UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT

TECHNOLOGY AND INNOVATION REPORT 2023

Opening green windows

Technological opportunities for a low-carbon world

OVERVIEW

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OPENING GREEN WINDOWS
Technological opportunities for a low-carbon world

1. Green windows of opportunity

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 energy and food security.

The most difficult choices are in developing countries where this conjuncture of crises threatens hard-won development gains. To eliminate poverty, they need diversified and more productive economies to create more and better jobs and boost household incomes. 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.

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.

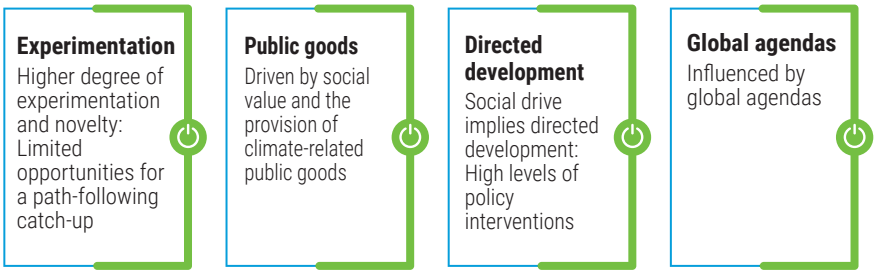
The 2023 edition of the Technology and Innovation Report focuses specifically on what can be achieved by technological innovation, by opening 'green windows of opportunity'. It does not suggest that these problems will be solved by technology alone, nor that new technology is necessarily beneficial – since the gains for one group can be detrimental for others. 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.

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. Developing countries now have opportunities to catch up, reduce poverty, and at the same time help tackle climate change and set the world on a more sustainable course.

For countries aiming to catch up with the more technologically advanced countries, switching green requires more than simple imitation; it demands

creative adaptation and innovation. The pathways are likely to differ substantially from those taken by advanced economies. The figure below sets out the four main components of green innovation. The starting point is experimenting with new ideas and technologies and adapting these to local circumstances, values and priorities (Figure 1). To take advantage of these ideas, countries will need the appropriate infrastructure and in the form of public goods – through direct government intervention, supporting the establishment of new green sectors, for example, or introducing regulations such as on air or water pollution. Green innovation is also influenced by global agreements and agendas, rules, and mechanisms, especially those related to climate change, such as the Paris Agreement.

Figure 1
The sequence for opening green windows



Source: UNCTAD.

2. Moving fast with frontier technologies

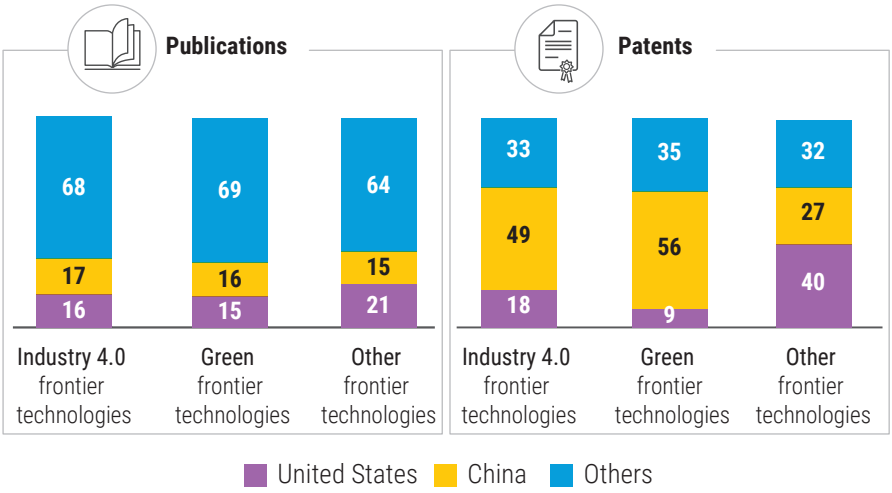
At the leading edge of green innovation are new and rapidly developing technologies that take advantage of digitalization and connectivity. The Report examines 17 of these 'frontier technologies' – from artificial intelligence (AI) to green hydrogen to biofuels – highlighting their potential economic benefits and assessing country capabilities to use, adopt, and adapt these innovations.

These technologies have experienced tremendous growth in the last two decades: in 2020 the total market value was $1.5 trillion and by 2030 could reach $9.5 trillion. Around half of the latter is for the Internet of things (IoT) which embraces a vast range of devices across multiple sectors. These technologies are supplied primarily by a few countries, notably the United States, China and countries in Western Europe.

As with previous waves of automation, frontier technologies are both destroying old jobs and creating new ones. Current job expectations may be more pessimistic because of the increasing capacity of AI to mimic human intelligence. Nevertheless, most alarmist scenarios often fail to take into account that not all tasks in a job are automated, and, most importantly, that technology also creates new products, tasks, professions, and economic activities throughout the economy. The net impact on jobs will depend on the final balance between creation and extinction.

For these new technologies, the knowledge landscape is dominated by the United States and China, with a combined 30 per cent share of global publications and almost 70 per cent of patents (Figure 2). Other countries compete in specific categories, notably France, Germany, India, Japan, the Republic of Korea, and the United Kingdom.

Figure 2
Country share of publications and patents, by frontier technology (percentage)

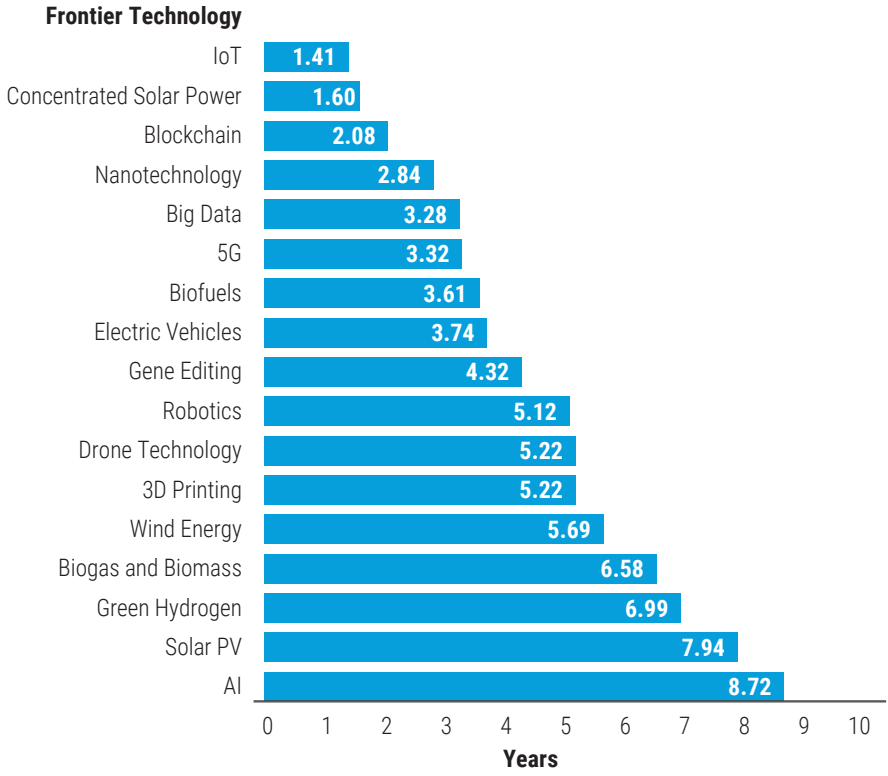


Source: UNCTAD calculations based on data from Scopus and PatSeer.

All these technologies are at the frontiers of change, but some are more mature than others, as is evident by the record of patents and publications. On the basis of the years in which patents were first sought and the period

over which the original patents were subsequently cited, the most mature technology is AI. Most patents for this technology were applied for in 2014 and cite patents on average from 2005, producing a difference of around 9 years. This may seem counterintuitive. But today's AI patents, such as those for autonomous vehicles and the metaverse, are technologically closer to those for search engines and digital maps, and many of the underlying principles patented in 2005 are still valid.

Figure 3
Patent maturity of frontier technologies



Source: UNCTAD.

Note: For each technology, the number in the bar graph shows the patent maturity, which is the difference between the weighted average patent application year and the weighted average year of the 20 most cited patents between 2000 and 2021.

IoT, on the other hand, is relatively immature, with an average patent application year of 2017 and an average citation date of 2016. This suggests that the dominant design behind IoT innovation is being updated almost yearly, reflecting a technology that is still evolving fast.

For developing countries that need to catch up, the more mature technologies may seem simpler and more affordable options since they demand less research and development. Biomass and solar PV, for example, have well-tested technologies that latecomers can absorb and use with imported machinery from the outside. For solar PV, for example, China initially imported foreign production machinery and benefited from economies of scale. However, these markets may now be more difficult to enter since the incumbents will have developed strong and efficient production processes and are able to trade internationally at more competitive prices.

3. Laying the foundations

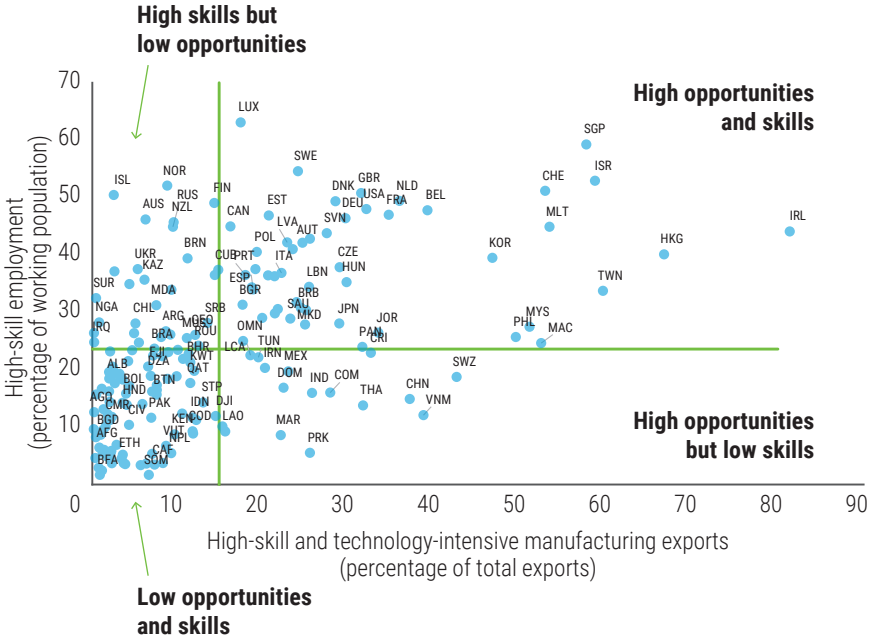
If developing countries are to capture the economic gains associated with new technologies, their firms must have the required capabilities. This includes not just scientific or technical skill, but also the necessary policies, regulations, and infrastructure. To assess national preparedness to equitably use, adopt and adapt frontier technologies, this report presents the 2023 results of the 'readiness index' that combines indicators for ICT, skills, R&D, industrial capacity and finance. This ranking for 166 countries is dominated by high-income economies, notably the United States, Sweden, Singapore, Switzerland, and the Netherlands. The second quarter of the list includes emerging economies – notably Brazil, which is ranked at 40, China at 35, India at 46, the Russian Federation at 31, and South Africa at 56. China's lower-than-expected position in the ranking, when compared with its productive and innovative capacities in frontier technologies, is due to urban-rural disparities in Internet coverage and broadband speed. Further behind are countries in Latin America, the Caribbean, and Sub-Saharan Africa, which are the least prepared to use, adopt and adapt frontier technologies and are at risk of missing current windows of opportunity.

Data on individual components of the index highlights areas that need to be improved. Overall, developing countries as a group have lower rankings for their indicators on ICT connectivity and skills. The LDCs, LLDCs, and SIDS

rank lower than 100 for all the indicators, with particular weaknesses in ICT infrastructure and research & development.

The countries best placed to move to smart production are those with higher levels of skill and stronger manufacturing industries. The figure below shows the balance between workforce skills and market opportunities – based on high-skill and technology-intensive manufacturing exports as a percentage of total exports, and high-skill employment as a percentage of the working population.

Figure 4
Readiness to benefit from the diffusion of Industry 4.0



Source: UNCTAD (2022). Industry 4.0 for Inclusive Development (United Nations publication, Sales No. E.22.II.D.8, New York and Geneva).

Note: The solid lines represent the global unweighted averages under these two indicators. Data labels use International Organization for Standardization economy codes.

Windows opening and closing

For developing countries and specific renewable energy products, the rapidly changing technological scene offers green windows of opportunity. Countries should take advantage of these now, if possible, since they are likely to close as other countries take over the markets. Otherwise, they may be firmly locked into fossil-fuel pathways, leaving the markets entirely to foreign investors. Much depends on the national preconditions and capacities and willingness to take opportunities and respond strategically as they arise.

Looking at renewable energy technologies, there is significant variability in catch-up trajectories at the sector and country level. The table below considers four scenarios – illustrating which windows have been open, or are within reach, and countries and technologies that have taken advantage of them.

Table 1
Four green window scenarios

Responses / Readiness	Strong	Weak
Strong	**Scenario 1: Windows open** Solar PV, Biomass, CSP – China Bioethanol – Brazil Hydrogen – Chile (potentially)	**Scenario 2: Windows to be open** Solar PV – India Biogas – Bangladesh CSP – Morocco Wind – China
Weak	**Scenario 3: Windows within reach** Biomass – Thailand and Viet Nam Hydrogen – Namibia	**Scenario 4: Windows in the distance** Wind – Kenya Bioenergy –Mexico and Pakistan

Source: UNCTAD.

The best scenario is the one in which strong preconditions are combined with strong responses. For green hydrogen in Chile, for example, the country has adequate preconditions and can show a strong response in development of the technology. Brazil, on the other hand, is in a strong position for biofuel. It has a long history of sugarcane cultivation and from the 1970s started to make significant investments in the technologies, while creating demand, and establishing a supportive framework. With that, the country has managed to catch up and become a global leader both in terms of technology, usage of ethanol, and fuel exports.

However, the lack of strong preconditions does not mean that the window of opportunity is closed. Much depends on the responses at different levels of government and the involvement of various public and private stakeholders. For example, the Thai government addressed weak initial preconditions for biofuel through strong policy responses.

Countries should surpass their initial constraints if they want to reap economic gains. While the opportunities differ greatly from one renewable energy technology to another, there are two main stages for countries switching green. The first is to identify and open windows of opportunity, based on the availability of natural resources, such as favourable wind conditions, and using policies to boost demand and national capacity to use or build the necessary technology. The second is to assess what is needed to sustain the processes. There are also likely to be feedback loops requiring regular adjustments.

Pathways to more complex and sustainable production

The best direction for developing countries is to switch to products that are more complex,[1] have greater value added and lower carbon footprints.

In most low-income developing countries, economic diversification involves emulating industries in more developed countries – a steady progression that builds on existing industries – it is thus 'path-dependent.' If a country already has the capacity for manufacturing medium and high technology products, it is in a stronger position and can move in a number of directions. But if it is largely producing primary products, it has fewer starting points. If basic technologies need to be learned or transferred from abroad, then innovation is likely to require greater government support. But whatever path they choose for switching green, governments in low and lower-middle-

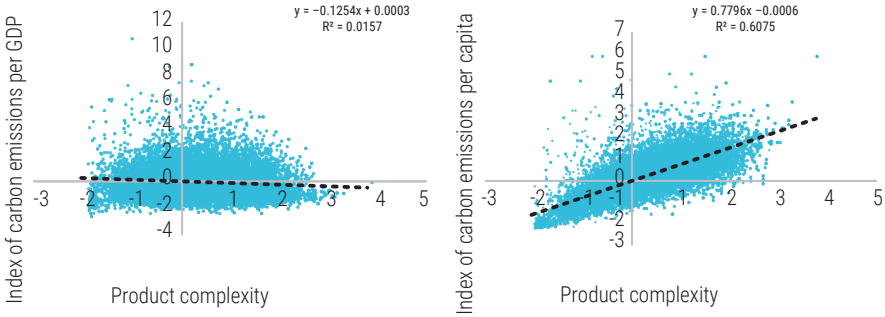
[1] More complex products are considered to require higher levels of technology to be produced.

income developing countries have to act fast and decisively; otherwise, they will be left further behind.

Generally, as countries move from agriculture to industry, and to medium and high-tech manufacturing, complexity increases. But this does not necessarily lead to greener production. The less-complex sectors that also have lower carbon footprint include textiles, vegetable products, foodstuffs and footwear. The sectors that are more complex and have higher carbon footprints include chemicals and allied industries, metals and mineral products. However, much will depend on the product mix, because within each industry, one can find products in a range of carbon emissions - from below to above the global average.

To help countries choose greener pathways UNCTAD has produced indices of economic complexity and carbon footprints for 43,000 products exported in international markets. As the product mix becomes more complex and more sophisticated, carbon emissions can fall per unit of GDP, though if more products are being produced for more people total emissions will rise (Figure 5).

Figure 5
Association between carbon footprint and product complexity, 2018

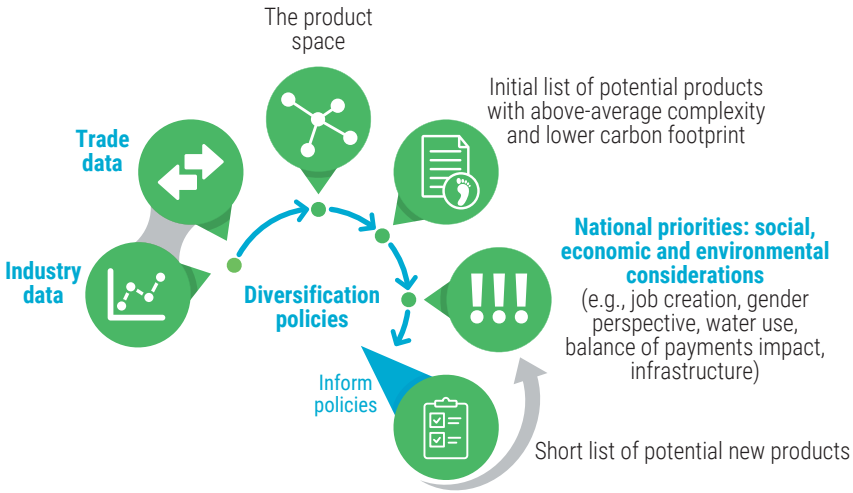


Source: UNCTAD.

For selecting more complex and greener directions, governments should strengthen national capacities for analysing new sectors (Figure 6). This will mean taking stock of the country's existing technological and productive capacities and the availability of natural resource such as wind or agricultural waste. The evaluation can also take advantage of international tools, such

as UNCTAD's Catalogue of Diversification Opportunities 2022. They also need to consider how they can fit into global value chains. And as the windows of opportunity open, policymakers should be prepared to adjust their institutional frameworks.

Figure 6
Selecting realistic opportunities for diversification



Source: UNCTAD.

Note: Product space is a network representation of the similarity between products traded in the global market in terms of the technology required for their production.

Twin transitions for global value chains – green and digital

For most countries their capacity for moving to complex and greener products will depend on trade – on how they can fit into global value chains (GVCs). By participating in GVCs, countries can diversify by producing and exporting parts and components of final products or by upgrading existing output to have greater value added.

The greening of GVCs in manufacturing industries is driven by 1) national environmental legislation and trade agreements including environmental provisions, 2) new patterns of demand preferences and consumer behaviours, and 3) new technologies inducing efficiency gains to meet greener demand requirements. These drivers can open green windows of opportunities for

firms in latecomer countries involved in GVCs, but seizing these opportunities is not automatic and the failure to do so may leave enterprises worse off than before.

GVCs can become greener through two main routes. The first is by manufacturing the goods used for green production, such as solar PV panels and wind turbines. The second is by greening traditional manufacturing industries, such as food, garments and textiles, leather and shoes, and furniture.

Greening of traditional GVCs can be achieved by switching to digital frontier technologies associated with smart manufacturing – often referred to as Industry 4.0. For example, data collected from online-connected sensors, and from GPS tracking systems, can optimize logistics and significantly reduce carbon emissions.

So far, digital technologies have only diffused slowly in most of developing economies. Manufacturing companies more likely to use Industry 4.0 technologies are found in the more advanced economies. Countries with largely lower-skilled labour are less likely to benefit. There are also differences between companies – in many developing countries, only a minority of larger companies tend to adopt digital technologies; while the majority are still confined to analogue production. To promote the twin transition of green and digital, latecomer countries will need to build digital competency along with the necessary infrastructure and institutions, while building innovation capacity and overcoming financial barriers.

Within value chains, governments can consider targeted policies, such as support for small and medium-size enterprises with finance for new machinery and other requirements for upgrading. They can also create training or technology demonstration centres as well as industrial institutes.

As they upgrade, companies and countries should embed strong social and environmental values. Social upgrading refers to improving the rights and entitlements of workers and their employment. Environmental upgrading refers to a firm's ecological footprint, including its use of natural resources, its emission of greenhouse gases and its impact on biodiversity. These ideals are increasingly being demanded by consumers who are seeking more ethical products, as well as by governments and others who now have more exacting social and environmental standards.

Upgrading value chains can be based on voluntary sustainability standards (VSS) which have emerged mainly through collaboration among NGOs, industry groups or multi-stakeholder groups. By 2020 there were 150 VSS in agriculture, and around 30 for mining and industrial products.

4. Priorities for opening green windows

For opening green windows, governments need to assess the current conditions and then strengthen sectoral innovation systems. Much of this happens within 'green industrial policy,' which mainly involves mobilizing the necessary actors and resources and directing how knowledge capacities are upgraded – often amid considerable technological, economic, and political uncertainties.

The report identifies a set of priorities for latecomer countries. They can build digital competency along with the necessary infrastructure and institutions, while strengthening innovation capacity and overcoming financial barriers. This requires collaboration between the private sector and other stakeholders.

A lead agency within government should mobilize resources and convene stakeholders to assess overall state capacity in the areas related to the new technology, as well as the strengths of relevant public agencies, particularly for regulation, extension support systems, and for providing required public services. Overall policy should be mission-oriented – going beyond levelling the playing field to fixing market failures and involving broader programmes of market co-creation and shaping.

In industries where the technology is more mature, as with wind and solar, it may be difficult for latecomers to produce core components. But there can be opportunities further down the value chain related to deployment, such as project development, engineering, procurement and construction.

Governments need to assess at various stages where and how production and innovation should be strengthened and changed. To do so, they can take advantage of UNCTAD's Science, Technology and Innovation Policy reviews which cover the activities of national and local governments, private companies, universities, research institutes, financial institutions, and civil society organizations.

While the options differ from one country and company to another, there are some common priority areas.

Set the direction

Align environmental and industrial policies

Governments need transformational agendas to mitigate climate change, commit to renewable energy production and consumption, electrify rural communities, and increase energy security. Policies that might previously have been developed in separate domains need to be co-created across the energy-environmental and industrial spheres. This requires a whole-of-government approach involving ministries of education, industry, trade, to cultivate design and engineering capabilities and prepare the economy and businesses for responding.

Invest in more complex and greener sectors

The government, the private sector and other stakeholders should develop the capacities and build the institutions to continuously and strategically identify new technologies and sectors for diversification that are more complex and greener. The priority sectors should be supported through vertical policy instruments such as clusters, smart specialization initiatives, pilot and demonstration projects and areas, and the associated finance.

The government and the private sector should also expand financing opportunities for developing and commercializing green technologies. These can include Investment funds for green technology, technical assistance in innovation and technology, and advisory services. To encourage the private sector, both government and donor agencies should come forward as early investors. These activities can be complemented by foreign direct investment.

Build consumer demand

Governments can offer the incentives and infrastructure that help shift consumer demand to encourage recycling and the circular economy. This can be supported by green procurement to create a ripple effect across the rest of the economy.

Build green productive and innovative capacities

Invest in R&D

Nascent green technologies usually require significant investments in R&D. Governments can offer subsidies to build up research, with the collaboration

of universities and industry, both domestic and foreign. Public R&D investments are also needed in process improvements and complementary technologies. And when technologies are rapidly evolving, as in the wind industry, this investment will need to be continuous. In the early stages, when the domestic market cannot support a competitive industry, governments can set up technology demonstration projects.

Raise awareness of green technologies

The government, private sector and other stakeholders should create greater awareness of the potential of green technologies. This should start within basic education, along with campaigns to inform the private sector and consumers of the benefits of these technologies and their capacity to reduce carbon footprints. Within firms, technical education and skills development upskill and prepare the manufacturing sector to adopt green technology.

Organized civil society is also important for sensitizing the public about the significance of green technology. Civil society organization can support transfer of knowledge and capacity development activities for farmers and other small businesses. They can also start pilot projects that can be scaled-up by governments. Civil society organizations and the academia can serve as incubators or accelerators for young entrepreneurs interested in starting businesses in green agricultural technologies.

Develop digital infrastructure and skills

As these technologies progress, all countries will need stronger digital infrastructure, in particular high-speed and high-quality Internet connections. This will mean public and private investments in ICT infrastructure along with regulations to foster competition in the telecommunications sector. Governments should also address the connectivity gaps between small and large firms and between urban and rural regions. Some technologies, such as drones, may also need specific regulations.

Skills are needed for adopting existing technologies, for basic use, for adapting these technologies, and finally for creating new ones. For developing countries, it is particularly important to have the capacity to adapt and modify technologies since these are likely to be used in circumstances different from those in which they were originally developed.

Governments should support businesses, including SMEs, to help them build digital skills in areas such as market research, product development, sourcing, production, sales, and after-sales services. Special consideration should be given to women in informal and artisanal small and microenterprises, particularly for entrepreneurs. Countries also need to reduce brain drain, retain skilled professionals, and attract skilled expatriates.

5. International collaboration for more sustainable production

In developing countries, opening green windows is unlikely to happen naturally as a result of businesses seeking greater efficiency and profits; it has to be the consequence of deliberate government action.

The least technologically able countries cannot seize green opportunities without the support of the international community and official development assistance. This should be based on equitable partnerships – to build local innovation capabilities and marshal the necessary technologies. Collaboration on innovation not only transfers capital goods and equipment, it also enables people to develop the skills needed to operate and maintain the equipment (know-how) and understand why it is running (know-why). Green technologies typically need more adaptation to local conditions.

Empowering developing countries for switching green thus requires broad and comprehensive development strategies that can deal with multiple tensions and develop partnerships for common public goods.

Cooperation through international trade

Given the extent to which the production and consumption of products related to green technology are traded internationally, much will depend on the conditions on which this trade takes place. Trade rules should, for example, permit developing countries to protect infant green industries through tariffs, subsidies and public procurement – so that they not only meet local demand but reach the economies of scale that make exports more competitive. There should also be requirements for local content though these need to be carefully managed and deliberately sequenced so as to avoid the pitfalls that earlier industrial policies faced in most developing countries.

To support these efforts, the World Trade Organization can review trade rules to make them more consistent with the Paris Agreement. However,

member countries can also take steps within existing WTO rules. Countries with larger domestic markets, for example, can subsidize nascent sectors for components for domestic solar and wind energy products. They can thus start producing for import replacement while strengthening capacity for exports, by improving trade facilitation, and ensuring a stable and competitive exchange rates that would have effects similar to those of export subsidies.

The international community should also be innovative and propose new and bold trade mechanisms to support the development of innovation and technological capacity in developing countries for cleaner and more productive production. Developed countries can use development assistance to help countries to emulate the production of more advanced countries. On the demand side, developed countries should open their markets to production from latecomer economies. Identifying the products and countries that should benefit from such a proposal would, however, probably need a new institutional structure. A pilot could be an international programme of guaranteed purchase of tradable green items – such as products, parts and components used for renewable energy.

Reform of intellectual property rights

When the developed economies were producing new products and catching up with Britain after the Industrial revolution, or when a few Asian countries started upgrading their productive and innovative capacities – they were often copying production processes with or without permission. Now the intellectual property rights (IPR) regime is tighter, making it harder for new producers to break in. The international IPR system should be reformed to enable governments in developing countries to manage their systems to support climate action, based on the needs of different sectors and different stages of development. Manufacturers in technologically weak and less diversified countries should be allowed to imitate the production of more technologically advanced economies.

The principle that sustainable development should take precedence over commercial objectives was demonstrated during the COVID-19 crisis. In 2022, the WTO allowed eligible Members until 2027 to produce and supply vaccines without the consent of the patent holder to the extent necessary to address the COVID-19 pandemic. Similarly, flexibilities in the TRIPS Agreement should be given for environmentally-sound technologies to make the trade regime more consistent with climate change agreements.

Partners for green technology

Global efforts should be put in place to accelerate the development and deployment of green technologies under the philosophy of common contributions to common goods. One ground-breaking model for this approach is the Intergovernmental Panel on Climate Change (IPCC). Others are the Paris Agreement of 2015 and the agreements for the Sustainable Development Goals. Even under such an approach, governance mechanisms should be put in place to avoid the North-South divide in knowledge management and ensure that developing countries' views and priorities are fully considered.

There are also successful examples of collective research whose results belong to all participating countries, particularly in natural sciences, including the European Organization for Nuclear Research (CERN), the International Thermonuclear Experimental Reactor (ITER) and the Square Kilometre Array (SKAO) project. Similar collaborations can also shape international cooperation for green innovations that equitably incorporate the views and priorities of developing countries.

Multilateral and open innovation

Most science, technology and innovation efforts are governed at the national level and generally reflect the priorities of developed countries. The international community can offset this bias by shifting research from the national to the multinational level. Such research should be based on open innovation – with all the results available to international experts and knowledge communities. A useful model is the Consultative Group on International Agricultural Research.

Multilateral research can cover the whole value chain, or just a part of it. Research institutions could, for example, bring products or processes close to technology maturity and invite private companies to take care of rapid deployment. Or they might take concepts only to the laboratory stage or to early demonstration projects.

Assessing technologies

Most technologies can have both positive and negative consequences depending on the local context and on how they are used. Each country needs to be able to assess the benefits and dangers of each technology

according to their own needs, priorities and concerns. To date, technologies have largely been assessed either from the perspective of the developed countries or emerging economies. UNCTAD is currently carrying out pilot projects involving three African countries to build capacity for technology assessment. What is needed however is a more general multilateral system for assessing new technologies – such as AI and gene editing – based on the opportunities and risks they offer to different types of country. It could also consider how developing countries can be systematically supported to use such technologies.

Regional and South-South cooperation in science, technology and innovation

Technological innovations to address the global climate crisis should increasingly be generated at transnational or even global levels. However, cooperation has been limited, even in issues in which countries in the same region often face similar problems. Researchers and investors in the poorer countries have little incentive to cooperate with their regional peers and are more likely to enter research projects with developed countries and emerging economies which can offer access world-class research and laboratories as well as computing power. Moreover, small and vulnerable countries also have limited domestic markets to attract local or international investment in the manufacture of goods related to green innovation. More technologically advanced developing countries should step up and strengthen efforts to promote regional and South-South cooperation for green innovation. Developed countries can support regional centres of excellence for green technologies and innovation – such as the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) and West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL).

A multilateral challenge fund "Innovations for Our Common Future"

Successful innovation systems create multiple incentives for companies and entrepreneurs to develop their own ideas and transfer them to practice. However, most developing countries lack the financial or management capacities to develop similar incentives. This Report proposes therefore a multilateral challenge fund "Innovations for our common future." Funded by international organizations, donors and international philanthropy the fund would mobilize creative thinking and stimulate innovations that could

respond to many global challenges. The next step would be to design a global green innovation competition. The criteria for assessing projects would be the extent to which they incorporate North-South and South-South STI cooperation for green innovation.

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