. Here, technology diffusion is offering an alternate pathway: **decentralized renewable energy solutions** that can leapfrog the need for full grid expansion [32][56].

Chief among these are **solar photovoltaic (PV) systems**. In areas where extending the grid is uneconomical, small-scale solar setups have become a game-changer. Thanks to a steep drop in global PV prices, even low-income households can potentially afford solar panels for basic power. A typical **"solar home system"** includes a solar panel, a battery, LED lights, and ports to

charge phones or power a radio/TV. Such systems, often sold on a pay-as-you-go basis, have proliferated across Africa and South Asia. For example, in 2018 alone, about **5 million people in Africa gained electricity access through solar home systems** [57]. Companies like M-KOPA, Off-Grid Electric, and d.Light distribute these systems with financing models where users pay little by little (often via mobile money) for the solar kit while using it, after which it becomes theirs. The pay-as-you-go model, enabled by mobile connectivity, ensures affordability and aligns with local income flows [58]. This is a prime example of two innovations (mobile finance and solar tech) diffusing together to solve a development challenge.

In parallel, larger-scale **mini-grids** are being deployed to power villages or clusters of households. These are essentially small, localized grids, often solar-based (sometimes with wind or small hydro, plus battery storage, and occasionally diesel backup). Advances in control systems and batteries have made mini-grids more reliable. A system like MHI's "Eblox" hybrid power unit can combine solar panels, a battery bank, and a backup generator to supply stable electricity to **500–2,000 households** per unit, and multiple units can link for larger needs [59]. Many African governments, in partnership with donors, are now supporting mini-grid rollout in rural areas where grid extension is too slow. For instance, Nigeria and Tanzania have ambitious rural electrification plans centered on solar hybrid mini-grids. Communities that once relied on smoky kerosene lamps for light can leapfrog directly to solar-powered LED lighting and appliance use, with dramatic improvements in quality of life (better studying conditions for children at night, reduced indoor air pollution, etc.).

Renewable energy diffusion is not only happening off-grid. Even on national grids, **solar and wind farms are being adopted across developing countries** as costs have become competitive. Countries like India, Brazil, Morocco, and Kenya have built large solar parks and wind corridors,

bringing clean power into their energy mix faster than was conceivable a decade ago. Africa, for instance, despite having the world's richest solar resource, had installed only about **5 GW of solar capacity by 2020 (less than 1% of the global total)** [60], but this is now rapidly changing. Solar deployment is accelerating: one report noted that Africa's solar panel imports hit record highs in 2025, indicating a "take-off" phase for solar installations [61]. **Renewables are now seen as the least expensive way to achieve universal electrification in many off-grid areas** [23] – a remarkable shift from a time when renewables were dismissed as too costly.

The concept of leapfrogging is clearly visible in energy: **Africa could leapfrog the developed world by moving straight to decentralized, renewable power grids** instead of building out massive fossil-fuel infrastructure [62]. This has climate benefits too, avoiding future emissions. We see already that some African nations have embraced this. For example, Kenya generates a large share of its grid electricity from renewables (geothermal, hydro, wind) and also leads in household solar adoption. Ethiopia and Morocco have invested heavily in renewables for new capacity. Even oil-producing nations like Nigeria are piloting solar to reduce diesel generator use. The **"energy trilemma"** of access, affordability, and sustainability [63] might be solvable by these new models, whereas older development pathways struggled to meet all three.

Energy tech diffusion extends beyond electricity access to modern cooking fuels (replacing wood-burning with LPG or electric induction stoves) and to industrial energy efficiency. It also includes innovations like **micro solar irrigation pumps** for agriculture and **solar water heaters** – simple technologies that can drastically improve productivity and welfare in rural economies.

However, significant obstacles persist. Upfront costs, even if much lower than before, can still be a barrier without financing. Many solar home system companies rely on external investment and face foreign exchange risks in importing equipment. Regulatory frameworks for mini-grids and

independent power producers are still evolving, and sometimes utilities see them as competition. Moreover, off-grid solutions typically provide limited power (enough for lights, phone charging, small appliances) but not the kind of power needed for heavy industry or large-scale value addition. Thus, leapfrogging with renewables is often a partial solution: it can cover basic needs quickly, but robust economic growth will eventually require grid integration and higher-tier energy supply. The ideal approach is a hybrid one – *expand the main grid where viable, but use decentralized renewables to fill the gaps*.

Encouragingly, the economics keep improving. As battery prices fall, storing solar energy for night use becomes easier. Emerging technologies like **low-cost electric motorcycles or solar EV charging** could solve transport energy needs in a clean leapfrogging way (imagine skipping gasoline motorbikes for electric ones charged by solar in African cities). There are also efforts to retrofit or **hybridize existing diesel-based systems (like cell tower generators or remote health clinic power) with solar** to cut costs and pollution [64].

In conclusion, the diffusion of optimized energy technologies – particularly solar PV, battery storage, and smart microgrid controllers – is enabling developing countries to chart a greener and more inclusive energy future. It is a prime example of how a global technological breakthrough (cheap solar energy) can spread and be locally adopted to solve long-standing development challenges (like rural electrification), thereby potentially skipping over the high-carbon, highly centralized model of the past.

Healthcare and Public Health

Healthcare innovations are also spreading rapidly and often *skipping traditional barriers* to reach underserved populations. The challenges in health (shortage of doctors, remoteness of

communities, lack of infrastructure) have spurred creative solutions in many developing countries, and the global diffusion of medical technology is saving lives in places that previously lacked access.

One striking example is the use of **drones for medical deliveries**. In countries with poor road networks, delivering blood, vaccines, or medicines to remote clinics used to take hours or be impossible in bad weather. Today, **autonomous drone delivery networks are operating in Rwanda, Ghana, Nigeria, and beyond**, ensuring that even rural patients can quickly get critical supplies. Rwanda partnered with the California-based startup *Zipline* to launch the world's first national drone delivery service for blood transfusion supplies in 2016. This service has since expanded and proven extremely effective. According to one study, after drone deliveries began, **postpartum hemorrhage deaths (a leading cause of maternal mortality) fell by 51% in the serviced regions** due to timely delivery of blood for transfusions [65]. This equated to hundreds of mothers' lives saved, a testament to how cutting-edge technology (autonomous drones) diffused to a low-income country and solved a deadly problem [65]. Zipline's drones now operate in **Ghana, Côte d'Ivoire, Kenya, and Nigeria**, delivering not just blood but vaccines, antivenoms, and other essential medicines to hundreds of health facilities [66]. They have effectively leapfrogged the need for an extensive cold-chain trucking system or all-weather roads in those areas – what used to take **many hours by road now often takes 30 minutes by drone**, a potential life-or-death difference [67].

Drone delivery networks have **dramatically reduced delivery times** for blood and vaccines to remote African clinics, exemplifying technological leapfrogging in healthcare logistics. In Rwanda, the introduction of medical drones led to a **51% reduction in postpartum hemorrhage deaths**, as urgent blood units could reach rural hospitals within minutes [65].

Another area of leapfrogging is **telemedicine and digital health services**. In regions with few specialists, telemedicine allows urban doctors to consult on patients in remote areas via video or mobile phone. During the COVID-19 pandemic, telehealth usage surged globally, including in parts of Africa and South Asia, as regulators temporarily eased restrictions. But even prior to that, programs like *Babylon's AI health app* (Deployed in Rwanda as "Babyl") or India's telemedicine initiatives have been expanding access to medical advice. Patients can get symptom checks or talk to a doctor through mobile apps, which is revolutionary for someone in a village with no clinic nearby. Simple mobile phone-based innovations have also made an impact – for example, in some countries pregnant women receive SMS reminders for prenatal care and can call toll-free hotlines if complications arise.

Diagnostic technology is also diffusing: **point-of-care testing kits** for diseases (malaria rapid tests, HIV self-test kits, etc.) mean that you don't need a full lab to get basic diagnostics. Innovations like portable ultrasound devices or smartphone-based electrocardiograms are being used by health workers in rural clinics, enabled by cost declines. In India, for instance, GE developed a low-cost portable ultrasound ("Vscan") which has been employed in remote maternal health clinics to check fetal growth. **AI-powered diagnostic tools** are another promising leapfrog – e.g. applications that analyze medical images or even just a photograph taken by a community health worker to detect illnesses (like an app to detect cataracts from an eye picture, or skin lesion analysis for cancer). These tools can help overcome the shortage of specialists by providing decision support to general practitioners or nurses.

Immunization and disease surveillance have benefitted from technology diffusion too. *Electronic health records* and data systems, often leapfrogging straight to cloud-based or tablet-based systems, are being adopted in some African health systems, improving tracking of patients and

stock management of vaccines/medicines. For instance, Tanzania and Zambia introduced an electronic Logistics Management Information System for health commodities, improving availability by tracking stocks in real-time. Mobile phones have been used for polio vaccination campaign tracking and for sending health promotion messages (e.g., the mT obaacco cessation program sends SMS tips to help quit smoking).

One cannot overlook the crucial role of **pharmaceutical diffusion** – while not "high-tech" in the digital sense, the spread of medical innovations like new vaccines, drugs, and treatments is a form of technological diffusion that has saved millions of lives. For example, effective antiretroviral therapy (ART) for HIV/AIDS was initially expensive and limited to rich countries in the 1990s; by the mid-2000s, thanks to generic production (much of it in India) and global health programs, ART diffused widely in Africa, turning HIV from a death sentence to a manageable chronic condition for over 25 million people on treatment. Similar stories exist for vaccines: the introduction of cheap conjugate vaccines in sub-Saharan Africa has drastically cut meningitis and pneumonia deaths. The diffusion of these health technologies often depends on international cooperation and financing (e.g., Gavi, the Vaccine Alliance helping low-income countries afford new vaccines).

Healthcare leapfrogging does have hurdles. Regulatory frameworks for drones, telemedicine, and AI in health are still developing; governments must update policies to accommodate these tools while ensuring safety and privacy. The health workforce needs training to effectively use new tech – e.g., a nurse needs to know how to operate a portable ultrasound or interpret an AI decision support suggestion. Some technologies face skepticism or cultural barriers among patients (for instance, trusting an AI chatbot for medical advice can be uneasy at first). And there remains the core issue of resource constraints: while a diagnostic kit might leapfrog need for a

lab, you still need roads to get patients to a hospital for surgery, or reliable electricity in clinics for devices – basic investments that cannot be skipped.

Nonetheless, the trajectory is clear: developing countries are increasingly *early adopters* of health tech innovations, not laggards. In some cases, they even lead: e.g., **Rwanda's success with drones** is now prompting developed countries to consider similar networks, essentially reverse diffusion of innovation. The COVID-19 vaccine rollout also showed some leapfrogging, where countries used novel approaches like mass SMS scheduling and drive-through clinics, and benefitted from global scientific collaboration at unprecedented speed.

In summary, **the circulation of medical innovation** – from simple mobile tools to advanced drones and AI – is enhancing healthcare delivery in poor regions and saving lives. It exemplifies how crucial outcomes (like maternal survival, child health, disease control) can improve rapidly when developing nations gain timely access to the world's best technologies adapted to local needs.

Agriculture and Food Security

Agriculture remains the backbone of many developing economies, and technological diffusion in this sector is vital for improving productivity and food security. In much of Africa and South Asia, farmers have traditionally operated with minimal mechanization, low-yield seed varieties, and limited information, leading to stubbornly low crop yields. The diffusion of **optimized agricultural technologies** – from improved seeds to digital advisory services – offers the chance for these countries to leapfrog from subsistence farming to climate-smart, productive agriculture.

A primary area of impact is the spread of **improved crop varieties** (sometimes called the "Green Revolution" technologies). While the original Green Revolution of the 20th century largely

bypassed Africa, there is ongoing diffusion of high-yield and drought-resistant varieties of staples like maize, rice, and wheat tailored to African conditions. International research centers (CGIAR institutes like IITA and IRRI) have developed seeds that can dramatically raise yields if used with proper practices. For instance, hybrid maize varieties now adopted in parts of East Africa have significantly higher yields than the traditional open-pollinated varieties. Along with seeds, the diffusion of **fertilizer use and better agronomic practices** is key – and here knowledge dissemination is the tech, often via mobile phones.

Digital agriculture advisory services have proliferated, taking advantage of the nearly universal mobile phone access among farmers. Services like Kenya's *Digifarm* or India's *e-Choupal* provide farmers with information on weather forecasts, pest outbreaks, best practices for planting and harvesting, and market price updates via SMS or apps. In Uganda, the *EzyAgric* app uses AI to diagnose crop diseases from photos taken by farmers' phones, providing treatment recommendations. These are instances of leapfrogging agricultural extension – rather than waiting for an expert to physically visit (which may never happen given extension worker shortages), farmers can now get tailored advice remotely. **Studies have shown that when farmers receive timely weather or price information on their phones, they can adjust planting decisions and marketing to earn more and reduce losses** [53].

Mechanization is another facet where technology is slowly diffusing. While the average African farmer still uses a hand hoe, there is growth in small-scale mechanization – for example, **two-wheeled hand tractors, small rice mills, and motorized pumps** for irrigation are becoming more common as they become cheaper (often imported from China or India). Even more cutting-edge, companies like Hello Tractor (sometimes dubbed "Uber for tractors") in Nigeria allow farmers to rent tractor services via a mobile app, enabling a form of leapfrogging ownership

through the sharing economy. Drones are also used in agriculture for tasks like aerial spraying of crops or monitoring field health (though still nascent in Africa). These precision agriculture tools, combined with satellite data, can identify issues in fields early, allowing interventions that increase yield.

One significant leapfrogging opportunity is **AI-powered farm management**. For example, machine learning models can use remote sensing to predict yields or detect drought stress. While these models might be developed in advanced research labs, they are increasingly offered through accessible platforms to farmers or cooperatives in developing countries. AI-based credit scoring (as mentioned earlier) is also enabling agricultural credit – lenders use phone data or satellite images of farms to assess a smallholder's creditworthiness, then extend loans for inputs. This addresses one of the biggest barriers to technology adoption: financing for seeds, fertilizer, or equipment.

Livestock herders are benefiting from tech diffusion too. Mobile apps and solar-powered cold chains help pastoralists get veterinary care alerts and vaccines for their animals. GPS tracking collars and IoT sensors are being piloted to manage grazing patterns and prevent overgrazing, which could be revolutionary for sustainable pastoralism in the Sahel, for instance.

The outcome of these diffusions is slowly visible: some African countries have started to see improved yields and production. For instance, Ethiopia's cereal yields have more than doubled since the 1990s after large-scale diffusion of better seeds and fertilizer. Rwanda's "Crop Intensification Program" disseminated improved inputs and saw maize yields quadruple in a decade. These are positive convergences toward global average yields (though still with a long way to go in many places). The hope is that with climate change threatening traditional farming, new technologies (like drought-tolerant seeds, index insurance delivered via mobile, and agro-

forestry techniques shared through apps) will help farmers adapt and maintain productivity – essentially leapfrogging to *climate-smart agriculture* rather than repeating the unsustainable practices of the past.

Challenges in agricultural tech diffusion include cultural factors (farmers may be cautious in adopting new seeds or methods without seeing proof on their own fields), infrastructural issues (e.g., machines need fuel and maintenance, which can be lacking), and education (literacy and numeracy are needed to use some tools effectively). Moreover, some technologies like genetically modified crops remain politically sensitive in parts of Africa, slowing their adoption despite potential benefits. Ensuring equity is also key: larger, wealthier farmers adopt tech faster, which can widen gaps unless measures (like subsidies or group financing for small farmers) are in place.

Nevertheless, the general direction is that the knowledge and tools to greatly improve agriculture are becoming available everywhere. If the diffusion continues and accelerates, the coming decades could see a significant closing of the yield gap between developing and developed world farms – a core aspect of economic convergence that directly impacts poverty (since agriculture still employs the majority of people in many poor countries). That would mean not only higher rural incomes but also improved food security for growing populations, aligning with global goals to end hunger.

Industry, Automation, and AI

Industrialization has been the classic engine of convergence (e.g., East Asian economies catching up through manufacturing). However, today's frontier technologies in industry – robotics, advanced manufacturing, and artificial intelligence – present a nuanced picture for developing

countries. On one hand, there is concern that automation in rich countries might reduce opportunities for labor-intensive exports (the "robots will take our jobs before we industrialize" fear). On the other hand, these same technologies are diffusing and becoming accessible, which could enhance productivity in developing-world industries and even services.

Evidence suggests that **developing countries are adopting industrial robots and automation at increasing rates**, albeit from a low base. One analysis found that from 2000 to 2016, the growth rate of new robot adoption in regions like Asia (outside high-income countries) outpaced that in North America or Europe [68]. Countries like China have already become the world's largest users of industrial robots, and this know-how spills over – Chinese robot models, cheaper than Western brands, are being marketed to factories in countries like Vietnam, India, and some African nations. For instance, **Africa currently averages only about 2 industrial robots per 100,000 manufacturing workers** (very low compared to ~100+ in advanced economies) [69], but initiatives are underway to boost automation where it makes sense. South African automotive plants use robots on assembly lines similarly to plants in Europe. Nigeria and Kenya have startups focusing on simple robotics and process automation in sectors like agri-processing and textiles. Governments are also keen on positioning for the Fourth Industrial Revolution – **several African countries (e.g., South Africa, Nigeria, Kenya, Egypt) have adopted national AI or Industry 4.0 strategies** to foster skills and innovation in these areas [70][71].

AI is a particularly interesting domain of diffusion. Most cutting-edge AI research happens in a few advanced economies, but the *applications* of AI are spreading globally. Cloud computing and open-source AI frameworks mean that a skilled developer in Africa or Latin America can build AI solutions without massive infrastructure. As noted earlier, AI is being applied in agriculture, finance, and healthcare in developing contexts. It's also used in government (e.g.,

analyzing satellite images to detect illegal mining or plan infrastructure). A 2024 index found a surprisingly high engagement with generative AI in some African countries – for example, it reported that **27% of Kenyans were using ChatGPT daily** [72], reflecting a rapid diffusion of this new technology even beyond the advanced world. If accurate, this signals an enthusiastic uptake of AI tools by young populations, which could translate into innovative local uses.

From an economic convergence standpoint, **automation and AI can potentially boost productivity in emerging markets**, allowing them to produce goods and services more efficiently. Rather than undermining development, moderate automation could make industries in places like Africa more competitive by lowering production costs and improving quality. For example, in Ethiopia's budding apparel factories, even partial automation (like computer-controlled cutting machines) has improved efficiency and made it viable to take on large orders. In agriculture, simple automation like motorized threshers or AI-guided precision farming can greatly raise output. **Africa's industrial automation market is expected to grow to about $7.4 billion by 2029**, as companies invest in technologies like robotics, process control systems, and data analytics to modernize production [73]. Key sectors driving this include not just manufacturing, but also mining (where automation can improve safety and output, e.g., automated drills in Zambia's copper mines) and energy (where oil & gas operations in Nigeria or Angola use automation for efficiency) [74].

Additionally, the rise of digital services provides new growth avenues. Business Process Outsourcing (BPO) and IT services in countries like India, the Philippines, and increasingly Kenya or Ghana rely on digital connectivity and skilled human capital rather than heavy industrial investment. The diffusion of cloud computing means an entrepreneur in Lagos can serve global clients with software services, effectively leapfrogging into the knowledge

economy. If AI is harnessed by these workforces, they might move up the value chain (e.g., doing data analysis or AI model training for international firms). There is an opportunity for developing countries to *not just adopt* AI, but to shape it to their needs – for example, developing AI that works in low-resource settings or languages not covered by big tech (there are startups focusing on AI in African indigenous languages, voice assistants that work offline, etc.).

Of course, the **risks and disparities** cannot be ignored. Automation can displace workers, and in poor countries with surplus labor, this is a social challenge. If, say, garment factories automate heavily, they might create fewer jobs for unskilled workers, complicating the classic development model. There's also risk of a digital divide where large firms adopt AI/automation and prosper, but smaller informal businesses are left behind. To manage this, policies need to focus on retraining and education so that workers can move into new roles that technology creates (for instance, robot maintenance technicians, or leveraging human skills in areas AI complements). Encouragingly, many analyses (e.g., by Brookings or the World Bank) suggest that *wholesale job loss in Africa from automation is not imminent* – partly because labor costs are still low and technology cost high, and also because new sectors will emerge. One perspective is that **automation in advanced economies might actually push manufacturing to developing countries in the near term**, as robots make production less about labor cost and more about other inputs (like raw materials or market proximity). In this scenario, African and South Asian countries rich in resources could attract manufacturing with semi-automated processes that still employ many locals. Indeed, **certain industries where labor costs matter less (e.g., some food processing, resource-based industries) are growing in Africa**.

Finally, **international collaboration is influencing diffusion**. Countries like India and South Africa are part of multi-nation research on AI ethics and governance, ensuring developing

country voices in how these technologies are directed. Initiatives to provide open data sets and open-source AI models (as discussed in the CSIS excerpt [75][76]) can empower Global South developers. The open-source movement in AI could be a great equalizer, allowing local adaptations without always relying on proprietary systems from a few big companies.

In summary, while automation and AI present challenges, they are also potent tools for development if wisely adopted. The circulation of these innovations to developing economies can **enhance competitiveness, open new service export niches, and solve local problems**. The key will be human capital – making sure the workforce is equipped to work with these new technologies – and strategic policies to foster homegrown innovation. Given the patterns so far, it's reasonable to expect that the gap in technology usage between advanced and developing economies in industry will diminish, albeit with different pathways than those taken in the 20th century.

Education and Human Capital Development

The diffusion of technology in the education sector is creating new opportunities to leapfrog in human capital development. Traditional education systems in many developing countries face shortages of qualified teachers, textbooks, and schools, especially in rural areas. Digital technology offers ways to expand access and improve quality without reproducing the entire brick-and-mortar model of the past.

One major development is the spread of **online learning and educational content via mobile devices**. As noted under digital connectivity, millions of students now have access to learning materials through phones and computers. For example, in West Africa, basic phones using SMS/USSD have been leveraged to deliver quizzes and tutorials (the *Eneza Education* platform

in Kenya and Ghana has reached nearly 5 million users with curriculum-aligned lessons via text) [41][77]. During COVID-19 school closures, countries that had e-learning platforms or TV/radio educational broadcasts could continue instruction for some students, highlighting the value of EdTech. Governments and telecom companies formed partnerships: **Airtel Africa, for instance, committed $57 million with UNICEF to connect schools and provide free access to online learning content across 13 countries** [38]. Similarly, MTN in South Africa launched an *Online School* portal with curriculum content, zero-rating it so that any student on MTN's network could use it without data charges [78][79].

Higher education and skills training are also being transformed by tech diffusion. Students in Africa or Latin America can now take **Massive Open Online Courses (MOOCs)** from top universities worldwide (platforms like Coursera or edX see significant enrollment from developing countries, sometimes in the hundreds of thousands for popular courses). This is a form of knowledge circulation that allows a motivated learner in, say, Nigeria to acquire coding skills or even complete a degree online from an international institution. Some platforms have partnered with local organizations to provide certificates and career connections. The availability of **open educational resources (OER)** – textbooks, lectures, and tutorials freely accessible – has grown, reducing dependency on expensive imported textbooks.

Another leapfrog is occurring in how education is delivered locally. **Digital classrooms and smart devices** are being introduced in some public schools. For example, Rwanda's One Laptop per Child initiative distributed rugged low-cost laptops to primary students; more recently, tablets and projectors have been introduced in schools in Kenya, Ghana, and others. While early challenges (like teacher training and maintenance) tempered some of these programs, over time they are being refined to genuinely enhance learning (e.g., using offline content servers where

internet is weak, training teachers in interactive pedagogies). There are also successful examples of **interactive radio instruction** – a decades-old idea revitalized with newer tech – where students listen to lessons via radio or phone, which has shown learning gains in remote areas with no qualified teachers.

Crucially, technology also helps in education system management: **Education Management Information Systems (EMIS)** allow better tracking of school enrollments, performance, and resource allocation when properly implemented, often through mobile data collection by school principals. This data-driven approach, a hallmark of advanced systems, is diffusing via donor-funded projects and enabling more evidence-based interventions in countries from India to Uganda.

The overall impact is that more people can access learning opportunities beyond what the physical capacity of schools and universities would normally allow. A young person can learn coding through an online platform and potentially get a remote job, effectively bypassing the lack of a local computer science program. Or a rural child can gain literacy and numeracy through an interactive radio or tablet program even if their local school is under-resourced. Over the long term, these boosts in human capital contribute to convergence by improving productivity and innovation capacity in developing economies.

Of course, **limitations and quality issues** exist. E-learning requires self-motivation and some level of digital access that not everyone has. There is a risk that tech-based education could exacerbate inequalities if only wealthier or urban students benefit. If 4% of Sub-Saharan African schools have internet as one statistic noted [80], relying solely on online solutions can leave many out – so hybrid solutions (mix of traditional and tech) are needed. Additionally, language and cultural relevance of content is crucial; much online material is in English, which may not be

accessible to all students. That said, localization is happening: e-learning content is being produced in local languages (for example, educational apps in Swahili or Hausa are emerging).

One encouraging sign is that **governments are increasingly including EdTech in their education strategies**. Investments in digital literacy (training both teachers and students to use technology effectively) are ramping up. Private sector and startups are also active – African EdTech startups raised significant funding in recent years to scale solutions for tutoring, exam prep, or management of schools.

In summary, the diffusion of technology in education is still at an early stage, but it holds promise to help developing countries rapidly improve educational outcomes without waiting to build tens of thousands of new schools or train tens of thousands of teachers in the traditional way. If each teacher can be empowered with digital tools, their reach and effectiveness expand. And if each student can eventually have a device connecting them to the world's knowledge, the gap in educational opportunity between a child in Nairobi and one in New York could narrow dramatically. Education is the ultimate enabler of all other convergence drivers, so success in this realm would amplify gains across the board – producing the engineers, entrepreneurs, and informed citizens to drive further innovation diffusion locally.

Challenges in Achieving Equitable Diffusion

While the case studies above paint an optimistic picture of rapid technological diffusion, it is essential to address the **challenges and caveats**. The speed and extent of diffusion vary widely, and many barriers can slow or distort the process. Ensuring that the spread of innovation truly leads to global *convergence* (and not new forms of disparity) requires overcoming these hurdles:

- **Infrastructure Gaps:** Physical infrastructure (electricity, internet connectivity, roads) is the backbone enabling technology use. Many regions still lack reliable power or broadband. For instance, large parts of rural Africa have no electricity, making it difficult to use digital devices or even basic electric tools. Although solar and off-grid solutions are helping, the scale of the deficit is huge. Without addressing these gaps, diffusion will remain uneven – urban areas surge ahead with 4G and smart grids while remote villages lag on 2G and kerosene lamps. **Expanded investment in both traditional infrastructure and innovative off-grid solutions is needed** to create the minimum platform for tech adoption everywhere.

- **Human Capital and Skills:** Adopting advanced technologies requires knowledge and skills, both among workers and consumers. Low levels of literacy, technical education, or digital skills in some populations mean that even when technology is available, it might not be effectively used. For example, a farmer might have a smartphone but not know how to interpret satellite-based advice, or a factory might import new machines but lack engineers to maintain them. **Education and training systems must evolve in tandem with tech diffusion**, or else countries risk a scenario where technology is present but underutilized (or, conversely, where automation displaces workers who cannot retrain).

Encouragingly, we see initiatives like coding bootcamps across Africa, and NGOs teaching basic digital literacy, but scaling these efforts is urgent.

- **Economic and Financial Constraints:** Many frontier technologies, even if cheaper than before, still require upfront investment that can be challenging for poorer nations or small firms. The high cost of capital in developing countries (high interest rates, perceived risk) means financing tech upgrades is not easy. Blended finance models and development aid can help de-risk some investments (e.g., subsidizing solar home systems for the poorest, or providing loans for startups). Additionally, low incomes among consumers can limit diffusion – for instance, not everyone can afford a smartphone or broadband subscription. **Affordability strategies** (like low-cost models, micro-payments, or subsidies for essential connectivity and devices) are needed to broaden access. Without them, diffusion may concentrate among the middle-class and exclude the poor, undermining convergence goals.

- **Governance and Policy Environment:** Governments play a double role – they can accelerate diffusion through supportive policy, or hamper it through poor governance and conflict. Stable, open economies that invest in innovation adoption tend to benefit more. On the other hand, countries facing conflict or severe corruption often see technology bypass them or be misused. For example, war-torn regions might have mobile coverage, but frequent network shutdowns or lack of safety prevents effective use. Or if customs procedures are corrupt and slow, importing new equipment becomes costly and delayed. Additionally, regulatory bottlenecks (like not updating laws for mobile money, or banning drones outright initially) can stall diffusion. Getting the policy mix right is tricky: regulators must encourage innovation but also guard against downsides (like data

privacy breaches, cybercrime, or monopolies by big tech firms). **Institutional capacity building** is thus an integral part of enabling tech diffusion – governments need knowledge to regulate new domains like AI or biotech in ways that maximize public benefit.

- **Cultural and Social Factors:** Adoption of new technology is not just a rational economic decision; it is also influenced by culture, trust, and social norms. Some communities may be wary of certain innovations (for instance, misinformation led to vaccine hesitancy, or there might be skepticism towards digital payments among those used to cash). Generational differences also play a part – youth are often quick to try new tools, whereas older generations might resist. Addressing these soft barriers requires **awareness campaigns, inclusion efforts, and demonstrating value**. When people see tangible benefits and feel included in the design of solutions, acceptance grows. An example is how mobile money in its early days had to build trust that mobile balances were safe; through marketing and word-of-mouth, it overcame skepticism and is now mainstream.

- **Inequality and "Club Convergence":** A caution in convergence literature is the idea of *club convergence*, where only those countries or groups that meet certain preconditions converge, while others are left out. There is a risk that some poorest nations (especially those with weak states or in conflict) could fall further behind even as others catch up. Similarly, within countries, educated urbanites may become part of a global tech-connected class, while rural poor remain in a technological shadow. This is not inevitable, but it is a trend observed in some contexts. For instance, connectivity and tech sector growth are booming in Nigeria's cities, but many rural Nigerian communities have

seen little change. To counter this, **targeted interventions for lagging regions and marginalized groups** are necessary – be it rural broadband programs, ICT training for girls and women (to narrow the gender gap in tech), or subsidized community tech hubs in low-income neighborhoods. Otherwise, diffusion might paradoxically increase internal inequalities even as it decreases international inequalities.

- **External Shocks and Geopolitics:** The global diffusion of technology can be disrupted by shocks such as pandemics or geopolitical tensions. COVID-19 temporarily disrupted supply chains for electronics, and while it also boosted digital adoption, the recovery has been uneven. Geopolitical competition, like the US-China tech rivalry, could potentially bifurcate technology flows (for example, export controls on certain chips may limit some countries' access to top AI hardware [27][28]). Developing countries may face pressure to align with one bloc or another for technology partnerships, which could complicate access. A fragmented global internet (splinternet) or diverging standards (e.g., in 5G equipment) might force choices that delay adoption. Maintaining a **globally cooperative approach** to technology – keeping it as much as possible a positive-sum exchange – is important so that diffusion does not get stymied by politics.

Despite these challenges, the overall evidence and momentum suggest that many of them can be overcome, or at least mitigated, with smart policy and international support. It will be critical for stakeholders (governments, private sector, civil society, international organizations) to continuously monitor the diffusion process and course-correct. As one analysis of leapfrogging in Africa concluded, *concerted policy action is needed to harness technology for the future* [81] – technology won't automatically solve problems unless steered towards inclusion. This includes

investing in people (education, health), ensuring open yet secure markets for innovation, and addressing basic needs so that people are able to take advantage of new tools.

Conclusion: Toward a Convergent Future

In the broad sweep of history, technology has often widened gaps before eventually closing them. The industrial revolution created a yawning divide between industrialized and non-industrialized nations in the 19th and early 20th centuries. Today, we stand at a different juncture: the digital age, with its rapid diffusion mechanisms, offers a chance to compress those gaps much faster. As we have seen, **technological optimization is no longer confined to a few advanced economies—it is rapidly dispersing across the world**. Innovations in AI, automation, fintech, healthcare, energy, agriculture, and infrastructure are being adopted in developing contexts at an unprecedented pace, reshaping living standards for billions.

The examples highlighted – from **mobile money lifting Kenyans out of poverty [51]**, to **drones cutting maternal mortality in Rwanda[65]**, to **off-grid solar lighting up remote villages [57]** – all tell a story of hope. They show that we are not doomed to follow a linear development ladder; under the right conditions, poorer nations can jump to higher rungs quickly by leveraging the knowledge and tools already forged elsewhere. The result is visible progress: higher productivity, improved health and education outcomes, and more inclusive financial and economic systems. In quantitative terms, global measures of human well-being (life expectancy, literacy, access to services) have improved markedly in recent decades, in large part due to this spread of technologies that reduce the cost of essentials and extend access to opportunities [16].

However, this optimistic trajectory is not automatic. The speed and equity of diffusion will define whether the 21st century fulfills its promise of convergence. If innovations spread *quickly* but only among the already better-off, we will see a form of growth that leaves pockets of poverty intact. If they spread *slowly* or not at all to certain regions, those places could fall into

deeper despair relative to a tech-advanced world. Therefore, a central imperative for policymakers and international partners is to **accelerate and broaden the diffusion process**. This means investing in connectivity, education, and health (so people can use technology), fostering entrepreneurship and local innovation ecosystems (so that technologies are adapted to local needs), and enacting policies that encourage competition and access (so that prices fall and supply expands).

Encouragingly, there is growing consensus on these points. Initiatives abound: from the World Bank's programs on digital transformation in Africa, to UNICEF's Venture Fund investing in open-source solutions for underserved communities, to regional integration efforts like the African Continental Free Trade Agreement which, among other goals, aims to facilitate technology and knowledge exchange across borders. Moreover, as developing countries become sources of innovation themselves, they will play a bigger role in driving diffusion to their peers (South-South cooperation). For example, India's affordable space technology or Brazil's tropical agriculture techniques are being shared with other nations in the Global South.

We should also recognize the role of *adaptation and frugal innovation* in diffusion. Not every technology developed in Silicon Valley or Berlin can directly solve a problem in Bamako or Dhaka. Often, it's the recombination and tweaking of technologies that yields breakthroughs for the poor – like combining mobile phones with banking to create mobile money, or using drone tech for medical payloads, or applying AI to local languages. Thus, diffusion is not a passive copy-paste; it is an active creative process in each new context. The more countries engage in that creative adaptation, the more they build their own innovation capabilities. In time, this virtuous cycle can lead to a world where innovation is truly multipolar and inclusive.

In conclusion, the narrative of global development is being rewritten by the rapid circulation of innovation. The old divides are beginning to blur as smartphones light up previously dark corners, and new vaccines immunize children everywhere, and renewable power flows to off-grid communities. The **21st century will indeed be defined not only by technological breakthroughs, but by how quickly and equitably they spread**. If we succeed in spreading them widely and fairly, we could witness a historic convergence where living standards across the globe rise toward a shared horizon of prosperity. The gains in poverty reduction, health, education, and income would be immense – fulfilling the aspirations of billions for a better life. Achieving this vision will require continued global cooperation, wise policy, and the empowerment of people to harness technology for inclusive ends. The trends so far give reason for optimism: more than ever before, the tools to end extreme poverty and enable broad-based prosperity are within humanity's collective grasp. The task now is to open that grasp and extend those tools to all.

Sources:

- Piazza, R., Ho, G., Jaumotte, F., & Eugster, J. (2019). *Technology diffusion and global living standards*. VoxEU/CEPR. (Analysis of international knowledge flows and productivity)[12][13]

- Kenny, C., & Yang, G. (2022). *Technology and Development: An Exploration of the Data*. Center for Global Development Working Paper. (Convergence in technology usage vs. incomes)[15]

- Eugster, J., et al. (2018). *How Knowledge Spreads*. Finance & Development, IMF, September 2018. (Documenting increased patent citation flows and impact on innovation)[21]

- ISS African Futures (2021). *Leapfrogging* theme report. (Explores technology leapfrogging scenarios for Africa)[8][9]

- Al Jazeera (2025). *State of Broadband in Africa 2025*. (Data on mobile network coverage and internet usage in Africa)[34][35]

- Our World in Data (2023). *Mobile Money* dataset and article by Hannah Ritchie. (Statistics on mobile money accounts and financial inclusion)[47][51]

- Berkeley IEOR (2025). *Flying Hope: How Drones are Transforming Healthcare in Africa*. (Case study of Zipline drone delivery impact in Rwanda and Ghana)[65][66]

- The AI Innovator (2025). *AI Development in Africa – An Overview*. (Noting AI startup ecosystem and usage stats like ChatGPT adoption in Africa)[72][82]

- MHI Spectra (2021). *Can Africa leapfrog the world with renewable electricity?*. (Discussing off-grid solar, microgrids and energy access trends)[57][23]
- Electronica Trade Fair News (2023). *Spotlight on Africa: The next growth region for industrial automation*. (Examples of automation adoption in African industries)[73][83]
- NTU-SBF Centre for African Studies (2021). *Mobile phones expand access to education in Africa*. (Examples of telco-edtech partnerships and e-learning initiatives)[38][41]
- Additional references embedded in text as inline citations for specific data and quotes.
