CHAPTER II

MOVING FAST WITH FRONTIER TECHNOLOGIES

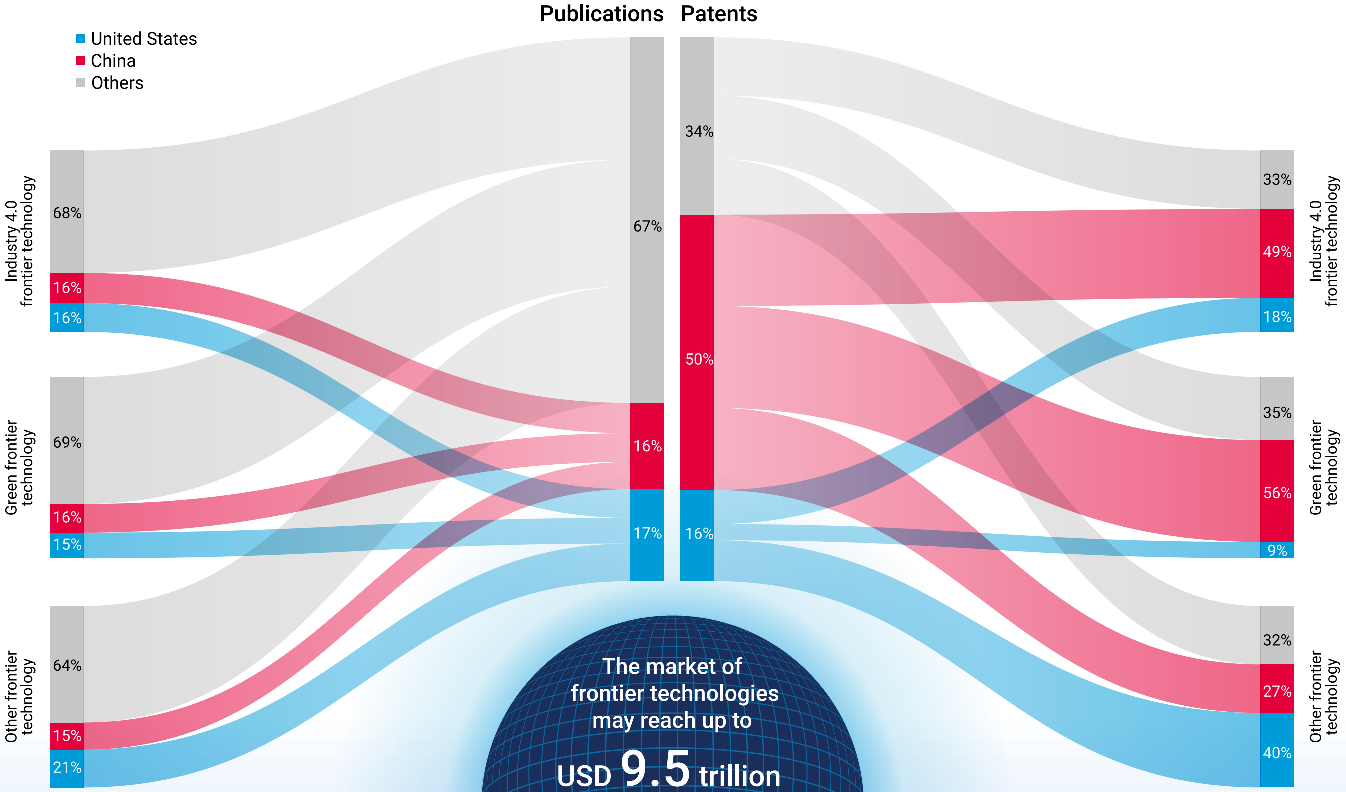
Few have the needed skills to take advantage of frontier technologies, so countries must be proactive to grow with the green transformation

The Technology and Innovation Report 2023 covers 17 technologies divided into three broad categories:

Industry 4.0: artificial intelligence (AI), the Internet of things (IoT), big data, blockchain, 5G, 3D printing, robotics, drones

Green and renewable energy technologies: solar PV, concentrated solar power, biofuels, biogas and biomass, wind energy, green hydrogen, and electric vehicles

Other frontier technologies: nanotech and gene editing



The market of frontier technologies may reach up to

USD **9.5** trillion by **2030**

The trade of these technologies is expanding. For example, the exports of electric vehicles of the top 15 exporter countries jumped from USD 28 billion in 2018 to USD 105 billion in 2021.

There is concentration in terms of suppliers, R&D outputs, and technology presence in developed economies.

Only a handful of countries supply frontier technologies and almost all of them are developed economies

Most publications and patents in frontier technologies are from developed economies and China

There is a limited presence of technologies like EVs in developing economies

This chapter examines frontier technologies – new and rapidly developing technologies that take advantage of digitalization and connectivity – highlighting their potential economic benefits. It also assesses country capabilities to use, adopt, and adapt these innovations.

As indicated in Figure II-1, the chapter focuses on 17 technologies divided into three broad categories: Industry 4.0, green and renewable energy technologies, and other frontier technologies. Nevertheless, these categories also intersect and overlap. For instance, drones are not classified here as a green frontier technology, though delivery by drone can cut GHG emissions due to their lower energy consumption per package when compared to vehicles.[1] Similarly, nanotechnology can improve the use of renewable sources, for example, by enabling lighter rotor blades for wind turbines.[2]

Figure II 1

Frontier technologies covered in this report

Industry 4.0 frontier technologies	Green frontier technologies	Other frontier technologies
Artificial intelligence	Solar PV	Nanotechnology
Internet of things	Concentrated solar power	Gene editing
Big data	Biofuels	
Blockchain	Biogas and biomass	
5G	Wind energy	
3D printing	Green hydrogen	
Robotics	Electric vehicles	
Drone technology		

Source: UNCTAD.

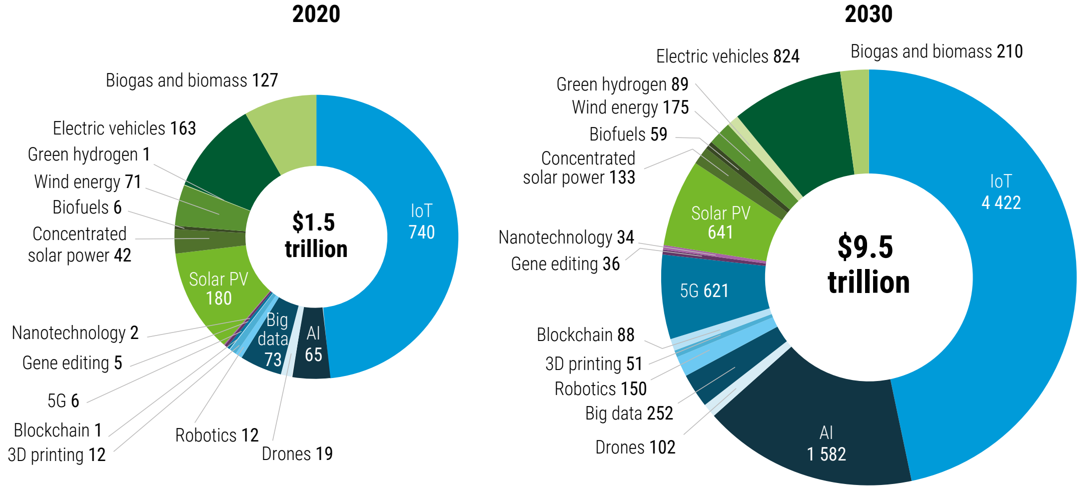
These technologies have experienced tremendous growth in the last two decades and will continue to affect economic and social structures, offering possibilities for market growth and a chance for economies to develop their labour markets. In addition, countries that have the required capabilities can enter and develop new sectors like renewable energy sources or EVs, opening green windows to drive their economic growth. Nonetheless, developing economies have to optimize their preparedness and close the gaps for the use, adoption, and adaptation of frontier technologies. The readiness index included in this chapter can help countries do so using an evidence-based approach.

A. TECHNOLOGIES IN THE FAST LANE

Frontier technologies have experienced tremendous growth in the last two decades.[3] In 2020 their market value was $1.5 trillion and by 2030 could reach $9.5 trillion (Figure II-2). For comparison, over this period the global market for smartphones is expected only to double, from $508 billion to $983 billion.[4] But it is important to note that these estimates may be inflated by double counting – for instance, many IoT technologies also involve the deployment of AI and big data.

Figure II 2

Market size estimates of frontier technologies, $ billion



Source: UNCTAD based on various estimates.[5]

Around half the market value of these technologies is for the Intern of things (IoT) which embraces a vast range of devices that are ubiquitous across multiple sectors. Industry 4.0 has accelerated the use of these multiple interconnected devices – from Tesla's automotive factories to Amazon's warehouses to IoT devices in sustainable aquaculture.[6] By 2030, IoT revenues could reach $4.4 trillion.[7]

There is also a rapidly expanding market for AI, which by 2030 might be contributing between $13 trillion and $16 trillion to the global economy.[8] Growth is driven by continued technical improvements in multiple sectors, such as AI-enabled self-programming robots for manufacturing, and AI-based software in financial investment, trading, and loan screening. AI is also improving urban service delivery in smart cities and drone delivery – by directing semi-autonomous vehicles, cars, trucks, and buses, in which drivers are assisted by cameras, radar, and navigation systems.[9]

Between 2020 and 2030, the market revenues for electric vehicles (EVs) could increase from $163 billion to $824 billion. This growth is being driven primarily by demands from consumers who wish to reduce their carbon footprints but are also responding to rising prices for gasoline and diesel that have arisen from geopolitical instability. This demand is now being met by many more suppliers, including companies who previously only produced vehicles with internal combustion engines. Greater competition has reduced prices, encouraging better charging infrastructure, and supportive government regulations and incentives.

The numbers in Figure II-2 are significantly higher than those given in the previous *Technology and Innovation Report*. This is partly because this report adds six more green technologies but also because the use of several technologies accelerated after the COVID-19 pandemic and triggered more rapid digitalization.[10] For the global investment promotion agencies, ICT is now reported as the second most important industry, with technologies like blockchain, big data, 5G, and IoT as the main choices for online activities.[11]

Frontier technologies are supplied primarily from a few countries, notably the United States, China, and countries in Western Europe (Table II-1). The biggest providers of Industry 4.0 technologies are from the United States which is home to major computing platforms that offer a wide range of one-stop, pay-as-you-go services.[12] Companies from China are particularly active in 5G, drone technology, and solar PV. Robotics and green frontier technologies suppliers, on the other hand are more evenly spread among developed economies in Western Europe and East Asia, where companies have benefitted from favourable regulation and rising demand for renewable energy. Only two of the top frontier technology providers are from developing economies, and both are in the renewables sector. Firms in these countries urgently need more government support if they are to operate more effectively close to technological frontiers.

Table II 1
Top frontier technology providers

AI	IoT	Big data	Blockchain	5G
Alphabet	Alphabet	Alphabet	Alibaba	Ericsson
Amazon	Amazon	Amazon Web Services	Amazon Web Services	Huawei (network)
Apple	Cisco	Dell Technologies	IBM	Nokia
IBM	IBM	HP Enterprise	Microsoft	ZTE
Microsoft	Microsoft	IBM	Oracle	Huawei (chip)
	Oracle	Microsoft	SAP	Intel
	PTC	Oracle		MediaTek
	Salesforce	SAP		Qualcomm
	SAP	Splunk		Samsung Electronics
		Teradata		

3D printing	Robotics	Drone technology	Gene editing	Nanotechnology	Solar PV
3D Systems	ABB	3D Robotics	CRISPR Therapeutics	BASF	Jinko Solar
ExOne Company	FANUC	DJI Innovations	Editas Medicine	Apeel Sciences	JA Solar
HP	KUKA	Parrot	Horizon Discovery Group	Agilent	Trina Solar
Stratasys	Mitsubishi Electric	Yuneec	Intellia Therapeutics	Samsung Electronics	Canadian Solar
	Yaskawa	Northrop Grumman	Precision BioSciences	Intel	Hanwa Q cells
	Hanson Robotics	Lockheed Martin	Sangamo Therapeutics		
	Pal Robotics	Boeing			
	Robotis				
	Softbank				
	Alphabet/Waymo				
	Aptiv				
	GM				
	Tesla				

Biofuels	Wind energy	Green hydrogen	Electric vehicles	Concentrated solar power	Biogas and biomass
Archer Daniels Midland	GE Power	Siemens Energy	Tesla	Abengoa Solar	Future Biogas
ALTEN Group	Mitsubishi Heavy Industries	Linde	Ford	Iberolica Group	Air Liquide
Louis Dreyfus	ABB	Toshiba Energy	Hyundai	ENGIE	PlanET Biogas Global
Brasil Bio Fuels	Siemens Gamesa Renewable Energy	Air Liquide	Chevrolet	NextEra Energy Resources	Ameresco
BIOX Corp	Goldwind	Nel ASA	BYD	BrightSource Energy	Quantum Green
Renewable Energy Group	Enercon	Air Products and Chemicals	Volkswagen		Envitech Biogas
Wilmar international		Guangdong Nation-Synergy Hydrogen Power Technologies	Renault-Nissan-Mitsubishi Alliance		Weltec Biopower

Source: UNCTAD based on various sources.

Notes: American companies in dark blue, Chinese companies in orange, others from developed economies in light blue and developing economies in yellow.

Given the multiple overlaps between various technologies, it is difficult to arrive at market sizes. A more accurate way of evaluating each is to project the value they add to the global economy. Some estimates for 5G, for example, suggest that between 2022 and 2030 its economic contribution will increase from $150 billion to $1.3 trillion.[13] Similarly, by 2030 AI could be adding $13 trillion to global economic output – 1.2 per cent of global GDP, while IoT could be adding between $5.5 trillion and $12.6 trillion.[14] Finally, blockchain is estimated to generate $176 billion of value by 2025 and $3.1 trillion by 2030.[15]

1. CREATION AND EXTINCTION OF JOBS

As with previous waves of automation, frontier technologies have both destroyed old jobs and created new ones.[16] Current job expectations may be more pessimistic because of the increasing capacity of AI to mimic human intelligence and recent job cuts by some big technology companies, nevertheless the alarmist scenarios often fail to take fully 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.[17] The net impact on jobs will depend on the final balance between creation and extinction.[18]

Industry 4.0 frontier technologies

AI – A study in the United States using data on online job vacancies found that between 2010 and 2019 demand for AI skills rose sharply across most industries and occupations. The highest demand was in IT occupations, followed by architecture, engineering, scientific and management occupations.[19]

Big data – There is a booming demand for data scientists in the United States. Between 2020 and 2030 there are expected to be 7,100 job openings, with annual job growth projected at 15 per cent or higher.[20]

Blockchain – Between 2020 and 2021, on Indeed.com the number of postings for blockchain jobs doubled.[21] Blockchain developers continue to be remunerated well, with an estimated annual income in the United States of $136,000, in Asia of $87,500 and in Europe of $73,300. The five biggest blockchain employers are Deloitte, IBM, Accenture, Cisco, and Collins Aerospace.[22]

Drones – Between 2020 and 2040, in Australia, on average drones are expected to support 5,500 full-time job equivalents per annum.[23] Meanwhile between 2013 and 2025 the United States should add more than 100,000 drone-related jobs. The top three drone job locations are the United States, China, and France.[24]

5G – Between 2022 and 2034, around 4.6 million 5G-related jobs will be created in the United States, driven largely by employment in agriculture, construction, utilities, manufacturing, transportation and warehousing, education, healthcare, and government.[25] By 2035, the global 5G value chain is expected to support 22 million jobs.[26]

3D printing – Additive manufacturing is demanding more skilled professionals, such as engineers, software developers, material scientists and a wide range of business support functions including sales, marketing, and other specialists. In the United States, it is estimated that 3D printing will add between three and five million new skilled jobs in the next decade.[27]

IoT – The growth of IoT has led to skills shortages. According to one study, between July 2021 and April 2022 the number of online job ads that included IoT increased by one-third.[28] LinkedIn data suggest more than 13,000 IoT-related job openings in the United States.[29]

Robotics – Job growth in robotics is more modest. In the United States, in 2016 there were 132,500 robotics engineers and the job market for this professional type is expected to grow by 6.4 per cent between 2016 and 2026.[30] Robotics careers include robotics engineers, software developers, technicians, sales engineers, and operators.[31]

Green frontier technologies

Biofuels – Worldwide, the liquid biofuel market employs an estimated 2,411,000 people.[32] Although biofuel jobs declined between 4 and 5 per cent in the United States in 2020 because of the Covid-19 pandemic, the demand for workers is projected to rebound.[33]

Biogas and biomass – Job markets will keep growing. Biomass is estimated to create 73 permanent full-time direct jobs per 100MW of installation capacity. Solid biomass employs around 765,000 individuals worldwide, while biogas employs approximately 339,000 people.[34]

Solar PV – Solar PV is the largest contributor to employment among the renewable energy industries, accounting for almost four million jobs worldwide.[35] Solar energy jobs are set to grow rapidly but there is little evidence of solar hiring boom. Growth in the solar energy sector has been slowed by political and industry turbulence due to regulatory uncertainty and the bankruptcy and layoffs of big companies due to lower prices and shifts in the technology, making old ones obsolete.[36]

Concentrated solar power – Worldwide, the concentrated solar power industry has created an estimated 32,000 jobs.[37] In the best-case scenario, concentrated solar projects could create 100,000 to 130,000 new jobs by 2025. Of these, 45,000 would be permanent roles in operations and maintenance.[38]

Wind energy – The job market is expected to experience rapid growth. Wind energy currently employs an estimated 1,254,000 people worldwide,[39] and another 3.3 million direct jobs are expected to be created by 2025 as a result of additional 470GW of wind capacity.[40]

Green hydrogen – Between 2030 and 2050, green hydrogen is expected to create as many as two million jobs, through investments in electrolysers and other green hydrogen infrastructure.[41]

Electric vehicles – Electrifying the transportation industry is expected to result in net job growth. In Europe by 2030 around 200,000 permanent jobs could be created to provide EV infrastructure – for battery manufacturing, charger manufacturing, installation of the chargers, grid connections, and charge point operations.[42] Likewise, by 2035 globally there could be more than two million net jobs.[43]

Other frontier technologies

Nanotechnology – The nanotechnology job market is expected to expand at a modest rate. In the United States, the nanotechnology engineer job market is set to grow by 6.4 per cent between 2016 and 2026.[44]

Gene editing – Labour demand in gene editing is expected to soar, especially in developed countries. In the United Kingdom, an estimated 18,000 new jobs will be added between 2017 and 2035,[45] while in the United States, medical scientists and biomedical engineers together are expected to add 22,500 jobs between 2021 and 2031.[46]

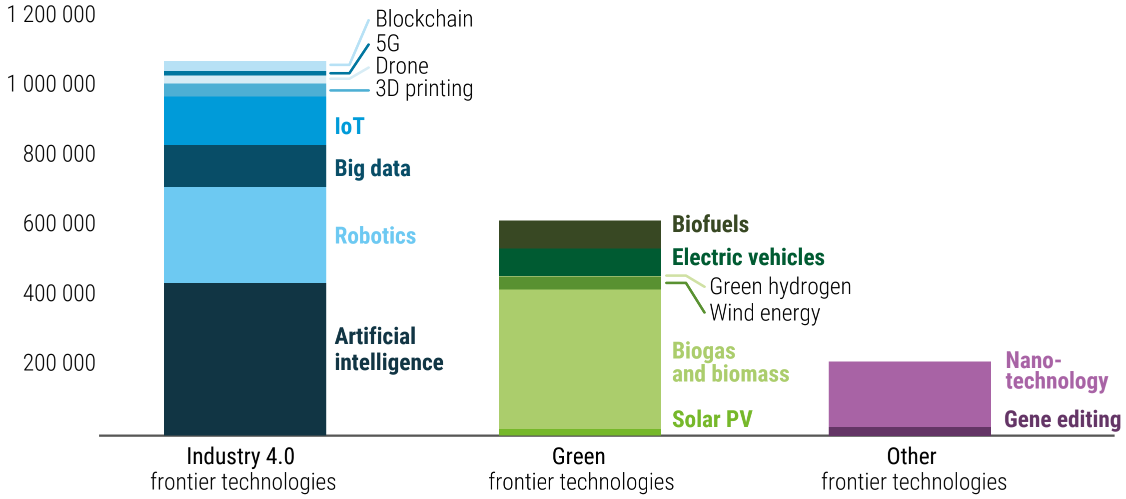
2. KNOWLEDGE ON FRONTIER TECHNOLOGIES

Over the past two decades, frontier technologies have generated increasing interest amongst academics and innovators. The number of associated publications and patents has soared (Figure II-3 and Figure II-4). Particularly high volumes are evident in Industry 4.0 – for AI, 438,619 publications and 214,365 patents; for robotics, 276,027 publications and 122,940 patents; and for IoT, 139,805 publications and 147,906 patents. In green frontier technologies in 2000-2021: for electric vehicles 79,732 publications and 206,049 patents; and for wind energy 37,514 publications and 58,134 patents.

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 II-5, Figure II-6, and Box II-1). Other countries compete in specific categories, notably India, the Republic of Korea, Germany, the United Kingdom, France, and Japan.

Figure II 3

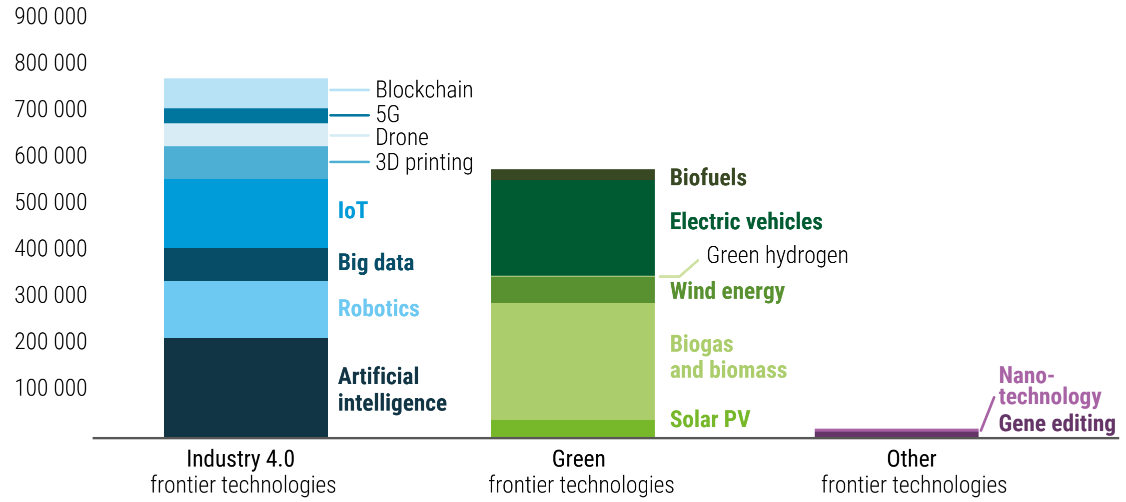
Number of publications on frontier technologies, 2000 – 2021



Source: UNCTAD calculations based on data from Scopus.

Figure II 4

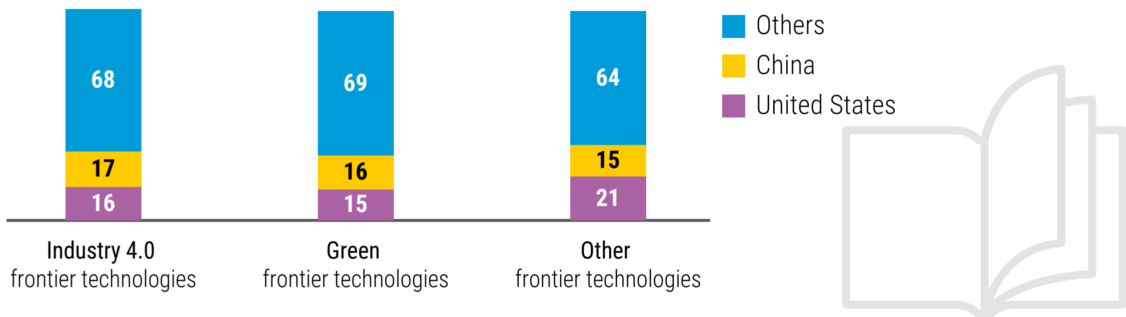
Number of patents for frontier technologies, 2000 – 2021



Source: UNCTAD calculations based on data from PatSeer.

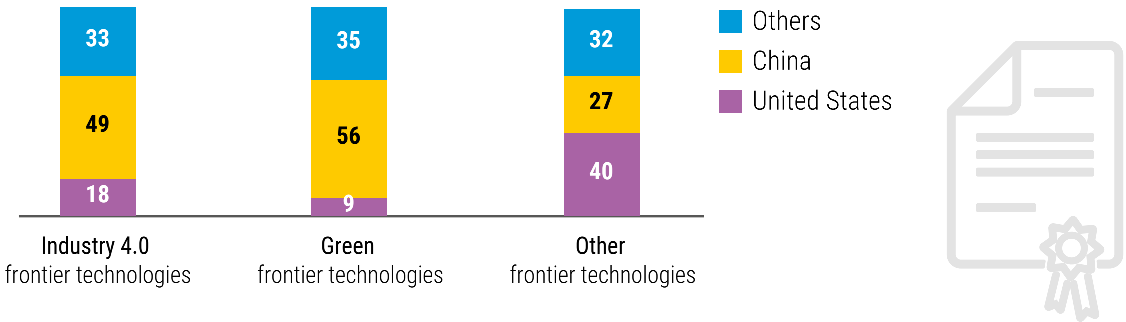
Figure II 5

Country share of publications, by frontier technology



Source: UNCTAD calculations based on data from Scopus.

Figure II 6
Country share of patents, by frontier technology



Source: UNCTAD calculations based on data from PatSeer.

Box II 1
China and the United States dominate patents on frontier technologies

For 14 of the 17 categories of frontier technology, the United States and China are the two largest sources of published research and are always in the top three. They are also the top sources of patent assignees in nine and make up two of the top three in seven categories. China is absent only in concentrated solar power – which is the smallest of the categories.

Over the period 2000-2021, China has been particularly dominant in Industry 4.0 and green frontier technologies, accounting for approximately half of all patents. China produced a total of 536,115 patented technologies, which included IoT (100,958 patents), AI (71,055 patents) and big data (62,063 patents). Over the same period, the United States, generated 169,447 patents, which includes robotics (49,318 patents), AI (43,193 patents) and electric vehicles (19,523 patents).

China places technological development as a priority. In the 14th five-year plan, for example, it aims to reach an average annual growth rate of 20 per cent of the number of robots, form a group of leading enterprises that are internationally competitive, build industrial clusters, and double the intensity of robots in manufacturing.[47] According to a study, the country is the leader in granted patents in robotics considering the period between 2005 and 2019, accounting for 35 per cent of the total. Others in the top of this ranking are Japan, the Republic of Korea and the United States.[48]

The gap between China and the United States in patent is even wider in green frontier technologies. China has 56 per cent of overall patents for these innovations, and the United States only 9 per cent. Over the past two decades, firms in China created 33,066 patents for wind energy while firms in the United States generated just 2,963 patents. In solar panels, China created 31,365 patents, while the United States generated 1,586. China's domination reflects the priority status given since 2012 to green technologies in its patent examination system, as well as the determination of policymakers to create a hospitable environment for green innovation.

Source: UNCTAD.

The data shown here highlights the concentration of knowledge creation for these frontier technologies. The accumulated knowledge in countries such as the United States, China, India, and United Kingdom needs to be shared with countries in the Global South, especially LDCs, LLDCs, and SIDS, through international cooperation and multilateral forums and initiatives. Key indicators for the frontier technologies covered in this report are shown in Table II-2. Detailed information is presented in Annex A.

Table II 2
Key indicators

Category:	AI	IoT	Big data	Blockchain	3D printing	Robotics	Drones	5G
Publications	438 619	139 805	119 555	27 964	36 367	276 027	23 526	13 045
Patents	214 365	147 906	72 184	63 767	70 799	122 940	48 613	32 412
Price	Video/speech analysis AI : $36,000-56,000 Intelligent recommendation engine: $20,000-$35,000	ECG monitors: $3,000-$4,000 Energy management system: from $27,000	Data warehouse (cloud storage): ~$359,951/year Data warehouse (on-premises storage): ~$372,279/year	NFT marketplace: $50,000-$130,000 Decentralized Autonomous Organization (DAO): $3,500-$20,000 Cryptocurrency exchange app: $50,000-$100,000	Entry-level 3D printer: $100+ Industrial 3D printer: $10,000+	$50,000 - $150,000 for industrial robot	Commercial drone: $2000+ Military drone: $800,000 to $400 million	$60-70+/monthly for unlimited US 5G network access
Market size	$65 billion (2020) $1,582 billion (2030)	$740 billion (2020) $4,422 billion (2030)	$73 billion (2020) $252 billion (2030)	$1 billion (2020) $88 billion (2030)	$12 billion (2020) $51 billion (2030)	$12 billion (2020) $150 billion (2030)	$19 billion (2020) $102 billion (2030)	$6 billion (2020) $621 billion (2030)
Major providers	Alphabet, Amazon, IBM, Microsoft, Alibaba and Tencent	Accenture, TCS, IBM, EY, Capgemini, HCL and Cognizant	Amazon, Microsoft, IBM, Google, Oracle, SAP and HP	Alibaba, Amazon, IBM, Microsoft, Oracle and SAP	Stratasys, 3D Systems, Materialise NV, EOS GmbH and General Electric	ABB, Fanuc, KUKA, and Yaskawa (industrial robotics), Alphabet/Waymo, Aptiv, GM, Tesla (autonomous vehicles)	3D Robotics, DJI Innovations, Parrot, Yuneec (commercial) Boeing, Lockheed Martin, Northrop Grumman (military)	Ericsson, Huawei, Nokia, ZTE, Samsung, and NEC
Major users	Retail, banking, discrete manufacturing	Manufacturing, home, healthcare and finance	Banking, discrete manufacturing and professional services	Banking, process manufacturing and discrete manufacturing	Discrete manufacturing, healthcare and education	Discrete manufacturing, process manufacturing and resource industry	Utilities, construction and discrete manufacturing	Mobile operators, industrial automation, manufacturing

Category:	Gene editing	Nano-technology	Solar PV	Wind energy	Green hydrogen	Electric vehicles	Biofuels	Biogas and biomass	Concentrated solar power
Publications	24 802	186 827	19 875	37 514	802	79 732	74,801	400,062	3,195
Patents	13 970	6 175	38 425	58 134	58	206 049	22,325	251,251	1,101
Price	$373,000 to $2.1 million for human genome editing therapies	$80 for 1mg gold nanoparticles	$2.94/watt	$0.053/kWh (onshore) $0.115/kWh (offshore)	$2.5-6/kg H2	$46,526 (average transaction)	Cellulosic ethanol: $4/gge HEFA: $3.70/gge	$0.030 to $0.140/kWh	$ 0.108/kWh
Market size	$5 billion (2020) $36 billion (2030)	$2 billion (2020) $34 billion (2030)	$180 billion (2020) $641 billion (2030)	$71 billion (2020) $175 billion (2030)	$1 billion (2020) $89 billion (2030)	$163 billion (2020) $824 billion (2030)	$6 billion (2020) $59 billion (2030)	$127 billion (2020) $210 billion (2030)	$42 billion (2020) $133 billion (2030)
Major providers	CRISPR Therapeutics, Editas Medicine, Horizon Discovery Group, Intellia Therapeutics, Precision BioSciences, Sangamo Therapeutics	BASF, Apeel Sciences, Agilent, Samsung Electronics, Intel	Trina, Canadian Solar, Jinko, Hanwha Q-Cell, SunPower	Vestas, Siemens Gamesa, Goldwind, GE, and Envision	Air Liquide, Air Products and Chemicals, Engie, Green Hydrogen Systems, Siemens, Toshiba, Tianjin Mainland Hydrogen Equipment	Tesla, Renault–Nissan–Mitsubishi Alliance, Volkswagen, BYD, Kia and Hyundai	Cosan, Verbio, ALTEN Group, Archer Daniels Midland, Argent Energy UK, REG, Cargill, Louis Dreyfus, and Wilmar International	Future Biogas, Air Liquide, PlanET Biogas Global, Ameresco, Quantum Green, Envitech Biogas, and Weltec Biopower	Abengoa Solar, S.A., Ibereolica Group, ENGIE, NextEra Energy Resources, and BrightSource Energy
Major users	Pharma-biotech, academia, agrigenomic	Medicine, manufacturing and energy	Residential, commercial and utilities	Agricultural, residential, utilities, industrial	Heavy industry, transportation, heating and power generation	Transportation, e-commerce, delivery	Transportation, heating and electricity generation	Industrial, transportation, residential and electric power generation	Industrial, commercial and residential

Source: See Annex A.

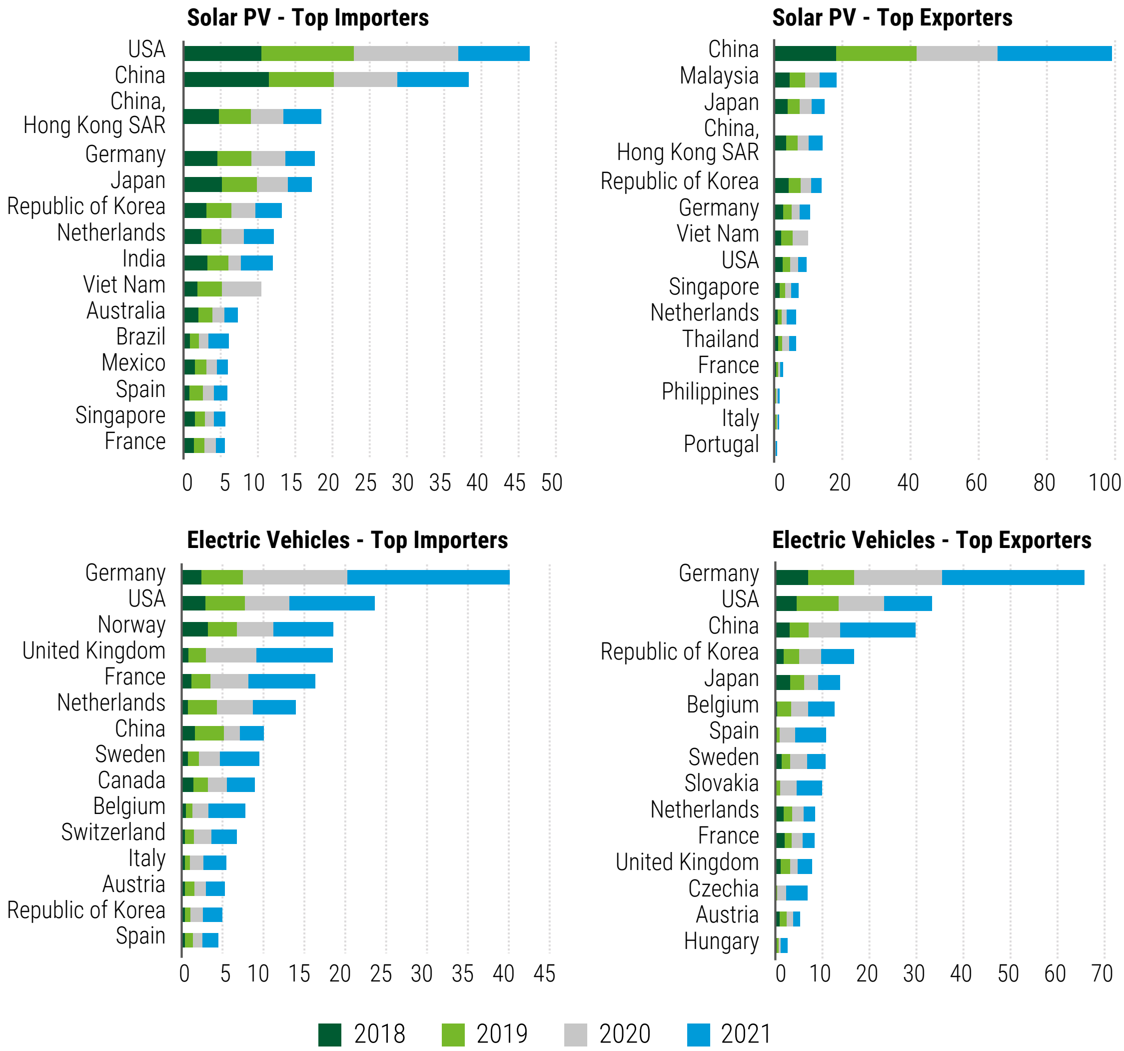
Notes: Publication and patent data are from the period 2000-2021. Market size data are rounded.

3. TRADE EXPANSION

One of the main channels for innovation transfer is trade. This can happen through the imports of capital goods as well as contact with export markets which favours learning-by doing and increases the scope for imitation.[49] Figure II-7 illustrates the increases in trade for solar PV and electric vehicles. For example, the exports of electric vehicles of the top 15 exporter countries jumped from $ 28 billion in 2018 to $ 105 billion in 2021. Considering green technologies, total exports of developed economies jumped from around $ 60 billion in 2018 to over $ 156 billion in 2021, while imports went from $ 89 billion to $ 188 billion. In the same period, exports of developing countries increased from $ 57 billion to $ 75 billion, while imports jumped from $ 48 billion to 63 billion.

Figure II 7

Technology imports and exports by top countries, 2018-2021 ($ billions)



Source: UNCTAD.

Note: Viet Nam's values for 2021 were not available. Imports and exports of solar PV refer to "Photosensitive photovoltaic LED semiconductor devices" classified under HS 854140, "Polysilicon" classified under HS 280461 and "Luminaires and lighting fittings: Photovoltaic, designed for use solely with light-emitting diode (LED) light sources" classified under HS 940541. Imports and exports of electric vehicles refers to electric motorcycles classified under HS 871160, electric cars classified under HS 870380, electric tractors/trucks classified under HS 870124 and hybrid cars classified under HS 870360 and HS 870370. All values represented are in current USD.

Among the developing countries, trade is greater for solar PV, following the drop in prices between 2010 and 2015, with an average reduction of 65 per cent in the expense of employing utility-scale solar PV.[50] Market expansion has translated into further efficiency-led cost reductions, opening up more options for developing countries.

Developing countries have less trade in EVs than in solar PV. This could reflect the fact that the former is a less mature technology, as explored in greater levels of detail in Chapter 3. In general, more immature technologies require greater efforts in terms of science and R&D, which tends to be lower in developing economies, as shown previously. There are also cost and infrastructure-related barriers to the broader EV adoption in developing economies. In addition, for oil-reliant countries, EV trade has been limited by the political economy of fossil fuels and the transition to renewables needs a nuanced approach that balances sustainability with economic stability and poverty alleviation.[51]

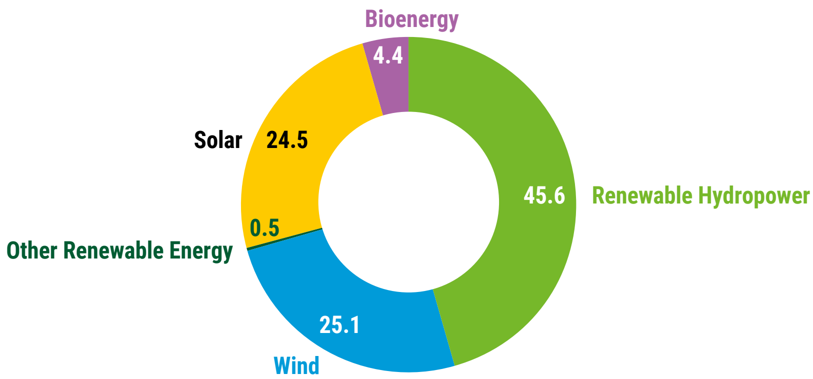
B. THE EXPANSION OF GREEN FRONTIER TECHNOLOGIES

Economies that depend on fossil fuel imports will need to move towards renewable energy sources that allow for greater energy autonomy and self-sufficiency, especially given the recent increase in energy prices due to geopolitical events. These same forces also push the faster adoption of electrified transport than previously anticipated.

As indicated in Figure II-8, installed capacity of renewable energy is dominated by wind and solar.[52]

Figure II 8

Installed renewable energy capacity, 2020 (percentage of world total)

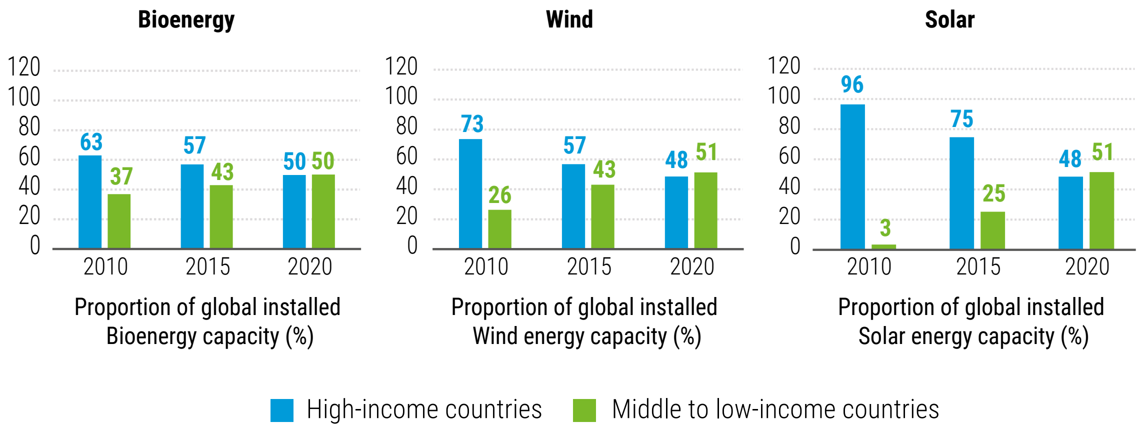


Source: UNCTAD based on IRENASTAT (2021).

Figure II-9 compares the positions for country groups for bioenergy, solar PV, and wind.[53] Between 2010 and 2020, the installed capacity for all three sources increased in middle- and low-income countries which now host over 50 per cent of total installed capacity – with a notable growth in the share for solar energy, which grew from 3 to 51 per cent.

Figure II 9

Installed renewable energy capacity by regions (percentage of world total)

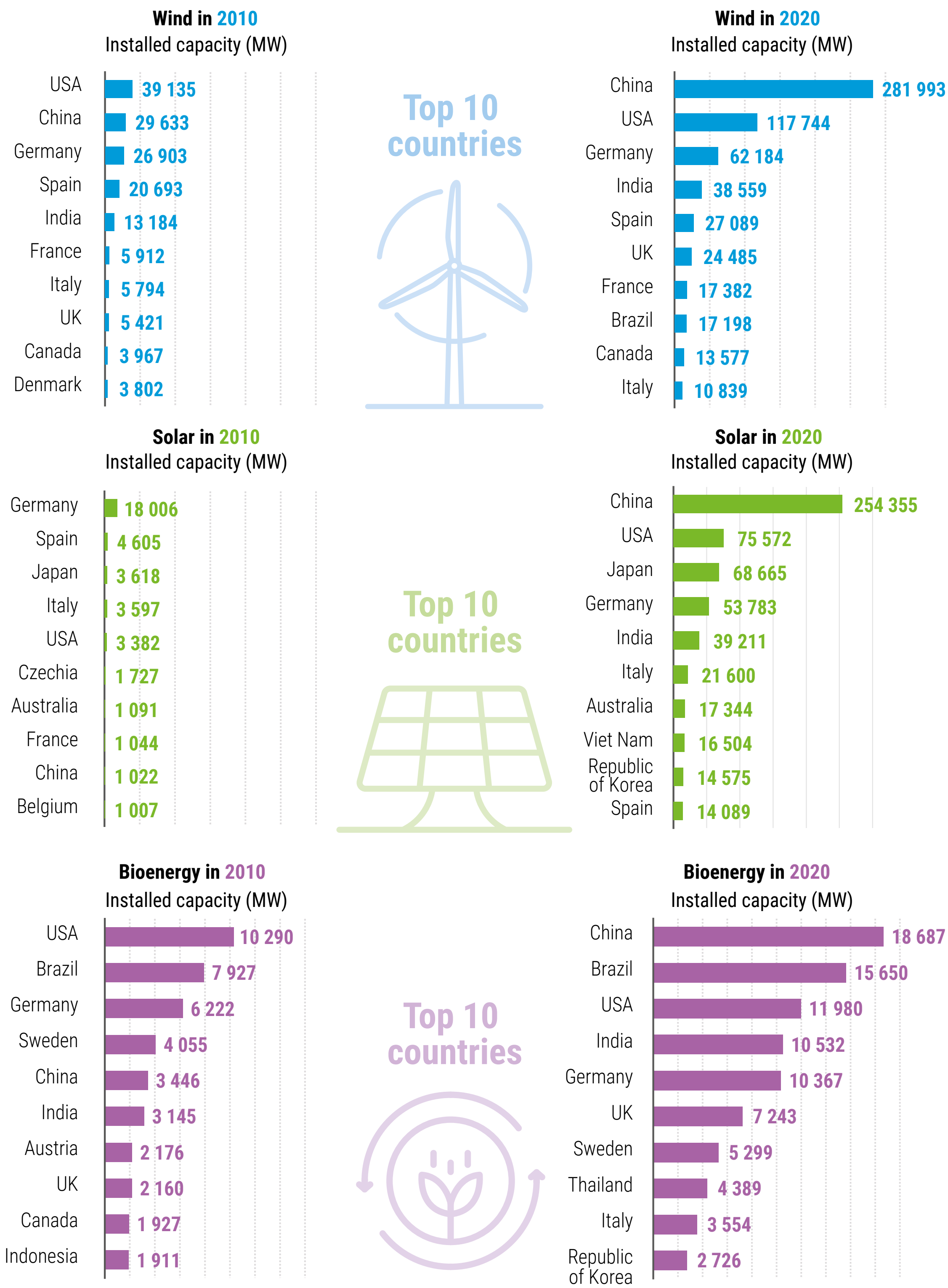


Source: UNCTAD based on IRENASTAT (2021).

These expansions are mainly driven by China, which is now the leading country globally, and is being joined by lower-middle-income countries such as Viet Nam and India, and upper-middle-income countries like Brazil and Thailand. With Africa possessing the world's greatest renewable energy capacity potential, estimated to reach 310GW by 2030, there is scope for significant progress if encouraged by public policy. Figure II-10 shows the distribution of installed capacity for bioenergy, solar and wind, indicating the increasing participation of developing economies. Given political will, there is scope for significant progress, with the prospect of greater energy security and many new jobs.[54]

Figure II 10

Top 10 countries in renewable energy sectors according to installed capacity (MW), 2010 and 2020



Source: UNCTAD based on IRENASTAT (2021).

As EV and green hydrogen are the most recent markets, they are examined in greater detail in the following sections.

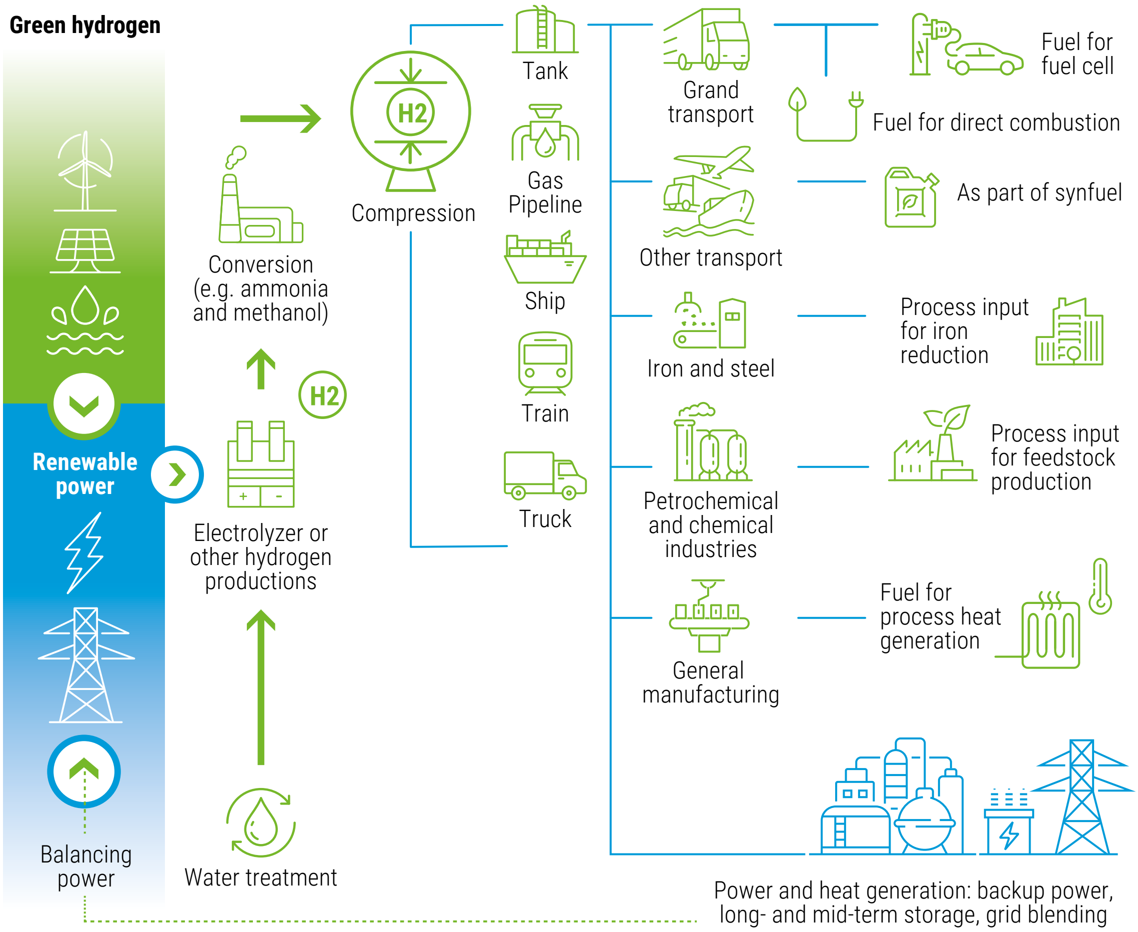
1. GREEN HYDROGEN

Green hydrogen, also called clean hydrogen, refers to hydrogen produced through the electrolysis of water, using energy sourced from renewables. When used as a fuel, hydrogen releases nearly three times as much energy as the same weight of gasoline and nearly seven times than the same weight of coal.[55]

Green hydrogen has a number of advantages and is gaining momentum. It can be stored for long periods and unlike solar or wind can be provided more easily and flexibly to meet consumer demand. Nonetheless, the market is still incipient, and represents only four per cent of global hydrogen production.[56]

Green hydrogen can be used for vehicle fuel, petroleum refining, metal processing, fertilizer production, and food processing. Hydrogen also represents the 'missing piece' in the energy transition because it can be employed in hard-to-abate sectors such as cement and steel that cannot use electricity from intermittent supplies from solar or wind. Moreover, green hydrogen can be converted to feedstock and to chemicals such as ammonia and methanol, which are easier to store and transport than regular electricity (Figure II-11).[57]

Figure II 11
The value chain of green hydrogen from inputs to production to final use



Source: UNCTAD.

Nevertheless, green hydrogen faces a number of barriers, notably cost and the immaturity of the technologies, many of which are not ready for widescale commercialization, as for example with gas turbines. There is also significant energy loss along the production chain, making the process more energy intensive. There are fears regarding the availability of renewable energy to meet the needs of increasing green hydrogen production as this sector's demand for renewable energy could reach 21,000 MW by 2050, which is almost as much electricity as is produced globally today. There are also uncertainties about regulation and infrastructure.[58] Most of these barriers are not structural, and could in principle be mitigated by innovation, which might, for instance, improve the energy efficiency of green hydrogen. At the same time, increasing prices for fossil fuels could make green hydrogen more competitive for certain uses. Furthermore, much of the world's existing natural gas infrastructure can be converted for use with hydrogen,[59] and there are efforts to establish regulations and standards (Box II-2).[60] Carbon pricing will also have an effect.

Developing economies could become net exporters of green hydrogen. Europe is expected to be unable to satisfy its own demand as it will exceed the ceiling of its renewable energy production capacity and may thus become a net importer, mainly from Africa and the Middle East which have the highest technical potential (Table II-3).[61] Nonetheless, this potential is no guarantee of successful production, and countries must foster the necessary framework and infrastructure.

Table II 3

Technical potential for producing green hydrogen at less than $1.50/kg (in exajoules) by 2050

Sub-Saharan Africa	Middle East	North America	South America	Oceania	Asia	Europe
2 715	2 023	1 314	1 114	1 272	960	88

Source: IRENA (2022).

Box II 2
Green hydrogen standards and regulations

A global certification system is an important step to the commercialization of green hydrogen, signalling compliance with regulation and production criteria, and allowing consumers to differentiate green hydrogen from grey hydrogen (produced with fossil fuels) and blue hydrogen (produced with natural gas). This opens the possibility of companies acquiring this hydrogen and willing to pay a premium for clean sources. There are several green hydrogen standards already in place:[62]

- *TÜV Süd* – Has a green hydrogen standard for the transport and the industrial sectors (CMS 70), basing it on European legislation.
- *ISCC PLUS* – ICC is a multistakeholder initiative recognized by the EU, which offers voluntary certification, ISCC PLUS, for bio-based and recycled raw materials for all markets and sectors not regulated as transportation fuels under the European Renewable Energy Directive or Fuel Quality Directive.
- *Zero Carbon Certification Scheme* – Launched in 2020 for hydrogen and its derivatives by the Smart Energy Council, an Australian NGO.

However, the criteria in these standards vary substantially, which creates difficulties in harmonising them to constitute a global certification system.[63]

Governments have also been enacting regulations and strategies and plans. Examples include:

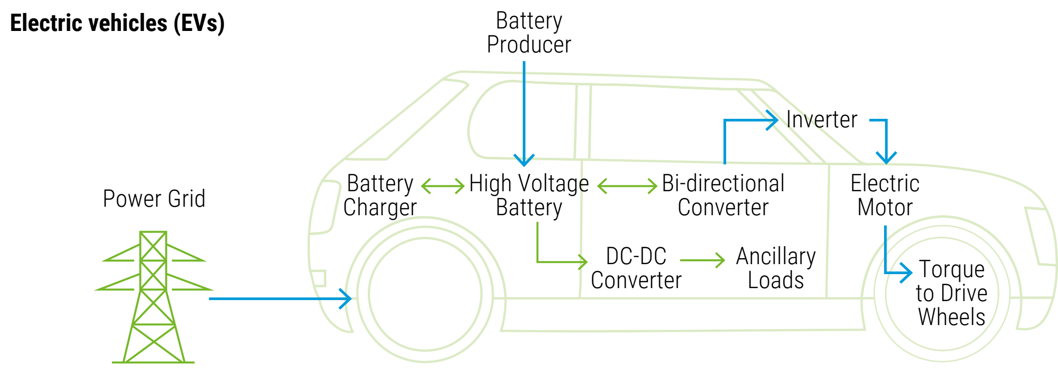
- *Renewable Energy Directive II* – Launched in 2022 by the EU, this considers renewable fuels of non-biological origin as those produced based on renewable energy (wind, solar, geothermal, ambient energy tide, wave or other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas) as electricity sources for production. It adds that the renewable energy source has to come in operation after or at the same time as the unit generating the fuel and is either not connected to the grid or connected but providing evidence that the electricity was supplied without decreasing the electricity in the grid.[64]
- *Low Carbon Fuel Standard* – Launched in 2011 by the state of California, in the United States, this allows three possible ways to produce renewable hydrogen: (i) through electrolysis using renewable energy, (ii) via catalytic cracking or steam methane reforming based on biomethane, or (iii) through the thermochemical conversion of biomass.[65]
- *Inflation Reduction Act* – Implemented in 2022 by the United States, this seeks to stimulate the production of clean hydrogen through tax credits – increasing the benefits as emissions decrease – and considering GHG emissions throughout the lifecycle. Clean hydrogen is defined according to emissions thresholds, with the highest benefit being for production that emits less than 0.45 kg of CO_2 per kg of hydrogen.[66]

Source: UNCTAD.

2. ELECTRIC VEHICLES

The technology employed in EVs present different benefits. EVs use one or more electric motors for propulsion. They can be powered by a collector system, with electricity from extra-vehicular sources, or autonomously from a battery, and will have an electric motor, inverter, boost converter, and an on-board charger (Figure II-12).

Figure II 12
Main components of an electric vehicle

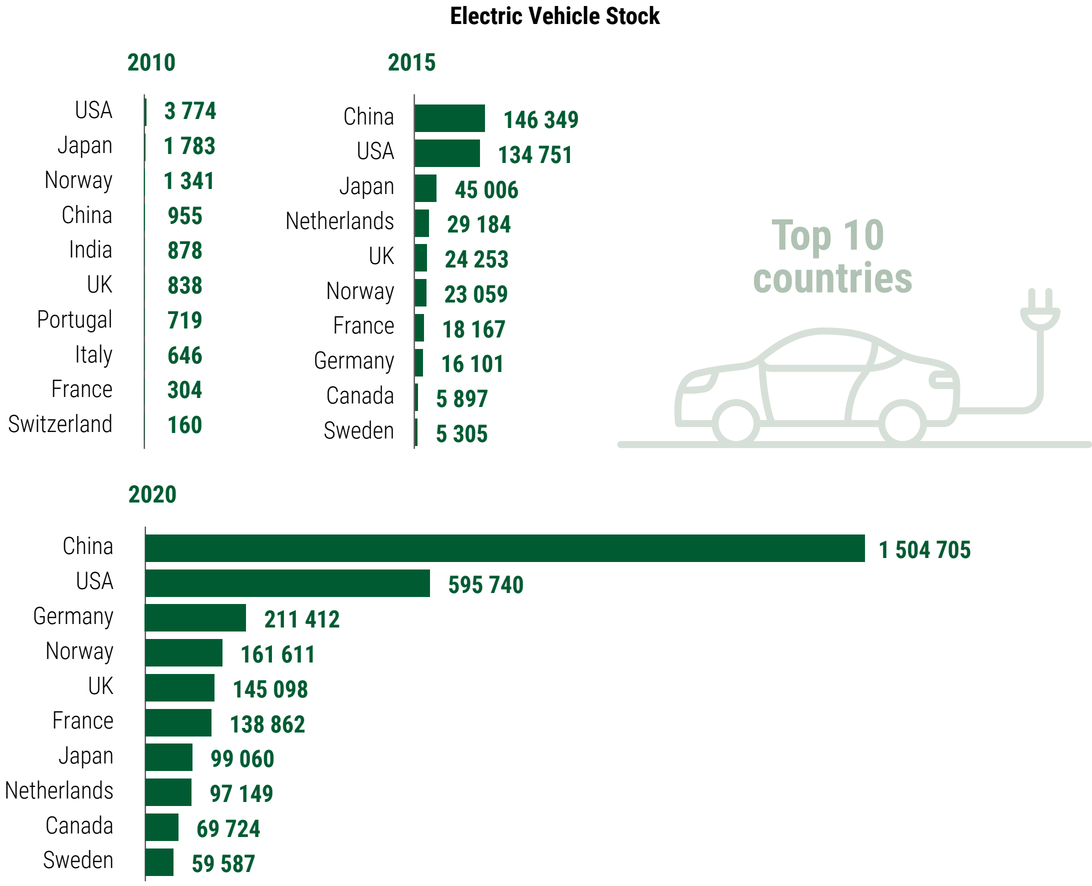


Source: UNCTAD.

As energy-consuming technologies, EVs create new demands for electricity that can be supplied by renewables. In addition to the benefits of this shift, such as reducing carbon dioxide emissions and air pollution, electric mobility also creates significant efficiency gains and could emerge as an important source of storage for variable sources of renewable electricity. However, the market expansion for this technology might require infrastructure adaptations to enable sufficient power stations. For example, in Europe, the current system is considered to be able to cope with the complete replacement of the car fleet for EVs.[67] But this is not necessarily the case in other regions. In terms of diffusion, electric cars are less common in developing than in developed economies. In 2010, only two developing economies were among the top ten countries in terms of EV stock.

By 2015, China had managed to reach first position in this ranking, but India had dropped out. India, Indonesia, and Brazil have demonstrated that while low- and middle-income countries can support two-wheeler EVs, they may not yet have policies for a full-scale transition to electricity-powered transportation.[68] This is a missed opportunity to generate growth in other sectors. Electric mobility offers great opportunities to create synergies with other technologies particularly by increasing the demand for renewable energy. EVs can also provide decentralized storage for variable sources of renewable electricity through their batteries.

Figure II 13
Top ten countries: electric vehicles stock 2010-2020



Source: International Energy Agency (IEA) – Global EV Data Explorer (2022).

C. READY TO ACT

If developing countries are to capture the economic gains associated with new technologies, their firms must have the required capabilities to enter new and growing sectors while their governments need to establish the necessary policies, regulations, and infrastructure to support them. To assess national preparedness to equitably use, adopt and adapt frontier technologies, this report presents the 2022 readiness index that combines indicators for ICT, skills, R&D, industrial capacity and finance (Table II-4).

The readiness index ranking is dominated by high-income economies, notably the United States, Sweden, Singapore, Switzerland, and the Netherlands. Emerging economies are primarily found in the second quarter of the list – notably Brazil is ranked at 40, China at 35, India at 46, the Russian Federation at 31, and South Africa at 56.

Table II 4

Readiness towards the use, adoption and adaptation of frontier technologies, selected countries

	Rank in 2022	Rank in 2021	Movement in rank	ICT ranking	Skills ranking	R&D ranking	Industry ranking	Finance ranking
Top 10								
United States of America	1	1	–	11	18	2	16	2
Sweden	2	4	▲	6	2	16	11	18
Singapore	3	5	▲	7	8	17	4	17
Switzerland	4	2	▼	21	13	12	5	5
Netherlands	5	6	▲	4	9	15	10	31
Republic of Korea	6	7	▲	15	26	3	9	7
Germany	7	9	▲	24	17	5	12	40
Finland	8	17	▲	22	5	21	20	30
China, Hong Kong SAR	9	15	▲	9	23	29	2	1
Belgium	10	11	▲	13	4	23	19	48
Selected transition and developing economies								
Russian Federation	31	27	▼	43	32	13	54	69
China	35	25	▼	117	92	1	8	4
Brazil	40	41	▲	50	55	18	51	57
India	46	43	▼	95	109	4	22	75
South Africa	56	54	▼	71	77	36	67	25

Source: UNCTAD (see the complete table in Annex B).

Countries in Latin America, the Caribbean, and Sub-Saharan Africa are the least ready to use, adopt, or adapt to frontier technologies and are at risk of missing current technological opportunities.

Compared to the initial index in 2021, there are several economies with notable changes in their 2023 rank. Finland and China, Hong Kong SAR, for example, increased their position significantly due to increases in their human capital, notably the increase of high-skill employment.

Furthermore, among the emerging economies, Brazil was able to improve its position despite slower industrial activities, due to increase in ICT development. Meanwhile, China's lower-than-expected position in the ranking when compared with its productive and innovative capacity in frontier technologies is due to urban-rural disparities in Internet coverage and broadband speeds (Box II-3).

Box II 3
Download speeds in China

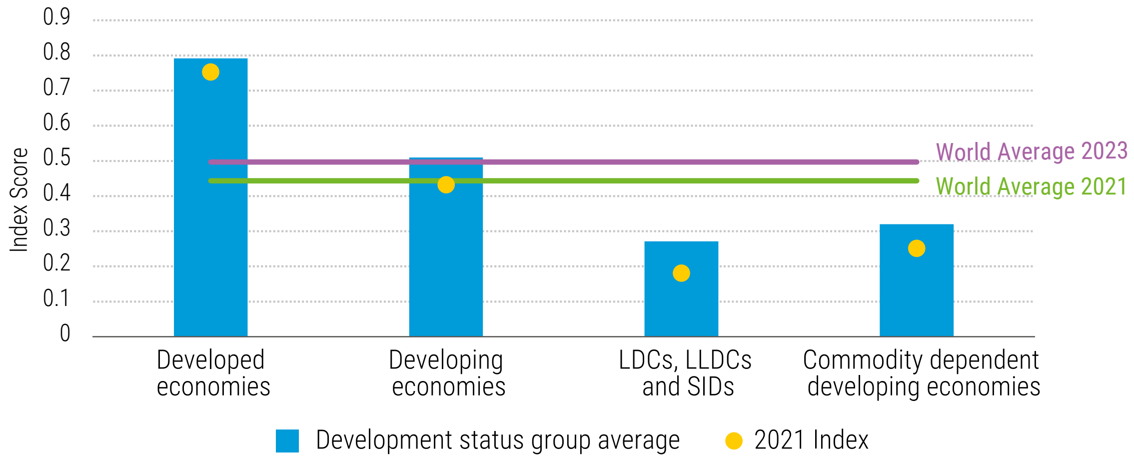
China's position in the 2022 Index can be partially explained by its changing position in the ICT ranking. In the 2022 Index, China had an ICT rank of 117, compared to its ICT rank of 99 in the 2021 Index. This change was largely driven by China's mean download speed (Mbps), which was slower relative to its peers according to data collected from M-Lab. Some reasons for this might include:

- The wide urban-rural disparities in Internet access, with Internet coverage comparable to Portugal and Poland in urban areas and similar to Cambodia and Côte d'Ivoire in rural areas.[69] There are also stark differences in broadband penetration and Internet speed across the different provinces in China. According to a 2021 report by the Chinese organization Broadband Development Alliance, provinces in the West continue to experience much lower Internet speeds than Eastern provinces. This might drive down average broadband speeds in China.
- China's system of Internet firewalls decreases the network performance and download speed of content from many non-Chinese sites.[70] Internet speed is negatively affected as incoming and outgoing traffic is routed through a limited number of access points which increases latency, while Deep Packet Inspection is used to monitor the Internet which might cause packet loss.[71] As a result, while Internet speeds might be significantly higher for accessing content hosted on in-country servers, poorer performance might be reported if downloads were attempted from sites behind firewalls.
- Internet speeds decreased during lockdowns globally, with China experiencing the highest percentage loss in speed (52 per cent) of all the countries studied.[72] One explanation for this is that lockdowns generate Internet congestion due to higher online traffic as people increasingly work and study from home.[73] If this were the case, given that lockdowns persisted in China through 2021 while they were lifted in other parts of the world,[74] China might have experienced relatively lower Internet speeds in 2021. However, it should be noted that a variety of Internet speed rankings exist apart from M-Lab, including Ookla, SpeedTestNet.io, and BandwidthPlace.com. These rankings adopt different methodologies and assumptions in calculating broadband speed, leading to a range of estimations of the Internet speed of any given country.

Source: UNCTAD.

Since 2021, the overall value of the index has increased by 14 per cent, from 0.44 to 0.50 points. For developed economies the average is 0.80 points; for developing economies 0.50 points; for LDCs, LLDCs, and SIDS 0.28 points; and for commodity-dependent economies 0.32 points. The gaps between these groups are wide, but they are starting to narrow.

Figure II 14
Average index score by development status



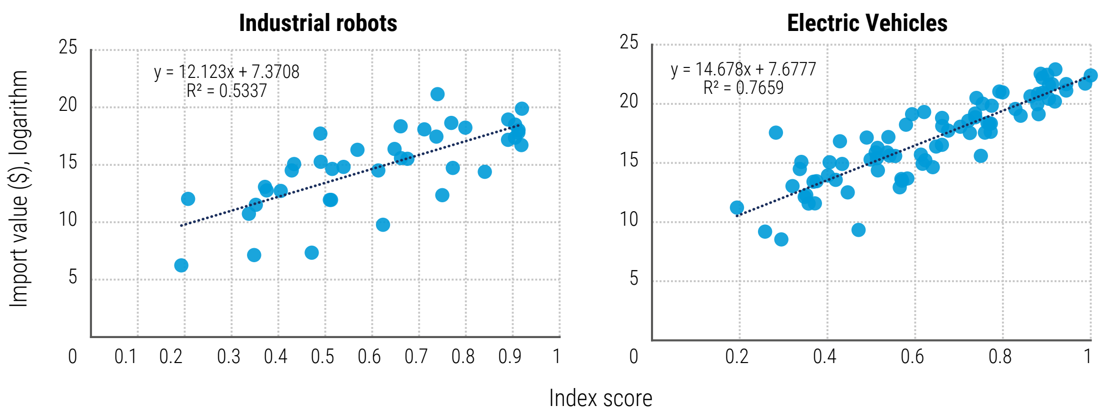
Source: UNCTAD.

Having low index scores suggests a lack of the foundational capacity to take full advantage of green windows. Countries with a lower readiness index will face greater challenges as they seek to revitalize their transport systems, shifting away from fossil fuels and reducing CO_2 emissions in line with Paris Agreement Nationally Determined Contributions. The EVs market, for instance, shows a strong correlation between a country's readiness index and the total value of imports of electric vehicles (Figure II-15). Developed economies with very high index values have advanced infrastructure and highly skilled populations, as well as access to the finance to purchase EVs (Figure II-16).

It is important to note that there is no causal relationship between the index and trade activities. In other words, achieving a higher index does not necessarily lead to an increase in trade activities as measured by import, or vice versa. Robotics that are commonly used in industry 4.0, for instance, have a positive and significant correlation between the index value and imports of the goods (see Figure II-15). However, for the last five years, the imports of this industrial robots have been constantly higher in developing than in the developed economies (see Figure II-16). It is interesting to note that the COVID-19 pandemic has affected the global distribution which caused a slowing down of the import of industrial robots in 2020 before picking up again in 2021.

Figure II 15

Correlation between the index score and the adoption of selected frontier technologies, 2021

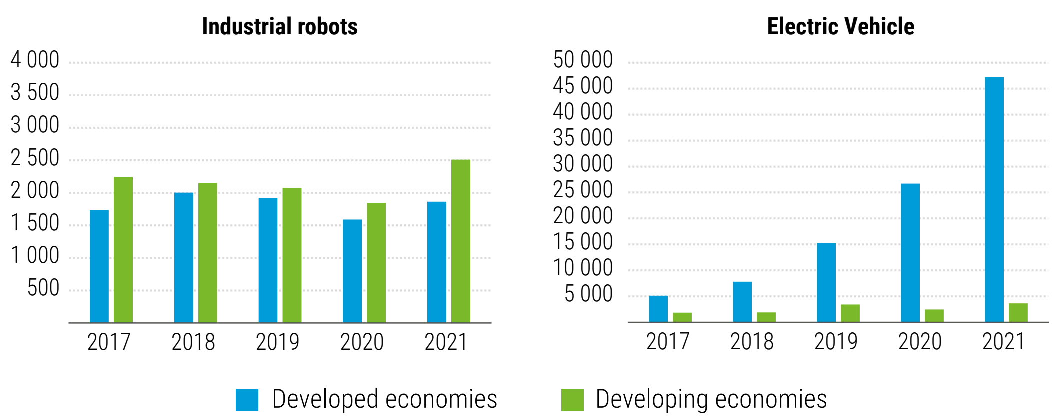


Source: UNCTAD based on data from UN COMTRADE and IRENA, 2022.

Notes. Import of electric vehicles refer to "Vehicles, with only electric motor for propulsion" classified under HS 870380. Import of industrial robots refer to "Machinery and mechanical appliances: industrial robots, n.e.c. or included" under HS code 847950. The correlation in the three graphs is statistically significant at 0.01 level (p <,001).

Figure II 16

Import value of selected frontier technologies ($ millions)

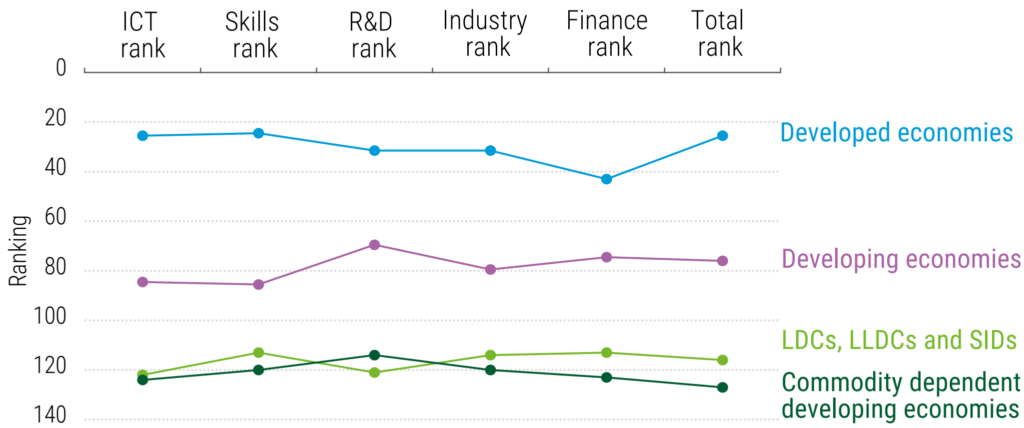


Source: UNCTAD based on data from UN COMTRADE.

The index highlights areas that need to be improved to enable greater use, adoption, and adaptation of frontier technologies. Overall, developing countries as a group, and even the top five developing countries, have lower rankings for ICT connectivity and skills (Figure II-17). LDCs, LLDCs, and SIDS rank lower than 100 in all the building blocks, with particular deficiencies in ICT infrastructure and in research & development.

Figure II 17

Average index ranking by building block (selected country groupings)



Source: UNCTAD.

The readiness index highlights areas in which countries need to improve – to place themselves better in the race to develop new sectors and establish themselves as leaders. However, a high value for the readiness index does not necessarily mean the country will be able to open the green windows for frontier technologies, as this also requires appropriate policies and investments.[75] The following chapter shows how this has been working out in practice for green industries in developing countries.

1 Rodrigues et al., 2022

2 Ahmadi et al., 2019; Zang, 2011; Hussein, 2015

3 UNCTAD, 2021a

4 Persistence Market Research, 2022

5 Data estimates from Chui et al., 2021; Precedence Research, 2022a; Allied Market Research, 2022a; Research and Markets, 2021; Valuates Reports, 2022; Lux Research, 2021; Precedence Research, 2021; Allied Market Research, 2021c; Allied Market Research, 2021a; Prophecy Marketing Insights, 2022; Next Move Strategy Consulting 2020; Allied Market Research, 2021b; Precedence Research, 2022c; Precedence Research, 2022d; Allied Market Research, 2022c; Precedence Research, 2022b; Allied Market Research, 2022b

6 Abraham et al., 2021; Buntz, 2020

7 Froese, 2018; Lueth, 2018

8 McKinsey & Company, 2018; PwC, 2017a

9 West and Allen, 2018

10 Amankwah-Amoah et al., 2021; UNCTAD, 2021c; McKinsey & Company, 2020a

11 UNCTAD, 2021b

12 UNCTAD, 2021c

13 PwC, 2021

14 McKinsey & Company, 2018; Chui et al., 2021

15 Kandaswamy et al., 2018.

16 Frey and Osborne, 2017; McKinsey Global Institute, 2017; PwC, 2018; Maddison, 2001

17 For example of empirical and theoretical research supporting the labour-friendly nature of frontier technology product innovation, see Vivarelli, 2014; Dosi et al., 2021; Barbieri et al., 2020; Vivarelli, 2022; Damioli et al., 2022. Frontiers technologies may also have adverse labor market impacts; in this respect, see for example Montobbio et al., 2022; UNCTAD, 2021a. See also Forbes, 2022a

18 UNCTAD, 2021a

19 Alekseeva et al., 2021

20 Bright Outlook, 2022

21 Konkel, 2021

22 The Blockchain Academy, 2021

23 Australian Government, Department of Infrastructure, Transport, Regional Development and Communications, 2020

24 Radovic, 2019

25 Mandel and Long, 2020

26 Campbell et al., 2017

27 Kearney, 2017

28 Hasan, 2022

29 Hiter, 2021

30 CareerExplorer, 2020a

31 Grad School Hub, 2020

32 IRENA, 2021a

33 U. S. Department of Energy, 2021

34 IRENA, 2021a; Ravillard et al., 2021

35 IRENA, 2021a

36 Chamberlain, 2018 and 2017

37 IRENA, 2021a

38 Sooriyaarachchi et al., 2015

39 IRENA, 2021a

40 Global Wind Energy Council, 2021

41 IRENA, 2021a

42 Pek et al., 2018

43 UC Berkeley and GridLab, 2021

44 CareerExplorer, 2020a

45 Thompson, 2017

46 Bureau of Labor Statistics, U.S. Department of Labor, 2019a

47 Ministry of Industry and Information Technology of the People’s Republic of China, 2021

48 Konaev and Abdulla, 2021

49 Hoppe, 2005

50 IEA, 2016

51 Dioha et al., 2022

52 Annex C shows that renewable hydropower represents an important share of the total installed capacity. The industry is not included in the present study for several reasons. There is an ongoing discussion about how “green” the hydropower sector really is. The proponents of the hydropower sector argue that it is a renewable, low carbon energy technology that is crucial for mitigating climate change. However, hydropower opponents argue that large hydropower has large-scale and irreversible environmental impacts including ecosystem destruction, geomorphological changes, hydrological changes, impacts on aquatic species, habitat, and biodiversity loss. Besides, it is an industry characterized by large economies of scale and fully dominated by China, where about half of the world’s large dams are based. For an interesting account of how China has gained market and technological leadership in the sector see Zhou et al., 2021. See also Hamilton et al., 2020.

53 Based on the World Bank classification.

54 African Development Bank, 2019; Nasirov et al., 2021

55 Skyllas-Kazacos, 2010

56 IRENA, 2020

57 IRENA, 2022a

58 IRENA, 2022a

59 UNIDO, 2022

60 German Energy Agency/World Energy Council, 2022

61 van Renssen, 2020

62 German Energy Agency/World Energy Council, 2022

63 German Energy Agency/World Energy Council, 2022

64 EU, 2018

65 German Energy Agency/World Energy Council, 2022

66 US Congress, 2022

67 Slednev et al., 2022

68 TRT Magazine, 2022

69 UNCTAD, 2021a

70 Normile, 2017

71 Schmitz, 2022; Geerts, 2018

72 M-Lab, 2022

73 World Bank, 2020; Basso et al., 2020

74 *Financial Times*, 2022

75 *Brookings*, 2021