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Beyond Catch-Up

The end of business as usual for industrial development

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Progress by innovation

Acknowledgements

This report on the Foresight Study on BEYOND CATCH-UP: THE END OF BUSINESS AS USUAL FOR INDUSTRIAL DEVELOPMENT was authored by Prof. Raphael Kaplinsky (Institute of Development Studies, University of Sussex) and Prof. Mike Morris (OneWorld Europe and PRISM, School of Economics, University of Cape Town) with inputs from Carlota Perez, Belynda Petrie, Masuma Farooki and Justin Barnes. It benefited from the valuable feedback, guidance and support received from colleagues at the United Nations Industrial Development Organization (UNIDO), including Frank Hartwich, Aymen Ahmed, Hannah Grupp, Nobuya Haraguchi, Alejandro Lavopa and Gabor Molnar. Their inputs helped to strengthen the analytical depth and policy relevance of the study. Special thanks are extended to the UNIDO Communications team for their professional editing and typesetting of the report.

Published by the United Nations Industrial
Development Organization (UNIDO)
Vienna International Centre
PO Box 300
1400 Vienna, Austria
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www.unido.org

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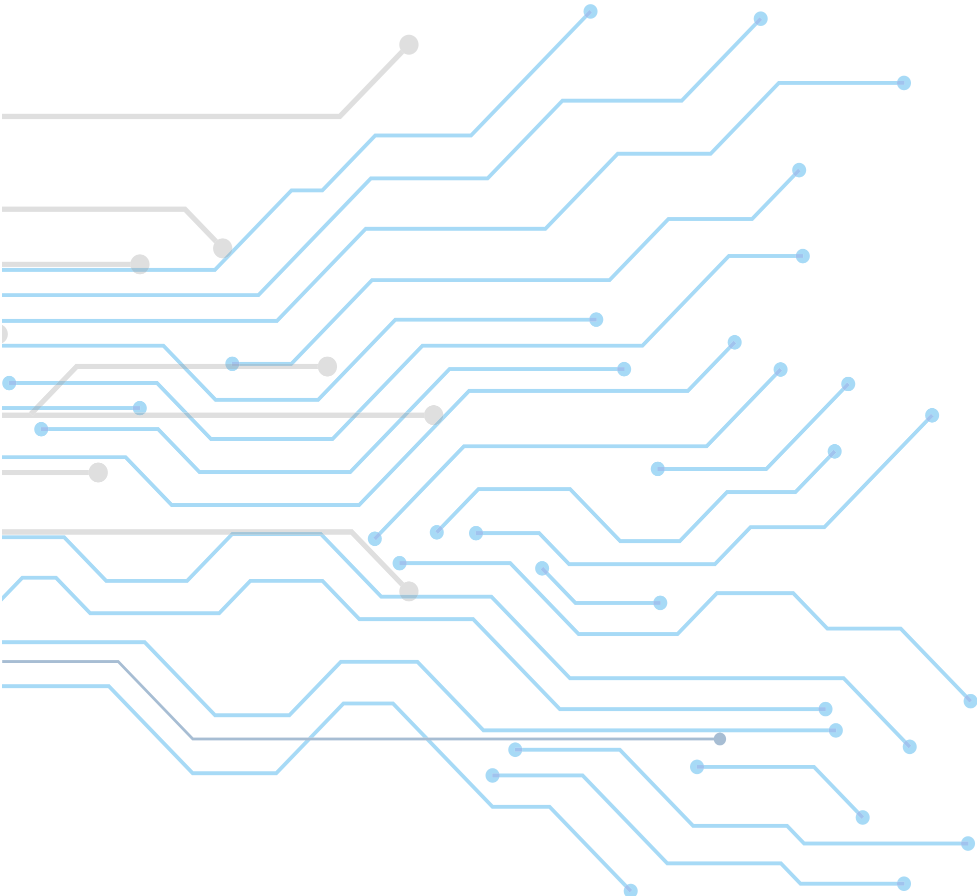

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EXECUTIVE SUMMARY

The global growth paradigm that historically powered economic expansion and poverty reduction is no longer sustainable - marking the end of Business as Usual for industrial development. Developing economies can no longer rely on replicating the pathways of today's leading economies. Instead, they must chart a new development trajectory that is both more equitable and more sustainable.

Innovation has long been a driving force behind economic growth and industrial development. Four broad categories can be distinguished:

- **Incremental innovations**, which involve small, continuous technical improvements.
- **Radical innovations**, which introduce fundamental changes within specific sectors.
- **Systemic innovations**, which are radical in nature but applied across a limited set of sectors, with impacts largely confined to the economic domain.
- **Revolutionary innovations**, which are disruptive and transformative, reshaping all sectors and dimensions of society - including economic, social, cultural, political, and environmental spheres.

Revolutionary innovations unfold in long waves of five to eight decades, driven by coevolution across production, markets, social structures, infrastructure, lifestyles, organisational models, and governance systems. These long-wave transformations define successive social and economic paradigms. Five such paradigm waves have shaped modern economic history:

- Waterpower and factory organisation (late 18th century).
- Steam and railways (from the 1830s).
- Steel, heavy engineering, and telegraphy (from the 1870s).
- Mass Production (20th century).
- Digital (the current, still-emergent paradigm).

Governments have historically played a pivotal role in both the emergence and deployment of each paradigm, shaping demand and directing investment. Yet transitions between paradigms are typically turbulent - marked by crises, political shifts (e.g., populism, nationalism), and sometimes conflict.

The Mass Production paradigm delivered unprecedented improvements in living standards, benefiting advanced economies and many middle- and low-income countries, including China and those in East Asia. But like previous paradigms, it eventually entered a period of decline. After the "Golden Age" (1950s–1970s), productivity growth slowed and profitability weakened.

The paradigm was prolonged by tapping low-cost labour through Global Value Chains (GVCs), enabling deep globalisation and the separation of production and consumption. While this facilitated rapid, export-led industrialisation in several developing economies, it also generated widening inequalities, economic and political instability, and growing environmental fragility, rendering "Business as Usual" unviable.

The End of Business as Usual: Four Major Disruptions are arising:

1. **Shifts in the Global Trade Regime:** The rules-based global trade system that underpinned the Mass Production paradigm is weakening. GVC participation peaked in 2008 and has since declined. Protectionism is rising - especially in major economies such as the United States - prompting trends toward reshoring, nearshoring, and friendshoring. South–South and intra-regional trade are expanding. The "flying geese" model that enabled China's export-led success is becoming less replicable. Traditional trade-led industrialisation is increasingly constrained.

2. **Rising Economic and Social Exclusion:** Global poverty reduction - concentrated largely in China and East Asia - has been uneven. Manufacturing's capacity to absorb labour is declining due to automation and AI. This is especially problematic for low- and middle-income countries with large youth populations. Informality is expanding, especially in urban areas, where livelihoods are precarious. Labour-displacing technologies offer limited solutions under a Business-as-Usual model.

3. **The Intensifying Environmental Crisis:** The Mass Production paradigm has driven significant environmental degradation, deepening the climate crisis. Fossil fuel dependence, single-use consumption patterns, and resource inefficiencies are increasingly untenable. Low- and middle-income economies face heightened vulnerability to climate impacts - affecting agriculture, water systems, and overall economic stability. Climate change makes Business as Usual impossible.

4. **Geopolitical Realignment and the Rise of New Hegemons:** The Pax Americana and the Washington Consensus - both foundational to deep globalisation - are being challenged. China and other emerging economies increasingly assert economic and geopolitical influence. Industrial policy is returning worldwide, including in advanced economies, opening new policy space for developing countries. However, a more contested multipolar world also brings heightened risks.

Beyond Business as Usual: The emerging Digital Paradigm offers a potential pathway to a more inclusive, equitable, and sustainable development model - though it introduces new risks. Digital transformation is reshaping production, consumption, and governance through "gales of creative destruction." Key features include:

- **Flexibility:** ICTs are inherently flexible and reprogrammable, enabling differentiated/customised products and adaptation to diverse production environments, allowing innovation to meet a wider range of user needs. This is accompanied by a process of 'servitization' in which the physical product is bundled with post-sales services.

- **Descaling of Production:** Unlike Mass Production's need for large-scale production of standardised goods, ICTs enable smaller-scale, modular expansion, allowing for customised products and for production closer to consumption and lowering barriers to entry for small enterprises.

- **Dispersal of Power:** Digital technology facilitates less hierarchical governance, horizontal information flows, and decentralised decision making, but also enhances centralised control and concentrated power by large tech firms.
- **Increasingly Disembodied Technologies:** Productivity gains come from intangible technologies, freeing production from physical limitations and hard-wired controls. This impacts skills and income distribution, favouring digital skills and potentially benefiting developing countries with digitally knowledgeable youth.
- **Inherently Systemic:** Digital systems use a common language, allowing seamless communication and integration across production, logistics, use, and disposal. These interconnected systems permeate social and governance spheres, offering potential for enhanced equitable and sustainable growth.
- **Different Patterns of Appropriability:** Intangible digital innovations are akin to public goods with near costless reproduction.

Niche Innovations as Pathways Beyond Catch-Up: This report presents ten case studies of "niche innovations" demonstrating how developing economies can leapfrog legacy systems and pursue a distinct development trajectory. These include:

- Mobile telephony for financial inclusion
- Green industrialisation and renewable energy-driven decentralisation
- Green hydrogen for low-carbon steel
- Smart cities for efficient service delivery
- Smart energy management (ICTs + solar)
- South–South trade enabling labour-intensive technological diffusion
- District heating using renewables and digital controls
- Climate-smart ICTs for agriculture
- Drones and sensor technologies for remote service delivery

These niches illustrate opportunities for productivity improvement, environmental sustainability, and social inclusion.

Policy intervention areas: As the digital paradigm presents both threat and opportunity, policy interventions are essential to foster innovation that supports the broader development of less-developed countries and provides clear directionality toward a more equitable and sustainable future. Key policy areas identified for moving Beyond Catch-Up include:

1. **Prioritising Informal and Urban Clusters:** Shift from a narrow focus on formal sectors toward the needs of the poor and excluded - supporting small-scale, employment-intensive production and deploying digital technologies for livelihoods, not just services.
2. **Meeting the Environmental Challenge:** Use ICTs to support systemic greening across production and consumption cycles, promote circularity, strengthen the WEFE nexus, and expand decentralised renewable energy.

3. **Developing and Deploying ICTs:** Lower connectivity costs, build digital skills (especially among youth), strengthen entrepreneurship (including in the informal sector), and reinforce National Innovation Systems.
4. **Renewable and Distributed Energy:** Accelerate the shift to modular, scalable renewable energy systems to support decentralised, locally oriented industrial activity.
5. **Making the Most of Commodities:** For resource-rich economies, strengthen upstream/downstream linkages, leverage digital technologies to improve extraction and processing efficiency, and expand local value addition.
6. **Expanding South–South Trade and Industrial Collaboration:** Advance regional industrial policies and promote regional value chains that support inclusive, labour-intensive specialisation.
7. **Decentralising Governance:** Empower regional and municipal authorities to design and implement industrial and innovation policies aligned with decentralised digital systems.

Implementation - Managing Paradigm Change: Paradigm change requires a systemic, integrated, contextual, dynamic, and process-oriented approach, a departure from past policies. Successful implementation involves a number of critical steps:

- Establishing a clear vision and leadership at both national and regional levels.
- Developing mission-oriented approaches targeting Grand Challenges (e.g. water–energy–agriculture nexus, industrial greening).
- Marshalling a coalition of the willing across stakeholders,
- Confronting obstacles — structural, institutional, and political.
- Assembling coalitions to pioneer niche innovations and promote wider rollout, and
- Sharing agendas and experience across countries with international support.

A contextual development challenge: Development paths must be context-specific, reflecting each country's social structures, resources, geography, and geopolitical position. There is no universal blueprint. Yet the principles outlined here - and the opportunities presented by digital technologies - provide a foundation for leapfrogging legacy systems and forging a new trajectory. **The challenge is no longer simply "catching up" but transitioning toward a new, inclusive, and sustainable paradigm of industrial development.**

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1. INTRODUCTION

The traditional global growth paradigm is no longer sustainable. The growth model that drove decades of global expansion and poverty reduction cannot continue if development objectives are to be met and the environment safeguarded.

Historical analysis explains why Business as Usual is no longer viable and guides the search for new development trajectories. This Report situates the collapse of the traditional growth model within a historical framework, examining the evolution of frontier and catch-up economies since the Industrial Revolution. This perspective not only clarifies the limits of Business as Usual in industrial development but also informs the policy directions necessary to transition toward a new, dynamic, and inclusive growth path. The challenge for developing economies is no longer simply to emulate leading global economies - including the remarkable progress of East Asia – but to move beyond catch-up toward a development model that is equitable, resilient, and sustainable.

Understanding the historical evolution of industrial systems provides the foundation for UNIDO's Vision 2050 "The Future of Industries for Development". The historical trajectory of industrial production systems frames this background study, as it is essential to understanding how feasible pathways forward for industrial development can be identified. History and theory are central to the analysis, forming the intellectual foundation for the visions and policy recommendations presented in this Report.

This report is structured as follows: After the introduction, section 2 observes the centrality of innovation to economic growth and industrial development, based on a historical analysis of patterns of growth since the Industrial Revolution., Section 3 distinguishes four major types of innovation and explores long waves of revolutionary innovation, or paradigm shifts, essential for understanding the polycrisis currently confronting the global economy. This section also examines the critical role of governments in managing innovation and guiding transitions between paradigms. Section 4, The End of Business as Usual, analyses why the crisis results from the decline of the 20th Century Mass Production paradigm and its social, economic, and environmental consequences. The Report then outlines pathways for developing economies to respond effectively, emphasizing that traditional catch-up strategies are no longer sufficient and a new growth trajectory - Beyond Catch-Up - is required. Section 5, Beyond Business as Usual, introduces the emerging Digital Paradigm and illustrates how its attributes can support more inclusive and sustainable development. Section 6 presents ten case studies demonstrating the practical application of these innovations in diverse contexts. Section 7 identifies policy measures that enable low- and middle-income countries to transform disruption into opportunity, while Section 8 concludes with reflections on leadership and effective policy implementation.

This report combines academic insight with practical experience from across the globe. The analysis draws on literature in industrial and trade policy, economic history, and innovation studies, complemented by practical insights from policy implementation in various countries. Interviews with leading scholars and policymakers from both the Global North and South provide additional depth. Contributors come from multidisciplinary backgrounds including economics, engineering, sociology, politics, and environmental studies — reflecting the Report's focus on the interconnected nature of economy, society, and environment.

2. INNOVATION AND GROWTH

> **Innovation is at the heart of human development**

The Holocene set the stage for human settlement and technological innovation. Approximately 13,000 years ago, the earth's climate warmed and stabilized, marking the beginning of the Holocene epoch. This environmental shift triggered an explosion of ecological diversity, and by around 9,000 BCE, humans began establishing the first permanent settlements. The transition from hunter-gatherer lifestyles to settled, agrarian societies - the neolithic revolution - was enabled by the introduction of food crops - initially in South and North China and in Latin America - and the domestication of cattle in Southeast Asia. These technological innovations spread across communities, allowing settlements to expand geographically and enabling the gradual development of new and improved technologies. For instance, the first wheels appeared in Sumeria around 3,500 BCE, sparking innovations in crop production, transport infrastructure, and pottery manufacturing. Human development has always been closely intertwined with industrial and technological advancement.

The combination of technology, infrastructure, and industry improved human living conditions, though unevenly. New technologies, investments, infrastructure, and the development of industry allowed humans to live longer, more comfortable lives and satisfy a broader range of needs. However, the benefits of innovation were often unequally distributed (Acemoglu and Johnson 2024). While empires rose and fell, the majority of the human population experienced little sustained improvement in living standards until the second half of the 18th century.

The Industrial Revolution transformed living standards and global economic structures. Ten millennia after the first human settlements, the Industrial Revolution decisively changed human development. Beginning in England in the 18th century, it spread to Belgium and France in the early 19th century and then to Germany and the USA in the latter half of the 19th century. By the 20th century, the USA had become the world's dominant economy, while industrial capabilities and per capita incomes expanded rapidly worldwide, particularly in East Asia. As summarized in UNIDO's Vision 2050 (UNIDO 2025a):

> *"Two centuries ago, more than 80% of the global population lived in extreme poverty. In recent decades, this figure has fallen to less than 10%: lifting millions out of poverty and giving rise to a middle class in many low- and middle-income countries. Critical indicators such as life expectancy, education, and per capita income all showed continuous improvement."*

However, these gains are fragile and increasingly under threat. Global crises—including financial shocks, pandemics, armed conflicts, climate change, resource depletion, habitat degradation, and biodiversity loss—have disrupted the trajectory of human development. These crises affect migration, inflation, and social welfare, causing absolute poverty to rise, hunger to surge, and to reverse the decline in inequality which followed the Second World War.

Understanding historical growth patterns helps explain current challenges. How can we make sense of millennia of stagnation, rapid improvements over just three and a half centuries, and the recent degradation of living standards for hundreds of millions?

A key factor in human development is investment. Basic investment is required to maintain and replace worn-out productive assets. But improvements in living standards demand investment in new productive capabilities, which include not only physical capital but also human and organizational capabilities, as well as infrastructure to deliver inputs and outputs efficiently.

Investment drives growth through both extensive and intensive pathways. The link between investment and output growth has two components: extensive growth, which replicates existing technologies ("more of the same"), and intensive growth, which improves the quality or character of productive capabilities ("better than before"). These paths are not mutually exclusive and often occur simultaneously.

> **Economic growth depends on innovation**

Historically, innovation (that is intensive growth) has been the primary driver of economic growth. In some cases, extensive growth has dominated—for example, globally before the Industrial Revolution, in Korea during the 1970s–1990s, and in China until the turn of the millennium. Yet, evidence shows that the primary source of sustained economic growth has been innovation: new products and services, novel production methods, improvements in transport and marketing, and changes in consumption and recycling practices. In the US and European economies catching up after World War II, extensive investments explained less than 20% of total output growth (Abramovitz 1956 and 1993).

To anticipate future challenges, we must understand the complex dynamics of innovation. Since the onset of the Industrial Revolution, innovation - rather than replication alone - has driven improvements in living standards and economic growth. Understanding the determinants, forms, and mechanisms of innovation is therefore essential for foresight and policy design in the face of contemporary and future global challenges.

3. THE DIFFERENT TYPES OF INNOVATION

Innovation can broadly be defined as doing something new and different that improves processes, products or services. Yet the character of innovation varies significantly, and these differences matter greatly for designing effective policy responses to the many crises confronting humanity — especially in low- and middle-income countries. As shown in Figure 1, four main types of innovation can be distinguished (Freeman and Perez 1988): These spheres of innovation are not mutually exclusive; on the contrary, they are interdependent and must be advanced together to achieve sustainable and inclusive development.

FIGURE 1. THE DIFFERENT TYPES OF INNOVATION

TYPES OF INNOVATION	TYPE OF CHANGE	DESCRIPTION	FOCUS
Incremental Innovations	What and how produced	Small marginal technical changes to what and how produced and consumed	Results from structured programmes to meet identified goals
Radical Innovations	What and how produced	Fundamental change in production process but implications limited to a particular sector	Tends to be science and R&D intensive
Systemic Innovations	Production systems	Innovations affecting number of sectors	Widespread general use to some sectors, limited to economic sphere
Revolutionary Disruptive Innovations	Economic and social disruption of entire society	Destroys economic basis of old order, creates new growth surge, affects economic, social, cultural, political and environmental activities	Widespread application, massive productivity increases, major cost reductions, no practical limits to supply

Source: Adapted from Freeman and Perez (1988)

3.1 INCREMENTAL INNOVATIONS

Incremental innovation - small, continuous improvements in products, processes and consumption patterns - is a universal and perennial feature of human production. From humanity's earliest history, small adjustments occurred daily as producers adapted to changing constraints, resource availability, and user preferences. Such incremental improvements are especially vital for firms operating behind the global technological frontier, where learning-by-doing, problem-solving and adaptation are essential for catching up.

The *systemisation* of incremental innovation in modern industries can be traced back to post war Japan during the 1970s, pioneered in what became known as Toyota Production System. A relative newcomer as a global producer in the auto industry, Toyota ran up against quality problems when it first began exporting to the USA in the late 1960s. There was no big jump available which would allow for competitive production of quality cars, so, instead, Toyota began by introducing structured programmes of rapid, sustained and small incremental innovations. Each worker was expected to make suggestions for improvements in process and product. Its workforce contributed more than 2.5m suggestions for improvement in 1985 alone. The critical factor in the contributions made by these minor changes – known as kaizen – is that they did not take place haphazardly and by accident but resulted from structured programmes to meet identified goals.

Toyota's Kaizen model spread rapidly across Japan's automotive, electronics and other industrial sectors, and was later adopted - with varying degrees of success - by major global manufacturing and service firms. China's rise in manufacturing capability has similarly been driven by system-wide commitments to continuous incremental improvement. A recent Financial Times article even attributes the emergence of China's low-cost DeepSeek AI tool in part to structured programmes of continuous, incremental innovation. The rapid enhancement of Chinese industrial competitiveness illustrates the power of kaizen-style approaches for countries seeking to converge toward the global innovation frontier.

3.2 RADICAL INNOVATIONS

Radical innovations involve fundamental changes in industrial processes, but their transformative effects are largely confined to a single sector. The textile and apparel sector - the oldest non-agricultural economic activity and the leading manufacturing sector in the early stages of industrial growth - offers a canonical example. Initially reliant on animal hides, the sector eventually shifted to natural fibres such as hemp and cotton. The industrial revolution globalised textile production, separating fibre cultivation from spinning, weaving and garment-making across countries.

The invention of synthetic fibres profoundly reshaped the structure and geography of the textile and apparel value chain. Rayon, introduced in the 19th century from wood pulp, offered a silk-like product at half the cost. Nylon, developed in the 1930s, and acrylics and polyesters in the 1950s, triggered further transformation. By 2023, cotton accounted for only one-fifth of global fibre use. As another example, nuclear power represents a radical break from hydrocarbon-based electricity, using distinct technologies, firms and value chains.

Radical innovations are typically more science- and R&D-intensive than incremental ones, yet their impacts remain sectorally bounded. While synthetic fibres transformed textiles, and nuclear energy reshaped electricity generation, these changes had little direct transformative effect beyond their respective sectors.

3.3 INNOVATIONS IN SYSTEMS

Systems innovations are radical technologies whose effects spread across multiple sectors, reshaping broad segments of the economy. Plastics exemplify this category. Their versatility - mouldable, extrudable, lightweight, durable, flexible and inexpensive - enabled mass adoption. Global plastics production now exceeds 400 million tonnes annually, and the largest 50 plastics companies collectively generate more than $1 trillion in sales. End uses range from packaging (over one-third) to construction materials, textiles, consumer goods and transport components.

The cross-sectoral diffusion of plastics has fundamentally altered global material consumption patterns. Since their invention in 1839 and widespread industrial use from the late 1930s, plastics have become the most widely used material input; by 2000, global plastic use exceeded aluminium use by more than double (by weight). Plastics thus constitute a systems innovation: a radical technology permeating many sectors, yet still largely economic in scope and not universally transformative across all human activities.

3.4 REVOLUTIONARY INNOVATION

Revolutionary innovations differ from incremental, radical and systems innovations in both scale and scope: they transform all sectors of the economy and fundamentally reshape social, cultural, political and environmental systems.

As far back as 1912, Schumpeter highlighted the manner in which transformative innovations periodically reshape economies and societies far beyond the scope of everyday incremental change. He argued that standing above routine innovation are episodes of major disruption driven by the diffusion of powerful general-purpose technologies (Schumpeter 1912 and 1942). Their spread unleashes “gales of creative destruction”: they render existing technologies obsolete, undermine the viability of established industries and institutions, and sweep away much of the old order. Yet these same disruptive forces simultaneously open vast new opportunities for growth, productivity gains and the emergence of entirely new sectors.

Revolutionary technologies unfold over many decades, progressing through phases of emergence, rapid diffusion and eventual degradation. As these technologies lose dynamism, established routines cease to deliver productivity and social cohesion—business as usual becomes unsustainable. Freeman and Perez (1988) identify four defining characteristics of revolutionary:

- **Widespread application across all economic and social spheres**
- **Decisive cost reductions and major improvements in existing products, as well as new product creation**
- **Rapid and ongoing declines in cost over long periods**
- **No practical limits to supply**

Revolutionary technologies - disruptive in nature as they are - unfold in multi-decade waves that transform economies, societies, and institutions. Typically they last five to eight decades and begin with the invention of a core technology. In the inception phase, the technology is applied in related innovations that reveal its revolutionary potential to transform production and generate new products (Perez 2002).

Once the transformative potential becomes evident, the technology spreads rapidly across all sectors and spheres of society. As adoption accelerates, major gains in productivity and societal change are realised. Eventually, marginal improvements decline, and the wave begins to degrade. At this stage, "Business as Usual" no longer delivers growth or social cohesion. After a period of turbulence, the degraded innovation wave is replaced by a new revolutionary technology. The transition between these epochs is typically disorderly, often accompanied by major financial crises, social upheaval, political instability, and, in some cases, war (Perez 2026).

Each wave establishes dominant social, economic, and institutional norms that define an era. Standard ways of behaving, forms of economic organisation, social structures, and institutional designs emerge and become widely accepted as "common sense." Economic historians refer to these enduring configurations as paradigms, which shape the interaction of nearly all aspects of society during each epoch.

3.5 HISTORICAL PARADIGMS OF REVOLUTIONARY INNOVATION

Since the early 18th century, five major paradigmatic waves have transformed global production, consumption and social organisation. Each involved interconnected changes in industrial processes, market structures, the social division of labour, infrastructure systems and societal norms.

1. **The Waterpower Paradigm (late 18th century, England):** Factory-based production replaced household manufacturing, initially centred on textiles. Canals facilitated the supply of inputs, expanded market reach and deepened specialisation.
2. **The Steam Power Paradigm (from the 1830s):** Coal-fired mechanisation spread across sectors. Railways liberated producers and consumers from geographical constraints, enabled long-distance trade in food and materials, and gave rise to national brands.
3. **The Steel, Heavy Engineering and Telegraphy Paradigm (from the 1870s):** Large corporations and monopolies began to dominate. Steel underpinned global transport and migration, while telegraphy enabled cross-continental coordination. Industrialisation spread to the USA and global economic integration intensified through colonialism and imperialism.
4. **The Mass Production Paradigm (early 20th century, USA):** Large-scale factories, vertically integrated corporations and mass unionisation defined this era. Cheap oil enabled global production systems, suburbanization and new consumer lifestyles. Plastics, chemicals and pharmaceuticals expanded rapidly, while labour-saving household appliances transformed domestic life and facilitated women's entry into paid employment. Though the paradigm's dynamism waned by the 1970s, global value chains extended its life by integrating hundreds of millions of workers in low- and middle-income countries.
5. **The Digital Paradigm (late 20th century to present):** Information and Communication Technologies (ICTs) revolutionise productivity, create entirely new products and services, and enable the coordination of complex global information, production and logistics networks. Digital technologies also increase flexibility and reduce labour requirements, reshaping the geography of production and bringing production and consumption closer together.

Each paradigm wave is accompanied by profound social, institutional and environmental transformations that reshape how economies and societies are organised (see Figure 2). In the first wave (waterpower), production was concentrated in small firms relying on local capital and serving nearby markets in relatively small towns. The second wave (steam power) enabled the emergence of much larger firms, supported by innovations in legal structures - such as limited liability and joint-stock companies - that encouraged risk-taking and capital mobilisation. Railroads catalysed the growth of larger towns and more dispersed industrial settlements, as production and consumption no longer needed to cluster around waterways.

FIGURE 2. SOCIO-ECONOMIC PARADIGMS IN HISTORICAL PERSPECTIVE

PARADIGM	ECONOMIC DRIVER	IMPACT ECONOMY	SOCIAL LIFE
Industrial Revolution	Waterpower Canals	Small firms, extended local market reach, deepened social division of labour	Growth of small towns
Steam and Railways	Coal fired steam power	Steam driven machinery, growth of coal and iron industries, great port cities, extension of domestic markets across local boundaries	Growth of large urban areas & consumer markets, movement of people across national borders
Steel, Heavy Engineering	Coal fired electricity	Great railways, mechanised production, steel steam ships, electrical equipment, chemical industries, telegraphs, market extension across national border	Science in production, industrial cities, new industry elites/working class, large corporations, mass migrations, colonialism, paper & packaging, canned/bottled food
Mass Production	Oil power, internal combustion engine	Vertically integrated corporations, product & process standardisation, large factories, continental markets, mass production of goods, long distance communications & transport, plastics industries, GVCs, global dispersion of production	Automobiles, mass transport, suburbanisation, mass consumer goods, revolutionised domestic work, mass connectivity (wireless & telephone), welfarism, global income rises, global economic integration
Digital Paradigm	ICTs	Computer based production & consumption, information and telecommunication spread	Wholly new products and services, flexibility & integration of production & consumption, high speed mass transport

Source: The Authors

In the third wave (heavy engineering, steel and telegraphy), very large corporations and monopolies came to dominate production and exert growing influence over political power. Ownership separated from management, and specialised managerial hierarchies emerged. Towns expanded into major industrial cities marked by widespread poverty and the rise of an organised working class. Critically, economic dynamism and urban growth became globalised: colonialism and imperialism restructured economies across Asia, Africa and South America, supplying raw materials to industrial powers and serving as markets for their final goods.

The fourth wave (Mass Production) in the twentieth century saw the rise of large-scale manufacturing, vertically integrated corporations and globally expanding foreign direct investment. Living standards increased for millions, and new lifestyles - mass consumption, urbanisation and suburbanization - took hold. Social norms shifted in what has been described as an era of "possessive individualism (Macpherson, C.B. 1962). Importantly, in its later phase, the Mass Production paradigm expanded through global value chains (GVCs), integrating hundreds of millions of people in low- and middle-income countries into global manufacturing. This not only raised living standards, but also transformed social relations, especially for many women employed in export-oriented factories.

3.6 THE ROLE OF GOVERNMENT IN PARADIGM INCEPTION AND DEPLOYMENT

Governments play a foundational role in both the inception and deployment of new technological paradigms. In the inception phase, the state creates the conditions for breakthrough innovation by building robust national innovation systems and providing sustained support for research and development, which is increasingly necessary as technologies become more complex and science intensive. Historical experience illustrates this role clearly: the US government, notably through the Department of Defense, was instrumental in developing core digital technologies, while China has, over the past two decades, systematically strengthened its science and technology base through a mix of industrial and trade policies, domestic standards, and large investments in higher education, with particular emphasis on ICT and renewable energy as engines of future growth.

The role of government expands further during the deployment phase, when the state must not only support adoption but also prevent incumbent firms and institutions associated with the previous paradigm from obstructing diffusion. This tension is evident in sectors such as energy, where fossil fuel incumbents resist the transition to renewables, and in areas like healthcare and public administration, where institutional designs inherited from the mass-production era constrain the transformative potential of AI. At the same time, governments face the challenge of regulating emerging technologies in ways that protect society without stifling innovation, especially in domains such as social media where risks and benefits are closely intertwined.

Providing clear directionality to the new paradigm is particularly critical for low- and middle-income countries and involves three key governmental roles. First, when existing development models become unsustainable, governments must articulate a credible vision and create enabling conditions for paradigm-wide change, as exemplified by the New Deal in the United States, China's proactive ICT strategy, Rwanda's promotion of knowledge-intensive digital services, and Costa Rica's transition toward a carbon-neutral economy. Second, the scale and externalities of the digital paradigm require international cooperation, as challenges such as climate change, social media governance, digital infrastructure, and global tax avoidance cannot be addressed through national policies alone. Third, governments must manage the balance between production and consumption to maintain macroeconomic stability, ensuring that labour-saving innovation is matched by sufficient purchasing power through rising wages, lower prices, or targeted demand-shaping policies, so that the digital transformation supports inclusive and sustainable development.

4. THE END OF BUSINESS AS USUAL

The exhaustion of the Mass Production paradigm has brought an end to Business as Usual. During the 20th century - particularly in the two decades following the Second World War - Mass Production generated unprecedented improvements in global living standards. Yet, as with the Belle Époque in late-19th-century Europe, every technological paradigm eventually degrades and loses its dynamism. When this occurs, economies enter a phase of systemic instability that persists until a new paradigm is successfully deployed, enabling a renewed era of growth and prosperity. The world is currently undergoing such a transition. This shift not only marks the end of Business as Usual but also presents low- and middle-income countries with a critical opportunity to adopt a different and more sustainable growth trajectory.

4.1 MASS PRODUCTION FRACTURES

Mass Production rapidly transformed industrial organisation worldwide. Mass production as a form of productive organisation was invented by Henry Ford in 1908. Once the benefits of this production organisational system became apparent, mass production diffused rapidly to other auto manufacturers and then began to spread to other sectors. Although productivity gains were already apparent in the 1920s and 1930s, the extraordinary scale of these gains became dramatically visible in the wartime factories of the 1940s, which demonstrated the full potential of tightly organised, standardised production systems.

Mass production was accompanied by sweeping structural changes in social organisation and the expansion of mass consumption. The significance of Ford's innovation extended far beyond the factory floor. A collapse in demand had contributed to the Great Depression, and while Roosevelt's New Deal helped revive confidence, it was the demands of the wartime economy (1939–1945) that fully consolidated the dominance of mass production in the United States and later Europe. After 1945, consumption surged through a massive housing boom, large infrastructure investments to support personalised automobilization, and the growth of the advertising industry promoting televisions and a range of labour-saving household appliances. In Europe—more so than in the US—the expansion of the welfare state further bolstered mass consumption.

As mass production diffused, it reshaped economic, social, and political structures in profound ways. What began as a technical innovation in a single firm evolved into a paradigm that reoriented lifestyles, consumption patterns, labour markets, urban planning, and even public administration. Governments themselves adopted Fordist organisational principles—emphasising scale, hierarchy, and uniform service delivery. Like all paradigms since the Industrial Revolution, mass production co-evolved with characteristic consumption patterns and ways of life. Figure 3 illustrates how lifestyles during the deployment of the mass production paradigm contrasted sharply with those of the preceding era. As discussed later in this Report, low- and middle-income economies transitioning to the Digital Paradigm will likewise need to adopt new consumption patterns and lifestyles; technological adoption alone will not be sufficient.

FIGURE 3. PARADIGM CHANGES IN LIFESTYLES: MASS PRODUCTION AND EMERGENCE OF THE 'AMERICAN WAY OF LIFE'

AS A PARADIGM SHIFT FROM THE 1910s	...	CONSOLIDATED AS A "LIFESTYLE" AFTER WWII
Energy is expensive, often inaccessible	→	Energy is cheap with unlimited availability. Energy-intensive homes & mobility.
Trains, horses, carriages, stagecoaches, tramways, ships, bicycles	→	Automobiles, buses, trucks, planes, motorcycles
Local newspapers, posters, theatres, parties	→	Mass media, radio, movies, television
Ice boxes, coal stoves	→	Refrigerators and central heating
Doing housework by hand	→	Doing housework with electrical equipment
Natural materials (cotton, wool, leather, silk)	→	Synthetic materials
Paper, cardboard, wood & glass packaging	→	Preference for disposable plastics of all sorts
Fresh food bought daily from specialised suppliers	→	Refrigerated, frozen or preserved food bought periodically in supermarkets
Urban or country living and working	→	Suburban living separate from work

Source: C. Perez, personal communication

The deployment of Mass Production generated unprecedented economic progress during the post-war Golden Age. Between 1950 and 1975, rates of economic growth in high-income countries were historically unmatched, and these gains also spread—though unevenly—to the developing world. Yet by the early 1970s this long expansion began to slow. Between 1961 and 1973, the US economy grew annually by 4.6 per cent and Europe by 5 per cent; afterwards growth fell to around 3 per cent and declined further to roughly 1 per cent between 2006 and 2017 (Kaplinsky 2021).

A critical factor underlying this falling rate of economic growth was a prolonged decline in productivity growth. Except for a temporary IT-led surge in the United States (1997–2006), labour productivity growth fell steadily across high-income economies after the early 1970s. The drivers included diminishing marginal gains from extending mass production techniques, the growing share of services - where mechanisation is more difficult - and increased bargaining power of large trade unions. Declining productivity depressed corporate profitability (Kaplinsky 2021), which in turn reduced investment - further reinforcing the slowdown.

As profitability fell, firms sought a new route to competitiveness by exploiting low-cost labour in developing economies. Many developing countries had abundant labour supplies, and following decolonisation, state investments had expanded access to education, creating a growing pool of semi-skilled and skilled workers. Large firms thus began relocating production to lower-cost locations to sustain profitability within the mass production paradigm.

The emergence of global value chains (GVCs) enabled the global dispersion of production on an unprecedented scale. Rising production volumes, the growing importance of knowledge-intensive activities, and expanding marketing requirements pushed corporations to internationalise their operations - not only into other high-income countries but deeply into the developing world. Through GVCs, countries such as China became offshore export platforms and major suppliers of intermediate and final goods for lead firms in advanced economies. As these firms pursued ever-lower production costs, GVCs spread unevenly across Asia and selected developing regions.

> **Global Value Chains led to the global dispersion of production extending the life of the Mass Production Paradigm and leading to economic growth and higher living standards for some export oriented developing countries.**

GVCs fundamentally reshaped the global economic order. Where once competitive manufacturing was concentrated in industrialised economies, the new international division of labour enabled extensive production in the developing world. Meanwhile, consumption remained concentrated in high-income countries. This deep form of globalisation was embedded in a new rules-based governance system - the Washington Consensus - which promoted free trade, liberalisation, and the global integration of markets.

A limited number of Asian economies achieved extraordinary growth by integrating into GVCs. Beginning with the Asian Tigers (Hong Kong, Korea, Singapore and Taiwan) and accelerating with China, these countries experienced rapid export-led growth and historic improvements in living standards. Although inequality rose within China, the sheer scale of income gains meant that global inequality — measured across the world's population — declined significantly, as did global poverty, largely due to China's size. Outside this East Asian growth pole, however, the impact on living standards and poverty reduction was more limited.

A spectacular improvement in living standards in China and other east Asian economies played a determining role in growth, industrial and trade policy globally. These achievements in Asia - rooted in long-term, evidence-based strategies and continual upgrading into new sectors such as industrial automation - became a model for low- and middle-income economies and for international institutions supporting the MDGs and later the SDGs. By the end of the 20th century, the dominant orthodoxy was clear: liberalise, open up, and participate in global trade to benefit from specialisation.

Yet by the early 2000s, the foundations of this extended Mass Production paradigm were already eroding. Multiple pressures - culminating in the 2008–09 Global Financial Crisis - exposed deep structural weaknesses. The COVID-19 pandemic further highlighted the fragility of long supply chains. GVC expansion slowed and then began to retreat. Rising unemployment, stagnant wages, and increased migration contributed to the rise of populist, anti-immigration, and protectionist political forces. Geopolitical shifts, especially during the first and now the second Trump administration, have fundamentally disrupted the world economy and its systems of global governance.

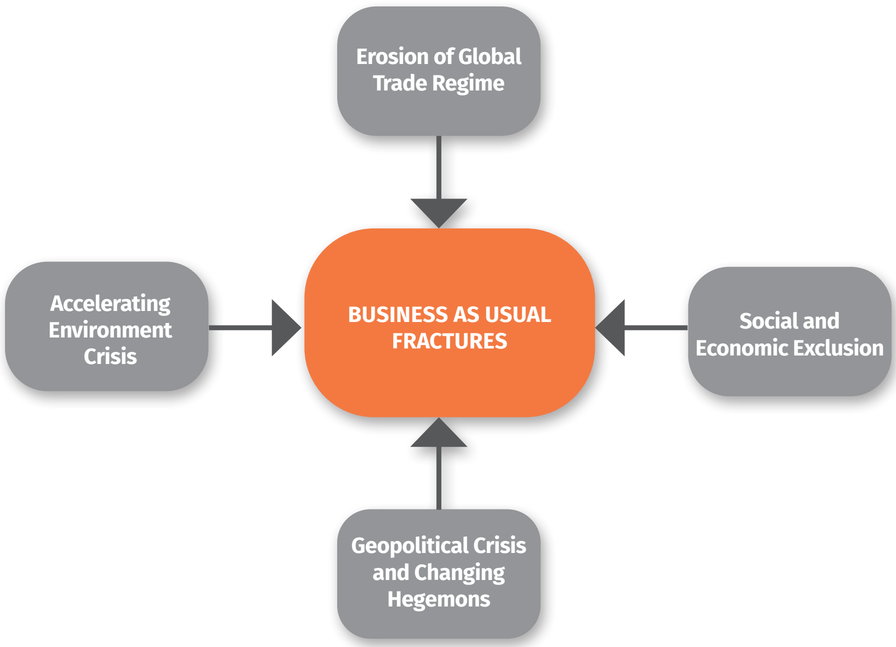
The result is a world in profound transition where Business as Usual is no longer viable. The fractures in the Mass Production paradigm, combined with geopolitical realignments and social tensions, underscore the urgent need for a more equitable world economy.

> **Deep globalisation stutters, GVC share of global trade hit barriers, mass production starts to decay, protectionism reappears, and increasing global disruption pervades.**

Four major sets of disruption affect low- and middle-income economies and determine the policy options open to generate equitable and sustainable development (Figure 4).

- Changes in the global trade regime and the erosion of rules based global governance
- The systemic prevalence of economic and social exclusion
- The rapidly accelerating environmental crisis and degradation as well as depletion of natural resources
- Geopolitical changes and the rise of new hegemons

FIGURE 4. FORCES OF DISRUPTION FRACTURING BUSINESS AS USUAL



Source: The authors

4.2 CHANGES IN THE GLOBAL TRADE REGIME AND EROSION OF RULES-BASED GLOBAL GOVERNANCE

GVCs were the primary vehicle for the deep globalisation in industry after the early 1980s. The impetus to outsourcing in the manufacturing sector followed from the adoption of core competence strategies in the corporate sector (Kaplinsky 2005). Firms focused on capabilities which were difficult to copy and outsourced those which were devoid of rents. Outsourcing first occurred locally - most notably in Toyota City - but as logistics, containerisation, and trade facilitation improved, it rapidly internationalised. Production was initially relocated to the four Asian Tigers and, from the mid-1980s, increasingly to China and subsequently to peripheral economies in Asia and Latin America, including Vietnam, Bangladesh, Indonesia, Mexico, Colombia, Costa Rica, and Honduras.

The first steps in global outsourcing were initiated by the US retail chains which became increasingly concentrated and dominated by a small number of large retailers. Faced with growing competition, and selling at scale, these retailers cultivated suppliers in the Asian Tigers and later Asian and Latin periphery countries as a source of low cost and large volume production (Hamilton and Gereffi 2009). This established a global outsourcing structure which fed into the emerging core competence revolution in manufacturing and services. Thus, the growth of global supply chains across the spectrum of traded goods and services was initiated at the consumption end of the value chain. (As we will see below, particularly in low- and middle-income countries the role played by demand and consumption in promoting supply has been under-recognised in policy formation).

The expansion of GVCs was enabled by a systemic shift in global economic governance and institutions. The maturation of the mass production paradigm and slowing productivity growth drove outsourcing, while multilateral trade rules under the GATT and WTO, liberalisation promoted through the Washington Consensus, harmonised standards, and investments in trade infrastructure created the conditions for global production fragmentation. These changes were reinforced by shifting values and consumption patterns away from “buy local” toward ”buy the best international brand.”

> Deep globalisation driven by outsourcing, global dispersion of production to low-cost economies and harmonisation of standards required a rules-based global regulatory framework. However, this rule- based trading system is now in crisis.

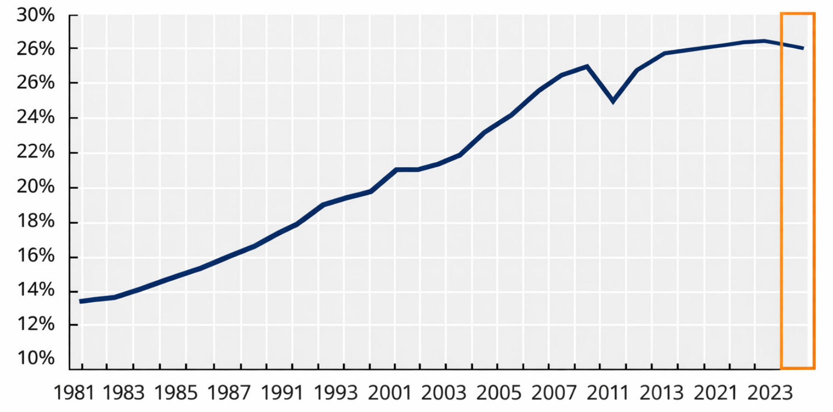
Rapid GVC expansion led to a centrifugal global division of labour separating production and consumption across borders. Fragmentation first transformed manufacturing and later services, geographically distancing production from final markets in ways that mirrored earlier intra-national patterns of suburbanization and spatial separation of work and residence.

For some developing economies - particularly in East Asia – GVC integration delivered export-led growth and technological upgrading. Between 1995 and 2022, developing economies’ share of global trade rose from 21 to 38 per cent, alongside rising technological intensity of exports (WTO 2024). Significantly, the dynamism of these successful Asian exporting economies was reflected in an increasing technological intensity in their exports (UNIDO 2016). Starting with low value-added assembly, several economies built capabilities in high-technology goods and services, enabling firms such as Samsung and BYD to emerge as global leaders.

GVC-driven globalisation also generated large trade imbalances and social dislocation in high-and low-income economies. Major high-income economies—particularly the United States and the United Kingdom—accumulated persistent and widening trade deficits, mirrored by large surpluses in export-oriented Asian economies and in high-income exporters such as Japan and Germany. Across much of the advanced industrial world, this contributed to labour displacement, rising structural unemployment, and growing poverty. Previously prosperous industrial regions degenerated into "rust belts," while consumption in deficit economies was increasingly sustained through rising household, corporate, and sovereign indebtedness. Political opposition to trade openness intensified, and the combination of frictionless trade and rules-based governance came under sustained challenge. Slogans such as "buy local," "Make America Great Again," and renewed emphasis on "industrial policy" came to dominate public discourse. Simultaneously, technological change—particularly robotization—began to erode the low-wage advantage of labour-abundant developing economies. These dynamics underscore the systemic and mutually reinforcing nature of change across trade regimes, innovation trajectories, value systems, and industrial geography.

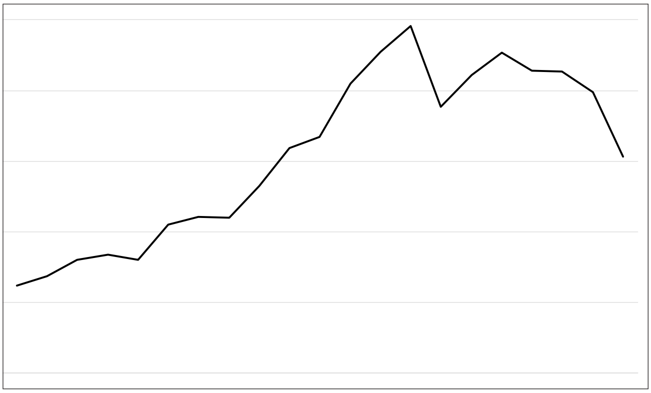
These cumulative pressures contributed to a structural slowdown in globalisation after the 2008 financial crisis. After decades of steady growth, the ratio of global trade to GDP stabilised after 2008 (Figure 5). This slowdown in trade intensity was reflected in the decline in the GVC intensity of global trade. After two decades of rapid GVC deepening, the share of GVCs in global trade peaked in 2008 at 52 per cent. By 2014 the share had fallen to 48 per cent (Figure 6).

FIGURE 5: RATIO OF GLOBAL EXPORTS TO GDP (%)



Source: OECD (2024)

FIGURE 6: SHARE OF GVCS IN GLOBAL TRADE (%)



Source: Calculated from World Bank (2020)

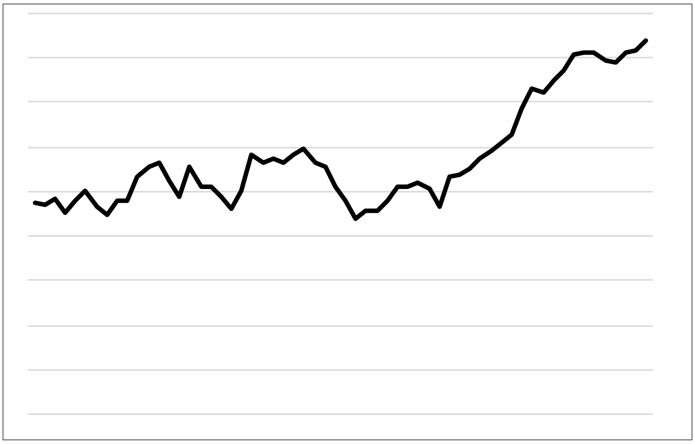
Rising protectionism and geopolitical tensions are reshaping the global trade environment. As of early 2025, protectionist pressures – particularly in leading economies – are intensifying, raising the risk of fragmentation into rival trade blocs, potentially centred on US–China rivalry, with severe implications for global growth and governance. There is much uncertainty about the shape of the growth of protectionism but as two prominent trade economists (Goldberg and Reed 2023) observe, [it is possible that] *'the world will end up fragmented in rival camps and that a new cold war will unfold, this time between the US and China (and their respective allies). The consequences of the latter scenario could be severe.*

What does this evolving landscape imply for low-income, East Asian-style export-oriented growth strategies? One possibility is partial reshoring of production to advanced economies, accompanied by the domestication of new manufacturing activities using highly skilled, knowledge-intensive, and digitised technologies. These processes reduce reliance on low-cost labour, undermining the traditional rationale for offshoring. A second trajectory involves a shift from dispersed global outsourcing towards nearshoring, reflecting heightened concerns over supply-chain vulnerability, as starkly revealed by the 2021 Suez Canal blockage and attacks on shipping routes. Rising transport costs and environmental externalities further weaken the viability of geographically extended GVCs. Nearshoring, in turn, is closely associated with regionalisation and the growth of regional value chains. Finally, intensifying geopolitical tensions suggest that "friendshoring" may increasingly shape the geography of global production and trade.

> **GVCs will not vanish but there will be a trend towards reshoring, nearsourcing and friendsourcing and domestication of supply.**

Amid uncertainty regarding the future structure of global production and trade, two under-analysed trends warrant attention. First, the share of South–South trade in global trade increased threefold, from 8 per cent in 1995 to 25 per cent in 2024 (WTO 2024).Second, intra-regional trade expanded more rapidly than total global trade. This trend was especially pronounced in low- and middle-income economies, where intra-regional trade rose from less than 25 per cent of total trade in 2000 to over 40 per cent by 2017 (Figure 7).

FIGURE 7: SHARE OF INTRA-REGIONAL TRADE (%), EMERGING AND DEVELOPING ECONOMIES, 1960-2017



Source: World Bank (2020)

Part of the expansion in intra-regional trade reflects the growth of regional value chains, particularly in East Asia. As wages rose in China and expectations of protectionism increased, Chinese firms progressively outsourced labour-intensive assembly activities to neighbouring economies. This regionalisation is evident in Southeast Asia's trade patterns, with China emerging as the region's largest trading partner in 2021, accounting for 17.6 per cent of regional exports and 25.4 per cent of imports.

However, the rise in intra-regional trade in the developing world extends beyond China-centred reconfiguration. There has also been significant growth in trade oriented towards developing-country final markets. In Africa, the African Continental Free Trade Agreement (AfCFTA), signed in 2021, reflects growing recognition of the regional market as a key driver of future trade expansion. Progress has however been slow and there is as little sign that of an increase in intra-African trade.

Looking ahead, nine interrelated factors will shape the contribution of external trade to equitable and sustainable development in low- and middle-income economies:

- Trade growth is fundamentally demand-led; supply responds to market opportunities.
- The rules-based global trade order is now under strain, with access to the world's largest market - the United States - becoming increasingly restricted.
- Chinese exports previously destined for the US market are likely to be redirected elsewhere, posing both competitive threats and opportunities for developing economies.
- Large multinational firms are increasingly reshoring, nearshoring, and friendshoring their supply chains.
- Despite these shifts, scope remains for South–North manufactured exports, albeit at more modest growth rates than those observed after 1985.

- Recent decades have seen disproportionate growth in exports from low- and middle-income economies.
- Intra-regional trade among developing economies has expanded particularly rapidly.
- Future trade may increasingly occur within preferential trade blocs, although their ultimate configuration remains uncertain.

In this context, a "business as usual" approach to trade policy is no longer viable.

4.3 ECONOMIC AND SOCIAL EXCLUSION – MANUFACTURING CAN CREATE JOBS BUT OFTEN DOESN'T!

Aggregate global development indicators improved markedly between 1990 and 2020, reflecting substantial progress under the MDGs and SDGs. The World Bank reports that per capita incomes rose across many economies, and the share of the global population living in extreme poverty declined sharply from 38 per cent in 1990 to 8.7 per cent in 2018 (World Bank 2018). Other dimensions of welfare also improved, including access to basic services such as water and energy, increased participation of women in paid employment, and major health gains, notably reductions in infant mortality and the incidence of diseases such as polio and malaria.

Behind these positive aggregates, however, lie uneven and fragile development outcomes. A large share of progress was concentrated in China and the wider East Asian region, while advances elsewhere were more limited. Poverty reduction was highly uneven within and across countries, genders, and age cohorts, and rising income inequality—arguably a negative public good—became increasingly evident, including in China. In addition, conflict, insecurity, and climate-related shocks have eroded many of the gains captured in aggregate indicators.

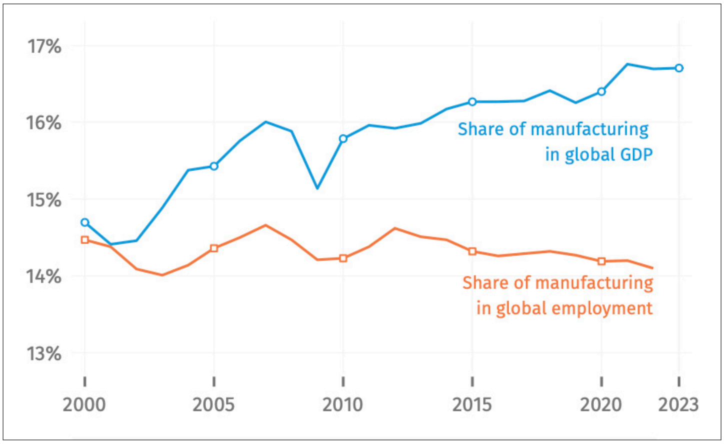
Recent global shocks have reversed or stalled earlier development progress. The aftereffects of the COVID-19 pandemic, the slowdown of the Mass Production paradigm, and uneven global growth have halted poverty reduction and, in some cases, reversed it. Absolute poverty has increased, with around 700 million people living in extreme poverty; global hunger is rising; 760 million people lack access to electricity and 2 billion lack clean drinking water (UNIDO 2025b). If current trends persist, the number of malnourished people could exceed 230 million by 2050, particularly in Sub-Saharan Africa and Central and Southern Asia. Importantly, poverty, homelessness, and precarity are no longer confined to developing economies, as declining life expectancy and rising social pathologies are now evident in some high-income countries.

Industrialisation — particularly manufacturing — has historically been central to income growth and poverty reduction. The rapid rise in living standards in China and neighbouring East Asian economies during deep globalisation mirrored earlier experiences in Europe and the United States, where manufacturing expansion generated employment and incomes. Conversely, declining manufacturing employment in advanced economies contributed to falling incomes and growing precarity, partly linked to the export success of China and a small number of emerging economies. Developmental welfare has therefore been closely tied to manufacturing employment in both the Global North and South.

This historical relationship between manufacturing growth and job creation has weakened significantly. Over the past two decades, the employment intensity of global manufacturing growth has declined (Figure 8), and in many countries manufacturing employment has fallen. Part of this reflects statistical reclassification driven by GVC fragmentation, as firms outsource design, coordination, and marketing to specialised service providers. However, the erosion of manufacturing employment extends well beyond these structural shifts.

> Manufacturing played a critical role in employment for development, but its employment intensity is declining.

FIGURE 8: SHARE OF MANUFACTURING IN GLOBAL GDP AND EMPLOYMENT



Source: UNIDO (2024)

Labour-saving technological change is likely to further reduce manufacturing employment in advanced economies. The diffusion of digital automation, robotics, and AI will exacerbate job displacement, even as it supports productivity growth in ageing societies facing labour scarcity. These dynamics pose major challenges for reskilling and structural transformation but may nonetheless underpin sustainable growth in high-income contexts.

> Industrialised countries seek AI for labour saving innovation. The developing world with high levels of unemployment needs AI to create employment Industrialised countries seek AI for labour saving innovation. The developing world with high levels of unemployment needs AI to create employment.

Developing economies face a fundamentally different employment challenge. They must pursue labour-intensive industrialisation to absorb large pools of underemployment—especially among youth—and manage rapid urbanisation. At the same time, productivity-enhancing digital technologies must be deployed through complementary relationships between newly skilled workers and AI platforms, rather than through labour-displacing automation alone.

The declining employment intensity of manufacturing is compounded by the restructuring of global value chains. Unlike advanced economies seeking to revive historically high levels of industrial employment, low- and middle-income countries must create manufacturing jobs from a limited industrial base. Moreover, China's export-led growth model—enabled by post-1970s outsourcing, open markets, and labour-intensive production—is increasingly difficult to replicate due to rising protectionism, reshoring, and advances in automated manufacturing.

Insufficient job creation in manufacturing has fuelled the rapid expansion of informal employment. The failure of formal industry to absorb growing urban labour forces has driven workers into unregulated and insecure forms of employment, loosely termed the informal sector. While a small fraction of informal activities yields high incomes, most informal livelihoods are low-paid, unstable, and lack social protection.

> The 'informal sector' has grown alarmingly particularly in the developing world but also in industrial economies, generating low and precarious livelihoods.

Informal employment now dominates non-agricultural labour markets in much of the developing world. As shown in Figure 9, more than half of workers outside agriculture in developing economies are informally employed, rising to aroaund 75 per cent in Sub-Saharan Africa and 64 per cent in Southern and South-Eastern Asia. Informalization is no longer confined to poorer economies; hidden unemployment and precarious work are increasingly prevalent in advanced economies as well.

FIGURE 9: SHARE OF THE INFORMAL ECONOMY IN NON-AGRICULTURAL EMPLOYMENT (MOST RECENT YEAR, LATER THAN 2012)

	Share of the informal economy in non-agricultural employment
Sub-Saharan Africa	74.5
Western Africa	81.5
Central Africa	78.7
Eastern Africa	71.2
Southern Africa	63.6
Southern & South-Eastern Asia	63.7
Latin America and the Caribbean	54.7
Western Asia	48.8
Northern Africa	48.3
Central Asia	39.1
Transition countries	21.7

Source: Adapted from Charmes (2020)

These trends imply profound constraints on equitable and sustainable development.

Six conclusions follow:

- The employment intensity of manufacturing-led growth has declined sharply.
- Without sustained growth in manufacturing employment, income generation will remain insufficient to support equitable development.
- Weak employment growth undermines fiscal capacity, limiting investments in infrastructure, skills, and climate resilience.
- Digital automation is likely to further reduce labour demand in industry.
- The export-led "Chinese model" is unlikely to be replicable under current global conditions.
- Without substantial improvements in the quantity and quality of informal employment, inclusive income growth will remain elusive.

> **Developing countries dominated by informal economy. Need manufacturing growth to raise employment. But replicating Chinese and Southeast Asian path is difficult in the new global economic order.**

The central conclusion is stark: manufacturing, as currently structured, cannot on its own deliver equitable and sustainable development. Business as Usual is no longer a viable option.

4.4 THE RAPIDLY ACCELERATING ENVIRONMENTAL CRISIS

Human activity under the Mass Production paradigm has sharply intensified environmental impacts since World War II. This period, termed "The Great Acceleration" by climatologists, saw profound pressures on the Earth system. An international team of Earth system scientists identified nine Planetary Boundaries, six of which had already been transgressed by 2023, producing observable climate disruption and rapid changes in ecosystems.

Global warming is a key driver of climate-related risks and disruptions. Even a 1.5°C rise in global temperatures is projected to have major economic and social impacts (Figure 10), while a 2°C increase magnifies these effects and introduces cumulative, self-reinforcing changes. Consequently, delayed corrective action may render some climate and biosphere changes irreversible.

FIGURE 10: PROJECTED IMPACTS OF GLOBAL WARMING AT 1.5°C AND 2°C

Impact	1.5°C	2°C
Extreme Heat – Global population exposed at least once every 5 years	14%	37%
Arctic Ice – Number of ice-free years	1 every 100	1 every 10 years
Sea level rise by 2000	0.4 metres	0.46 metres
Vertebrate species loss	4%	8%
Plant species loss	8%	16%
Area of global land with shift in local ecosystems	7%	13%
Amount of arctic permafrost thaw	4.8m sq kms	6.6m sq kms
Reductions in crop yields in tropics – e.g. maize	3%	7%
Decline in coral reefs	70-90%	99%
Decline in marine fisheries	1.5m tonnes	3m tonnes

Source: IPCC (2019)

The systemic nature of Mass Production has amplified environmental harm. Beyond population growth and rising living standards, its dependence on fossil fuels, disposable consumer goods (notably plastics), individualised consumption, and externalisation of environmental costs has intensified ecological stress. Choices in social organisation and technology—such as car-centric urbanisation—have further entrenched negative environmental outcomes. Each of these adverse drivers of environmental impact reflects a societal choice, as well as the intrinsic character of the technologies central to Mass Production, notably individualised, fossil-fuel automobilization.

> Mass production paradigm has led to environment and climate change crises heavily impacting developing countries.

The unfolding environmental crisis has important implications for low- and middle-income economies. The dependence on hydrocarbons for production and transport has been a direct cause of climate change raising global temperatures and disrupting and creating unpredictable weather and rainfall patterns, as well as the increasing frequency of extreme events (such as flooding, droughts and wildfires). Floods have devastating effects on households, agriculture and the built environment, washing away or damaging crops, key infrastructure (such as roads, bridges, schools, hospital and telecommunication infrastructure), and disrupting service delivery. Although the effects of these adverse climatic events are not confined to low- and middle-income countries (witness the fires in Los Angeles in 2024), in general it is the poorer members of the population who most suffer the consequences because they lack the resources needed to enhance their coping capacities and resilience.

Agriculture and urbanisation are particularly impacted by climate variability. "Climate chaos" has contributed to rural-urban migration, overwhelming city infrastructure in developing countries. Informal settlements dominate urban peripheries, straining water, sanitation, and energy systems, while food insecurity has risen due to the inability of agriculture to meet urban demand.

Resource scarcity is accelerated through the interlinked crises of water, energy, food, and ecosystems (the WEFE nexus). Developing countries can improve resource security by adopting integrated nexus-informed policies, abandoning siloed sectoral approaches, and optimising synergies while minimising trade-offs across sectors.

Migration pressures exacerbate socio-economic challenges in low- and middle-income countries. Rural depopulation drives both internal and international migration, which, in turn, has contributed to rising protectionist pressures in major consuming markets - markets that previously facilitated export-led growth in China and other developing economies.

Hence, climate change undermines equitable and sustainable development through multiple channels.

- It is not solely a consequence of population growth but reflects systemic societal and industrial organisation, particularly features of the Mass Production paradigm.
- It reduces agricultural output, undermining economic growth and national food security.
- It disrupts water availability and flows, critical for agriculture, industry, energy, and livelihoods.
- It increases the frequency and intensity of extreme events, disproportionately harming the poor.
- It contributes to social conflict, economic crises, and mass migrations, which strain urban infrastructure, political stability, and the sustainability of rules-based governance.

In conclusion, climate change represents an urgent, systemic challenge for equity, sustainability, and governance. It underscores that Business as Usual is no longer a viable policy path and demands integrated, urgent, and transformative action across environmental, social, and economic domains.

4.5 GEOPOLITICAL CHANGES AND THE RISE OF NEW HEGEMONS

2025 marks a pivotal inflection in the global economy, reflecting major disruption to the post-war rules-based order. The second Trump administration's retreat from the neoliberal global order established after Bretton Woods evidences the exhaustion of the Mass Production paradigm and foreshadows changes in the conditions shaping global growth.

Hegemonic powers have historically defined global rules and shaped economic development. Each of the four preceding industrial paradigms was dominated by a hegemon. The first three - water, steam, and heavy engineering/steel - were dominated by Britain, especially during the third wave in the late nineteenth century, when English manufacturing demanded raw materials and markets. The Royal Navy policed trade routes, ports were expanded, and the British Empire grew in Africa and Asia, adding 400 million people between 1815 and 1915. Countries were pressured to adopt free trade policies, effectively "kicking away the ladder" of protective industrial development that Britain and other pioneers had used (Chang 2002). This era is known as Pax Britannica.

Britain ceded global hegemony to the United States in the twentieth century. After two decades of protectionism and world wars, the US became the dominant global power, constructing a trading regime to serve the Mass Production paradigm. Early FDI by American firms clashed with import-substituting policies in developing countries, but as US firms outsourced production to low-cost locations, global supply chains expanded. Export-oriented industries grew in selected developing economies—first the Asian Tigers, then China and others—accelerated by neoliberal reforms, the Washington Consensus, and interventions by the IMF, World Bank, and bilateral aid agencies. The nineteenth century saw Pax Britannica, the twentieth century Pax Americana.

> **The USA played the key role in creating the global framework for the spread of GVCs in the era of Deep Globalisation.**

Developing economies were integrated into hegemonic orders as suppliers and low-cost production hubs. During Pax Britannica, they provided raw materials and markets for European manufacturing. Under Pax Americana, some low-income economies—primarily in East Asia, later in Central America and North Africa—became low-labour-cost export platforms within GVCs.

China emerged in the late twentieth century as a new challenger to US hegemony. Its global expansion relied on developing economies in Africa, Asia, and Latin America, initially to secure raw materials. The Belt and Road Initiative improved infrastructure to ship materials to China and open final markets for Chinese exports.

China's growth was driven by state-led industrial policy, investment, and trade management, contrasting sharply with the Washington Consensus. While a formal Beijing Consensus has not been codified, the demonstration effect of China's success legitimised industrial policy and focused protectionism, which has influenced OECD economies as well as low and middle income economies.

Early 2025 geopolitical developments are fluid and disruptive. Interventionist US policies have weakened the rules-based trade regime, disrupted alliances, overturned development cooperation practices, and undermined climate agreements. Rebuilding trust in a global regulatory framework will be more difficult even under a post-Trump administration, reinforcing the fragmentation of the Mass Production paradigm and complicating a return to Business as Usual.

The global economy may be transitioning toward multiple economic and trading blocs. The US may consolidate "friendshoring" economies, Europe may expand influence in Africa, and China strengthens trade across Asia, Africa, and Latin America. The role of other emerging economies such as India, Brazil, Turkey, and Indonesia remains uncertain. Trade patterns are likely to shift from predominantly south-north flows, altering the growth trajectory of low- and middle-income economies, particularly in East Asia.

> **New global players have entered. A new global multipolar order is emerging, with strengthened regionalisation, further fracturing mass production paradigm and making Business as Usual to achieve equitable and sustainable growth less tenable.**

What implications does this changing geopolitical environment from a unipolar to a multipolar world have for the capacity of low- and middle-income economies to pursue equitable and sustainable growth?

- New policy spaces have opened, legitimising a more active role for the state in industrial policy, in trade policy and for state-owned industries
- In many respects, a new powerful hegemon, China, has more relevant experience of industrial and trade policy than the USA and other leading global economies. India's growing presence provides another point of reference and potential source of support for other low- and middle-income economies
- Regionalisation will be strengthened, as existing regional blocs look inwards. Within these regional blocs, 'economic hub' economies such as Nigeria and South Africa in Africa will play an important role in the promotion of intra-regional trade.
- Low- and middle-income countries now operate in a multipolar world, with more bargaining power to achieve assistance and trade concessions from regional hegemons.

The US policy shift in 2025 is thus a major point of disruption. It complements the redirection of trade which we observed earlier and offers new policy space to low- and middle-income countries. With the withdrawal and reduction of aid flows from the US and Europe in 2025, it is another reason by the pursuit of equitable and sustainable growth cannot be achieved by following a Business-as-Usual strategy.

5. BEYOND BUSINESS AS USUAL – TURNING THREAT INTO OPPORTUNITY

2025 marks a pivotal inflection in the global economy, reflecting disruption to the post-war rules-based order. As we observed earlier, each of the long waves is driven by a major general-purpose technology. These revolutionary technologies provide very substantial benefits to innovators; have a trajectory of dramatic falling prices; the expectation that improvements in price and performance will continue in the future; have no supply constraints; and, crucially, have pervasive applications generally throughout the economy and society. In each case, the new revolutionary technology is invented whilst the old wave begins to lose its dynamism. Once its potential becomes recognised the technology diffuses through pioneering firms and sectors. After a period of considerable economic, social and political disruption – which is inevitable given the revolutionary and systemic character of the new wave – the technology is deployed and spreads throughout the system. A period of prosperity follows with the different components – economic, social and political – synergistically reinforcing each other.

The Mass Production wave is now ending. Invented by Henry Ford in the early twentieth century, it emerged in the 1920s, led to a stock market bubble and depression in the 1930s, and matured during and after WWII in the United States and Europe. This Golden Age of growth lasted from 1950 to the mid-1970s, after which globalisation and GVC expansion led to its maturation and gradual atrophy by the end of the century.

The ICT wave now supersedes Mass Production. It is based on four key inventions: the solid-state transistor (1947), the programmable multi-transistor chip (1971), the internet (1990s), and the current artificial intelligence revolution.

Low- and middle-income economies are confronting the disruptive clash of paradigms. Understanding this requires identifying the key elements of ICT technologies and contrasting them with Mass Production (Figure 11).

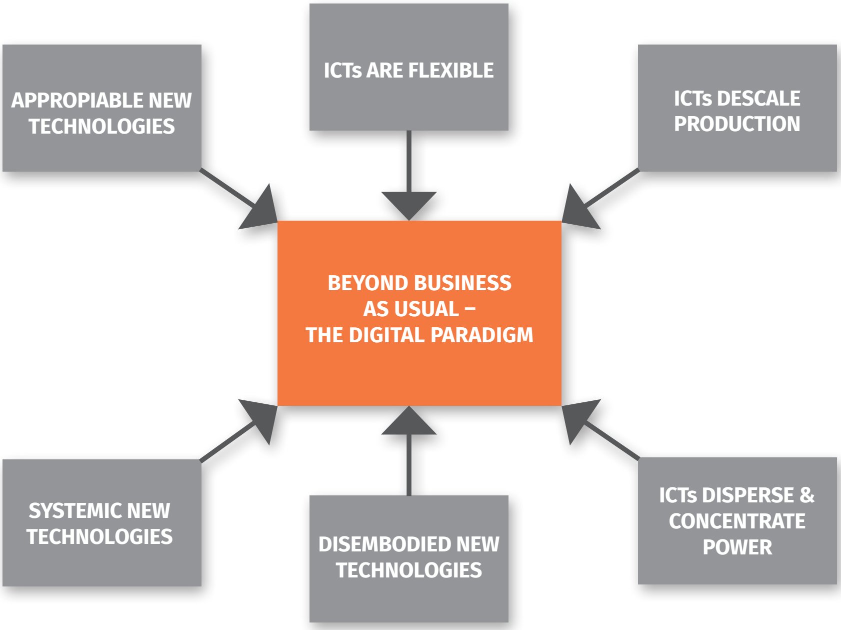
FIGURE 11. THE CONTRAST BETWEEN MASS PRODUCTION AND DIGITAL TECHNOLOGIES

	MASS PRODUCTION PARADIGM		DIGITAL PARADIGM	
CHARACTERISTIC	**DEFINITION**	**EXAMPLES**	**DEFINITION**	**EXAMPLES**
Variety	Standardised products, specialised machinery	Model T Ford Dedicated pick-and-place assembly machines	Differentiated and customised products, Flexible machinery	Made-to-order photo albums Programmable robotic assembly and warehousing
Scale	Large scale Scale as entry barrier Standardised products	Large scale nuclear and hydro energy	Smaller scale plants, modular expansion	Small modular nuclear reactors, SPV and wind renewable energy
Location	Large plants maximising economies of scale Production and consumption separated	Global Value Chains and cities dedicated to production of single sector products	Flexible production reduces geographical distance between production and consumption	Nearshoring regional value chains
Power and control	Central state Taylorist work organisation	Top down ministerial budget allocation Quality control at end of production line	Regional government Worker-oriented continuous improvement	Citizen assembly budget allocation Total Quality Control, kaizen
Hard and soft automation	Knowledge embedded in machine	Fixed line telephony	Reprogrammable products and machinery	Mobile phone updates
Connectivity	Standalone machinery – 'mechanisation'	Individual stamping machines and lathes	Flexible manufacturing systems	Digitally controlled Flexible Manufacturing Systems (FMS)
Appropriation	Patents, replication involves new machinery	Films in cinemas	Copyright Replication costless	Films through streaming

Source: The Authors

Mass Production is in crisis while the Digital Paradigm is deploying rapidly. This transition offers the potential for a new Golden Age, but realization depends on societal and political responses to the possibilities of the Digital Paradigm, particularly in developing countries (Figure 12).

FIGURE 12. BEYOND BUSINESS AS USUAL – THE DIGITAL PARADIGM



Source: The Authors

5.1 ICTs ARE FLEXIBLE

ICTs are inherently flexible, unlike Mass Production's rigid systems. Henry Ford's moving line specialised tasks and products with inflexible machinery, whereas ICT-enabled robotics and reprogrammable machinery can perform multiple tasks and reconfigure products, allowing maintenance, upgrades, and mass customisation.

Additive manufacturing demonstrates extreme flexibility but will be limited in scale. Additive manufacturing (3D printing), which is able to produce one-offs, lies at the extreme end the spectrum of flexibility. However, it is highly unlikely that bespoke production will be widely used across the manufacturing sector. Instead, it will primarily be used to manufacture products required in very small numbers and spares (including replacement 'parts' for the human body!). These products are highly specific, often of high value and may be required at very short notice. But whilst 3D printing shows the extreme potential of flexible production, other ICT based technologies (such as robotization and inventory control) offer an enhanced degree of flexibility – not single unit production or mass production but varying degrees of flexibility across the spectrum of economic and social activity.

Enhanced flexibility supports equitable and sustainable development. It allows innovations to meet diverse user needs and adapt to different productive environments, expanding the developmental potential of ICTs.

5.2 ICTs ARE DESCALING OF PRODUCTION

ICTs reduce the need for large-scale, centralised production. Mass Production relied on inflexible machinery and heavy investments in specialised plants, making economies of scale critical. Factories grew ever larger, and suppliers in the value chain followed suit. At the extreme, very large plants became 'world factories', shipping products globally. For example, in 2020, 5,000 footwear firms in Jinjiang, China, produced 20% of global sports shoes, employing 500,000 workers.

> Descaling production promotes more distributed production, brings production closer to consumption, and lowers entry barriers for SMEs.

Mass Production relied on distant, centralised production and consumption. Large plants served relatively undifferentiated markets, with production in China targeting North America and Europe. Within economies, production, consumption, and residence became dislocated, goods were transported long distances and commuting increased. These centrifugal forces have characterised industrial societies since the Industrial Revolution. The infrastructure required to support these developments transitioned from canals to railways, from railways to bulk carrying steamships, and from steamships to air and containerised shipping. Electricity was generated in large plants, with significant losses during distribution. Massive hydroelectric dams were high-cost and environmentally damaging, while dependence on geographically concentrated fossil fuels required long-distance, polluting transport of coal and oil, further dislocating production and consumption.

The Digital Paradigm enables centripetal, locally concentrated production. Whereas Mass Production involved a centrifugal trajectory (production spreading to the periphery), the Digital Paradigm enables a centripetal trajectory (production located closer to consumption). Staying with the example of power generation, renewable energy technologies (which are centrally dependent on ICT technologies), provide greater scope for bringing production and consumption closer together. Moreover, renewables are also less susceptible to cost over runs and delay and are more scalable. This further facilitates the decentralisation of production and power. Recent heavy investments in small modular nuclear reactors are an indicator of the increasing logic of descaled production.

Descaling production supports equitable and sustainable development. The capacity to descale production has very significant implications for the promotion of more equitable and sustainable development. It provides the capacity for a more distributed productive sector, both within and between countries. It reduces the need for energy intensive transport since production and consumption can be brought closer together. Smaller scale production can also lower barriers to entry for small scale and micro enterprises.

5.3 ICTs BOTH DISPERSE AND CONCENTRATE POWER

Mass Production imposed hierarchical decision-making. Henry Ford drew on the structure of work organisation schema produced by F. W. Taylor which differentiated tasks in production and introduced a hierarchical pattern of specialisation. Decisions were made at the top of the pyramid and passed down – worker autonomy was limited. A similar configuration of top-down authority came to be the dominant pattern in a wide range of social and political institutions. In all these cases, information was fed up the system (often with increasing error as it ascended the decision scale) and instructions were passed down to the operating level. Horizontal flows of information were generally minimised, as was decentralised autonomy in decision making. As in the case of scale, we are observing trends across a spectrum rather than absolute states of behaviour.

ICTs enable more distributed governance and service delivery. Just as the flexibility of the technology enables a greater variety of production processes and products, so too do ICTs provide the potential for more distributed and differentiated forms of governance and service design and delivery. The systemic nature of information capture and communication provides much greater scope for horizontal interactions – not all information and instructions need to be communicated vertically. Moreover, the integrity of information is often more reliable than in paper-based systems and is available in real time. Handheld devices put this information at the disposal of many more people, allowing for decentralised decision-making. Horizontal transmission of information also empowers social interactions, and ICT based social media provide the opportunity and glue for local action.

The Digital Paradigm simultaneously supports decentralisation and concentration. Allthough ICTs disperse power across production and society, reinforcing descaled production and enabling more localised decision-making and governance. At the same time, they enhance capacities for centralised control, evident both socially - through technologies such as CCTV and facial recognition - and economically. Economic power has become increasingly concentrated in the high-tech ICT sector: in the United States, the Magnificent Seven (Apple, Nvidia, Microsoft, Amazon, Alphabet, Meta and Tesla) have captured almost all stock market gains over the past five years and are often accused of acquiring innovative firms to stifle competition. While these mega-firms are currently concentrated in the US, similarly powerful corporations are emerging in China. The transition to the Digital Paradigm therefore combines pressures towards descaling in production and governance with heightened concentration of ownership and political influence, while expanding opportunities for decentralised policies and localised enterprises, such as distributed energy generation at municipal, community, or household levels.

5.4 NEW TECHNOLOGIES ARE INCREASINGLY DISEMBODIED

ICTs differ from previous paradigms by reducing reliance on physical power. Each of the four paradigms preceding the ICT wave increased productivity in manufacturing by substituting inanimate power for human power. Water mills mechanised human-paced weaving; steam power was not just more powerful than waterpower but also allowed mechanisation to be spread away from sources of running water; electricity (from the late 19th Century) meant that individual machines could be mechanised independently. During Mass Production in the 20th Century the generalisation of electric power and the internal combustion engine, allied to changes in the organisation of production, vastly improved manufacturing productivity. This increased productivity and fuelled the growth of industrialisation, leading to the vast improvement in human welfare.

Digital technologies are 'soft' rather than embodied, changing the driver of productivity. In previous paradigms, human skills and hard wired 'baked-in' controls set machinery in motion and guided its progress. But each of these control-mechanisms faced natural constraints – skills could be improved, but only incrementally; machine controls could be improved, but only at the stage of machine construction. The digital revolution has freed production from these constraints and transformed these processes of machine control (Kaplinsky 1984, Kaplinsky 2021). In the extreme form of 'Artificial Intelligence', machine learning algorithms lead to improvements in productivity without any increase in the skills of workers operating the machines, and without the need to stop the machinery and introduce new hard wired control mechanisms.

> **ICTs demand new skills and institutions to take advantage of the new digital opportunities.**

Disembodied technologies reshape skills, wages, and employment. Digital technologies require wholly different skills to embodied technologies, and this characteristically has major impacts on patterns of employment and on relative wages. 'Blue collar' wages have fallen as college-educated 'white collar' salaries have increased; younger workers with digital skills have gained at the expense of older workers; in many cases, a reduction in the need for physical force (electronic typesetting rather than hot metal typesetting) has also allowed for greater participation of women in the labour force.

This transition from hard to soft technology has changed the locus of productivity growth. From the factory floor to the office and from the manufacturing sector to the service sector. It is one of the reasons - but not the only reason - why employment in manufacturing has fallen (coterminous with a non-commensurate increase in employment in the service sector). It is one of the factors which explains the rising power of The Magnificent Seven and other large digital mega corporations. And it is one of the reasons why despite a significant growth in employment in exporting developing economies, the fruits of industrial growth continue to be appropriated by high income countries where the disembodied digital technologies have been developed.

Economies best positioned for equitable and sustainable development are those that have built the skills, institutions, and routines needed to harness the shift from embodied to disembodied technologies. Since many low- and middle-income economies are not saddled with the legacy of skills required to operate the mass production economy, and have a plethora of youth who are more digitally knowledgeable and also lower cost relative to advanced economy workers, in some respects they may be advantaged by the transition to economies which are more reliant on disembodied skills.

5.5 THE NEW TECHNOLOGIES ARE INHERENTLY SYSTEMIC

Digital technologies operate as integrated, systemic platforms. Digital systems enable all data to be recorded and analysed in binary terms. Different digital equipment to speak a common language and communicate with immediacy and accuracy, at very low cost (Kaplinsky 2021).

Systemic gains expanded from machines to entire firms and GVCs. In the manufacturing sector, these systemic gains were initially confined to individual machines (intra-activity digitalisation), then to what is termed 'intra-sphere digitalisation (within design, coordination and manufacture), and ultimately to 'inter-sphere' digitalisation (the integrated firm). Innovations after the 1980s provided the capability to interface digital equipment over very long distances, thereby facilitating the expansion of GVCs (Kaplinsky 2005). It also enabled the outsourcing of knowledge intensive systems from manufacturing to the service sector.

Systemic digitalisation extends to social and governance domains. After the millennium, these systemic gains were no longer confined to production processes but allowed an interface between digitally controlled products as well. The Internet-of-Things (IoT) has come of age, and we can now observe the emergence of an industrial system which integrates conception and design with production, logistics, use and disposal. These interconnected digital systems are not confined to the world of production. They also permeate the social and governance spheres, including in the explosion in social media and horizontal flows of information across society.

Interconnected digitally based systems are omnipresent, including in low- and middle-income countries. As the case studies in Section 6 show they provide the potential to enhance equitable and sustainable growth. But crucially the capacity to reap these gains will depend on the capacity to access the internet. In this respect the rapidly growth of low orbit, satellite internet connectivity provides the potential for a globally connected population. It will be much easier for those living in distant rural areas and nomadic populations to be connected to national, and in some cases global production systems and knowledge bases, and to connect with others with similar interests and to customers. This offers the capacity to reinforce descaled and decentralised production, service provision and general living.

> **"New digital interconnected systems create opportunities to enhance productivity, employment and sustainable and equitable growth."**

5.6 THE NEW TECHNOLOGIES INVOLVE DIFFERENT PATTERNS OF APPROPRIABILITY

Physical innovations are rival and excludable, unlike digital innovations. They are 'private goods' – one person or an operating unit can use it at a time, and (with varying degrees of 'life') these products are used up in consumption. Characteristically they are owned, and their use is restricted. Ownership also extends to intellectual property which is routinely protected through a range of well-developed intellectual property rights such as patents. Replications of the technology are costly; if additional units are required, they need to be physically created.

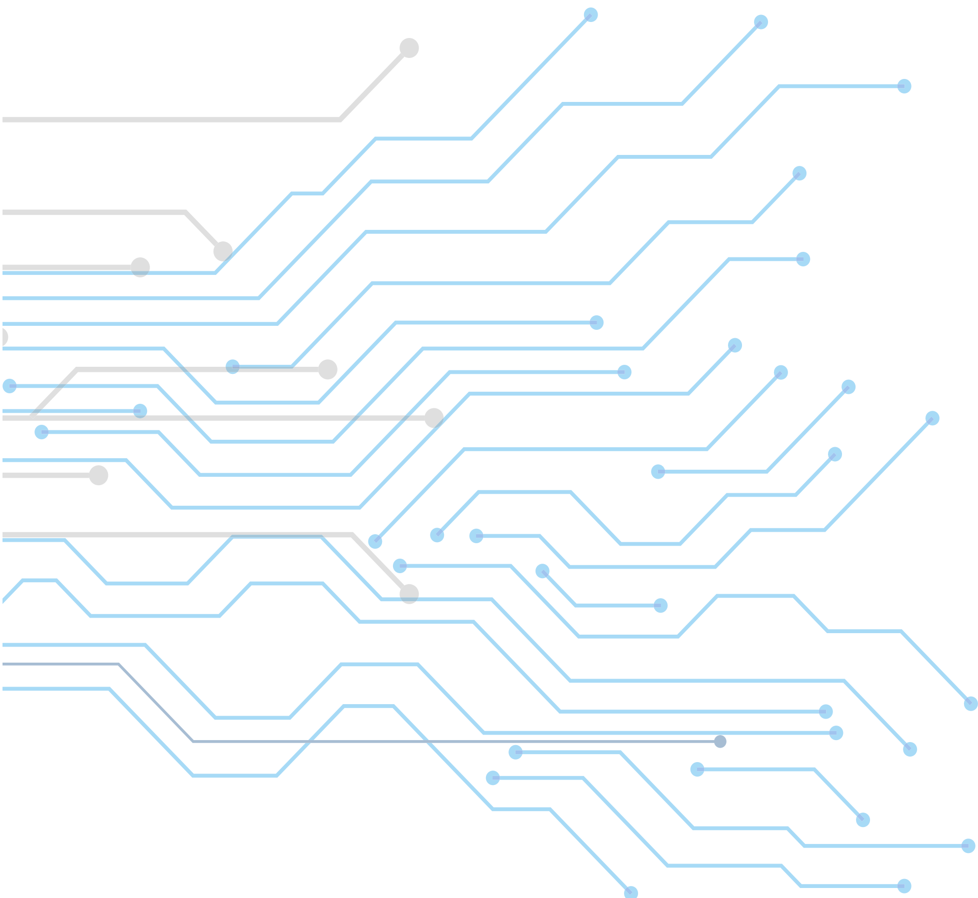
Intangible ICT innovations behave more like public goods. They are not used up in consumption and unlike tangible technologies, the marginal costs of reproduction are often almost costless. Intangible technologies are much more difficult to appropriate. The challenges required to balance the incentive to innovation in knowledge intensive technologies

> **"The new digital technologies create opportunities to expand public goods."**

with the need to protect social interest pose new challenges and are much more complex (Mason 2015). This shows up in the very large profits which have been earned by some high-tech firms such as The Magnificent Seven.

Disembodied technologies present both opportunities and challenges for low- and middle-income economies. One the one hand, the physical barriers to entry are low and disembodied technologies are relatively easily replicated. The absence of traditional skills, honed in decades of manufacturing production, are no longer such a constraint to countries with low levels of industry. But on the other hand, the new ICT based disembodied technologies are increasingly protected by copyright and other forms of IPRs, and the skills-based barriers to entry can often be formidable.

> **"The digital divide must be addressed to provide access for all and achieve equity, employment, economic growth and a sustainable environment."**



6. NICHE INNOVATIONS

Economic historians emphasise the critical role of niche innovations in periods of paradigm transition (Geels 2005). These innovations emerge in specific local contexts, respond to concrete social and economic needs, and exploit the opportunities opened by new general-purpose technologies. They function as experimental spaces in which alternative technological, organisational and institutional configurations can be tested, demonstrated and refined. While often small in scale, niche innovations play an outsized role by signalling future trajectories, shaping expectations, and informing policy and investment decisions. Importantly, they are rarely purely technological: successful niches typically involve complementary changes in behaviour, regulation, organisational forms and patterns of coordination among public and private actors.

The ten niche innovations discussed in this chapter (Figure 13) illustrate how the emerging Digital Paradigm can support more equitable and environmentally sustainable development pathways. Most originate in low- and middle-income economies and, in different ways, rely critically on digital technologies. Collectively, they demonstrate how digitalisation can enable decentralisation, inclusion, resource efficiency and resilience, while also highlighting the institutional and policy conditions required for scaling. Each case is presented using a common analytical structure to facilitate comparison.

FIGURE 13. SUMMARY OF TEN NICHE INNOVATIONS IN RELATION TO THE DIGITAL PARADIGM

NICHE INNOVATION	DESCRIPTION - MEANING FOR DIGITAL PARADIGM	KEY MESSAGES	DIGITAL PARADIGM PRINCIPLES
Mobile Telephony	Low cost distributed access to finance for poor, lower income, women, rural households, distant regions. Linked to low cost solar energy. Supported by government and banks. Raised employment and entrepreneurship. Broadens access to education and training. Allowed escape from bureaucratic administrative procedures	▸ Driven inclusiveness ▸ Public/private support key ▸ Widened digital spread ▸ Raised education/skills ▸ Productivity gains facilitated	▸ Flexibility ▸ Descaling ▸ Dispersion ▸ Disembodied ▸ Systemic ▸ Appropriation
Green Industrialisation	Showed green investment innovations can synchronise with economic growth/profitability. Can retrofit green investment/innovations. Government support in three industrial zones in Tunisia to integrate resource efficiency and adopt global environmental management standards. In an Ethiopian industrial park green policy across value chain led to increased growth and exports.	▸ Private sector engagement critical ▸ Environmental investments yielded economic benefits ▸ State support through green industrial policy was key	▸ Descaling ▸ Dispersion ▸ Systemic
Solar Renewable Energy growth	Illustrates exponential global growth of solar renewable energy (RE) generation and battery storage. Shows benefits of disruptive shift towards decentralised energy and breakup of centralised electricity generation monopolies. Growth is in both advanced and developing economies. Scale increases in market demand creates local manufacturing potential.	▸ Private sector plays key role ▸ Economic needs drives solar ▸ Dynamic now exponential ▸ Government support critical ▸ RE led to inclusive growth ▸ Scale facilitates localisation	▸ Flexibility ▸ Descaling ▸ Dispersion ▸ Disembodied ▸ Systemic

NICHE INNOVATION	DESCRIPTION - MEANING FOR DIGITAL PARADIGM	KEY MESSAGES	DIGITAL PARADIGM PRINCIPLES
Green Hydrogen	Green hydrogen driven steel plant in Brazil aimed to reduce climate damage. Projected to have spin off benefits for supply chain and local port. Shows fusion between RE and decentralised industrial development	▸ Collaboration between public and private sector critical ▸ Green can be profitable	▸ Descaling ▸ Dispersion ▸ Systemic
Smart Cities	Connecting digital technologies and data bases cuts service delivery costs and enhances consumer access to social services. Can enhance production and generate livelihoods for poor and marginalized. Smart cities in developing countries catching up with India good example. Depend on software which creates comparative advantage.	▸ Public/private collaboration critical ▸ Government intervention key ▸ Go beyond department silos ▸ Need to go beyond service delivery to economic activity	▸ Flexibility ▸ Descaling ▸ Dispersion ▸ Systemic
Digital/Solar Smart Energy Demand Management	Enabled by rooftop solar and home diffusion of IoTs. Households control energy supply and usage, significantly reduces energy costs. Can assist cities and utilities efficiently manage demand. Central role for government in reshaping of the energy market. Sidesteps mass production paradigm for energy. Uses local assembly manufacturing to enable flexibility in innovation.	▸ Demand not supply driven ▸ Smart balancing RE demand & supply ▸ Drives decentralised/ distributed RE ▸ Enables circular economy ▸ Private sector driven. ▸ Government facilitative role	▸ Flexibility ▸ Descaling ▸ Dispersion ▸ Disembodied ▸ Systemic
South-South Trade	Less standards intensive aimed at lower income consumers in developing countries. Allowed for integration of small enterprises in supply chains. South-South products cheaper but lower quality. Promoted the diffusion of more appropriate labour intensive technologies. Enhanced opportunities for greater inclusion and decentralised production.	▸ Greater regional integration ▸ Inclusive for small firms ▸ Promotes labour intensity ▸ Grows maintenance/ repair ▸ Decentralised production	▸ Descaling ▸ Dispersion ▸ Appropriation ▸ Systemic
Stockholm District Heating and Cooling	Collective provision of public goods made possible by RE. Heavy reliance on RE generated through circular economy. Led to similar air cooling system. Enhanced through applying digital technologies.	▸ Critical role by national and local government	▸ Descaling ▸ Dispersion ▸ Disembodied ▸ Appropriation ▸ Systemic
Climate Smart Technologies Agriculture and Agri Processing	Digital technologies enhance resilience and improve productivity across the food chain. Digitisation, particularly in agri-processing, enables systemic improvements. Projects (Slovenia and Ghana) reduced energy demands and emissions, water usage, climate change adaptation, enhanced supply chain productivity, educated farmers	▸ Helps small farmers ▸ Government and NGOs key ▸ Regional organization finance/education ▸ Inclusive of rural poor	▸ Descaling ▸ Dispersion ▸ Disembodied ▸ Systemic
Drone Technologies	Digital drone technologies key role in monitoring, constructing infrastructure and improving productivity across sectors. Allows delivery to producers/consumers in remote and inaccessible areas. India expanding drone usage and production. Local industry grown substantially.	▸ Equity in services delivery across regions and sectors ▸ Government policy critical ▸ Government incentives and regulation key to develop local industry	▸ Flexibility ▸ Descaling ▸ Dispersion ▸ Disembodied ▸ Appropriation ▸ Systemic

6.1 MOBILE TELEPHONES TRANSFORM THE FINANCIAL SECTOR AND FACILITATE INCLUSION

Mobile telephony has been one of the most transformative arenas of digital innovation, fundamentally reshaping communications infrastructure and lowering access costs. Unlike fixed-line telephony - which spread after the late nineteenth century through centralised, hard-wired grids requiring heavy upfront investment - mobile networks operate on a distributed architecture that does not depend on costly physical interconnections. This structural shift has dramatically reduced barriers to access, particularly for geographically isolated and low-density populations that were historically excluded from communications networks.

For low- and middle-income economies, mobile telephony enabled technological leapfrogging over legacy fixed-line systems. These economies had lagged significantly in pre-digital telecommunications, but the rapid diffusion of digital mobile phones allowed them to close, and in some cases surpass, the communications gap with high-income countries. A particularly consequential innovation was the use of mobile phones to bypass formal banking systems and enable person-to-person payments. The pioneering example is M-Pesa - “pesa” meaning money in Swahili - launched in Kenya in 2007 and subsequently diffused across Africa, Asia and Eastern Europe, including Egypt, Lesotho, Mozambique, South Africa, Tanzania, Afghanistan, India, Romania and Albania.

Mobile money systems quickly evolved beyond basic transfers to support decentralised service provision and asset financing. In Kenya, mobile payments are linked to rental and hire-purchase schemes for solar home systems, televisions and refrigerators through platforms such as M-Kopa. These systems have become integral to the supply, monitoring and payment models of utilities serving large concentrations of low-income consumers. By enabling pay-as-you-go models and remote monitoring, mobile payments facilitate access to essential services in both dense urban settlements and distant rural areas—services that had previously depended on centralised, urban-based infrastructure.

The economic and social impacts of mobile telephony have been broad-based, with particularly strong inclusion effects. In Kenya, mobile payments enable households in remote rural areas to participate more fully in the economy and strengthen social networks as family members migrated to urban centres. Mobile money plays a central role in facilitating domestic and international remittances, smoothing consumption and reducing vulnerability. Uptake has been highest among low-income households, and the share of households completely excluded from financial intermediation has fallen sharply - from 41 per cent in 2006 to 17 per cent in 2016. A defining feature of this transformation is its inclusiveness: a high proportion of users are women, rural residents and individuals with lower levels of formal education. Reflecting this user base, mobile banking is predominantly used for small-value transactions; while it accounted for only around seven per cent of the total value of national payments in 2014, it represented approximately two thirds of all financial transactions.

Supportive and adaptive regulation was critical to the success of mobile money in Kenya. The Central Bank of Kenya rapidly recognised the developmental potential of mobile banking and resisted pressure from incumbent commercial banks to restrict the expansion of M-Pesa. At the same time, new regulatory measures were introduced to address risks related to money laundering and consumer protection, creating a framework that balanced innovation with financial stability. This regulatory stance proved decisive in enabling scale, trust and sustained adoption.

Beyond finance, mobile telephony has generated economy-wide impacts across employment, entrepreneurship and service delivery. It has supported job creation both indirectly—through productivity gains and market expansion – and directly within the telecommunications and digital services sectors. Mobile connectivity has underpinned the rapid growth of informal and gig-economy activities, offering income opportunities to large cohorts of digitally proficient youth. It has also empowered entrepreneurs to connect to global value chains, facilitating exports and easing access to imported inputs and affordable consumer goods.

Mobile technologies are increasingly reshaping social services, particularly health and education. Telemedicine applications are improving health outcomes, including in rural areas previously cut off from formal health provision, while mobile-based disease surveillance systems enable faster responses to outbreaks. In education, mobile connectivity supports remote learning, expands access to global knowledge resources and allows teachers in remote locations to draw on previously unavailable materials and pedagogical support.

In agriculture and urban services, mobile telephony is raising productivity and reducing transaction costs, though the innovation frontier continues to evolve. In low-income economies, digital telephony enables more targeted use of fertilisers and pesticides, provides farmers with real-time advice on disease control, and improves access to input and output markets. Farmers can compare prices across locations and arbitrage between markets, strengthening their bargaining power. In low-income urban conurbations, mobile payments facilitate pay-by-use systems for utilities and transport, allowing households to settle bills in small increments and escape time-consuming, bureaucratic, queue-based payment systems.

Taken together, mobile telephony illustrates how digital technologies can simultaneously transform infrastructure, markets and inclusion outcomes. Its success reflects not only technological change, but also adaptive regulation, innovative business models and a strong alignment with the needs of low-income users. It also has led to major changes in lifestyles and consumption patterns. These lessons that are directly relevant for broader digital transformation strategies in developing economies.

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6.2 WIN-WIN OUTCOMES IN GREEN INDUSTRIALISATION

Green industrialisation is frequently framed as a cost imposed to mitigate climate change, yet evidence increasingly shows that it can deliver simultaneous economic, social and environmental gains. Rather than representing a trade-off between growth and sustainability, green industrialisation can generate "win-win" outcomes by reducing costs, raising productivity, creating employment, improving environmental performance and enhancing firm-level profitability. Recent experience in Africa demonstrates that these outcomes can be achieved through innovations that both retrofit existing legacy investments and shape the design and delivery of new industrial investments.

Retrofitting legacy investments illustrates how greening can rapidly improve competitiveness while reducing environmental pressures. A clear example is UNIDO's Green Industry Initiative implemented in 2011–2012 through the MED-TEST programme (Transfer of Environmental Sound Technology in the South Mediterranean Region). The programme aimed to demonstrate the effectiveness of best practices and integrated management systems while building national industrial capacity in the Southern Mediterranean region. Its core objective was to enhance productivity and environmental performance simultaneously, thereby reducing operating costs. MED-TEST supported 43 manufacturing sites—predominantly SMEs—across Egypt, Morocco and Tunisia, spanning multiple industrial sectors.

In Tunisia, MED-TEST focused on high-impact sectors where environmental pressures and economic importance intersect. The programme targeted textiles, agro-food processing and leather tanning—sectors that are central to the Tunisian economy but also among the largest contributors to industrial pollution, particularly in wastewater generation, organic loads and toxic discharges. Participating firms received technical assistance to integrate resource efficiency into their industrial management systems and to adopt international environmental management standards, including ISO 14001 certification. This integration embedded environmental performance directly into operational decision-making rather than treating it as a peripheral compliance activity.

The financial and environmental outcomes of these interventions were both rapid and substantial. A study of 15 firms (six in food processing, six in textiles and apparel, and three in tanning and leather) revealed impressive returns arising out of green practices. Firm size ranged from 35 to 546 employees, underscoring the relevance for SMEs. Aggregate short-term annual cost savings reached USD 3.3 million, compared with total investment costs of USD 4.5 million. In several cases, investments were fully recovered within a single year, and in all but one case benefits exceeded costs within two years. These financial gains were accompanied by major reductions in water and energy use, as well as sharp declines in BOD5 (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand), indicating significant improvements in water pollution outcomes.

These results demonstrate that greening legacy assets can be a profitability-enhancing strategy rather than a regulatory burden. By improving resource efficiency and reducing waste, firms lowered operating costs while strengthening compliance with international standards—an increasingly important factor in accessing global markets. The MED-TEST experience thus provides concrete evidence that environmental upgrading can be aligned with competitiveness, particularly when supported by targeted technical assistance and institutional capacity-building.

Green industrialisation can also be embedded at the outset of new investments, shaping entire value chains rather than retrofitting existing ones. The Hawassa Eco-Industrial Park (HEIP) in Ethiopia illustrates how a forward-looking strategy can leverage green design to create new export opportunities. Although the prospects of HEIP were later undermined by Ethiopia's civil war and the loss of preferential access to the US market following the introduction of tariffs in 2025, the initiative remains an important exemplar of how green industrialisation can be strategically deployed.

The Hawassa experience must be understood against the mixed record of Export Processing Zones (EPZs) in developing economies. EPZs played a central role in China's export-oriented industrialisation, and many low-income countries have attempted to replicate this model. While Mexico and some Caribbean economies achieved partial success, developmental and environmental outcomes were often weaker than expected. In Africa, EPZ performance has been particularly disappointing: despite substantial investments—often supported by Chinese finance and firms—many industrial parks failed to generate sustained exports, employment or manufacturing value added. Conventional supply-side policies targeting infrastructure provision, tax exemptions and regulatory relaxation proved insufficient.

HEIP diverged from this pattern by starting at the demand end of the global value chain. Rather than constructing the park first and seeking tenants later, the Ethiopian government engaged directly with major US apparel buyers and leading material suppliers in India, Sri Lanka, Indonesia, Hong Kong and China. These buyers identified a gap in their existing supply chains: legacy Asian suppliers had developed capabilities over decades in which environmental sustainability had not been a central concern. This created space for a new supply chain that was "green by design" from the outset—a strategic opportunity that Ethiopia deliberately sought to capture.

Established in 2016 at a cost of approximately USD 300 million, HEIP was designed as a large-scale, export-oriented eco-industrial park. The park was planned to employ up to 60,000 workers and generate annual exports of around USD 100 million. A major global apparel firm, PVH (formerly Phillips Van Heusen), was attracted as an anchor investor, and by early 2021 more than 20 firms had located in the park. At its peak, HEIP employed approximately 35,000 workers and generated exports exceeding USD 30 million before political instability disrupted its trajectory.

Greening at Hawassa extended across the entire production and logistics system. The park incorporates water recycling, LED and intelligent energy systems, natural ventilation and lighting, and a collective zero-liquid-discharge (ZLD) wastewater system. Environmental integration went beyond the park itself: all energy inputs are derived from renewable sources, and finished products are transported to port via Africa's first electric railway, also powered by renewables. HEIP performs strongly against international benchmarks for eco-industrial parks, which assess not only environmental criteria but also social dimensions such as labour conditions and community impacts.

Taken together, these experiences underline that green industrialisation can generate mutually reinforcing economic, social and environmental outcomes. Whether retrofitting legacy investments or designing new industrial systems, green approaches can enhance competitiveness, reduce costs and open access to demanding global markets. The central lesson is that green industrialisation succeeds not through isolated environmental measures, but through integrated strategies that align technology, regulation, market access and value-chain coordination.

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6.3 SOLAR RENEWABLE ENERGY SURGES GLOBALLY – VIETNAM AND SOUTH AFRICA EXAMPLES

Global renewable energy growth has reached record levels, with solar leading the surge in low-carbon electricity generation. In 2024, clean energy from all low-carbon sources surpassed 40 per cent of global electricity generation, reflecting an accelerating transition away from fossil fuels. Solar power, in particular, is the fastest-growing source of electricity worldwide, doubling between 2022 and 2024, with China accounting for 53 per cent of this increase. Globally, solar generation has doubled every three years, with 99 countries achieving at least a twofold increase between 2019 and 2024 (Graham et al., 2025).

The solar boom is no longer confined to industrialised countries or China. India became the world's third-largest generator of electricity from wind and solar in 2024, overtaking Germany, while Brazil rose to fifth globally for solar generation. The rapid expansion of solar capacity is equivalent to the total electricity demand of India in 2024, Russia in 2022, and Brazil in 2020, and has significantly reduced power sector emissions on a scale comparable to the annual output of the US, the Middle East, and ASEAN (Graham et al., 2025).

Advances in battery storage are magnifying the impact of solar generation by enabling round-the-clock energy supply. The cost of lithium-ion batteries has fallen 84 per cent over the past decade, including a 24 per cent decline between 2023 and 2024, while global battery storage installation capacity nearly doubled in a single year (Graham et al., 2025). This supports distributed energy systems, enhances grid stability, and accelerates the feasibility of continuous solar power for households, businesses, and industry.

The surge in solar adoption is also transforming global supply chains and industrial opportunities. Expanding markets for solar panels, inverters, and batteries creates opportunities for local manufacturing and assembly in developing countries, reducing dependency on imports - particularly from China - and supporting industrialisation. Localised production of solar technologies can strengthen energy security and create employment across the value chain.

Vietnam demonstrates how targeted policy interventions can drive rapid solar adoption at the household level. Prior to 2020, rooftop solar penetration was extremely low, particularly among rural peasants with limited access to energy. The government introduced a household solar investment programme with generous feed-in tariffs, resulting in rooftop solar capacity rising from 378 MWp in 2019 to 9,583 MWp by 2022. In 2022, total solar capacity reached 16.5 GW, accounting for roughly a quarter of national electricity supply. Distributed rooftop solar not only improved energy access for rural households but also generated additional income through feed-in tariffs, significantly reducing energy poverty and increasing household resilience.

South Africa provides a complementary example, where solar adoption has been driven primarily by supply constraints and rising electricity costs. Frequent load shedding by the coal-dependent national utility, Eskom, coupled with ageing power stations, corruption, municipal payment challenges, and widespread consumer nonpayment, has led households and businesses to invest heavily in rooftop solar. Rising electricity tariffs and a policy allowing surplus energy to feed back into the grid have further accelerated adoption, particularly among middle- and high-income households, commercial enterprises, and industrial facilities.

Innovations in modular solar-battery solutions are expanding energy access to informal settlements and small businesses. In South Africa, “plug-and-play” solar systems have been designed to address the specific challenges of informal structures and low-income, unbanked clients. Features include theft-resistant enclosures, low-weight modular panels, battery storage (up to 5 kW), inverters (up to 6 kW), point-of-sale devices, remote monitoring, and daily payment models. These solutions enable informal entrepreneurs and households to access reliable electricity without the upfront costs associated with traditional financing, promoting both economic activity and energy inclusion.

Estimates indicate that South Africa has installed approximately 8.5 GW of solar PV capacity, including utility-scale farms under the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). Residential and commercial rooftop installations have surged, reaching 6.2 GW by the end of 2024 - a 13 per cent increase from the previous year and nearly 230 per cent higher than in 2021. Around 22 per cent of household solar installations remain unregistered, suggesting that total capacity may be even higher, highlighting the rapid, decentralised adoption of solar energy across the country.

Taken together, these global and country-specific experiences illustrate that solar energy is a transformative force in both energy systems and industrial development. Rapid declines in technology costs, advances in storage, and enabling policy frameworks have allowed solar to scale across diverse geographies, from Vietnam’s rural households to South Africa’s urban and industrial consumers. The expansion of solar energy is not only mitigating emissions and improving energy security but also creating new economic opportunities, strengthening resilience for low-income households, and laying the groundwork for local manufacturing and industrialisation in the renewable energy sector.

The broader lesson is that solar energy adoption combines technological innovation, policy support, and localised solutions to achieve multiple objectives simultaneously. Distributed solar systems empower households and businesses, reduce reliance on ageing centralised utilities, lower emissions, and enable the development of domestic industrial capacities - demonstrating a clear pathway for sustainable energy-driven growth in developing economies. As a consequence, its diffusion not only involves investment in discrete technologies, but simultaneously also has led to changes in social organisation and economic geography.

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6.4 RENEWABLE ENERGY TO POWER GREEN STEEL MANUFACTURE AND INDUSTRIAL DECENTRALISATION IN BRAZIL

Steel remains a foundational general-purpose technology, critical to infrastructure, transport, and industrial production. Since the second half of the nineteenth century, steel has underpinned the construction of rail networks, ocean-going vessels, and industrial machinery. Today, approximately half of global steel output is used in building and infrastructure, 16 per cent in mechanical equipment, and 12 per cent in the automotive sector, highlighting its continued centrality to industrial development.

Steel production is also a major source of greenhouse gas emissions, creating a strong imperative for decarbonisation. Globally, steel-related emissions roughly double the weight of the steel produced, accounting for about seven per cent of total anthropogenic greenhouse gas emissions. While electric arc furnaces are less carbon-intensive than traditional coal-powered blast furnaces, their environmental advantage depends critically on the carbon footprint of the electricity used.

Hydrogen offers a promising pathway to reduce the climate impact of steel manufacture. By serving both as a reductant in the production process and as an energy source, hydrogen can substantially lower steel's carbon footprint. Currently, green steel remains more expensive than conventional steel, largely due to the high cost of hydrogen.

However, advances in renewable energy reduce this cost premium by enabling low-cost hydrogen production near steel plants, creating a synergistic relationship between renewable energy, hydrogen availability, and green steel competitiveness.

Brazil is emerging as a global frontrunner in green steel production, leveraging its resource endowments and renewable energy capacity. With 21 steel plants, Brazil ranks as the world's ninth-largest steel producer and exporter, and its high-grade iron ore deposits (exceeding 60 per cent) are particularly advantageous for hydrogen-based steel production. The country already generates 93 per cent of its electricity from renewable sources and, in 2022, was second only to China and the US in clean energy investments. Brazil is the second-largest producer of hydro and biopower, ranks seventh for wind energy, and ninth for solar power, with planned investments set to strengthen its position as a low-cost renewable energy leader.

Recent studies suggest that Brazil is well-positioned to produce cost-competitive green steel by the early 2030s. Analyses of levelized production costs (net of subsidies) indicate that access to low-cost renewable energy in proximity to hydrogen production and steel plants is crucial for economic viability. Brazil, alongside Australia, was identified as the most favourably located economy to achieve this goal, given its combination of high-quality iron ore, renewable energy infrastructure, and industrial capacity.

Government and private sector initiatives are aligning to realise this green steel potential. The National Hydrogen Programme, launched in 2021, established a legal framework to support low-cost hydrogen production. Private investments complement this policy, with the Port of Açu providing critical infrastructure for hydrogen and green steel production, and Vale investing in upstream ore processing. Together, these interventions aim to integrate resource production, renewable energy, and industrial processing into a cohesive regional industrial cluster.

The Port of Açu illustrates how green steel can drive decentralised industrial development. Located in the relatively poor North-East region, 320 km from Rio de Janeiro, the port has become the focus of over USD 5 billion in investments between 2021 and 2024. These investments span wind turbine manufacturing, metallic iron production, green hydrogen, ammonia, and sustainable aviation fuels. Key projects include a green hydrogen pilot plant by Shell Brazil, a large-scale ammonia project by YamnaCo targeting one million tonnes annually by 2030, and Fuella's planned ammonia facility. The port is developing renewable energy infrastructure, including a solar PV power plant dedicated to supporting hydrogen production, ensuring that almost all energy inputs for the regional industrial cluster will come from renewable sources.

These developments exemplify the convergence of renewable energy, industrial innovation, and decentralised agglomeration. By co-locating energy production, hydrogen generation, and industrial activity, Brazil is creating an integrated green industrial ecosystem. Collaboration between government and private actors has been critical in facilitating this process, from policy frameworks and infrastructure investment to industrial planning and technology adoption.

ICT and digital technologies play a foundational role in enabling these developments. Beyond their integration into renewable energy systems such as solar and wind, ICTs support logistics, plant design, monitoring systems, and broader industrial management.

Digital technologies – from communications to AI and real-time monitoring – enhance efficiency, optimise energy use, and make large-scale green industrial clusters feasible, illustrating how technological integration is essential for modern, low-carbon industrialisation.

In summary, Brazil's green steel initiatives demonstrate how renewable energy can catalyse both decarbonisation and regional industrial development. By leveraging renewable electricity, high-quality resources, and strategic public-private collaboration, Brazil is creating a model of decentralised, green industrialisation. This approach not only addresses climate imperatives but also strengthens competitiveness, stimulates local employment, and exemplifies how modern industrial strategy can simultaneously achieve economic, environmental, and social objectives.

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6.5 SMART CITIES: DIGITAL SYNERGIES AND DEVELOPMENT OPPORTUNITIES

Smart City programmes leverage the digital revolution to integrate and analyse urban data, enhancing the efficiency and quality of service delivery. These programmes, which gained momentum in the late 2000s, draw on datasets generated from service provision as well as from Internet of Things (IoT) devices, enabling the management of urban systems such as traffic, transport, water and energy utilities, schools, health facilities, libraries, community services, and policing. By aggregating and analysing these data streams, Smart Cities aim to optimise urban functionality, reduce costs, and improve the responsiveness of public services.

The most advanced Smart City initiatives remain concentrated in high-income countries, with limited representation in developing regions. A 2025 ranking placed eight of the top ten Smart Cities in Europe, while Singapore and China represented notable exceptions outside the OECD. In Africa, Cairo (117), Cape Town (124) and Nairobi (136) led the regional rankings, whereas Mexico City (118), Santiago (120) and Buenos Aires (131) were the highest-ranked cities in Latin America. Delhi (104) and Mumbai (106) were among the leading cities in Asia, illustrating that many low- and middle-income urban centres are still in a catch-up phase.

Despite these disparities, some developing economies are advancing ambitious Smart City programmes, leveraging local digital skills and large-scale data infrastructures. India's Smart Cities Programme, launched by the Ministry of Housing and Urban Affairs, targets more than 500 towns and cities with populations exceeding 100,000. The programme draws on the national 'Digital India' initiative, capitalising on abundant IT expertise and the databases generated by digitally connected citizens. Through the strategic application of artificial intelligence (AI), the programme performs six core functions: data identification and collection; forecasting and prediction; clustering to identify patterns; optimisation of response routes; anomaly detection; and enhanced decision-making. These activities rely on big data and inferential analytics to improve urban governance and service delivery.

Other developing countries are exploring complementary approaches to harness digitalisation for urban management. In Kenya, widespread mobile phone adoption has facilitated digital payments for utilities, particularly in densely populated, low-income urban areas. Mobile-enabled payments reduce transaction costs, simplify bureaucratic procedures, and improve access to essential services, demonstrating how digital technologies can improve inclusivity and efficiency even in resource-constrained contexts.

Smart City adoption in low- and middle-income countries benefits from the incremental nature of digital solutions and the relatively low barriers to entry. Unlike earlier urban governance and utility systems that required extensive physical infrastructure, Smart City innovations are primarily software-driven. The growing availability of digital skills further reduces implementation challenges and creates opportunities for leapfrogging older legacy systems. This explains why no US city ranks among the top 20 Smart Cities: mature cities are often constrained by entrenched infrastructure and rigid institutional arrangements, whereas developing cities can adopt flexible, digitally native solutions.

However, current global Smart City programmes exhibit a significant policy gap: they focus largely on service delivery, governance, and, in some cases, surveillance, while largely neglecting employment creation, production, and livelihood generation. Most initiatives are implemented through municipal authorities or single ministries - such as India's Ministry of Housing and Urban Affairs - without integration across Ministries of Industry, Innovation, or institutions in national innovation systems. As a result, Smart City interventions rarely harness synergies with industrial policy, entrepreneurship, or local economic development, limiting their potential to contribute to broader socioeconomic transformation.

Addressing this gap requires integrating Smart City strategies with industrial and innovation policy. By linking digital infrastructure to urban manufacturing, small business support, and local enterprise development, cities can transform digital data into actionable insights that promote employment, productivity, and inclusive economic growth. For example, predictive analytics used for traffic or utility management could also optimise supply chains, reduce operational costs for local enterprises, and identify opportunities for urban-based manufacturing clusters.

In summary, Smart Cities represent a powerful framework for modernising urban governance and service delivery, but their potential in low- and middle-income economies extends far beyond efficiency gains. By integrating AI, IoT, and big data analytics with industrial and innovation strategies, developing cities can simultaneously improve utility provision, reduce congestion, and stimulate economic opportunities. The combination of low infrastructure inertia, abundant digital skills, and policy alignment with industry and innovation systems provides a unique chance for these cities to leapfrog more developed urban centres and establish digitally enabled, inclusive, and economically vibrant urban ecosystems.

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6.6 SMART ENERGY MANAGEMENT THROUGH THE USE OF ICTs AND SOLAR POWER

In many low- and middle-income economies, energy utilities have traditionally managed electricity primarily through a supply-driven approach, with shortfalls addressed by rationing or cutting supply. These interruptions severely impact households, industry, and social services, including hospitals, schools, traffic control, and security. Utilities face these constraints because they lack mechanisms to manage energy demand flexibly, and households have limited ability to modulate consumption in response to grid conditions.

The limitations of centralized, mass production energy systems are exacerbated by their scale and inflexibility. Large, centralised generation and extensive distribution networks cannot differentiate among consumers with widely varying needs, and supply-side interventions are costly and disruptive. The transition to renewable energy, combined with digital technologies, creates an opportunity to overcome these structural limitations. Modular, scalable renewable installations can be deployed closer to consumers, reducing transmission losses and the vulnerability of centralized systems. Beyond generation, information and communication technologies (ICTs) allow for sophisticated demand management, lowering energy use, optimising consumption patterns, and enabling households to feed surplus energy back into the grid, effectively increasing supply.

Innovations in demand-side energy management are exemplified by Plentify, a South African start-up that integrates ICTs with household solar systems. Plentify's core system, SolarBot, optimises energy consumption by analysing IoT-connected appliances, solar generation forecasts, weather data, and utility load-shedding schedules. SolarBot prioritises charging the battery with solar energy, minimises grid reliance, avoids peak tariffs, and even temporarily switches off appliances when peak demand occurs. Surplus energy stored in household batteries can be fed back into the grid, providing financial returns and stabilising local electricity demand.

Modular devices such as HotBot extend the system's efficiency to individual appliances. HotBot attaches to a home hot water geyser, collecting data on usage patterns, geyser operation, and household preferences via a mobile app. Combined with weather forecasts and utility schedules, the system predicts hot water requirements and schedules geyser operation to maximise efficiency. When the battery is fully charged, SolarBot can activate intermittent-load appliances such as refrigerators or washing machines, optimising the use of locally generated solar power while feeding surplus energy to the grid.

Plentify leverages local manufacturing and assembly to enhance flexibility and innovation. Imported components are integrated by local contractors, allowing the company to monitor, adjust, and iterate system performance while reducing costs and ensuring adaptability. This localisation strategy also supports domestic employment and strengthens capabilities in the renewable energy and digital sectors.

The system is scalable beyond households, applicable to businesses and institutions with collective energy demand. Facilities such as retirement homes, residential estates, and shopping centres can integrate SolarBot and HotBot solutions to optimise energy use, feed surplus energy back to the grid, and reduce utility costs. However, maximising impact requires complementary changes in energy utilities and regulatory incentives, shifting the paradigm from a supply-only focus to a nuanced approach recognising differentiated consumer needs and bidirectional energy flows.

Pilot implementations demonstrate tangible benefits for households and utilities alike. In Cape Town, a trial deploying 500 HotBots delivered an average household energy saving of 24 per cent while providing aggregated data to the local utility to manage peak loads and prevent infrastructure stress. Similar innovations are emerging internationally, including in Portugal and South Australia, underscoring the global relevance of integrating ICTs with distributed renewable energy systems.

The underlying principle of the Plentify system is that data is central to energy optimisation. As founder Jon Kornik explains, data functions as the "brain" of the system, while hardware constitutes the "hands and eyes." By aggregating demand-side data across households, utilities can balance supply and demand more effectively, turning previously uncontrollable consumer demand into a manageable and valuable resource. The result is a two-sided system where both supply and demand can be actively managed, enhancing efficiency, reliability, and clean energy utilisation.

Experts highlight that this approach signals a systemic transformation in the energy sector. According to Poudineh (2025), renewable energy transitions dissolve the traditional boundaries between producers and consumers, create bidirectional networked energy flows, and generate complex adaptive systems. These shifts require new governance structures, market designs, and operational paradigms. The competitive advantages in this Digital Energy Paradigm increasingly accrue to nations and organisations capable of integrating manufacturing, technological innovation, and systems management—rather than those relying solely on fossil fuel resources or geological endowments.

In summary, integrating ICTs with solar energy systems enables a fundamental rethinking of energy supply and demand. Distributed renewables, intelligent energy management devices, and demand-side analytics collectively allow households, businesses, and utilities to optimise energy use, feed surplus energy back into the grid, and reduce dependence on centralized systems. This combination of technology, data, and system-level coordination offers a pathway for low- and middle-income economies to achieve energy efficiency, reliability, and sustainability while supporting broader economic and industrial objectives.

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6.7 SOUTH-SOUTH TRADE – NEW OPPORTUNITIES FOR INCLUSION (BUT WITH SOCIAL AND ENVIRONMENTAL COSTS)

Standards-intensive global value chains (GVCs) have reshaped southern exports to northern markets since the early 1990s. Firms seeking access to high-income markets face stringent quality, cost, and delivery (QCD) standards imposed by lead firms to ensure economic efficiency, as well as government-mandated safety regulations such as phytosanitary standards. Increasingly, consumer-driven demands for ethical and environmentally responsible production have added another layer of compliance requirements. These standards necessitate costly certification processes and continuous monitoring to demonstrate conformance, imposing significant operational burdens on firms and labour in southern economies.

Standards-intensive GVCs generate a range of developmental benefits. They enhance product quality, reduce child labour, promote the inclusion of women in production, and mitigate environmental impacts. By integrating firms into international markets, they expose local businesses to best practices in production, management, and sustainability. However, these benefits come with trade-offs. Small firms and informal sector operators often face exclusion due to the high compliance costs and technical requirements, and unskilled or less-educated workers may be disadvantaged. Capital requirements are higher than for domestically oriented production processes, favouring medium- and high-income consumer markets with stringent look-and-feel and brand expectations.

Low-income consumers in southern economies face a different set of constraints. While aspiring to the quality and branding found in northern markets, these consumers cannot afford the associated cost premiums. Producers likewise find that importing northern machinery entails high purchase and maintenance costs, requires large-scale operations, and is often technologically sophisticated beyond local capacities. These constraints create a divergence between the demands of northern consumers and the practical realities of low-income domestic markets.

South-South trade, particularly the import of machinery from China, India, and other relatively advanced developing economies, provides an alternative pathway. Comparative studies in East Africa — covering rice tilling in Tanzania, garment manufacturing in Uganda, and furniture production in Kenya — highlight the trade-offs between northern and southern origin capital goods. Southern machinery is cheaper, more labour-intensive, and operates at lower scale than northern counterparts, reducing production costs and enabling lower consumer prices. This accessibility supports local production and consumption patterns while fostering employment in labour-intensive sectors.

Southern-origin equipment also generates important local spillovers. Frequent breakdowns, a characteristic of lower-cost machinery, have fostered a network of small, decentralised workshops for repair and maintenance. These workshops require relatively low-level skills, supporting local skill development and creating employment opportunities in the informal economy. In addition, these workshops often diversify into other sectors such as general metalworking. Despite being less environmentally friendly—producing more noise and oil spillages—this machinery expands productive capacity and enables local enterprises to compete with imports.

Products manufactured with southern machinery are substantially cheaper than imports and those made with northern equipment. This affordability enhances access to locally produced goods for low- and middle-income households, stimulating domestic markets while generating employment. The broader economic and social appropriateness of southern-origin equipment has thus driven its widespread adoption across low- and middle-income countries.

The result is a rapid expansion of south-south capital goods trade. The share of Chinese machinery imports into Africa, Southeast Asia, and Latin America increased from near zero in 2000 to over 30 per cent in 2023. This trend demonstrates the capacity of south-south trade to promote social inclusion, employment, and local enterprise development, even if it introduces environmental and operational challenges. By providing affordable, labour-intensive technologies, south-south trade enables low- and middle-income countries to expand manufacturing and agricultural production while building local skills and business ecosystems.

In summary, south-south trade creates significant opportunities for inclusion and economic growth in developing economies. While these opportunities come with social and environmental trade-offs, particularly in terms of machinery reliability and ecological impact, the overall effect on employment, skill development, and access to affordable goods is strongly positive. This underscores the potential of southern-origin capital goods to complement standards-intensive northern value chains, offering a pragmatic pathway to industrialisation that aligns with the economic and social realities of low- and middle-income countries.

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6.8 DISTRICT HEATING IN SWEDEN: COLLECTIVE PRODUCTION AND COLLECTIVE CONSUMPTION

Air pollution and energy insecurity prompted Sweden to transition to collective heating systems in the late 20th century. During the late 1960s, Stockholm and other Swedish cities faced severe air pollution and acidification, largely caused by coal-fired home heating. The oil crises of 1973 and 1979 further exposed the economic vulnerabilities of reliance on imported fossil fuels, highlighting high costs, price volatility, and energy insecurity. These challenges prompted a national commitment to reduce dependence on carbon-based energy and to adopt environmentally sustainable energy solutions.

Sweden adopted a system of centrally generated, renewable-based heating, replacing individual gas or coal-fired home systems. Known as the “centralised chimney” model, this approach enabled efficient purification of flue gases and collective control over emissions. Unlike retrofitting legacy systems, the network was designed in parallel with the construction of over one million new homes, creating a purpose-built infrastructure for clean, centralised heating.

The system now spans more than 3,000 km of district heating pipes, primarily powered by renewable energy. Less than five per cent of the energy supplied originates from fossil fuels. Stockholm’s district heating draws on multiple sources: residual heat from residential wastewater, excess heat from data centres, heat displaced by supermarket cooling systems, biowaste, and energy from incinerating non-recyclable waste. The Hammarbyverket heat pump, the world’s largest, generates 225 MW - enough to heat approximately 95,000 two-room apartments during a typical winter. By 2023, collective heating and hot water systems accounted for more than half of Sweden’s national heating demand, demonstrating the scalability and efficiency of this model.

The collective energy model has been extended to cooling, leveraging renewable sources and digital optimisation. Stockholm now operates the world’s largest seawater-based cooling system, providing environmentally friendly cooling during summer months. Digital technologies have been introduced to optimise the integrated generation and distribution of both heat and cooling across the district network, ensuring precise matching of supply and demand and improving overall system efficiency.

Government intervention was central to the design, rollout, and continuous improvement of the system. At the national level, a carbon tax introduced in 1991 incentivised low-carbon solutions, while support for renewable energy innovation facilitated the development of hydroelectric plants and other clean technologies. Municipal and regional authorities provided planning, regulatory support, and operational oversight, creating a coordinated governance framework that reduced risk, encouraged private investment, and enabled the capture of environmental and social externalities.

The Swedish experience illustrates the benefits of collective energy production over individualised systems. Centralised heating allowed for higher environmental performance, job creation, and energy security, outcomes that would have been much more difficult to achieve under individual home-based heating systems, as seen in the UK, which faced similar pollution and energy challenges during the 1960s. By combining large-scale renewable generation, integrated distribution networks, and digital optimisation, Sweden has demonstrated a scalable, environmentally sustainable model of urban energy management that integrates production and consumption at the district level.

In summary, Sweden’s district heating system exemplifies how coordinated, centrally managed energy solutions can achieve multiple objectives simultaneously. These include reducing carbon emissions, improving air quality, enhancing energy security, creating employment, and enabling flexible energy use through digital control. The model highlights the importance of public sector leadership, long-term planning, and investment in renewable and digital technologies to transform urban energy systems, providing a blueprint for other cities seeking sustainable collective energy solutions.

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6.9 ADOPTING CLIMATE SMART TECHNOLOGIES AND PRACTICES TO CREATE CLIMATE RESILIENCE FOR SUSTAINABLE AGRICULTURE AND AGRI-PROCESSING

Climate change is creating new challenges for agriculture, requiring climate-smart strategies and technologies. Agriculture is increasingly exposed to extreme weather, temperature variability, and shifting pest and disease patterns. Sustainable agriculture relies on three interlinked pillars—environmental, social, and economic - and Climate Smart Agriculture (CSA) seeks to strengthen all three by promoting practices and technologies that enhance resilience, reduce greenhouse gas emissions, and improve productivity across the food value chain (FAO, 2018). CSA interventions cover every stage from harvest, storage, and processing to transport, packaging, renewable energy adoption, and postharvest loss reduction. Governments and NGOs play a central role in enabling farmers and other stakeholders to adopt CSA strategies effectively.

Digitisation and ICT adoption are transforming agricultural value chains. The use of digital tools in agri-processing enables real-time data sharing, predictive analytics on food quality, minimisation of waste, and optimisation of resource use. Digital marketplaces connect farmers directly to buyers, reducing intermediaries, lowering postharvest losses, and ensuring fresher produce reaches consumers. Blockchain and other traceability technologies enhance food safety, ethical sourcing, and fair-trade compliance, building trust and facilitating global market access. Chain-wide digitisation offers the potential for substantial system-level productivity gains by integrating decision-making and operational efficiency across all value chain actors.

Technological challenges remain significant in developing countries. Barriers include the digital divide, upfront investment costs, ongoing maintenance expenses, data security concerns, inadequate infrastructure, and skills gaps. National governments, supported by international partners, play a critical role in addressing these obstacles by providing information on benefits and costs, training, incentives, secure data sharing, and knowledge brokerage to facilitate CSA adoption.

Slovenia demonstrates CSA adoption through improved irrigation management. The Vipava Valley, a region with intensive agriculture, faces droughts, floods, frost, and high winds due to climate change. Traditional irrigation practices led to overuse of water and mistimed application. In 2016, a pilot project introduced a Decision Support System for Irrigation (DSSI), co-designed with farmers, to deliver optimal water volumes at the right time. Using sensor data, soil water retention metrics, weather forecasts, and crop-specific requirements, the system provided five-day irrigation recommendations via web or email. A 2019 evaluation showed a 25% reduction in irrigation water, 24% lower energy use, and a 24% reduction in CO_2 emissions. Successful piloting led to nationwide adoption, with DSSI now managed by the Slovenian Environment Agency and freely available to all farmers. Financing was shared between the European Commission (60%) and national partners (40%).

Ghana illustrates CSA in the cocoa supply chain, promoting resilience and livelihoods. Cocoa farming employs over four million smallholder households, making climate impacts a serious economic threat. From 2015 to 2019, the Rainforest Alliance implemented a CSA project across Ghana's cocoa belt, integrating applied climate science, certified supply chains, impact investment, and actionable strategies for farmers, processors, certifiers, and investors. Training materials helped stakeholders use climate data to make sustainable and profitable decisions. The project enhanced knowledge, supported inclusive participation of vulnerable populations, and strengthened climate resilience across the value chain.

Mobile technologies are accelerating CSA adoption in Africa. In Tanzania, the M-Kulima platform provides smallholder farmers with SMS and interactive voice information on climate adaptation, agricultural practices, and market prices, integrated with M-Pesa for payments and microfinance. In Kenya, DigiFarm combines mobile advice with drone-enabled monitoring to support timing of pest control and fertilisation. In Egypt, digital irrigation systems equipped with sensors allow farmers to control water delivery remotely via mobile devices, optimising water use and reducing waste.

Overall, CSA adoption demonstrates the synergy between technology, data, and climate resilience. By integrating ICTs, mobile platforms, and sensor-based management systems, farmers can optimise resource use, reduce emissions, and strengthen resilience to climate variability. Government intervention, international support, and participatory design are critical to overcoming structural barriers, ensuring the adoption of climate-smart practices translates into sustained productivity, improved livelihoods, and global food security.

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6.10 DRONES USING SENSOR TECHNOLOGY

Drones are rapidly transforming multiple sectors due to their versatility, low cost, and capacity to operate in inaccessible or hostile environments. Initially prominent in warfare, drones have expanded into civil, commercial, and humanitarian applications.

Their adoption is enabled by ICTs, which allow miniaturisation, connectivity, and the integration of drones into systemic innovations. These capabilities have significant implications for equitable and sustainable development, particularly in low- and middle-income economies.

Infrastructure inspection and maintenance is being revolutionised by drones. Drones can access hard-to-reach locations, enhancing monitoring while reducing costs and safety risks. They detect structural defects in bridges, buildings, and pipelines, and monitor construction progress against specifications and timelines. In the energy sector, drones inspect solar panels, wind turbines, power lines, and pipelines, enabling early fault detection, preventing accidents, and minimising downtime. They also streamline surveying and mapping in civil engineering, mining, and environmental management, capturing high-resolution data efficiently and safely in remote or hazardous areas.

Drones are advancing climate-smart agriculture by providing precise, real-time data. In crop and field management, drones assess soil conditions, irrigation needs, and plant health, helping farmers identify nutrient deficiencies, pests, and diseases. They optimise water use, reduce waste, and support decision-making for planting, fertilisation, pesticide application, and harvesting. By integrating drone data with ICT systems, farmers achieve higher yields, lower input costs, and improve resource efficiency, contributing to climate resilience.

Environmental monitoring and conservation benefit from drone deployment. Drones access remote locations to track ecosystem health, monitor wildlife populations, assess land use, and evaluate the environmental impacts of development. They support conservation by detecting illegal logging, monitoring deforestation, and assessing climate change impacts on species. Drones also play a vital role in disaster risk management and humanitarian response, providing rapid damage assessment, victim location, and delivery of essential supplies such as food, water, and medical equipment. Commercial and consumer delivery services are adopting drones for rapid, localised transport. Retailers in high-income countries, such as Amazon, are piloting autonomous drone deliveries. In Ireland, Manna Sero drones perform over 80 household drop-offs daily. In Shenzhen, China, drones deliver takeaway food via secure airdrop boxes, facilitated by relaxed local regulations, highlighting the potential for urban logistics innovation in both high- and middle-income contexts.

Drones are transforming medical and other critical freight delivery in remote areas. In Rwanda, drones deliver blood to mountainous rural regions, reducing wastage and saving lives. Following this success, the World Economic Forum has promoted drone delivery in other low- and middle-income countries, demonstrating the potential for drones to improve healthcare access and emergency response where conventional transport is limited.

India exemplifies the integration of drone technology into civilian and industrial applications. Initially adopted for military purposes, drones in India now serve agriculture, infrastructure inspection, and disaster management. Most businesses access drones via service providers due to the high cost of enterprise-level equipment. The government aims to establish India as a global drone hub by 2030, providing regulatory support, financial incentives, and policies to encourage domestic production.

The Indian drone industry is growing rapidly, driven by domestic manufacturing and policy support. Market value nearly doubled from $344 million in 2023 to $654 million in 2024 and is projected to reach $1.4 billion by 2029. Production is expected to increase from 10,803 drones in 2024 to 61,000 in 2029. Five leading manufacturers—IG Drones, ideaForge, NewSpace Research & Technologies, Paras Defence & Space Technologies, and Asteria Aerospace—produce drones across defence, agriculture, infrastructure, and surveillance. The government incentivises local production through the Production-Linked Incentive (PLI) scheme, encourages industry–academia collaboration, and restricts imports to specialised drones, thereby promoting industrial development and innovation in the sector.

Overall, drones illustrate the convergence of ICTs, sensor technologies, and autonomous systems in creating new economic, environmental, and social opportunities. Their applications - from infrastructure maintenance and precision agriculture to environmental monitoring, disaster response, and consumer delivery - demonstrate how emerging technologies can enhance efficiency, resilience, and inclusivity. Strategic government support, local manufacturing, and integration with ICTs are key enablers for scaling the benefits of drone technology, particularly in low- and middle-income economies.

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7. BEYOND CATCH-UP – POLICIES WHICH CAN TRANSFORM THREAT INTO OPPORTUNITY

This section asks how historical patterns of innovation can inform policies for equitable and sustainable development in low- and middle-income economies. What implications does our in-depth historical analysis of innovation have for the formulation and implementation of policies delivering a more equitable and sustainable developmental trajectory in low- and middle-income economies?

While this section identifies priority policy arenas it also focuses on implementation. Drawing on the insights provided by a series of niche innovations described in Section 6, we address the major policy arenas in which transformative action can be directed. Before making the policy recommendations in the last section 8, we briefly highlight the central conclusions from our historical analysis.

- **Industrial development has historically improved livelihoods, but its benefits depend on political and social context.** Industrial development provided the basis for longer and more secure livelihoods through investment in fixed assets, particularly innovations in processes and products. However, while innovation drives productivity and growth, its distributive outcomes depend on the social and political context, and the gains from innovation are not automatically shared equitably.

- **The gains of industrialisation are now under threat, especially in developing economies.** The Industrial Revolution led to unprecedented improvements in livelihoods, including in low- and middle-income economies. Yet in recent decades some of these gains have been eroded, and without a change in direction, the prospects for equitable and sustainable growth are bleak.

- **Not all innovations are alike, and their developmental impacts differ fundamentally.** Innovation lies at the centre of developmental progress, but innovations differ in scope and impact. Four broad types can be distinguished: incremental innovations, radical innovations, systems innovations, and revolutionary innovations.

- **Revolutionary innovations transform entire systems and require new policy frameworks.** Revolutionary innovations involve interlinked transformations across the economy, society, governance, and the environment. These long waves—referred to as Techno-Economic Paradigms—last for decades and are characterised by a dominant infrastructure connecting producers to markets. When paradigms decline and new ones emerge, periods of disruptive "creative destruction" ensue, making Business as Usual inefficient and requiring new institutional and policy responses.

- **Economic history since the Industrial Revolution has been shaped by successive technological paradigms.** Since the Industrial Revolution, the world has experienced four overlapping paradigms: waterpower and factory organisation; steam power and railways; heavy engineering, electricity, and internationalisation; and mass production, fossil fuels, and deep globalisation. The fifth revolution—the Digital Paradigm—is still in its early phase, constrained by institutional and social legacies of Mass Production.

- **Governments have always played a central role in enabling paradigm deployment.** Governments created the infrastructure, legal frameworks, and geopolitical conditions required for each paradigm. During the Mass Production Paradigm, states actively managed aggregate demand, while in the Digital Paradigm governments were central to the early development of core digital technologies.
- **Current global disruptions signal the exhaustion of the Mass Production paradigm.** As in previous transitions, today's paradigm shift is accompanied by severe economic, social, political, and environmental disruption. These include a fracturing global trade regime, persistent exclusion from productive employment, accelerating environmental crises, and weakened global governance institutions.
- **Disruption also opens new opportunities inherent in the Digital Paradigm.** As with all transitions, the threats of disruption are matched by new opportunities. ICTs are flexible and enable the descaling of production, proximity between production and consumption, and decentralisation of power. Their embodiment in products and infrastructure enables new needs to be met and new institutional and consumption patterns to emerge. Crucially, the Digital Paradigm is inherently systemic, interlinking economic, social, political, and environmental dimensions.

Niche innovations demonstrate the feasibility of a new development trajectory. The niche innovations discussed in Section 6 demonstrate the potential of the Digital Paradigm to support more equitable and sustainable growth in both advanced and developing economies. The central challenge is now to facilitate the rapid and large-scale diffusion of these complementary technological, economic, and social innovations.

Policy must be context-specific in a heterogeneous and uncertain world. The future remains highly uncertain, and national contexts vary widely. We therefore avoid prescribing specific sectors for intervention. Instead, we identify generic policy domains that can enable context-specific economic and social innovations aligned with the new paradigm.

Two Key Policy Lessons for Low- and middle-income Economies

Continuing with the past policy trajectory is not feasible. The world is experiencing a period of disruption across a number of fronts, and Business as Usual is no longer an option.

It is necessary to move from a 'catch-up' strategy (replicating the success of the rich countries, China and the 'Asian Tigers') to a bolder 'beyond catch-up' policy agenda, which charts a new path for a more equitable and sustainable development agenda.

Existing industrial structures remain relevant but must be redirected. These new policy agendas do not require the wholesale destruction of existing industrial and social structures. Nor do they invalidate the battery of industrial and innovation policy instruments which currently support economic growth. Much of what exists, such as heavy industry, minerals extraction, transport infrastructures, investments in human resources and trade with northern economies will continue to play a role in meeting future developmental needs. There is a continuing need to deepen a presence in early-stage growth sectors such as textiles, footwear, furniture and there remains a need to move into new more advanced and technology-intensive sectors, as well into the service sector. In all of these cases, policies designed to compensate for market failures and to promote long term capability growth remain of crucial importance. However the new Digital Paradigm creates many opportunities to transform the manner in which this inherited industrial structure operates and to provide the potential for new industries, new products and new services which will enhance living standards and welfare in a more equitable and more environmentally, socially and politically sustainable trajectory.

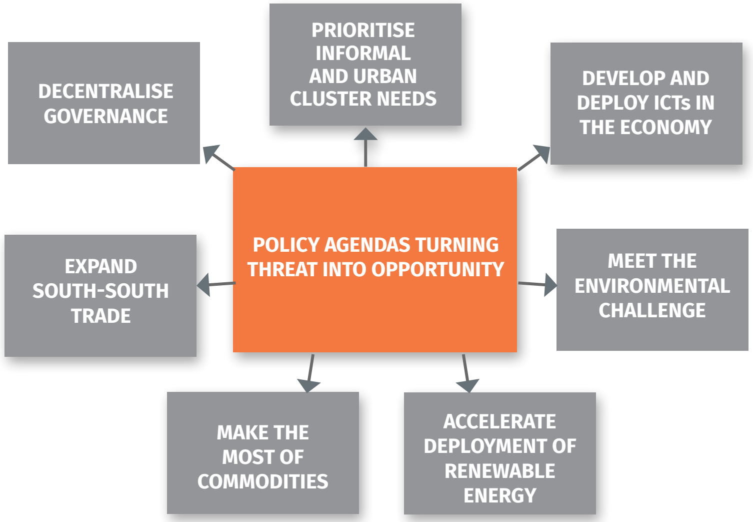
The proposal is for bold, digitally enabled redirection rather than incremental change. What is proposed is a set of bold policy interventions that exploit digital technologies to reshape growth trajectories within existing sectors and foster the emergence of new ones.

Transformation begins at the margins and accelerates through diffusion. The focus is on enabling a transition to a development trajectory which is appropriate to meeting context-specific developmental objectives. In each of the indicated areas of policy intervention we will highlight the importance of a systemic response and the key role to played by revolutionary ICT technologies. Both are central to the Digital Paradigm and stand in sharp contrast to the Mass Production Paradigm.

> "New and bold interventions, supplementing some existing industrial policies, to take advantage of new opportunities in the digital paradigm"

Equitable development now requires moving beyond imitation-based catch-up. Benefitting from the opportunities opened by the new Digital Paradigm requires a recognition that Business as Usual is no longer a feasible policy option and that low- and middle-income countries no longer seek to catch-up and mirror the path of the economies leading the Mass Production paradigm. Instead, they need to forge a new more equitable and sustainable path for development. Seven priority policy areas can help transform disruption into opportunity (Figure 14).

FIGURE 14. POLICIES TO TRANSFORM THREAT INTO OPPORTUNITY



7.1 PRIORITISE THE NEEDS OF INFORMAL AND URBAN CLUSTERS

Meeting the needs of excluded populations is one of the central development challenges facing low- and middle-income economies. More than two thirds of the non-agricultural population in Africa and South Asia, and more than half in Latin America, earn their livelihoods in the unregulated informal sector. Historically, expansion of large-scale, modern formal industry has failed to absorb these workers or improve their livelihoods, and in today's disrupted global economy it is even less likely to do so. Policies that continue to rely primarily on formal sector expansion therefore risk deepening exclusion rather than alleviating it.

Important lessons can be drawn from the historical evolution of the Mass Production Paradigm. Henry Ford's transformation of craft production into large-scale, standardised manufacturing dramatically increased productive capacity. However, during the Great Depression this capacity outstripped effective demand, prompting Keynesian analysis and Roosevelt's policy response through the New Deal. Massive deficit financing, rising wages secured by trade unions, wartime state procurement, and post-war welfare expansion and infrastructure investment collectively created the demand conditions required for mass production to succeed.

This experience demonstrates that demand is as important as supply in shaping industrial development and innovation. Government-driven demand creation was critical to the success of mass production, yet industrial and innovation policies have largely focused on supply-side interventions. Two conclusions follow. First, demand can be the handmaiden of supply, shaping investment, scale, and technological choices. Second, innovation is malleable: its direction is induced by the structure of demand. Where demand reflects high-income preferences, innovation tends toward capital- and skill-intensive, labour-saving technologies—a pattern clearly illustrated by the contrast between northern and southern capital goods discussed in Section 6.

Inclusive industrialisation therefore requires reorienting final demand toward the needs of the poor and excluded. A more appropriate production structure—one capable of generating manufacturing employment and inclusion - cannot be built solely around the consumption patterns of the global rich. It requires both adapting existing products and processes and developing entirely new goods and services aligned with the incomes, needs, and constraints of low-income consumers.

Three major obstacles complicate this reorientation toward inclusive demand. First, it demands a genuine political and policy commitment to prioritising the needs of the poor rather than treating them as a rhetorical add-on. Second, there is a profound lack of knowledge about the complex and interrelated challenges faced by excluded populations, spanning production, incomes, health, education, water, sanitation, and mental health. Third, these needs are systemically interconnected, yet policy interventions are typically fragmented across sectoral ministries, undermining their effectiveness.

> **"Committing to meeting the needs of the poor, knowing what these are, understanding their interlinkages, and committing to systemic interventions."**

In practice, policymakers know far more about high-income markets than about informal urban livelihoods. Global corporations invest heavily in understanding the preferences of middle- and high-income consumers, while the economic lives of informal urban populations remain poorly understood. In the absence of stable formal employment or living wages, households survive through portfolios of activities involving self-employment, family labour, social networks, and informal coordination with neighbours. Although these populations interact to varying degrees with public and NGO-provided services, the detailed structure of these interactions remains largely unmapped.

The first priority must therefore be to map the realities of informal and urban clusters in a systematic way. This includes understanding needs, consumption patterns, productive activities, social interactions, and the role of external actors. Central to this effort is listening directly to excluded populations through sustained social engagement. Digital technologies - particularly mobile phones - offer powerful tools for generating and analysing data on movement, communication, and commercial activity, provided that robust data anonymization and privacy protections are in place.

Big data analytics and AI can then be deployed to reveal the systemic nature of informal livelihoods. These tools can illuminate how income generation interacts with service delivery in areas such as energy, health, education, water, and social care, and how these interactions shape developmental outcomes related to nutrition, security, and wellbeing. Such insights are essential for moving beyond fragmented interventions toward integrated policy responses.

> "Using new technologies to understand the complex nature of communities and appropriate interventions."

Only once a nuanced picture of demand is established can effective supply-side strategies be designed. Demand analysis can identify which products and services are needed, whether they involve collective or public-good characteristics, and where low incomes suppress effective demand. It also clarifies where public resources or innovative financing mechanisms are required to address externalities and enable inclusive market formation.

Entrepreneurship should be recognised as a latent strength within informal economies rather than a policy gap. Entrepreneurship is widespread in excluded communities because it is essential for survival, yet it often remains invisible to policymakers. Supporting youth - many of whom possess digital skills - and women entrepreneurs can unlock new opportunities for inclusive growth, provided that appropriate business development services and institutional support are made available.

Appropriate production technologies are central to employment-intensive and inclusive industrialisation. Technologies must be small-scale, safe, employment-creating, and characterised by low barriers to entry. This requires reorienting national and local innovation systems away from their historic focus on high-income markets and highly skilled labour. Universities, research institutions, and training systems must adapt accordingly, enabling the emergence of domestic and local capital goods sectors suited to inclusive production.

> "Building on entrepreneurship in the informal sector with the involvement of the National System of Innovation."

Effective implementation will depend on coordination across existing government agencies. Many of the required interventions already fall within established mandates, but the challenge lies in aligning them toward low-income consumer needs and ensuring that agencies act in concert rather than in silos. This coordination challenge is taken up further in Section 8.

Smart City initiatives provide an underutilised platform for advancing this agenda. While such programmes have begun mapping service delivery and infrastructure use in large urban areas, they have largely neglected productive activities. Redirecting these efforts toward understanding and supporting informal production and livelihoods would allow digital technologies to play a transformative role in improving incomes and inclusion for populations excluded from the gains of the Mass Production era.

7.2 MEETING THE ENVIRONMENTAL CHALLENGE

Meeting the environmental challenge is a first-order development priority, on par with social inclusion. It encompasses a complex agenda of sustainable development, mitigation, and adaptation that spans the full range of human interaction with the environment, including production, consumption, recycling, disposal, and pollution. Environmental sustainability is therefore not a discrete policy domain but a systemic concern that cuts across economic and social systems.

The economic and social costs of environmental degradation, particularly climate change, are vast and well documented. Extensive analysis by the IPCC, UNEP, and other agencies has chronicled the scale of damage arising from ecosystem degradation and global warming. Resistance to greening the economy is often framed in terms of cost, yet this resistance is frequently short-term or misinformed. Many environmental costs are non-pecuniary, difficult to measure, or inadequately captured by conventional growth accounting frameworks.

Short-term investment horizons and discounting systematically undervalue climate-resilient innovation. Because many environmental damages unfold over long time horizons, their discounted financial value appears low relative to short-term investment returns. This weakens private incentives to invest in mitigation and adaptation, even where long-term social returns are substantial. These informational and temporal "blinkers" distort decision-making and delay necessary transitions.

As a result, the economic opportunities associated with greening the economy remain significantly under-recognised. Greening is not only about avoiding damage; it can generate new sources of value added, employment, inclusion, and equality. Some low- and middle-income countries - notably Costa Rica and Uruguay - have already begun to leverage these opportunities, demonstrating that environmental sustainability and growth are not mutually exclusive.

The scale of today's environmental challenge reflects the legacy of the post-1950 'Great Acceleration'. This period marked the transition from the Holocene to the Anthropocene, characterised by rapid growth in production, consumption, and resource extraction that has pushed multiple planetary boundaries beyond safe limits. Given the heterogeneity of environmental challenges, the discussion here focuses on three illustrative greening agendas with direct implications for industry, manufacturing, and employment: the water–energy–food–ecosystem nexus, dematerialisation of production, and value chain efficiency, particularly in logistics.

The Water, Energy, Food Security, Ecosystem Nexus

The WEFE nexus places interconnected resource systems at the centre of sustainable development strategies. By emphasising interdependencies - especially the central role of water security - the nexus approach is increasingly recognised as critical to economic

greening, particularly in food and agro-industrial value chains. Figure 15 illustrates the principal linkages and causal relationships within the nexus.

FIGURE 15. MULTI-DIMENSIONAL INTERLINKAGES OF THE WEFE NEXUS

Water ↔ Energy	Water is indispensable for energy generation across multiple technologies - powering hydroelectric plants, cooling thermal plants, cultivating crops for biofuels. Energy is essential for water related processes - the treatment and distribution of water, pumping groundwater, and seawater desalination.
Water ↔ Food	Water is the cornerstone of agricultural production and the broader agri-food supply chain, as well as urban life. However, water for agricultural uses may degrade water quality through runoff containing pesticides, fertilisers, or other pollutants. The manner in which water is used in agriculture, rather than the aggregate demand for water is often the driver of trade-offs.
Food ↔ Energy	Energy is a critical component of the food chain, supporting activities such as irrigation, food processing, storage (including refrigeration), and transportation. However, competing land uses can lead to conflicts, for example when land is allocated for large scale energy projects like solar farms, potentially limiting areas available for food production. Agrivoltaics (combining land for agriculture and solar energy), can improve water conservation by reducing water from evaporation (through shade from solar panels) while producing clean energy that decreases reliance on fossil fuels.
Ecosystem Sustainability	Healthy ecosystems underpin the resilience and sustainability of water, energy, and food systems. They provide critical services such as water storage, water filtration, soil fertility, and climate regulation. Unsustainable exploitation of water, energy, or food resources can degrade ecosystems, diminishing their ability to support human and environmental well-being. Preserving ecosystems is therefore essential to sustaining the nexus over the long term.

Source: Petrie et al. (2025)

Water and energy systems are deeply interdependent across multiple technologies. Water is indispensable for energy generation, including hydropower, cooling of thermal plants, and biofuel production, while energy is essential for water treatment, distribution, groundwater pumping, and desalination. Disruptions in one system therefore propagate directly into the other.

Water and food security are tightly linked through agricultural production and environmental quality. Water underpins agriculture and agri-food supply chains, but agricultural practices can degrade water quality through runoff of fertilisers and pesticides. Crucially, trade-offs often arise not from total water use but from how water is managed and applied within agricultural systems.

Energy plays a central role in food systems while also generating potential land-use conflicts. Irrigation, processing, cold storage, and transportation are all energy-intensive. Competition between land for food and for energy infrastructure - such as solar farms - can generate trade-offs, although innovations such as agrivoltaics offer synergistic solutions by combining energy generation with agricultural production while reducing evaporation losses.

Ecosystem sustainability underpins the long-term viability of water, energy, and food systems. Healthy ecosystems provide essential services, including water filtration, soil fertility, climate regulation, and biodiversity conservation. Unsustainable exploitation of resources undermines these services, weakening the resilience of the entire nexus and threatening both environmental and human wellbeing.

The WEFE nexus provides a systemic framework for resource management and investment. Isolated sectoral investments may achieve narrow objectives but often generate unintended negative impacts elsewhere in the system. A nexus approach explicitly evaluates synergies, trade-offs, and distributional impacts across interconnected systems, enabling more resilient and sustainable outcomes, albeit at higher analytical and coordination costs.

Managing trade-offs is central to nexus-based decision-making. Unlike siloed approaches that implicitly assume win–win outcomes, the nexus framework confronts resource constraints directly. For example, large-scale irrigation investments may improve food security while exacerbating water scarcity, increasing energy demand, or degrading ecosystems.

> The WEFE nexus approach requires considering all the interconnected issues – costs and benefits - but then deciding which drivers to focus on for appropriate strategic interventions.

Integrated nexus strategies can optimise synergies where conditions allow. Solar-powered irrigation systems, for instance, can simultaneously raise agricultural productivity, reduce fossil fuel dependence, and limit environmental damage, while promoting more equitable access to scarce resources such as water across sectors, including industry.

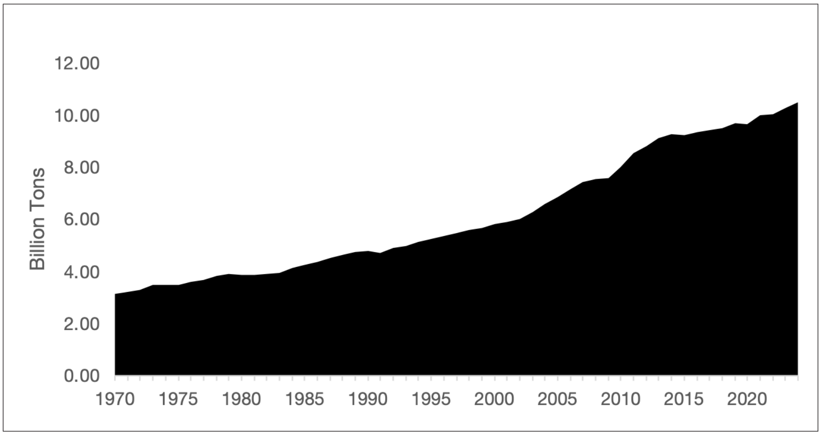
In contexts of acute scarcity, explicit trade-off decisions are unavoidable. Countries facing severe water stress—such as Egypt—may need to prioritise water use for energy generation over food production. Nexus-based cost–benefit analysis may reveal that food security objectives can sometimes be met more effectively through income growth enabled by expanded energy access rather than through water-intensive agricultural expansion.

Optimising the productive use of scarce resources requires active industrial and policy intervention. Where water is the binding constraint, government policy has a critical role in incentivising private investment toward technologies and practices that maximise productivity while minimising environmental stress. Since WEFE is essentially an interrelated system which cuts across a range of economic and social sectors, improvements in performance can benefit in material ways from the interconnected synergies central to digital technologies. Arguably, without exploiting these digital synergies, it will be difficult to make progress in restructuring the WEFE system.

Dematerialisation

The human footprint on the biosphere has expanded dramatically since the Great Acceleration after 1950. As illustrated in Figure 16, which aggregates all forms of resource extraction - minerals, hydrocarbons, and crops - global material use has grown without interruption. Between 1970 and 2024, total global material consumption increased by more than 340 per cent, reflecting the material intensity of post-war growth trajectories.

FIGURE 16. WORLD RAW MATERIAL CONSUMPTION 1970 - 2020



Source: Calculated from https://www.resourcepanel.org/global-material-flows-database

Absent decisive intervention, resource extraction is projected to intensify further, exacerbating environmental stress. Without immediate and concerted action, global resource extraction could rise by a further 60 per cent by 2060 relative to already unsustainable 2020 levels (UNEP 2024). A particularly damaging aspect of this trajectory is the hydrocarbon intensity of production and consumption, which remains the principal driver of global warming and climate change.

The Circular Economy framework provides a coherent and operational architecture for dematerialisation. It is structured around four interrelated strategies—the 'Four Rs': Reduce, Reuse, Recycle, and Regenerate—each requiring systemic and coordinated action across production, consumption, and waste management.

Reducing material intensity requires changes in processes, materials, and business models. The first R (Reduce) goes beyond energy efficiency to encompass the full range of material inputs used in production. It involves redesigning production processes, substituting materials, and developing new materials, areas already addressed by existing UNIDO programmes. Critically, it also entails transforming products into services wherever possible, a shift already evident in the digitisation of music, film, and written content enabled by ICTs.

> Circular economy analysis and interventions provide new opportunities.

Reuse challenges entrenched production and consumption patterns based on short product lifecycles. The second R (Reuse) requires design changes that enable upgrading, repair, and modularity - such as mobile phone upgrades - as well as behavioural changes by consumers, including the avoidance of single-use packaging and the adoption of refillable containers.

Recycling plays an increasingly important role as products and components reach the end of their useful lives. The third R (Recycle) seeks to ensure that materials are recovered rather than discarded. Significant progress has been made in recycling plastic packaging and, in response to growing shortages of critical materials, in the recovery of batteries, magnets, and electronic devices.

Regeneration addresses residual waste where reduction, reuse, and recycling reach their limits. The fourth R (Regenerate) involves using discarded waste in efficient processes to recover the energy embedded in materials, thereby minimising final disposal and closing material and energy loops.

Each element of the circular economy is inherently systemic and digitally enabled. The Four Rs are deeply interdependent: changes in production and use require parallel changes in design, and effective implementation demands coordinated action across value chains and consumption practices. Digital technologies are central throughout - design is ICT-intensive, value chain coordination relies on digital data exchange, and efficiency gains in production depend on ICT-based monitoring and machine control.
Dematerialisation opens substantial opportunities for employment growth, particularly in manufacturing-related services. Maintenance, repair, disassembly, recycling, and related activities are labour intensive and can generate significant employment as economies shift from throwaway models to repair-and-reuse systems of production and consumption.

Realising these opportunities requires behavioural as well as technological change. While these employment and sustainability gains have been widely recognised in high-income economies, particularly within the European Union, their successful adoption depends as much on shifts in values, in consumer behaviour, institutional practices, and regulatory frameworks as on technological innovation alone.

Value Chain efficiency

Inefficiencies in logistics across value chains represent a major but often neglected source of excessive energy and material use in low- and middle-income economies. In many cases, interventions to reduce waste and improve energy efficiency focus narrowly on individual links in the chain, typically reflecting the mandates of specific firms or ministries. The maize–flour–food value chain illustrates this pattern clearly.

Policy and investment efforts are frequently fragmented along institutional and sectoral lines. Ministries of Agriculture, often working with private actors, promote improved farm-level storage technologies to reduce postharvest losses, while Ministries of Industry and equipment suppliers - predominantly from higher-income economies - focus on marketing more energy-efficient processing machinery. These interventions are valuable and necessary, but they rarely address the chain-wide sources of inefficiency.

> A systemic value chain perspective enables reduction of energy and materials used arising from logistic inefficiencies

In practice, the largest sources of waste and energy loss often arise in logistics rather than at individual production stages. Although frequently unmeasured, energy losses caused by poorly maintained diesel trucks - such as dirty fuel injectors - may outweigh the efficiency gains achieved through upgraded processing equipment. Similarly, inefficient household cooking technologies contribute significantly to avoidable energy losses and could be replaced at relatively low cost, yielding immediate efficiency gains. These examples underscore the necessity of adopting a systemic value chain perspective to dematerialisation. Effective intervention requires a whole-chain approach that considers not only each link in isolation but also the interactions between links and the cumulative effects of these interactions on energy use and material waste.

The experience of the Toyota Production System illustrates the productivity gains that arise from managing interlinkages across the chain. As described in Section 3, Toyota recognised that factors such as container design directly affected wastage, quality, and efficiency within manufacturing plants. Crucially, it also learned that improvements within the firm would be undermined unless complementary changes were made throughout the supply chain.

Dematerialisation through value chain efficiency is therefore less about technological breakthroughs than about coordinated systems change. There is no 'rocket science' involved, but meaningful gains depend on aligning the actions of multiple stakeholders - firms, ministries, service providers, and households - who have historically operated in isolation.

ICTs play a central enabling role in delivering system-wide efficiency gains along value chains. Beyond improving the control of individual machines or processes, digital technologies facilitate the coordination of vertical and horizontal flows of materials, energy, and information. By enabling real-time data sharing and integrated decision-making across stakeholders, ICTs make it possible to implement coherent, chain-wide strategies that substantially reduce energy use, material waste, and environmental impact.

7.3 DEVELOPMENT AND DEPLOYMENT OF ICTS THROUGHOUT THE ECONOMY

Each technological paradigm since the Industrial Revolution has been shaped by the co-evolution of production systems and social organisation around a core general-purpose technology. The defining characteristics of such revolutionary technologies are that they generate manifold opportunities for profitable product and process innovation, that their cost falls rapidly and continuously, that they are available in effectively unlimited supply, and that they have pervasive applications across the economy. Digital technologies clearly meet all of these criteria.

The inclusive potential of digital technologies in low- and middle-income economies is already evident but remains largely underexploited. Section 6 illustrated a small number of low-cost innovations developed to meet the needs of populations largely excluded from formal economic growth. These examples represent only the tip of the iceberg, as a wide array of evolving digital technologies can be adapted to local conditions and unmet needs.

> ICT technologies to deliver services and products can be deployed across society to reap major economic and social gains.

The transformative impacts of digital innovation extend well beyond major urban centres. In Rwanda, drones are used to deliver medical supplies to remote rural areas, while in Kenya farmers can transmit images of diseased crops to specialised agencies that diagnose pests and recommend targeted treatments. These cases demonstrate the capacity of ICTs to overcome spatial barriers and extend essential services to geographically marginalised populations.

There is therefore abundant scope for large-scale initiatives to accelerate the development and deployment of ICT-based products and services across the economy and society. Whether implemented as a single comprehensive programme or a portfolio of coordinated initiatives, realising this potential requires confronting a set of enabling constraints. Several of the most critical are outlined below.

Connectivity

Digital connectivity is the foundational prerequisite for inclusive participation in the ICT-based paradigm. In most urban areas worldwide, mobile telephony provides access to both vertical communication with external actors and horizontal communication within social networks, although bandwidth constraints often limit data-intensive applications. Importantly, the gap in mobile and internet infrastructure between low-, middle-, and high-income countries is relatively narrow—much smaller than the gaps that characterised earlier paradigms reliant on railways, electricity grids, roads, or fixed-line telephony.

This relatively small infrastructure gap reflects the historical path dependency of earlier technological systems. In high-income countries, the extensive rollout of fixed-line telephony during the era of mass production slowed the adoption of mobile technologies, whereas many low- and middle-income countries were able to leapfrog directly to mobile networks.

Two obstacles nevertheless continue to limit the benefits of ICT connectivity for excluded populations. The first is the cost of access to devices and data services; the second is weak connectivity in remote and sparsely populated regions. Rapid advances in low-Earth-orbit satellite technologies now offer the technical potential to overcome both constraints, provided that appropriate regulatory and policy frameworks are adopted. The emerging challenge is therefore less whether universal connectivity is technically feasible than whether it will be realised in practice and who will reap the benfits of inclusion (users or internet providers).

Digital Skills

The nature of skills inequality has shifted fundamentally in the current technological paradigm. In previous eras, the dominant divide was between countries, with low-income economies suffering from deep and persistent skills deficits. In contrast, inequities in digital skills today are more strongly structured by age and gender than by national income level.

Young populations in many low-income countries display remarkably high levels of digital fluency. In many cases, their digital capabilities match or even exceed those of their peers in high-income economies, reflecting widespread exposure to mobile technologies, social media, and informal digital learning environments. This demographic dividend represents a major, yet underutilised, asset for inclusive digital transformation.

Entrepreneurship

Entrepreneurship is central to translating digital capabilities into employment and industrial growth. As in all economies, start-ups require targeted support, and mainstream industrial and innovation policies typically prioritise firms emerging from universities and formal research institutions within National Systems of Innovation (NSIs). Many low- and middle-income countries possess strong research linkages and skill bases, making these 'best practice' instruments relevant beyond high-income contexts.

Digitally based start-ups emerging from informal settlements and low-income communities remain systematically underserved. Their constraints are not rooted in a lack of entrepreneurial capability – innovation is often a necessity for survival in informal economies – but in the absence of business support tailored to new markets in low-income urban clusters and impoverished rural areas. At present, this gap is largely filled by NGOs, often externally funded and managed.

A fundamental reorientation of entrepreneurship support is therefore required. Policy attention must shift from an exclusive focus on formal, institutionally embedded firms toward the informalized sector, where large numbers of digitally savvy entrepreneurs operate without access to finance, mentoring, or market integration.

The growth potential of digitally enabled informal-sector start-ups should not be underestimated. Across Africa, there has been a rapid expansion of digital firms originating in informal urban settlements, frequently founded by unemployed but digitally skilled school and university graduates - Kenya being a prominent example (Melia 2020). Similarly, motorcycle ride-hailing platforms in Indonesia and Malaysia emerged from informal contexts and have evolved into large multinational, research-intensive firms.

National Systems of Innovation

Harnessing digital technologies for inclusive development also requires strengthening National Systems of Innovation. While innovation in informal and marginalised contexts demands greater policy attention, universities, research institutions, science-based ministries, and firms in producer services and capital goods sectors remain critical to skills formation and technological upgrading.

The challenge is therefore one of balance rather than substitution. Expanding opportunities for informal-sector entrepreneurship must proceed in parallel with sustained investment in NSIs, particularly in the development, adaptation, and diffusion of digitally based innovations across the economy.

In summary, the economy-wide diffusion of digital technologies requires a systemic approach that recognises their interconnected nature. Inclusive digital transformation depends on coordinated action across connectivity, skills, entrepreneurship, and innovation systems, and on policies that link economic and social objectives in ways that fully exploit the pervasive and integrative character of ICTs.

7.4 RENEWABLE AND DISTRIBUTED ENERGY

Energy has always been central to production, but the fifth wave marks a profound shift. By the third and fourth industrial waves, electricity became the backbone of both production and consumption, largely generated from hydrocarbons - coal, oil, petroleum, and gas - through centralised, large-scale utilities. This supply-focused model largely ignored patterns of consumption. The fifth wave, however, disrupts these conventions: energy generation is increasingly decentralised, renewable, and responsive to demand, transforming both economic structures and social opportunities.

> **Renewable energy is low cost, distributed and dispersed, and with ICTS balances supply and demand offering opportunities for a new growth path.**

Renewable electricity is rapidly replacing hydrocarbons and enabling localised energy generation. Unlike in the mass production era, electricity today is generated from solar, wind, biomass, geothermal, and nuclear sources, with emerging possibilities from wave power. While carbon-based interests continue to resist, renewables are increasingly cost-competitive despite intermittency challenges. Critically, energy is no longer confined to large utilities; distributed generation, particularly from solar, allows electricity supply to follow patterns of demand, opening opportunities for more equitable and sustainable economic growth.

Energy can now be produced near the point of use, reducing exclusion. Historically, water-based power constrained production to the site of waterfalls, while steam, hydrocarbon, and electric power progressively separated generation from consumption. Fossil fuels required global transport and large centralised stations, excluding many users in low- and middle-income countries who relied on expensive diesel generators. In contrast, renewables are less scale-dependent, and technologies like solar, wind, and biomass enable low-cost energy generation close to where it is needed, reducing barriers for remote or underserved populations.

Large-scale power generation carries substantial costs and risks. Centralised power stations require extensive distribution infrastructure, which is expensive and inefficient; energy losses can range from 7 to 14 percent in large hydro projects (Sovacool, Lovell and Ting 2018). Massive projects, such as Ethiopia's $5bn Renaissance Dam or South

Africa's Kusile and Medupi coal plants, often face cost overruns, delays, and corruption. Dependence on foreign technology further concentrates political and economic power, limiting inclusion in low- and middle-income countries.

Renewables provide modular scalability, supporting more distributed economic activity. Unlike centralised plants, renewable technologies allow capacity to expand incrementally as demand grows, facilitating local economic development. Lower capital and operational costs make energy more accessible, enabling smaller-scale production and inclusive growth trajectories across regions previously excluded from reliable power supply.

Renewable energy reduces the environmental damage associated with fossil fuels and large hydro projects. Hydrocarbon-based fuels produce large quantities of carbon dioxide and methane, while extraction and transport impose serious ecological costs, exemplified by the 2010 Gulf of Mexico BP spill. Large hydro dams disrupt ecosystems, agriculture, and public health. Distributed solar and wind energy reduce these environmental risks by shortening transmission distances and decentralising production, gradually lowering embedded carbon and improving sustainability.

> "Renewable energy brings together generation and consumption."

The shift to renewable power promotes both sustainability and equitable growth. Renewables not only reduce emissions but also lower entry costs and allow energy production closer to demand, decentralising economic activity and reducing incentives for concentrated political power or corruption. Technologies such as solar, wind, biomass and green hydrogen, are expanding rapidly, offering scalable solutions for industrial applications while supporting more inclusive development paths.

Digital technologies are critical to the deployment, management, and efficiency of renewable energy. Solar systems rely on inverters, isolators, and junction boxes for safe integration; wind turbines depend on ICT-enabled sensors for monitoring and maintenance. At a systemic level, national grids use digital control systems to integrate multiple sources, while smart meters and AI-enabled thermostats optimise consumption. ICTs thus underpin both the efficiency and scalability of renewable energy, making them integral to the fifth wave of industrial and economic transformation.

In summary, renewable and distributed energy creates a pathway for sustainable and inclusive growth. By reducing environmental harm, lowering costs, enabling decentralised production, and supporting equitable economic development, renewables - combined with ICT integration - offer transformative opportunities for both industry and society in the fifth industrial wave.

7.5 MAKING THE MOST OF COMMODITIES

Many low- and middle-income economies possess significant natural resources, but the ability to benefit depends on multiple factors. The resource rents which economies can earn from their gifts of nature will depend on the economic and environmental viability of extracting raw material deposits and the balance of global supply and demand for the commodities. The capacity of the raw material countries to appropriate resource rents will be determined by the policy regimes providing access to the deposits, the efficiency with which the materials are extracted from the earth, the social and environmental safeguards that are in place and the degree of political stability. These framing conditions are general to all countries, rich and poor alike. The transition to the Digital Paradigm increases the demand for some metals and rare earths such as antinomy, rhenium, hafnium, niobium, gallium and vanadium.

The industrial challenge for mineral-rich economies is to maximise value both upstream and downstream. With respect to upstream backward linkages, the primary inputs are capital equipment and services. With respect to downstream forward linkages there are a number of stages of value addition. The first is the removal of waste to increase the concentration of the targeted ores. Subsequently the purity level of the extracted ore has to be increased. In the case of copper, which is critical to the digital sector, the first stage concentrates the ore to a level of 20 per cent and then subsequent smelting refines the metal to a 99.9 per cent purity level. As in the case of producing first stage concentrates, refining tends to be very energy intensive. Downstream from concentration, refining and smelting, the ores are then turned into final products which are used throughout industry. Except in the case of countries which have economically attractive raw material deposits, the transformation of refined metals into intermediate and final products tends to occur in foreign economies.

> **The digital economy demands new raw materials. ICTs improve efficiency of exploration, extraction and processing; and reduce waste. Distributed energy production provides new opportunities for deepening value added and reducing waste and effluent by processing raw materials near the site of mining.**

The Digital Paradigm substantially increases the economic potential of commodity deposits. Minerals critical for ICT applications experience higher global demand, driving up prices for scarce materials with long extraction and processing cycles. This surge in demand offers major opportunities for countries to capture additional resource rents, particularly where deposits are strategically important to digital technologies.

ICT deployment enhances both extraction and processing efficiency. AI accelerates mineral exploration, while automated mining technologies increase productivity and reduce waste in low-grade deposits. Across the supply chain, digital tools streamline operations, from ore sorting to refining, reducing costs and improving output quality.

Renewable energy further strengthens the capacity of resource economies to capture value. By providing low-cost, reliable electricity onsite, renewables reduce dependence on expensive diesel or grid power, enabling energy-intensive processing closer to extraction sites. Modular and scalable energy solutions make smaller or lower-grade deposits economically viable, expanding opportunities for industrial development in remote mining regions.

Processing ores near extraction sites reduces environmental and logistical costs. Minimising transport of waste materials lowers carbon emissions, reduces pollution, and supports localised industrial activity. Renewable energy also enables more sustainable operations in sparsely populated regions, integrating production efficiency with environmental stewardship.

Systemic opportunities arise from coupling renewable energy with innovative processing technologies. The example of green steel production in Brazil illustrates how renewable power can transform commodity extraction and processing. These benefits extend beyond metals to 'soft commodities' such as agriculture and fisheries, demonstrating that the Digital Paradigm creates interconnected, environmentally and economically sustainable pathways across both hard and soft commodity sectors.

7.6 SOUTH-SOUTH TRADE

The Mass Production Paradigm's decline after the 1970s was offset by globalisation and the rise of global value chains. Productivity and corporate profitability fell in many industrial economies, which under previous paradigms would have led to rapid industrial atrophy. However, deepening globalisation and the development of GVCs extended the life of mass production by enabling firms to access low-cost labour in developing economies. This global dispersion of production fueled export-oriented industrial growth in several north Asian economies, including the 'Asian Tigers' and later China and Southeast Asia, generating significant economic transformation.

Export-led growth in China and other north Asian economies relied heavily on external markets but had global spillover effects. While China's export dynamism created rapid industrial expansion and global competitiveness, it also contributed to the erosion of manufacturing employment in high-income countries. Additionally, China's presence in major markets limited export opportunities for other developing economies and often displaced domestic production, constraining industrialisation and employment growth elsewhere in the Global South.

Rising trade protectionism has reshaped opportunities for developing countries. Employment impacts in high-income economies triggered political resistance, leading to tariffs and trade barriers. Some economies adjacent to China, such as Vietnam and Indonesia, have partially benefitted by attracting offshored production to bypass these barriers. However, these gains are limited, and overall protectionism constrains the potential for developing countries to expand in traditional South-North value chains, reducing the prospects for export-led growth.

> **South-South trade and regional value chains offers growth opportunities for low- and middle-income countries. Similarities in factor endowments and in consumer incomes and needs provides scope for more employment intensive and inclusive technologies, and small-scale and locally owned enterprises.**

South-South trade has grown more rapidly than inter-regional trade over the past decade. Unlike South-North GVCs, South-South value chains often produce goods tailored to lower-income consumers and rely on more labour-intensive production processes. While these regional chains sometimes lack ESG safeguards - leading to environmental degradation and exploitative labour conditions - their expansion offers significant development opportunities, including employment creation, small firm participation, and engagement of less skilled labour.

Policy frameworks are increasingly supporting South-South trade. Trade agreements within the Global South, reflecting the co-evolution of economic logic and policy, are fostering regional integration and market access. The African Continental Free Trade Area (AfCFTA), signed in 2018 and implemented in 2021, is a landmark example, encompassing 43 countries and over 1.3 billion people, although its full potential is still to be realised.

7.7 DECENTRALISE GOVERNANCE

The transition from the Mass Production Paradigm to the Digital Paradigm entails a fundamental shift in scale and governance. Governance encompasses political power relations (national, regional, local), institutional structures (such as education and health systems), and organisational hierarchies (vertical information flows and decision-making). Mass Production relied on centralised authority, standardised products, services, and institutions. By contrast, the Digital Paradigm is flexible, allowing for customised products and services, horizontal information flows, and increased bottom-up decision-making. This shift supports a more geographically decentralised, centripetal trajectory that promotes inclusive and sustainable development.

Institutional change in governance is gradual and path-dependent. As with all paradigm shifts, existing routines, behaviours, and values are "sticky" and take time to adjust. There is no single blueprint for governance in the Digital Paradigm; multiple configurations are possible. Nonetheless, recognising the direction of change provides important guidance for policy design and implementation.

> **"The flexibility of digital processes creates the opportunity for a more decentralised form of governance, but this requires restructuring and capacity building of appropriate institutions."**

Policy formulation and execution should shift from the centre toward local and regional authorities. The degree of decentralisation required depends on historical centralisation, the size and nature of entities involved, and local circumstances. Fiscal decentralisation and delegated expenditure may also be necessary. Strengthening regional and municipal governance is particularly critical when targeting equitable and sustainable growth in informalized and low-income urban communities.

The transition is driven by efficiency and opportunity, not solely by moral objectives. Shifts in economic geography, institutional power, and decision-making culture will take time, but the Digital Paradigm offers economic opportunities that make decentralised governance a strategic necessity. Incorporating the private sector into visions and policies is essential, as decentralisation, dispersion, and horizontal decision-making are the necessary complements to realise the paradigm's potential for equitable and sustainable growth.

8. IMPLEMENTATION AND LEADERSHIP

MANAGING PARADIGM CHANGE

- Paradigm change does not mean inherited policies are worthless or that existing industries must be scrapped.
- However, policies required to usher in more equitable and sustainable growth require a different approach and a different set of relationships between stakeholders.
- The new Digital Paradigm is systemic in nature and requires an integrated response which involves a combination of economic, social and environmental interventions.
- Policies are contextual, varying between countries, across sectors and over time.
- Policies need to be dynamic and flexible, changing with context and over time.
- Policies are a process dependent on a common approach between multiple stakeholders.

The era of Business as Usual has ended. The global economy, regional blocs, and individual countries are entering a period of profound transformation. Traditional markers of stability - 'normality', 'best practice', and the 'rules-based global order' - no longer hold. The introduction of widespread tariffs and the breakdown of international rules in the mid-2020s are not the root causes of this change; rather, they are symptoms of a deeper, epochal shift. Consequently, continuation of Business as Usual is no longer viable.

> "Business as Usual is no longer possible and for low- and middle-income economies a new development path has to be pursued in line with their need to increase industrial development and employment."

Purposeful action is essential for a successful transition. Historical experience demonstrates that major shifts in economic paradigms do not occur by accident. They require deliberate, coordinated action by societal actors across political, economic, and social spheres. The objective of this report is to provide a conceptual framework that allows key actors to transform the threats of this transition into opportunities for creation, inclusion, and sustainable growth.

Lessons from history must be adapted to context. While historical precedent offers valuable insights, each epochal transition is unique. Countries and sectors face distinct challenges, shaped by their structural characteristics, resources, and social dynamics. Detailed, prescriptive policy blueprints cannot be universally applied; instead, the principles of transition must be adapted to each nation's specific conditions, capacities, and development objectives. The future potential of the new Digital Paradigm is still emerging, adding further uncertainty.

The Digital Paradigm requires systemic gains, not just new technology. Unlike prior technological revolutions, the Digital Paradigm is distinguished by its capacity to deliver systemic improvements across social, economic, and industrial systems. Transition objectives therefore cannot be reduced to the adoption of digital or physical technologies alone. Policies must target integrated outcomes, leveraging the interplay between technology, social organisation, and institutional adaptation.

FIGURE 17. POLICY INITIATIVES FOR LOW- AND MIDDLE-INCOME COUNTRIES

- Addressing the needs of the mass of the population excluded from the fruits of economic growth, particularly those living in large urban conurbations
- Confronting the environmental challenges posed by climate change
- Developing and deploying digital technologies throughout economy and society
- Taking advantage of the systemic opportunities provided by the transition to renewable technologies
- Making the most of commodities
- Taking advantage of the opportunities opened by south-south trade
- Decentralising production and governance

Source: The authors

Section 7 identified seven broad policy initiatives shaping the economy and society in low- and middle-income economies (Figure 17). In advancing this policy agenda, two critical framing imperatives must be considered for these economies.

- **Low- and middle-income economies must pursue growth "Beyond Catch-Up."** Unlike high-income countries, which face aging populations and labor shortages, many developing economies have youthful populations and labor surpluses. Technological innovation must therefore prioritise inclusion - bringing more people into productive activity and addressing unmet needs. Advantages of backwardness - such as the ability to leapfrog outdated infrastructures - offer opportunities to adopt flexible, digitally based solutions without being encumbered by rigid legacy systems.

- **Replicating East Asia's growth trajectory is neither feasible nor desirable.** Low- and middle-income countries cannot simply emulate export-oriented, industrial-led strategies of China and other East Asian countries. Such replication would fail to address issues of social exclusion and environmental degradation. Without intentional directionality in technological adoption, industrial development risks reinforcing inequality rather than alleviating it. Yet many of these economies possess substantial innovative capabilities, often rooted in informal sectors and entrepreneurial youth networks, which can be harnessed to develop new, contextually appropriate growth pathways.

Hence, innovation deployment, not high-tech development, is the critical challenge. Scholars observe that "rocket science" – i.e. cutting-edge technological development - is often the easiest part of innovation. The harder challenge lies in deploying technologies effectively within complex social, economic, and organizational systems. Transitioning from the Mass Production Paradigm to the Digital Paradigm exemplifies this difficulty, as it involves integrated technological, social, and behavioral transformations.

The challenge therefore is to forge a new developmental path (Figure 18), one which does not seek to replicate outdated growth trajectories and to transition to a world which is Beyond Catch-Up

FIGURE 18. BEYOND CATCH-UP – FORGING A NEW DEVELOPMENT PATH

CRITICAL DEPLOYMENT STEPS TO FACILITATE THE DIGITAL PARADIGM		
VISION AND LEADERSHIP	⟷	GOVERNMENT
DEVELOP MISSION ORIENTED POLICY	⟷	GOVERNMENT WITH NATIONAL INNOVATION SYSTEM
COALITION OF THE WILLING	⟷	MINISTRIES, BUSINESS, CIVIL SOCIETY
CONFRONTING FETTERS TO CHANGE	⟷	BOLD LEADERSHIP BY GOVERNMENT
DEPLOY NICHE INNOVATIONS	⟷	PRIVATE SECTOR BACKED BY GOVERNMENT
GLOBAL SHARING OF AGENDAS	⟷	UN AGENCIES, WORLD BANK, DEVELOPMENT BANKS

1. **Vision and leadership are the foundation of effective implementation.** Historical examples, from Roosevelt's leadership during the Great Depression to Asia's post-war industrial catch-up, demonstrate that decisive leadership is indispensable. Vision provides the strategic orientation necessary to allocate resources effectively and guide systemic innovation. Without strong leadership, even technically feasible innovations may fail to achieve their potential.
2. **Developing a mission-oriented approach ensures coherent policy delivery.** Epochal transitions involve intertwined technical, social, economic, and political challenges. Achieving systemic objectives requires coordinated action across ministries, industries, and institutions. Analogous to the Apollo Moon Programme, which achieved its ambitious goals by uniting diverse stakeholders under a clearly articulated mission, modern policy initiatives must define high-level objectives and marshal cross-sector partnerships to achieve them. Too few missions indicate lack of ambition, too many risks loss of focus.

3. **Coalitions of the willing are essential for systemic change.** No single actor - public or private - can achieve the breadth of systemic transformation required. Coalition-building must occur across government ministries, private enterprises, research institutions, NGOs, and international partners. Collaboration within National Systems of Innovation, across public agencies, and with global organizations is critical to implement reforms effectively and to escape the constraints of siloed approaches. Leadership is context-specific: local governments, utilities, educational and health institutions, and industry must all coordinate within their domains to achieve collective outcomes.

4. **Overcoming blinkers and fetters to change is critical.** Resistance to change arises from two sources. First, blinkers: limited awareness or recognition of challenges and opportunities. This can be addressed through targeted education, communication, and capacity-building. Second, fetters: entrenched interests that benefit from the status quo, such as fossil fuel industries resisting the transition to renewable energy. Addressing these constraints requires honesty, boldness, and a combination of incentives, regulatory action, and coalition-building. Vision, leadership, and the ability to wield political and economic power are indispensable in overcoming these barriers.

5. **Niche innovations demonstrate the feasibility and benefits of the new paradigm.** Early-stage, localized innovations provide tangible evidence of the advantages offered by the Digital Paradigm. Section 6 presented ten such examples, spanning energy, agriculture, industry, and urban services. These innovations create demonstrable value, catalyzing wider adoption and accelerating systemic transformation. Rapid deployment of proven niche innovations is a key driver of successful paradigm transitions, as evidenced by China's recent growth in productive sectors and healthcare delivery.

6. **International collaboration and learning amplify national progress.** Transition to the Digital Paradigm is not only a national endeavor. Some challenges, such as environmental protection and climate adaptation, require supra-national coordination. Even when cross-border collaboration is not strictly necessary, learning from other countries' experiences can accelerate adoption, reduce risk, and inform policy design. International organizations - such as UNIDO, the UN family, the World Bank, the IMF, and regional development banks - play a critical role in facilitating knowledge exchange, providing technical and financial support, and fostering institutional collaboration.

In conclusion, effective implementation of the Digital Paradigm requires integrated leadership, mission-driven action, coalition building, overcoming resistance, rapid deployment of innovations, and cross-border learning. The transition is systemic, encompassing technology, social organization, governance, and economic practice. Low- and middle-income countries that strategically mobilize these elements can convert the challenges of the new epoch into opportunities for inclusive, sustainable, and resilient growth.

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