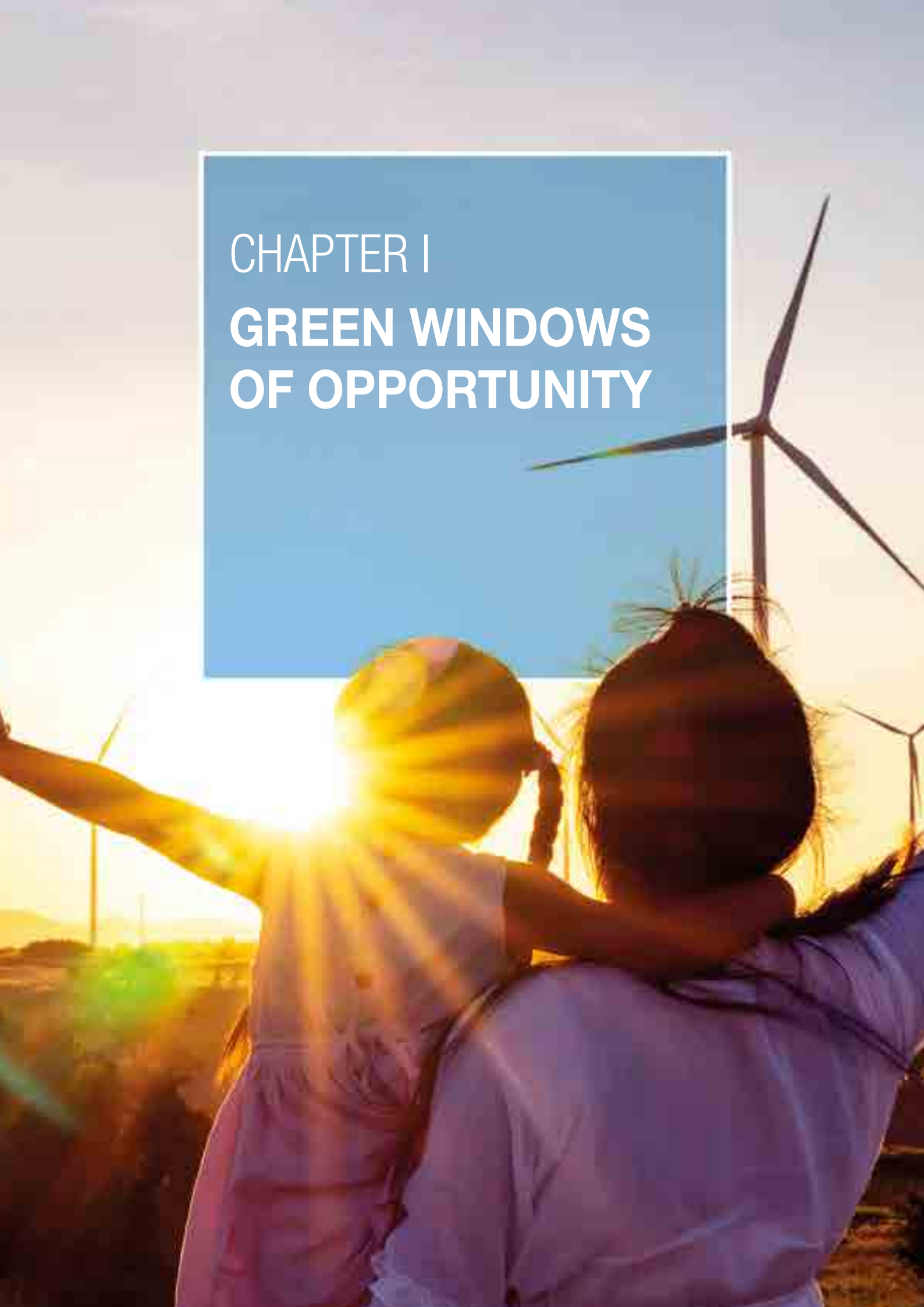
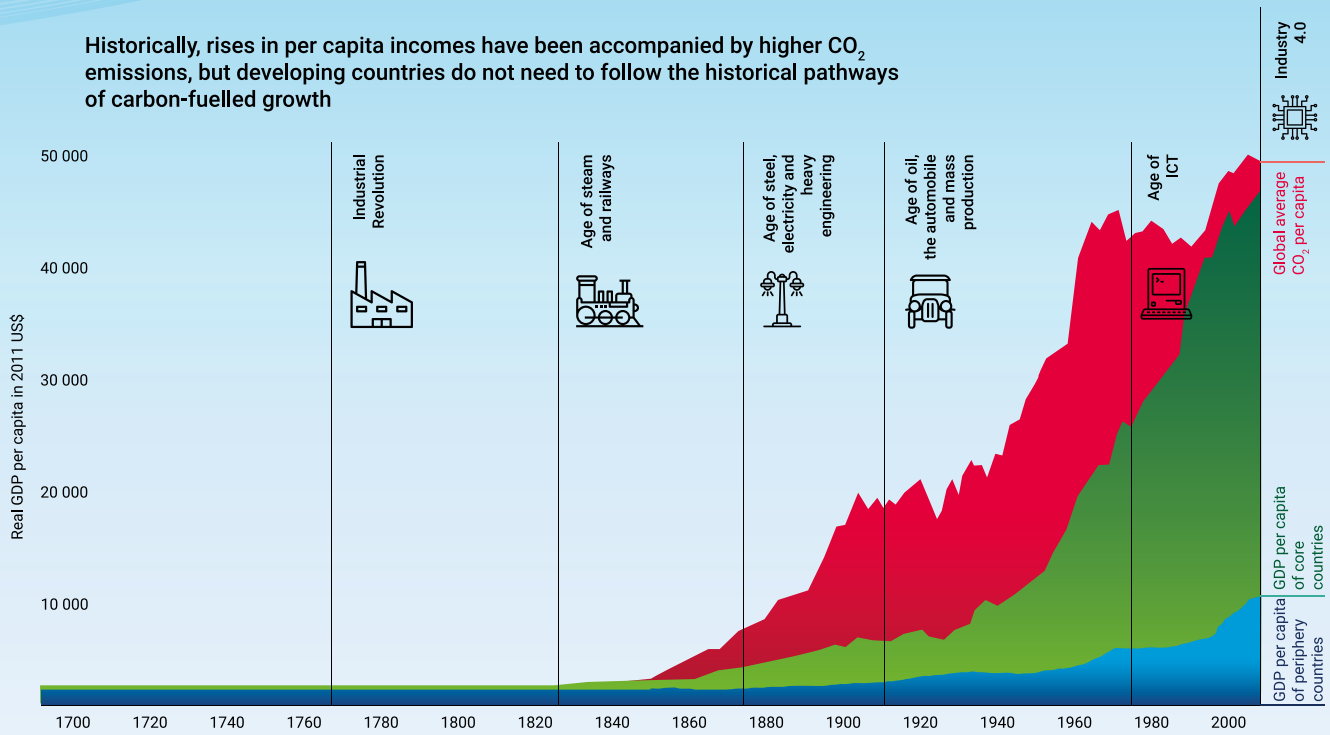


CHAPTER I

GREEN WINDOWS OF OPPORTUNITY

Countries must act now to use green technologies as a driver for sustainable economic development

Historically, rises in per capita incomes have been accompanied by higher CO_2 emissions, but developing countries do not need to follow the historical pathways of carbon-fuelled growth



Green innovation can spur economic and technological development and, at the same time, build resilience and mitigate climate disaster

Green innovation has four key characteristics:

- Higher degree of experimentation – countries have to be innovators. Path-following catch-up is not enough
- Driven by social value and the provision of climate-related public goods
- Direct government intervention
- Influenced by global agendas, rules, and mechanisms related to climate change such as the Paris Agreement

A technological shift based on renewables and digital technologies is happening now, and it creates Green Windows of Opportunities (GWOs)

Time-bounded opportunities that arise from changes in policy, markets, and technologies

National policies are key to open opportunities and build the capacity to take advantage of them

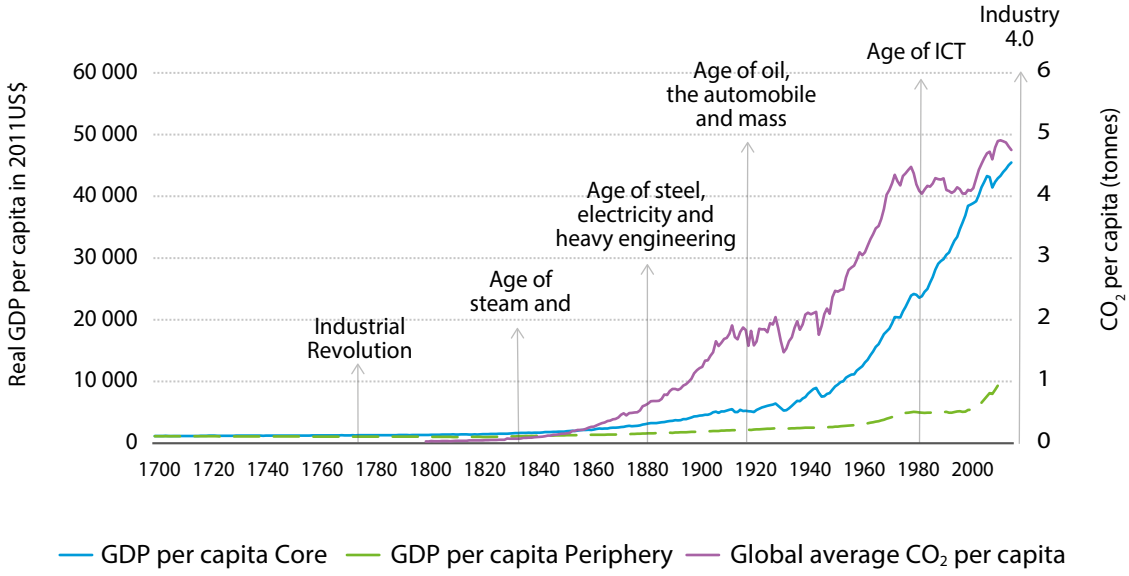
Access to technologies and knowhow is not enough – **TIMING IS ESPECIALLY CRUCIAL. WITHOUT IT, THE GREEN REVOLUTION WILL WIDEN GLOBAL INEQUALITIES**

In 2023, the world faces severe social and economic challenges. While trying to recover from the COVID-19 pandemic, many countries are now coping with the repercussions of the war in Ukraine, which has not only caused immense suffering but has also heightened geopolitical tensions and created threats to global trade, and to energy and food security.

Hovering over this sombre conjuncture is the climate crisis. As indicated in Figure I1, rises in per capita incomes have historically been accompanied by higher CO_2 emissions. Now, governments need to raise the incomes of the poor while also limiting carbon emissions. They must therefore make complex trade-offs between competing policy priorities – between promoting inclusive economic growth and protecting the planet.

Figure I 1

The great divide, rise in CO_2 per capita, and waves of technological change



Notes: "Core" corresponds to Western European countries and Australia, Canada, New Zealand, the United States and Japan. "Periphery" corresponds to the rest of the world.

Source: UNCTAD, based on data from Our World in Data and the Maddison Project Database, version 2018, Bolt et al. (2018), Perez (2002), and Schwab (2013).

The most difficult choices are in developing countries where this conjuncture of crises threatens hard-won development gains. They need more diverse and more productive economies to create more and better jobs, boost household incomes and reduce poverty. But faster economic growth will demand far more energy which, if sourced from fossil fuels, would send millions of tons of carbon billowing into the atmosphere.

Moreover, repeating the historical patterns of growth would further widen inequality. Before the industrial revolution, average incomes at the national level were similar across the world. Subsequently, as highlighted in the *2021 Technology and Innovation Report,* national incomes started to diverge, widening the gap between the developed countries at the core of the world economy and the developing countries at the periphery.[1] A hotter climate will affect everyone – rich and poor. And rising poverty and inequality will further heighten tensions within and between countries.

Developing countries need not, however, follow the historical pathways of carbon-fuelled growth – if the global community is committed to equitable social, economic and technological transformations guided by the Sustainable Development Goals.

This report focuses specifically on technological innovation. It does not suggest that these problems will be solved by technology alone, nor that new technology is necessarily beneficial – since the gains for one group can be detrimental for others. New technologies can destroy habitats, for example, or polarize societies, leaving many people further behind. But it does argue that innovation and advances in science and technology, if guided by the Sustainable Development Goals, can be used to drive the world along more sustainable and equitable pathways, particularly in the generation and use of energy. Developing countries need to open green windows now, at the beginning of the technological transformation, so that they can benefit from technological innovation and have a voice on the direction and pace of change, otherwise they will be once again left behind.

The report is built around the concept of green innovation – creating or introducing new or improved goods and services that leave lighter carbon footprints and open up green windows of opportunity that can help developing countries to catch up, achieve the SDGs, reduce poverty, tackle climate change and set the world on a more sustainable course. In terms of technology, developing countries typically lag behind richer countries. But as latecomers they can profit from earlier experiences, skipping some intermediate stages, and following their own trajectories and paths.[2]

For these transformations, developing countries should also rely on support from the more technologically advanced countries. In the past such assistance has been considered "technology transfer." In practice however, often firms have transferred manufacturing equipment with just enough training to operate it. Technology now needs to be transferred more through innovation cooperation – through equitable partnerships that evolve with changing technological needs and capabilities and with shifts in international political and economic landscapes. This will require new policies for innovation, along with new business models and approaches to financing.[3]

A report on these issues could be very wide in scope. It could, for example, consider how frontier technologies can affect climate change mitigation and adaptation, and how to balance the positive and negative sides of this transformation. Or it could address the impacts of greener products on inequality and elaborate on the important principals of the circular economy.

In the interests of brevity, however, the report focusses primarily on three topics, building on the recommendation of the *Technology and Innovation Report 2021* for developing countries to "adopt frontier technologies while continuing to diversify their production bases by mastering many existing technologies." First, developing renewable energy technologies. Second, applying frontier technologies to greener global value chains. Third, diversifying towards sectors that have lower carbon footprints. These topics are addressed across six chapters:

Chapter I – Green windows of opportunity – Describes the process of catch-up using green windows.

Chapter II – Moving fast with frontier technologies – With a special focus on green technologies and the preparations needed.

Chapter III – Growth powered by renewable energy - Examines the production of renewable energy in developing countries and provides insights on the opportunities for these countries to forge ahead in green sectors and related value chains.

Chapter IV – Twin transitions for global value chains – green and digital – How developing countries can use frontier technologies to go digital and go green.

Chapter V – Pathways to more complex and sustainable production – How developing countries can diversify their economies towards sectors with lower carbon emissions.

Chapter VI – International collaboration for more sustainable production – How international cooperation can transfer technology to and foster innovation in developing countries.

A. GREEN INNOVATION

Green innovation has its roots in the idea of a 'green techno-economic paradigm' first presented 25 years ago by economist Christopher Freeman. A techno-economic paradigm can be defined as a set of "common-sense guidelines for technological and investment decisions as pervasive new technologies mature."[4] A sustainable new techno-economic paradigm involves switching to greener technologies and modes of production.

Typically, each new techno-economic paradigm arises within the existing paradigm and may take 30 to 60 years to fully diffuse.[5] The current information and communications technologies (ICT) paradigm was born the early 1970s. The embryonic green paradigm is also benefitting from advances in ICT but more fully embraces digital technologies.[6]

Once a technological revolution matures, financial capital will explore the opportunities for higher profits, either by extending the paradigm to other countries or by investing in the development of further technologies, creating fresh technological waves.

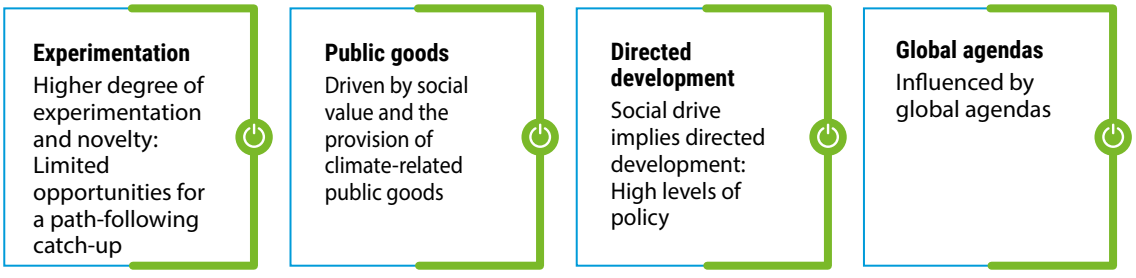
Typically, these waves reach developing countries after a delay – arriving initially in the form of consumer goods as, for example, with the introduction of smartphones and e-commerce. Only later have developing countries applied new technologies to their own production, through investment by multinational companies and later by domestic firms. The outcome is a patchwork of elements of different paradigms at different stages of diffusion in various sectors of the economy.[7]

Developing countries need not, however, wait for new technologies to arrive. They can start to ride the waves of technology in their earlier stages, using these advances to restructure their economies and to grow more rapidly (Box I-1). If they miss the earlier stages of a technological wave there is always the risk of falling irretrievably behind.[8]

Catching up requires more than simple imitation; it demands creative adaptation and innovation. As a result, current catch-up pathways differ substantially from those taken by technologically advanced economies.

Figure I2 illustrates four main components of catch-up based on green innovation. The starting point is experimenting with new ideas and technologies and adapting these to local circumstances, values and priorities (Figure I2). To take advantage of these ideas, they will need the appropriate infrastructure in the form of public goods which often require direct government intervention, supporting the establishment of new green sectors, for example, or introducing regulations such as on air or water pollution.[9] These public goods are freely available to all – they are non-excludable. Green innovation is also influenced by global agendas, rules, and mechanisms, especially, those related to climate change such as the Paris Agreement.

Figure I 2
Catching up with green innovation



Source: UNCTAD.

Box I 1
Overlapping technological waves

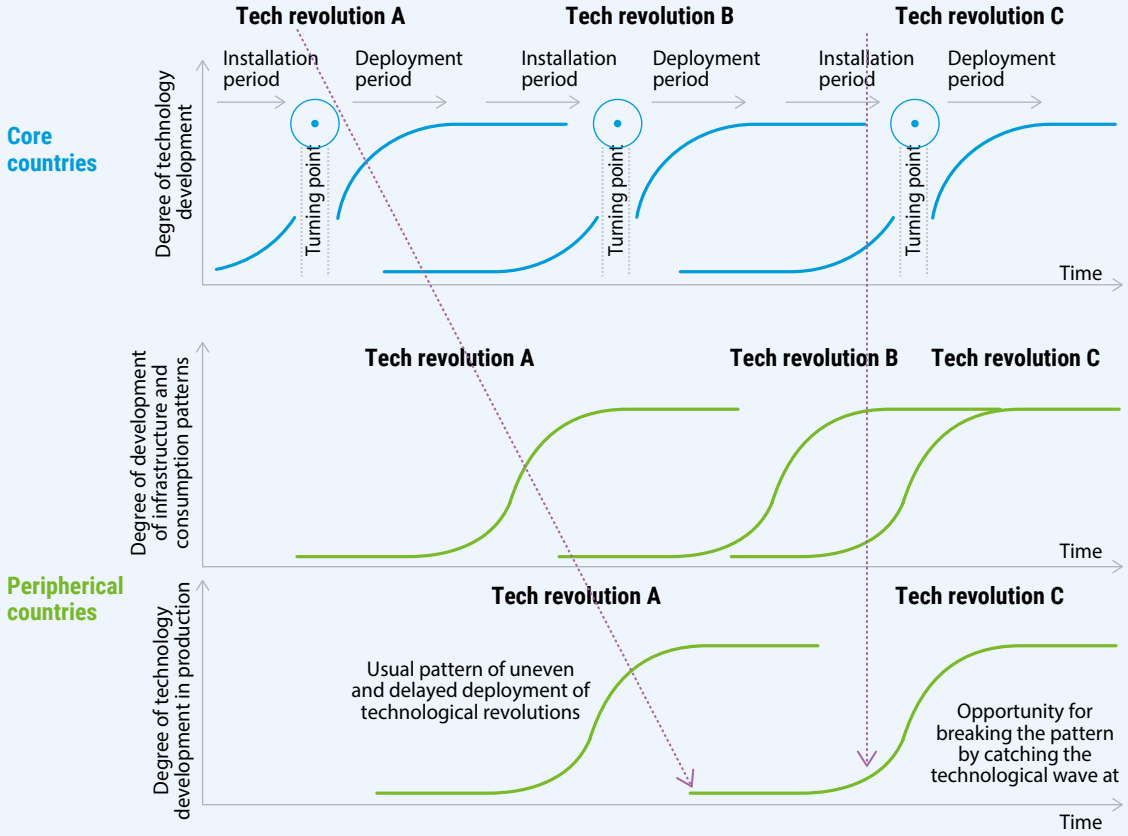
Technological changes can be very uneven and often arrive in overlapping waves. In the chart below, technological paradigm A reaches peripherical countries only when it has already matured in core countries. It first affects infrastructure and consumption patterns and only later is deployed in the production sectors. The pattern is similar for technological revolution B, which has yet to reach the production sectors of peripherical countries.

This pattern can be broken if developing countries take advantage of the emergence of a new technological revolution at its beginning. In technological revolution C, they actively take part in the installation phase – strategically and actively promoting:

a) Changes in domestic consumption pattern towards products related to the new paradigm

b) Installation and diffusion of the required infrastructure, and

c) Diffusion of the new technologies and related innovation in their domestic productive sectors.



Source: UNCTAD.

B. CREATING GREEN WINDOWS

Green windows are time-bounded opportunities that arise from changes in public institutions and policy interventions, markets, and technologies.[10] Previous opportunities have depended largely on external technology[11] or market changes,[12] but green windows of opportunity arise mainly within countries.

Created by public institutions – Green windows of opportunities are often institutional – promoted by public actions and related adjustments to the institutional framework conditions (rules, regulations, policies, etc). In Brazil, for example, the 1973 oil crisis triggered industrial policies to promote the use of biofuels. Similarly, in China in 2006 a renewable energy law stimulated the initial development of the

biomass industry,[13] which was supported by solar energy 'missions' such as the Rooftop Subsidy and the Golden Sun Demonstration Programs.[14] In Egypt, the 2014 Renewable Energy Law encouraged the private sector to produce more electricity from renewable resources. In the Philippines, the Renewable Energy Act of 2008 provided incentives for adopting new technologies.[15]

*Created by domestic market*s – Governments have been stimulating local demand for green products, for example, by feed-in tariffs aimed at creating competitive parity between green energies and fossil fuels. In India, the "Faster Adoption and Manufacturing of Electric Vehicles" plan stimulates the purchase and the deployment of charging infrastructure.[16] In the Philippines, the Green Public Procurement Roadmap aims to integrate the sustainability criteria in the public procurement process.[17] In China in 2013, the ""Guiding Opinions on Accelerating the Promotion of the Application of New Energy Vehicles" provided purchase subsidies for electric vehicles, supported by the 2015 "Guidelines for Accelerating the Plug-in Electric Vehicle Charging Infrastructure Deployment".[18] Local producers can also consider exports, but many green energy products are not readily tradable.

Created by research and development – Governments can also invest in public R&D programmes. Some examples are the wind offshore demonstration projects in China,[19] the demonstration project on the deployment of solar energy systems in rural health units in the Philippines,[20] and the governmental support for R&D, experimental proof and technology demonstration projects on Clean Energy in India.[21]

Throughout these processes, policymakers have to strike balances. They need to encourage local enterprises by subsidizing products, but if these capabilities are not to remain dormant, they must also stimulate market demand. At the same they must avoid the trap of stimulating green domestic sectors without corresponding investment in technical change, such that firms in developing countries may become market leaders but remain as technology followers.[22] Such institutional-cum-demand windows have been most effective for energy generation as with the use of solar PV in Brazil, China, and India which have large internal markets.

C. ALERT AND READY FOR CHANGE

If developing countries are to catch up, they should be alert to opportunities. This applies both to the policymakers and to firms and supporting institutions, such as universities, research centres, and standards organizations.[23] The firms most likely to be ready and alert are those operating in the same or closely related sectors.[24]

Readiness to seize opportunities has enabled some companies to become national champions. In China for example, this includes Dragon Power in the production of biomass, Suntec for solar PV, and Goldwind for wind technologies. Such firms can then expand to international markets – whether through licensing production overseas or establishing overseas subsidiaries. Goldwin's and Envisions' R&D subsidiaries in Europe, for example, established links with foreign universities and benefited from the recruitment of very experienced engineers.[25] These enterprises also expanded by buying companies in developed countries. For example, Dragon Power's acquisition of a Danish company was crucial for its leadership in the international biomass sector.[26]

In mature sectors, it is relatively easy for firms to acquire world-class technologies, and market success depends more on capital investment in organizational capabilities. In China, for example, following the 2006 renewable energy law, companies licensed core technologies and production plant designs for biomass and wind, mainly from European firms.[27] Similarly, for solar PV production capability they used foreign technologies to manufacture solar panels using globally dominant designs.[28]

In the domestic industry, innovation diffuses from first-movers to followers. In China, a relatively weak intellectual property regime has allowed knowledge to spill over from the leading companies to other domestic firms in related industries.[29]

Within specific sectors there can be intense interactions among lead firms, suppliers, technology providers, and financial institutions.[30] During the more demanding stages of technological upgrading, these contribute to technological deepening, as happened in the Chinese solar PV industry.[31]

Firm-level initiatives need to be supported by national institutions, particular in government and in universities – for example, through public R&D investments in process improvements and the application of complementary technologies.[32] In China, for wind power, university-industry collaboration facilitated the shift from onshore to offshore turbine technologies.[33]

For each of these sectors, the innovation system must continuously adapt to changing market and technological opportunities and take into account the different impacts and influences on men and women.

A key to all of this is smart sequencing. Typically, environmental and energy policies create demand which is then filled through industrial and innovation policies. For instance, the strategy may aim to create a demand through subsidies and price incentives for renewable energy, followed by a subsequent law allocating a share of domestic content for components in wind turbines.[34] Or conversely, in the case of the global shift from combustion engines to electric vehicles, innovation and industrial policies can support domestic design and manufacturing. Transportation policy then encourages domestic diffusion, followed by preparation for exports.[35]

D. CATCH-UP TRAJECTORIES

Catch-up refers to shifts in the balance of economic power between incumbents and latecomers, and can be driven by markets or technologies.

Market catch-up – This can start with government policies that stimulate a domestic market that can be satisfied by local products.[36] In renewable energy this may be quantified and measured as the share of energy generation capacity (in megawatts) sold and installed by domestic producers in the domestic and global markets. In other sectors, such as EV, it can be measured by domestic producers' number of units sold in domestic and global markets. Global market catch-up means achieving internationally competitive quality and prices for green products, such as wind turbines and solar PV panels, and related services. Marketplaces are small for certain pre-competitive, still immature technologies, such as concentrated solar power and green hydrogen.

Technological catch-up – To a significant degree, this relies on capabilities based on pre-existing knowledge and routines and strengthened by user-producer interactions.[37] There is however a distinction between technology that is new-to-the-country and world-class technology at the global knowledge frontier.[38] Both types interact during the latecomer development process since a closer connection to larger and more sophisticated markets may provide critical knowledge for technology improvements.[39] In addition, more robust technological capabilities may increase the competitiveness of national firms in the home and export markets.[40] However, this outcome is not automatic. A certain degree of technological capability attainment may enable domestic market development but may be insufficient for export competitiveness. Conversely, demand-led domestic development may help catch up in production capability, but not technological catch-up, which depends on firm-level advantages provided by access to lead markets.[41]

The next chapter assesses the current state of countries' technological capabilities in Industry 4.0 and green technologies.

1 UNCTAD, 2021a

2 Perez and Soete, 1988; Altenburg et al., 2008; Guennif and Ramani, 2012; Lee, 2019

3 Pandey et al., 2022; Hultman et al., 2012; WEF, 2022; IMF, 2022

4 Freeman, 1992, 1996; see also Kemp and Soete, 1992

5 Perez, 1983

6 Lema et al., 2020

7 Perez and Soete, 1988

8 Perez, 2002

9 Although the current ICT paradigm and the digital economy was very much spurred by public sector programmes and benefited from large investments in the military sector, much less deliberate direction was given by public policies. In fact, the digital economy is to a large extent an unintentional by-product, or positive externality, of investments in the military-industrial complex in the US, even if the state also sought to commercialise the outcomes of these investments. See also Deleidi et al., 2020.

10 Lee and Malerba, 2017

11 Wu and Zhang, 2010

12 Morrison and Rabellotti, 2017

13 Hansen and Hansen, 2020

14 Iizuka, 2015

15 UNCTAD, 2022a, 2022b

16 Press Information Bureau of India, 2022

17 GPPB-TSO, 2017

18 Kalthaus and Sun, 2021

19 Dai et al., 2020

20 UNCTAD, 2022b

21 UNCTAD, 2022c

22 Hain et al., 2020

23 Vértesy, 2017

24 Lee and Malerba, 2017

25 Haakonsson et al., 2020; Lema and Lema, 2012; Fu and Zhang, 2011

26 Hansen and Hansen, 2020

27 Dai et al., 2020; Hansen and Hansen, 2020

28 Binz et al., 2020

29 Hansen and Hansen, 2020

30 Fu, 2015

31 Binz et al., 2020

32 Shubbak, 2019

33 Dai et al., 2020

34 Lema et al., 2013

35 Lema et al (2020) discuss the sequencing of the various elements of GWOs. See also Konda, 2022.

36 Hain et al., 2020

37 This can be measured based on quantitative information (e.g., patent numbers and quality) or qualitative assessments of the distance from the global knowledge frontier in each sector.

38 Altenburg et al., 2008

39 Schmitz, 2007

40 Lee and Malerba, 2017

41 Beise and Rennings, 2005