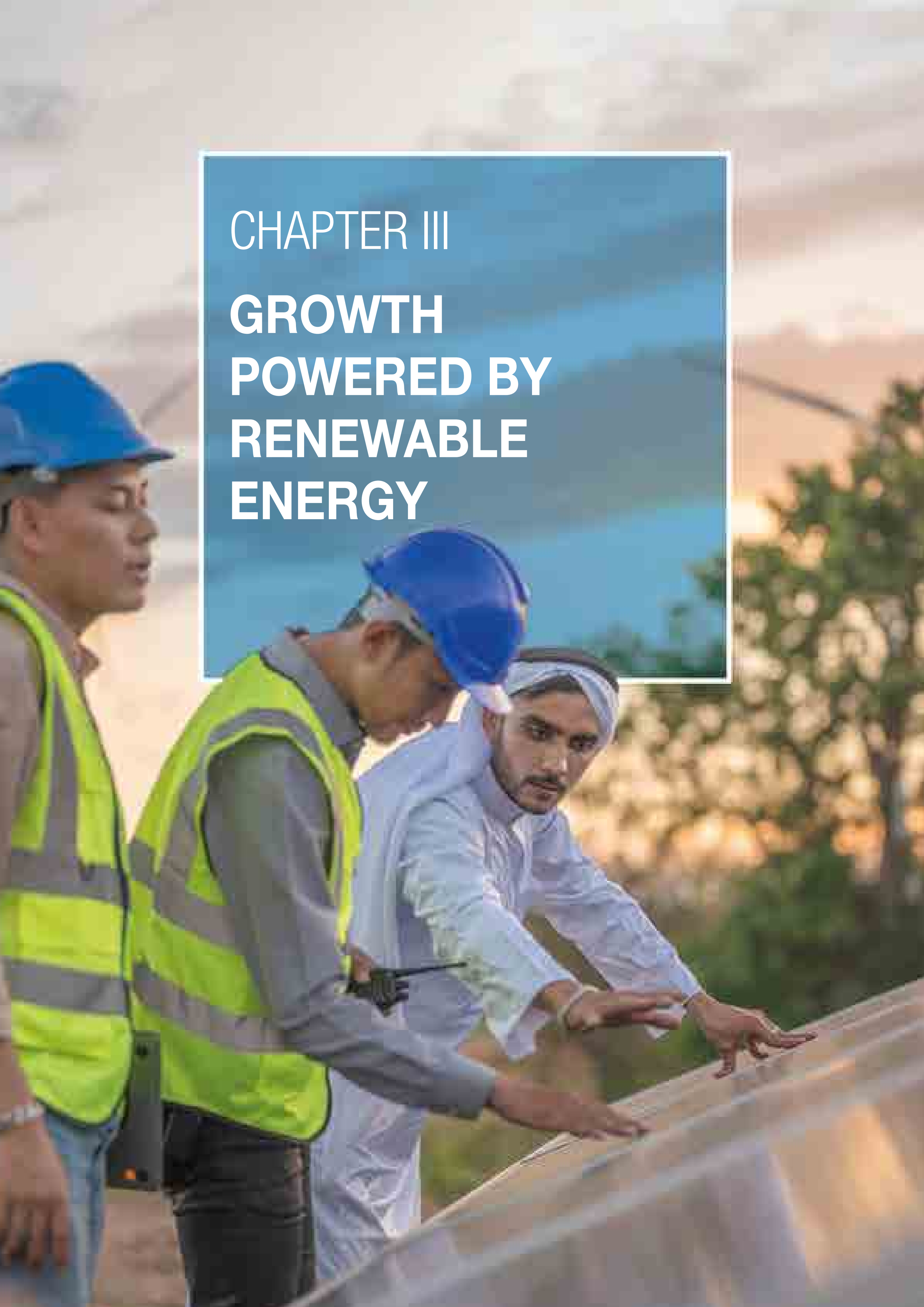
CHAPTER III

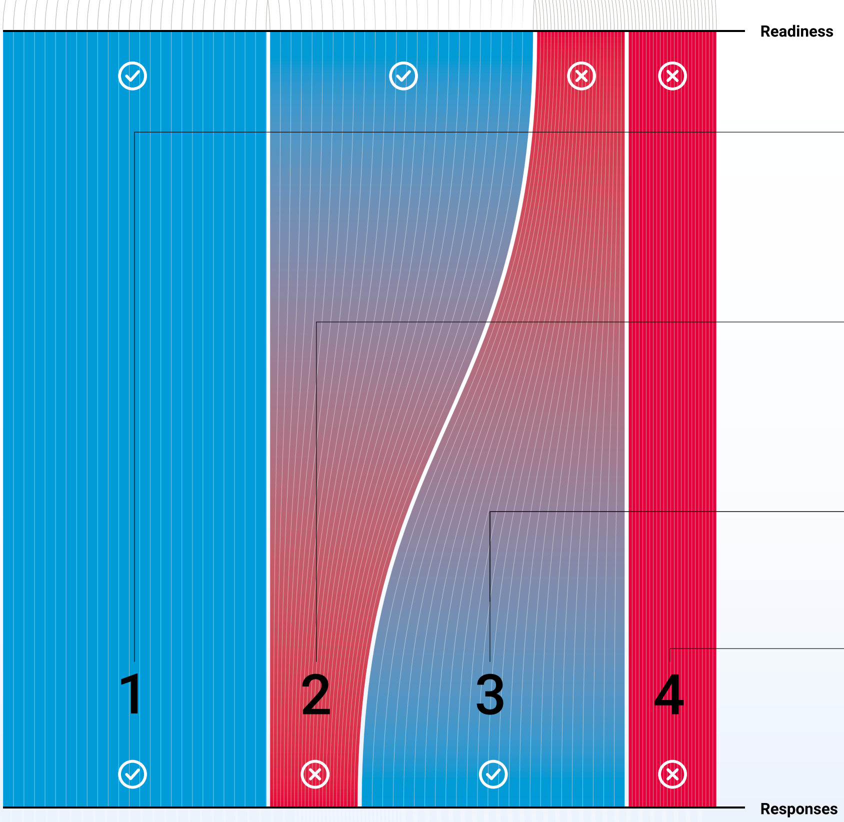
GROWTH POWERED BY RENEWABLE ENERGY



Combining strong initial conditions and strong responses make up the best scenario to seize GWOs but weak conditions can be compensated by strong efforts

There is no unique way of catching up but it does not happen without strong government effort.

The initial conditions in a sector do not make seizing its GWOs automatic or impossible - they are influenced by government action



Scenario:

Windows open
Solar PV, Biomass, CSP: China
Bioethanol: Brazil
Hydrogen: Chile *(potentially)*

Windows to be open
Solar PV: India
Biogas: Bangladesh
CSP: Morocco
Wind: China

Windows within reach
Biomass: Thailand and Viet Nam
Hydrogen: Namibia

Windows in the distance
Wind: Kenya
Bioenergy: Mexico and Pakistan

The maturity and tradability levels of technologies affect GWOs

- **Immature technologies** require stronger initial conditions in science and R&D
- **Mature technologies** tend to entail more market competition
- **Tradability** involves different dimensions that influence the competitive dynamics and modes of technological learning

Benefiting from GWO requires opening and augmenting them and enhancing relevant capabilities

Countries have employed policies like human capital attraction, government-created demand, and local content requirement to create and take up GWOs

GWOs develop over time, so the strategies and initiatives need to adapt

This chapter examines developing country experiences in producing, distributing, and using renewable energy technologies – bioenergy, solar and wind energy, and green hydrogen. The depth and speed of latecomer development vary according to sector. Mature sectors such as biomass or solar PV have readily available technologies and can provide a relatively fast track to boosting economic activities. But new technologies such as green hydrogen, concentrated solar power (CSP), or electric vehicles are more demanding in terms of developing new technological capabilities and require significant investment in innovation systems.

In most countries the speed of development is driven by national ambitions to generate economic growth, mitigate climate change, transform energy production and consumption, electrify rural communities, or increase energy security. As the same time, there are international and global pressures to diffuse green investments and establish promising new markets.

Each country needs to identify opportunities in specific stages of the value chain and orient research and development as well as education and training to build domestic capacity; even the more mature technologies that are easily imported can be adapted to the local context. Some countries start with natural advantages such high levels solar radiation, but these do not automatically offer opportunities for latecomer development. The key to generating growth through the green transition is to foster the necessary capabilities and respond to opportunities as they arise.[1, 2]

A. OPENING GREEN WINDOWS IN DEVELOPING COUNTRIES

The presence of Green Windows of Opportunity – favourable but time-bounded conditions for latecomer development associated with sustainable transformation (Chapter 1) – is specific of each technology and its characteristics depends on the related institutional, market, or technological changes. The following sections examine the experiences of some developing countries in producing, distributing, and using renewable energy technologies: bioenergy, solar and wind energy, green hydrogen, and electric mobility. Additional cases, in bioenergy, concentrated solar power, wind energy, and electric vehicles are presented in Annex C.

1. SOLAR PV

China

China has 254 GW of installed capacity in solar PV.[3] It has established this world-leading position by supporting a domestic production and innovation system that combines public and private business actors as well as by supporting and regulating research institutions (Box III-1). The 2006 Renewable Energy Law encouraged Chinese firms and research institutes to collaborate with foreign partners which enabled them to enter international markets. A key programme was the Thousand Talents Plan aimed at recruiting global experts and attracting the return of prominent Chinese researchers in PV cell technologies.[4, 5]

Local firms, universities, and industry associations[6] engaged in a progressive catch-up across the whole PV industry, starting from portable lightning devices, then moving to solar PV panels and ultimately creating a domestic cell and wafer industry with the technological capabilities to produce polysilicon, previously imported from the United States. China also started producing power devices such as inverters.[7]

Overseas sales suffered a setback with the 2008 financial crisis. Germany and several other countries reduced their PV subsidy programmes, which caused a considerable drop in demand and, consequently, prices. In reaction, the Chinese Government boosted domestic demand, through for example, the Concession Programme for Large-Scale Solar PV Power Plants, the Solar Rooftop Subsidy Programme, and the Golden Sun Demonstration Programme, offering subsidies of up to 70 per cent of total investment.[8] In this period the sector also benefited from intense interactions among leading firms.

Box III 1
How China came to dominate the global PV market

The 2008 financial crisis was a blow to China's overseas PV exports. After that, the State sought to transform local demand and supply of its PV sector. Supported by national policies, the PV industry promoted cooperation across the value chain and intensified technological innovation. In 2013, two leading enterprises agreed to procure each other's products. Yingli agreed to purchase silicon materials and wafers from GCL-Poly Energy while GCL-Poly Energy procured components and modules from Yingli to construct solar PV stations.

Later, five state-owned enterprises collaborated on attracting investment, project management, integrated construction, R&D, training, hardware maintenance, and setting the standards. With the support of the Central Bank, the industry partnership gained collective advantages globally along the whole value chain.

In the Talatan area of Gonghe county in northwestern China, thanks to the Concession Program for Large Scale Solar PV Power Plants, herds of sheep scamper through the blue 'forest' of solar PV panels and graze in the pasture below. The solar panels not only collect sunshine they bring water to the soil underneath from monthly washing, producing quality forage for livestock farming.

Meanwhile Qiejuntai, a villager in Gonghe county, now makes a living from both the solar industry and husbandry, obtaining an income of over 10,000 euros each year.[9] According to China Global Television Network, as of the end of 2020, 100,000 villages across China had installed PV power stations, generating 18.65 million KW of electricity and bringing an annual income of about 27,000 euros to each village.[10]

Source: UNCTAD based on Xinhua News Agency, 2020 (http://www.xinhuanet.com/nzzt/135/) and CGTN, 2021.

Mexico

To build local demand for solar PV, the Government carried out a national auction, through which successful bidders were awarded contracts, or power-purchasing agreements that guaranteed the price per unit of electricity generated.[11, 12] In the Mexican approach, these clean energy auctions are technology-neutral, meaning that all clean energy sources compete. The competition is based on offered price and is driven by free-market cost competition, with no explicit aim of developing a domestic renewable energy industry. This auction design attracted large foreign developers and specialized vertically integrated renewable energy companies, but it offered limited scope for developing domestic capabilities across the value chain.

South Africa

South Africa has developed the Renewable Energy Independent Power Producer Procurement Program. As in Mexico, this is market-based with government purchasing renewable energy through a reverse auction system. In this case, however, the auctions are technology-specific and there are additional regulatory requirements to foster black economic empowerment, create jobs, include local content, and have 70 per cent community ownership.

This produced a different outcome.[13] The auction attracted a diverse set of international and local project developers, and the local content requirements engaged national engineering, procurement, and construction companies. However, technological upgrade was restricted by an initial shortage of semi- and skilled workers, combined with local content requirements.[14] In addition, the regulations were not well enforced, and loopholes enabled foreign developers simply to use warehouses in South Africa rather than set up production plants.

India

Instead of building up a domestic manufacturing capacity, the Indian national programme prioritized cheaper prices that would maximize installed capacity. It attracted large projects offering low tariffs and incentivised energy developers to rely on cheaper imports of solar cells and panels. In general, limited emphasis has been devoted to R&D and building up domestic and production capabilities. When local content requirements were introduced, there was insufficient domestic capacity to fulfil the supply[15].

In 2018, under pressure from domestic manufacturers, the Government introduced a safeguard duty against solar cell imports from China and Malaysia. However, this forced developers to buy more expensive panels and slowed down the bidding process – while offering few benefits to domestic manufacturers. If the manufacture of cells and panels is now out of reach, there are still opportunities in the service stages of the value chain and for manufacturing other components.[16]

Viet Nam

Viet Nam has rapidly expanded its solar energy installed capacity and is considered more successful than other ASEAN countries like Malaysia and Indonesia.[17] In 2015, the Government launched the National Strategy on Renewable Energy Development and followed this in 2020 by a Party's Resolution on the Orientation for National Energy Development. Measures included a feed-in-tariff, temporary tax exemptions for solar developers, and tariff exemptions for imported equipment. Viet Nam also has a favourable environment for foreign direct investment, and no local content requirements. These measures attracted foreign developers and created a large domestic market. In 2020, Viet Nam was the world's eighth largest market in terms of installed capacity. However, this did not build domestic production or technological capacity (Box III-2).

Box III 2
The Mekong 'power delta' with the sun

Countries in the Mekong Delta have relied in the past for electricity on hydropower. However, output has been affected by lower rainfall and less runoff,[18] as well as unsustainable upstream dam construction and farming patterns. Solar power is a promising alternative that takes advantage of the natural conditions. Solar power stations are being built in barren land, on farmlands, or on the river in Viet Nam, Thailand, and Cambodia.

Viet Nam – In southwestern Viet Nam, at the foot of Cam Mountain, in 275 hectares of barren land the domestic private sector has invested heavily in solar electricity and is expected to produce 400 million kWh. Together with eco-tourism, the solar business drives the local economy by creating jobs.[19] Because the existing publicly managed grid network has been unable to keep pace, the local provincial government has invested in a 500kV transmission line connecting An Giang with O Mon in Can Tho, the largest city along the Mekong Delta, in the 2021-2025 period.[20]

On farmlands in north-western Viet Nam in Sơn La Province, for example, a 100-square-metre solar-powered dry-house processes 1.5 tons of fresh bamboo shoots every three days and produces 120-150kg of dried product.[21] The availability of rooftop solar power avoids the need to burn firewood and thus enables farmers to receive higher incomes with less time, energy, forest degradation, and air pollution.

Viet Nam also has South-East Asia's first floating solar power generating system. Floating solar power projects (i.e., solar panels installed on the surface of reservoirs, industrial ponds, lakes or near-coastal areas), can re-use reservoirs built originally for hydro power and existing transmission infrastructure, increasing supply with almost no marginal costs.[22] The Da Mi project is operated by a national power company, Vietnam Electricity, using a feed-in-tariff of $9.35 per kilowatt-hour.

Cambodia –After failures in a few solar power projects,[23] the Government is nevertheless determined to exploit the solar potential.[24] It has recently approved a 60 MW solar farm in Kampong Chhnang Province, the first part of a 100-MW National Solar Park, as well as a 60-MW farm in Pursat.[25]

Thailand – In 2021, At Sirindhorn Dam in Ubon Ratchathani province, Thailand, the world's largest hydro floating solar farm went online in November 2021.[26]

Source: UNCTAD.

Kenya

In Sub-Saharan Africa, there is a rapidly growing solar PV market. More recently, the initiative has been taken by private companies facilitated by international finance. Domestic solar PV firms have been able to face up to international competition and have established themselves in different market segments, having moved from standalone installations to larger-scale plants; from distribution to installation; and from government tenders and donor projects to commercial contracts.[27] This could make Kenya a global hub for clean energy companies, particularly in small-scale decentralized energy generation and consumption. In some cases, upgrading has been the result of strategic networking with international actors and of investments in national capacities and skills.

Nevertheless, domestic companies continue to face significant challenges in the areas of finance, skills and policy, which prevent them gaining larger shares of the growing domestic market. To develop a well-functioning and coordinated domestic solar PV industry, they will need closer collaboration between the industry players and supporting institutions, such as the commercial banks, the training and academic institutions, the ministries and various public bodies.[28]

Ethiopia

The country has enormous potential in solar energy which could be used to privatize and decentralize the electric power sector through off-grid and mini-grid technologies.

Iran

Thanks to government commitment, solar PV is taking an increasing share of renewable energy production, but local industrial capacity remains very limited. Some factories are assembling the modules using imported raw materials – though there are plans to exploit the country's silica resources. At present the country does not have clear and implemented regulations and incentives to attract investment and encourage R&D.[29]

2. BIOFUELS

A wide range of biomaterials can be combusted to produce heat, converted to electricity, or processed into biofuels – ranging from agricultural and forestry residues, solid and liquid organic wastes – including municipal solid waste, sewage, and animal manure. Some crops can also be cultivated specially for energy, such as corn and soybeans (Figure III-1).

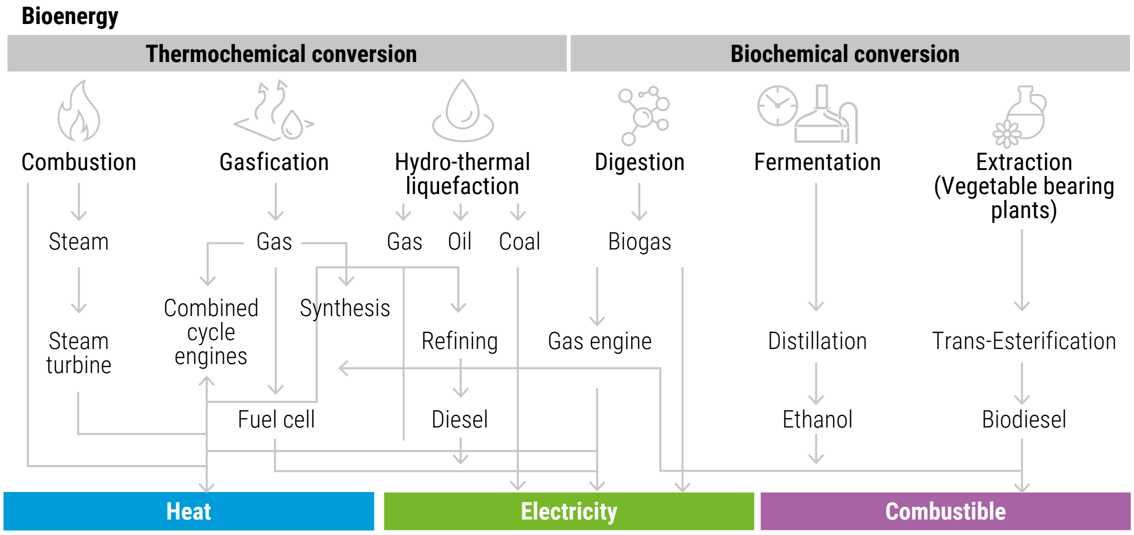
Liquid biofuels are convenient renewable substitutes for internal combustion engines running on gasoline, diesel or kerosene for use in road, sea and air transport. Apart from direct combustion, adequate energy utilization of biomaterials is also possible through high-temperature and pressure gasification, hydrothermal liquefaction converting biomass into crude-like oil, biochemical digestion, fermentation, and extraction (Figure III-1).

Bioethanol and biodiesel have opened opportunities within climate change strategies in a range of developing countries. This switch is particularly significant in countries with the potential for sugarcane production and other crops that do not compete directly with food production.[30]

While Brazil and other countries, such as Australia, developed biofuel industries based on sugar cane, many developing countries during the 2010s experimented with oil from palm or from the seed of the jatropha tree which can produce biodiesel or jet fuel. Jatropha has several favourable properties such as high yield and low water and fertilizer requirements, as well as high resistance to pests and the ability to thrive on marginal land without competing with food crops. After the turn of the millennium, many investors, governments, and NGOs highlighted jatropha as a promising opportunity.

According to multiple authors,[31] jatropha strategies have largely feel short from expected results. Countries like Mexico, India, China, Ethiopia, Mozambique, the United Republic of Tanzania, and Ghana did not meet their expectations regarding investments in this crop to use it as biofuel input to reap economic benefits consequent social gains like reduced poverty.[32] Governments and private investors adopted a "wait-and-see" stance, expecting that technological and land-use problems could be resolved but there were unexpected complexities, and most investment projects fell far short of initial prospects.[33]

Figure III 1
Processes for producing bioenergy



Source: UNCTAD.

Brazil

Brazil's success with bioethanol largely stems from government policy.[34] Experimentation with bioethanol started in the 1930s, but the current programme was largely a response to the oil crisis of the 1970s when OPEC placed an embargo on petroleum. The government has taken institutional efforts to increase the attractivity of the industry and develop the sector. Such efforts include for example the Sugarcane-based ethanol fuel program and the RenovaBio - Green Certificates for the production.

Brazil gradually developed its production system and knowledge base. The government also incentivised investments through programmes like BNDES' Climate Fund. As such, the country developed what became the most successful biofuel industry in the world so far. Since 1980, Brazil has reduced the far, cost of producing bioethanol by 88 per cent.[35] For comparison the United States has a long history of bioethanol production based on corn. But over the same period has reduced the cost by 60 per cent. Today, Brazil is the world leader both in terms of technology and usage of ethanol. Moreover, there is significant, yet unrealised, export potential[36] and Brazil has become the leading supplier of biofuels technology for the developed world.[37] There are also potential forward linkages. Brazil has for example, invented a flex-fuel engine for cars, enabling alternation between traditional and bioethanol-based fuels.[38]

Through its wide-ranging biofuel policy frameworks, Brazil has successfully stimulated both demand and supply,[39] and promoted learning by building productive and technological capacities of the private sector, research and development institutions and other related stakeholders.[40] Technologically it is now a leader in first-generation liquid biofuels and is pioneering new technology – drawing on first-generation capabilities to compete in the second-generation arena.

Today Brazil has around 30 per cent of the global market for ethanol. It has the largest fleet of flexible-fuel vehicles and fully supplies local gas stations where unblended fuel ethanol competes directly with gasoline. In addition, the country exports to a number of countries including the United States, the Republic of Korea, and the Netherlands.

In future, however, without a change in its innovation system Brazil may be unable upgrade to second-generation bioethanol based on food waste and crop residues which do not compete with food production.[41] The focus is still largely on sugarcane and Brazil's federal institutions are less committed to future technologies. At the federal level this is linked with the discovery of offshore petroleum reserves. If it does not respond to global technology changes, Brazil may thus experience a 'technological discontinuity trap'.[42]

Ghana

Ghana has focused on producing biofuels using jatropha. In 2006, to increase domestic demand the Strategic National Energy Plan and National Biofuel Strategy in 2006 enforced blends of gasoline and biodiesel at 5 per cent by 2010, and 10 per cent by 2015.[43] The National Jatropha Plantation Initiative has established 53 districts across the country to start pilot plantations on low-fertility agricultural land where they would not compete with food production.[44] The projects were strongly supported by NGOs and local 'jatropha champions.' Supported by GTZ, UNIDO, and UNDP, key firms and individuals made efforts to show-case jatropha biodiesel. Production also offered carbon credits through the clean development mechanism.[45]

However, the results fell far short of expectations. This was due to low yields and difficulties in ramping up production. Public R&D support was weak, with relatively little sharing of learning and a lack of the technical and managerial information needed to enter international markets.[46]

Ethiopia

The increasing number of sugar factories and the vast land suitable for growing feedstocks offer considerable potential for biofuels which could serve as alternative fuels for transport and cooking services. The country has been producing bioethanol from biomass for decades, but it supplies less than one per cent of power through this source.[47] Taking advantage of its potential for biofuel production would allow Ethiopia to decrease its dependence on fuel imports, and the country could explore difference sources such as sugarcane and jatropha. Nonetheless, there is a need to reform policies to provide greater support.[48]

The United Republic of Tanzania

Tanzania's sectoral system of innovation is unresolved.[49] By 2005 the system comprised a few loosely connected 'experiments' involving around 30 different actors in a grassroots-based organizational model. The system then evolved to a profit-driven model through which thousands of smallholder out-growers supplied jatropha seeds to a firm owning a centralized oil-processing facility.[50] In addition, transnational corporations established large plantations to export jatropha seeds to the West for processing. As in Ghana, initiatives were linked to foreign commercial investors or aid donors.[51]

India

India had an ambitious jatropha biodiesel development programme but many policy changes were not implemented, and production fell short of capacity. Public institutes did not carry out sufficient research on increasing yields, resulting in short-duration crops. A better approach would be to shift from jatropha to an approach using multiple types of feedstocks or inputs instead of jatropha alone, with a better system of incentives both at the feedstock and biodiesel production stages, and augmenting the efforts in research and development for increasing the yield from the feedstock. [52]

3. GREEN HYDROGEN

Hydrogen for energy can be produced in a number of ways, typically classified as black, brown, grey or green depending on the source of energy employed in its production. Black hydrogen uses coal or lignite as a source of energy, while grey hydrogen is created from natural gas, or methane, using steam methane reformation.[53] Green hydrogen, on the other hand, is made by electrolyzing water using electricity from renewable energy sources, such as solar or wind power (see Chapter 2 for a discussion of the status of green hydrogen).

Green hydrogen can reduce dependence on oil price volatility and supply disruptions, as well as lowering energy costs.[54] Since 2019, a number of European states have developed hydrogen strategies, including Austria, Denmark, France, Germany, Italy, the Netherlands, Norway, Portugal, the United Kingdome and Spain, as well as in Australia and Canada.

However, the most attractive sites for producing green hydrogen are in countries with abundant solar and wind resources – particularly in Africa, Southern Asia and the Western regions of South America.[55] There have been a number of initiatives in Brazil, Chile, Uruguay, Viet Nam, Türkiye, Morocco, Namibia and South Africa.[56] Most have relatively small domestic markets, but since green hydrogen can be transported over long distances by boat these countries can become significant exporters. For this, however they will need to improve their techno-institutional capacity and invest in electrolysers and infrastructure for storage and transportation.

Chile

Chile has ambitious climate targets with the expectation that, by 2030, 70 per cent of the power grid will use energy from renewable sources – capitalizing on solar in the north of Chile and wind in the south. In 2020 the Government published a three-phase Green Hydrogen Strategy. The first phase, starting from 2025, will mainly target the domestic market, replacing grey hydrogen for heavy and long-distance transportation. The second stage from 2030 extends local use along with exports. The third, long-term stage after 2035 anticipates opening new markets both domestic well and international.[57] However, Chile is a long way from markets in Asia and Europe. To overcome shipping costs exporters will need to produce hydrogen at a low-cost.[58]

Most of the impetus and coordination has come from the State which has helped lower barriers and reduced regulatory, financial, and technical risks. Private actors, academia and business associations can collaborate with the Government to invest in capabilities, technologies, businesses, and projects for both domestic and export markets. The plan includes:

- *Funds* – For supporting companies, and national and international consortiums to invest in scalable and replicable green projects.
- *Pricing* – A roadmap for pricing of fossil fuel emissions to level the playing field.
- *Regulations and standards* – To be clear and stable throughout the value chain to ensure safety and give certainty to investors.
- *Community participation* – Early and transparent involvement of local communities in green hydrogen-related projects.
- *Innovation system* – An R&D system involving industry, academia and technological centres.

Since 2017, Chile has had micro-grids powered by green hydrogen, providing 24-hour clean energy without requiring diesel-based power backup systems. Developed by the Italian company, Enel, these systems can be on-grid or off-grid and moved to locations such as small community camps.[59] The Chilean National Development Agency (CORFO) has six new pilot projects selected with the involvement of international investors.

Brazil

In 2021, the Ministry of Mining and Energy presented a baseline Hydrogen Strategy, which called for national stakeholders to “embrace the opportunities for the development of various technologies for the production and use of hydrogen, including green hydrogen, in which it can be very competitive.”[60] Several states have initiatives to kickstart production – taking advantage of their renewable energy capacity and port infrastructure. The state of Ceará for example, is developing a green hydrogen hub at the port of Pecém which connects solar and wind energy parks and an export processing zone. Pecém port is a joint venture between the State of Ceará and the Port of Rotterdam Authority – a link that could facilitate entry to European markets.[61] By October 2022, the State Government had signed 22 memoranda of understanding with companies from several countries: two of these, from Australia and United States, have moved to the pre-contract phase. Other initiatives are in the states of Bahia and Pernambuco.

China

China is the world's largest producer of hydrogen, but most of this is from coal. For green hydrogen, China lags behind advanced countries in key technologies for storage and transport, though these can be expected to emerge in the future.[62] China's policies for developing hydrogen date back to the 10th Five Year Plan (2001-2005).

In 2021, China launched a mega-project in Inner Mongolia to build a cluster of plants that will use solar and wind energy to produce 66,900 tons of green hydrogen a year.[63] A further project is the Renewable Hydrogen 100 Initiative, launched by the China Hydrogen Alliance which includes China Energy Corporation and several companies from the energy, transportation and metallurgical industries, along with universities and research centres. The aim is to install electrolysers to produce100 GW of hydrogen by 2030.[64]

China is also at the centre of the UNIDO Global Programme for Green Energy in Industry, through the International Hydrogen Energy Centre in Beijing which will operate as a knowledge partner by supporting research and development.[65]

South Africa

In September 2021, South Africa approved a Hydrogen Society Roadmap aiming to achieve competitive domestic production by 2030 (Box III-3). Three green hydrogen hubs have been identified in South Africa's 'hydrogen valley'.[66] The Johannesburg hub will primarily produce for industry. The Durban hub will produce for vehicles, as well as for port activities and oil refining. The Limpopo hub will produce for the mining sector. South Africa's Department of Science and Innovation points out that the country needs to identify the potential for green hydrogen in different sectors, scale up the number of electrolyzers and invest in the necessary transportation and storage systems.[67]

Box III 3

Green hydrogen is a game-changer in South Africa

Since 2007, people in South Africa have become accustomed to blackouts due to load shedding,[68] when the electricity demand exceeds the available supply.[69] In 2020, according to the Council for Scientific and Industrial Research of South Africa, the country spent 859 hours load shedding. During the decade from 2009 to 2019, the total economic cost of load shedding was estimated at ZAR338 billion (around 20 billion euros).[70] Demand for electricity has continued to outgrow supply. The state-owned Eskom is also heavily reliant on coal-power plants.

Green hydrogen could be a game-changer. The national Government is seeking a just transition by intensifying public-private cooperation through its Hydrogen Society Roadmap. The initial project, CoalCO_2-X, is in the eastern province of Mpumalanga, where flue gas in coal-fired power stations is stripped of pollutants and mixed with green ammonia to be converted into fertilizer.

To embark on the project, the Department of Science and Innovation of the national Government granted ZAR50 million (around €3 million).[71] In June 2021, the private-equity-owned energy producer Sasol and the state-owned financier Industrial Development Corporation, secured joint funding for the feasibility study.[72] More private- and public-sector investment is expected to follow.

In the local private sector, Mitochondria Energy Systems is developing bespoke fuel-cell technology in cooperation with the Austrian engineering consortium AVL, Co-funded by two state-owned financial institutions, the Industrial Development Corporation of South Africa and the Development Bank of Southern Africa Fuel cell systems could be a source of cleaner energy in industry and for combined heat and power.[73]

Source: UNCTAD.

Namibia

Namibia could produce low-cost renewable energy on a large scale and, given the limited national demand, most of this can be exported.[74] The Harambee Prosperity Plan Green identifies green hydrogen as a transformative strategic industry.[75] The Government has launched the Southern Corridor Development

Initiative and established a Green Hydrogen Council supported by a Technical Committee to collect and coordinate projects and infrastructures. These will include plans for both green hydrogen and ammonia, with wind, solar electrolysis and desalination assets, a wind blade manufacturing plant and adequate port facilities.

The Namibia Green Hydrogen Association provides a platform for public-private interactions. In January 2022 the President announced that the first bid to produce 300,000 tons of green hydrogen and ammonia per year had been won by Hyphen Hydrogen Energy.[76]

Namibia has established international cooperations to support hydrogen production. It established a partnership with Germany to identify suitable sites for green hydrogen production. This is part of the H2Atlas-Africa project, which will carry out research on green hydrogen production in arid areas using desalinated water. [77] To build domestic knowledge this also includes exchange programmes for researchers and experts, and scholarships for Namibian students. The country also signed agreements with Belgium and Rotterdam (Netherlands). These international agreements encompass funding, but Namibia is also considering options like green or sustainable bonds to achieve the necessary value for the projects.[78]

Morocco

The Middle East and North Africa region has an abundance of solar and wind power and has considerable potential for supplying green hydrogen demand to countries in the European Union – transporting it through existing gas pipelines.[79] In Morocco, the German Moroccan Energy Partnership will include technical support for the elaboration of a roadmap for local production and for exports to Europe and elsewhere.[80]

Oman

Oman has the advantages of consistent daytime sunlight and strong winds at night, so is starting to invest in green hydrogen. One of the world's largest plants is being planned by a consortium which includes the state-owned oil and gas company OQ, the Hong Kong SAR China-based renewable hydrogen developer InterContinental Energy, and the Kuwait-based energy investor Enertech. Most of the output will be exported as hydrogen or as ammonia, which is easier to store and ship, to Europe.[81]

Africa

The Africa Hydrogen Partnership Trade Association (AHP) is a non-profit company incorporated in Mauritius, which enables member companies to exchange knowledge on economic, technical, and other relevant social topics, including the treatment of political, legal and tax issues, as well as to lobby with governments and administrative bodies with one voice.[82] One of the AHP projects is the issuing of Green African Hydrogen Bonds to collect low-cost, long-term financial capital, creating mutually beneficial opportunities for African governments and financial institutions.[83]

B. GREEN WINDOWS OF OPPORTUNITY

This section considers the extent to which countries are in a position to take advantage of green windows of opportunity and how they have responded. Some countries may have the conditions to develop such technologies but unless they respond strategically to seize these opportunities, they may be firmly locked into fossil-fuel pathways, leaving foreign investors to capture the arising markets. Other countries may wish to take these opportunities but lack the necessary conditions, especially in terms of industrial capacity and sectoral system capabilities that are relevant to a given green technology.

Table III-1 considers four scenarios in terms of preconditions and responses – though is this necessarily a simplification. There are many grey areas and overlaps between weak and strong conditions.

Table III 1
Four green window scenarios

Preconditions \ Responses	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.

1. SCENARIO 1 – WINDOWS OPEN

China – The best scenario for seizing these economic opportunities is where strong preconditions are combined with strong responses. This is evidently the case for China which has large internal markets for green technologies and a diverse industrial structure. It also has design and engineering capabilities for biomass plant construction[84] and scientific knowledge in solar PV as well as R&D in nascent technologies such as CSP.[85, 86] Regarding responses, there have been efforts in several sectors to co-design environmental and industrial policies. Many initiatives have been put in place to diffuse knowledge among firms and knowledge institutions such as government stimulation of knowledge spillovers, with loose enforcement of property rights and diffusion through state-owned design institutes.

Brazil – Over many years, Brazil has built the preconditions to take up opportunities in green sectors. It has extensive sugar and ethanol processing plants and the technological learning linked to these sectors. Technology suppliers and research institutions have cooperated in sugarcane-related technology development. Private firms also responded to these opportunities by establishing collaborative consortia to develop cars with flex-fuel systems (i.e., engines that run on a combination of gasoline and methanol or ethanol).[87] Although driven initially by the local market, Brazil has been moving to a leadership position in the global market.[88]

Chile – Another case that can combine of adequate preconditions with strong responses is the development of the green hydrogen industry in Chile. The country has a relatively well-developed production system, and a tradition of public investments in sustainable industrial development.

Table III 2
Examples of opening green windows

China: Electric vehicle	Brazil: Ethanol
Green industrial policy, infrastructure, subsidies, public procurement etc.	Incentives have been in place since the 1970s; technological learning from innovation policies
Strong response by both existing OEMs and pure players (experimentation and many failures)	Response from the private sector, which created passenger cars with the flex-fuel system
New and important competitive advantages for leadership in battery technology, software integration electric buses	Leadership in the global market

Source: UNCTAD.

2. SCENARIO 2 – WINDOWS TO BE OPEN

A combination of strong preconditions with insufficient responses translates into possible opportunities that have not be taken up yet. This is the scenario in which many developing economies find themselves:

India – The National Solar Mission prioritized low-cost deployment above stimulating local manufacturing. This has resulted in a high dependency on imports. Insufficient attention was paid to training, promotion of linkages to relevant stages of the value chain and to R&D to boost competitiveness. This illustrates the importance of carefully designing and complementing domestic market stimulation to avoid insufficient protection of domestic investments.[89]

Bangladesh – An existing system of R&D organizations involving biomass energy has not been complemented with appropriate incentives to encourage biogas plant installations. Also, very little has been done to increase awareness among farmers about the potential of waste management.[90]

Morocco – Concentrated solar power has been promoted through strong political commitment towards solar energy. Thanks to an initial productive base, a few domestic companies have begun displaying some capabilities.[91] Nonetheless, by 2015, the practical opportunities for local manufacturing of solar energy inputs and components were still restricted because of a limited capacity in promoting technology and knowledge transfer.[92]

China – China had the heavy industry capabilities needed to manufacture and install wind turbines and strong university-industry linkages.[93] However, compared with its success in solar PV, China has been unable to achieve market leadership. Green windows develop over time, and strategies and initiatives need to adapt to continue to be effective. Those based on building basic production capacity may be insufficient for subsequently upgrading and deepening technological capabilities, especially when technologies are evolving. In the Chinese wind sector, there were good preconditions. However, it was unable to follow the successful pathway of other green sectors, such as solar PV. This would have required the integration of ‘smart systems’ for turbine and wind farm management which the Chinese wind industry could not deliver.[94]

Table III 3

Examples of windows to be open

China: Wind	South Africa: Electric vehicle
Driven by international and domestic environmental policy	Rich in key natural resources used in automotive and EV production and key auto hub
Active industrial policy (e.g. LCRs from 2005)	No response by the foreign OEMs for locating EV production in SA
Active approach by firm: licensing and co-design	Small market and mainly private mainly infrastructure solutions
Catching up close to frontier in 2010	Real risk of falling behind
Now falling behind in post-turbine technology due to insufficient IS response	

Source: UNCTAD.

3. SCENARIO 3 – WINDOWS WITHIN REACH

Some countries have weak preconditions but are nevertheless taking active steps to reach for the windows:

Thailand – For biogas, the Government has offered subsidies, tax incentives, and mandatory purchasing of electricity generated. This has encouraged private investors and a co-evolutionary pattern with shifts within and across learning mechanisms.[95]

Viet Nam – Viet Nam has the opportunity to generate biomass energy from rice husks. Private actors, including some foreign investors such as Decathlon, and public actors, including domestic research and development institutions, are developing a dynamic sectoral system.[96]

Ethiopia – Despite little experience in this area, the wind industry has grown through major projects. The Government is building key elements to ensure more local learning in and around projects. While still with several shortcomings, the Ethiopian Government has taken an active role in designing projects to ensure maximum local learning, by ensuring that professional users are more involved in project execution.[97]

Namibia – The Namibia Green Hydrogen Association has been created to provide a platform for private actors and government-business interactions. Namibia has also established a critical partnership with Germany, characterized by intense R&D interactions and collaborations to identify suitable sites for producing and training professionals specialized in this new industry.

Table III 4

Examples of windows within reach

Ethiopia: Wind	Thailand: Biogas
Wind part of energy policy and planning	Subsidies, tax incentives, mandatory biogas purchase
Active role in designing wind projects to guarantee maximum local learning, by ensuring the involvement of professional users in the execution of projects	Favourable conditions for private investments
Still limited industrial outcome but local learning secured	Strong response and learning by domestic firms

Source: UNCTAD.

4. SCENARIO 4 – WINDOWS IN THE DISTANCE

Weak preconditions and responses provide a meagre scenario for seizing green windows as shown in the examples here.

Kenya – Relatively weak starting points have impeded large-scale wind development. Insufficient strategies to ensure local embeddedness and to learn from projects resulted in a lack of success to seize opportunities for learning and supply chain development.[98, 99] Projects such as the Lake Turkana Wind Power Project should be more deeply integrated, with strategies for strengthening sectoral systems of production and innovation.[100] These could include initiatives regarding the training and certification of engineers and technicians and research programmes in universities.

Mexico – The country has vast potential for bioenergy but has weak regulations and a lack of technical competencies limits awareness of the potential.[101] As a result there has not been sufficient public and private investment to upgrade bioenergy technology.

Pakistan – The story in the bioenergy industry is similar to that of Mexico, with a lack of capabilities and effort.[102]

Table III 5
Examples of distant windows

Kenya: Wind	Mexico and Pakistan: Bioenergy
Driven largely by global finance and support	Lack of technical capabilities
Ad-hoc project approval with no industrial conditionalities attached	Little policy attention and weak regulation lead to insufficient investment
Virtually zero local content and learning	Lack of sufficient stimulus to develop the sector
Small number of local jobs in O&M	

Source: UNCTAD.

C. MATURITY AND TRADABILITY OF GREEN TECHNOLOGIES

As in Table III-6, Green technologies can be analysed in terms of their maturity and tradability. The distinction between mature versus immature technologies is explained by the existence and development of different socio-technical configurations, including infrastructure, regulations, market and technical standards, maintenance networks and user practices. The development of low-maturity (or immature) technologies requires significant policymaking efforts, including large R&D investments, market creation support, and technical standards.[103]

Tradability varies with the energy source. Electricity is difficult to trade over very long distances, whereas liquid fuels such as bioethanol or green hydrogen in the form of ammonia are easier to transport. More importantly, the underlying energy production technology also has variable tradability. At one end of the spectrum, hydropower technology needs to be almost fully produced at the point of energy generation and consumption. At the other end of the spectrum, electric vehicles are highly tradeable and can be produced far from the point of consumption.

Table III 6
Maturity and tradability of different sustainable industries

Tradability \ Technological maturity	High	Medium	Low
High	Solar PV; Biofuels	Electric Vehicles	Green hydrogen
Medium			Concentrated solar power
Low	Bioenergy (excl. Biofuels)	Wind	

Source: UNCTAD.

1. TECHNOLOGICAL MATURITY

Mature technologies are fully developed with stable, dominant designs – along with the infrastructure, regulations, market and technical standards, maintenance networks and user practices.[104] The automobile sector, for example, has high maturity for one dominant design of petrol and diesel cars, and is now arriving at medium maturity for the design of electric or hydrogen vehicles. Wind also has medium maturity – for onshore wind turbines and second-generation offshore turbines.

There is not, however, a unique and straightforward way of measuring technological maturity. One way is through considering the year the patent was applied for, and also the dates of other patents that it cites – which is here is termed the average 'citation date'. [105] Mature technologies are likely to have patents dating back many years. Thus, the gap between these applications can be taken as a measure of maturity in years. For example, a patent for a new technology in 2016 might cite patents from 2014, 2010, and 2006. The average year of citation would be (2014+2010+2006)/3= 2010. The maturity of the patent would be 2016 minus 2010, and thus six years.[106]

This report has calculated the average year of patent for each major technology, and for the top-20 most cited patents the average citation date. For AI, for example, on average, most patents were applied for in 2014 and cite patents on average from 2005, producing a difference of 8.72 years. The same calculations have been carried out for 15 frontier technologies (Figure III-2).

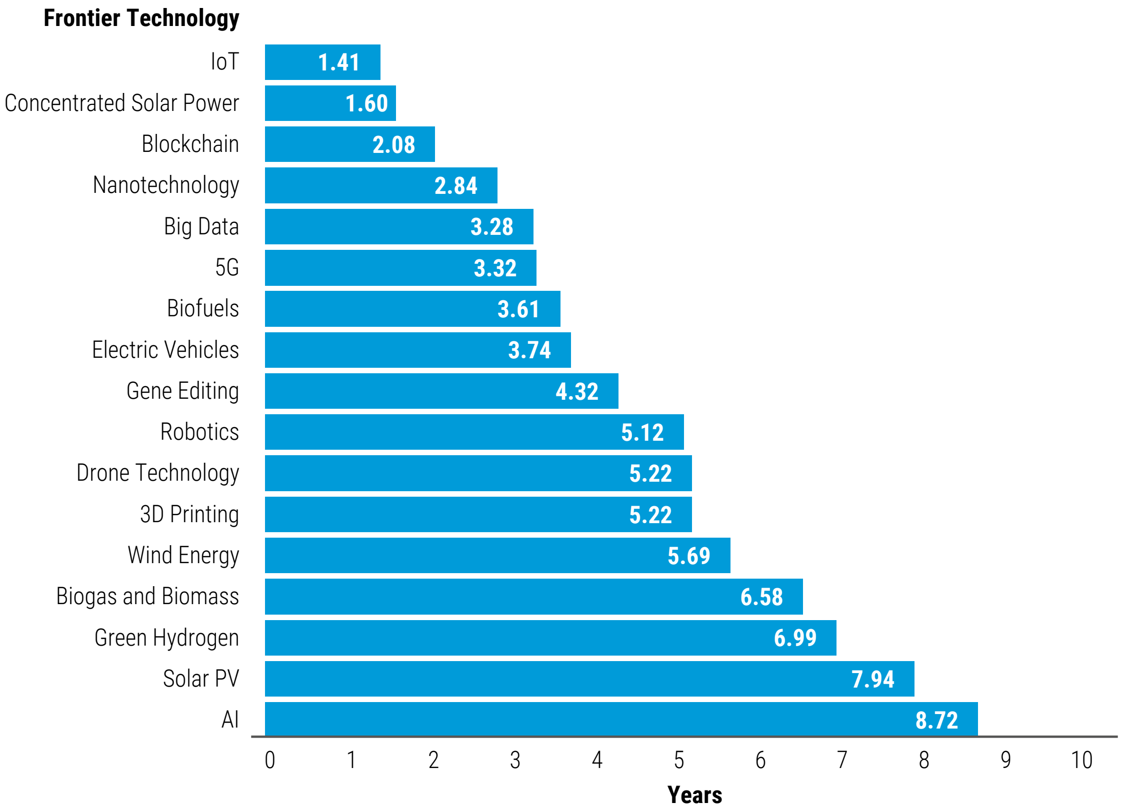
By this measurement, AI is a mature technology as, on average, most patents were applied for in 2014 but cited patents from 2005 (and thus a difference of 8.72 years between average applications and forward citations). This may seem counter intuitive. But today's AI patents, such as those for autonomous vehicles and the metaverse, are technologically close to those for search engines and digital maps, and many of the underlying principles patented in 2005 are still valid.[107]

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 every 1.4 years, reflecting a technology that is still evolving fast.

However, this methodology does create anomalies. Not all technologies are as mature as suggested by this measure. For green hydrogen, for example, progress over this period has been slowed by a lack of research in the past. Nonetheless, its pace is now picking up. Between 2020 and 2021 the number of applications jumped from 6 to 31.

Developing countries should take into consideration the level of maturity when deciding which frontier technologies to switch to. Immature sectors offer open opportunities that latecomers can use to disrupt the industry. However, these sectors are also more difficult to operate in since they require greater initial efforts in science and R&D that are only within the capacity of strong domestic systems, such as China for CSP and in Brazil for bioethanol. Mature technologies may demand less R&D, but they also present

Figure III 2
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.

potential barriers in terms of strong and efficient production processes and tradability that may deter new competitors.[108] Moreover, in such a setting, countries must be able to acquire technologies and adapt them to local circumstances.

Biomass and solar PV have mature technologies that latecomers can absorb and use with machinery from the outside. For example, in the case of solar PV, China was able to take advantage of the green window as it could import foreign production machinery and benefit from economies of scale. It required entrepreneurial dynamism in the private sector and state support on the supply side. In India, on the other hand, with weaker manufacturing capability, the sector did not develop as expected because of the inability to manage localization issues.

2. TRADABILITY

Like technological maturity, tradability is not easy to assess in a rapid appraisal. This is because tradability relates to at least three aspects of innovation – of capital equipment; of the technology itself and the processes needed to use it; and of energy being produced. An indication of the extent of the tradability of green technologies is indicated in Table III-7.

Tradability influences competitive dynamics as well as modes of learning. Sectors with high tradability may need a degree of market protection, and careful design and implementation strategies to boost demand.[109] Taking advantage of high tradability in capital equipment, however, requires strong capacities in related production domains. In the case of low tradability, learning may initially occur through FDI.

For example, for wind, where turbines can be traded, although at high transportation costs, Kenya was able to use FDI to import turbine technology. However, combined with the relatively small market size, the lack of preconditions in the private sector – in particular the capacity in heavy-industry and electrical engineering – have meant that the opportunity is still distant. In China, such preconditions were in place and enabled the catching up for required domestic deployment. Through dynamic localization, FDI was replaced or took on a new role over time. Low tradability offers a degree of natural protection in the home market. For technologies with low tradability and low maturity, countries can take advantage if they have the necessary R&D capabilities and the capacity to supply components. For CSP, China was able to open the window, while Morocco with a relatively weak supply base and limited R&D capability missed this opportunity.

Table III 7

Three dimensions of tradability

Dimensions of tradability	Capital equipment and inputs	Energy generation technology	Green energy outputs
Bioethanol	*Medium* (Distillery equipment)	*Low* (Ethanol distillery)	*High* (Ethanol)
Biogas (a)	*Low* (Heavy-duty machinery)	*Low* (Biogas plant, e.g., waste to energy)	*High* (Gas)
Biogas (b)	*High* (Anaerobic digestion equipment)	*Low* (Biogas digester)	*High* (Gas)
Biomass	*Low* (Equipment)	*Low* (Direct-fired biomass plant)	*Medium* (Electricity)
Solar PV	*High* (Industrial robots, assembly line designs)	*High* (Solar PV Panels)	*Medium* (Electricity)
CSP	*Low* (Heavy duty machinery)	*Low* (Solar farm)	*Medium* (Electricity)
Wind power	*Low* (Heavy duty machinery, steel)	*Medium* (Wind turbines)	*Medium* (Electricity)
Green Hydrogen	*Medium* (Electrolysis equipment)	*Low* (Conversion facility)	*High* (Ammonia)

Source: UNCTAD.

D. REQUIREMENTS FOR OPENING GREEN WINDOWS

Opening green windows in developing countries requires government activities at different levels – national and local – and the involvement of various public and private stakeholders. Overall policies to open and take advantage of these windows should be mission-oriented – going beyond levelling the playing field to fixing market failures and involving broader programmes of market co-creation and shaping (Box III-4).[110]

While the opportunities differ from one technology to another, benefitting from them involves two main stages.[111] The first to identify and open windows of opportunity. The second is to assess what is needed and to sustain the processes. However, the stages will often overlap. Some assessment must be done before the decision to invest otherwise the window may be missed. There are also likely to be feedback loops requiring regular adjustments.

Box III 4
Mission-oriented policymaking

Mission-oriented policies require foresight to identify future opportunities, recognize the conditions needed to take advantage of these opportunities, and how to overcome possible weaknesses and challenges in the national systems of innovation. This diagnosis should be the basis for new strategies, establishing organizations and institutions, and facilitating linkages in the innovation system. Mission-oriented policy making for a greener economy should:

a) Be well defined with clear intermediate goals and deliverables as well as embedded processes of monitoring and accountability.

b) Include R&D projects to account for possible failures which should be accepted as learning experiences.

c) Ensure investment across different sectors and involving different private and public actors.

d) Engage a wide range of public institutions, with a clear division of labour and well-defined responsibilities for coordinating and monitoring.

Source: UNCTAD based on Mazzucato, 2018.

1. IDENTIFY AND SWITCH

This can be a complex task since policymakers often have to make decisions over long time periods based on incomplete information and in the face of emerging developments. They need to identify the potential of particular windows in terms of the availability of natural resources, such as favourable wind conditions or the availability of agricultural waste, and also the national capacity to use or build the necessary technology.

Align environmental and energy, STI and industrial policies

For this purpose, policies that would previously have been developed in separate domains need to be co-created across the energy-environmental and industrial spheres. For example, initiatives to facilitate a green energy system, such as auctions or feed-in tariffs, should be aligned with industrial policy and measures to build local capacity for production and innovation.[112] This, however, is not always an easy endeavour, so it might require active effort to avoid conflicts (Box III-5).

In Thailand, for example, the Ministry of Energy developed environmental legislation but also encouraged factories to invest in biogas production and combined this with policies to strengthen the sectoral innovation system. At the same time, a network of other actors such as the Ministry of Science and Technology, was researching and developing biogas technology and setting up demonstration programmes. Also, the Board of Investment under the office of the Prime Minister, introduced tax incentives to attract private investors. Various research centres and universities established training programmes to build domestic capacity for setting up and maintaining the installed systems.[113]

Box III 5
Political economy challenges of renewable energy sectors

The development of green sectors entails political economy challenges. First, managing the incentives created is key to achieving the desired results. Due to market and coordination failures, governments must deploy incentive measures to stimulate investments in these sectors. However, adequate state-business relations (SBRs) are required to establish the necessary information exchange to implement and succeed with such incentive policies. Second, policies enacted by different governmental bodies influence the industrial development of green sectors – especially, renewable energy sources. However, different governmental bodies often have different priorities, which might create tensions between policies. Therefore, ensuring their alignment through intragovernmental coordination is necessary.

Links between the state and the private sector are important channels to improve information flows[114] so that the government manages to get the relevant information and the transfer of publicly produced knowledge.[115] However, this cannot occur in state capture by the private sector. The state bureaucracy must be able to retain its independence to adapt and withdraw incentive measures if they are not achieving its goals or are no longer necessary.[116] In Germany, for example, the institutionalization pattern of SBRs in the automotive industry created barriers for new firms and groups to engage with the State. Consequently, incumbent firms that invested in carbon-intensive vehicle technologies successfully delayed the introduction of further policies to incentivize EVs in the 2000s. Meanwhile, in the United States, the mode of SBR in this sector allowed for the participation of different stakeholders, including those with environmental-friendly agendas, which favoured the enactment of regulations incentivizing EVs.[117]

A second political economy challenge comes from the intersection of different policy domains. Sustainable development is a cross-cutting issue and relevant policies are spread across a wide range of government organizations. For example, energy, industrial[118], environmental[119], trade and competition[120] policies influence innovation in the renewable energy sector, as well as their interaction.[121] So, promoting the coordination of different governmental bodies is key to mitigating the risks of contradicting policies and facilitating the exploration of synergies between them. For example, policies to improve the competitiveness and capabilities of renewable energy producers and their inputs suppliers favour the deployment of renewable energies if they have a decreasing effect on prices, while energy policies can stabilize and expand the domestic market for these sources, reducing the uncertainties and risks that investors face.[122] In the opposite case, a lack of alignment between policies undermines their effect. For instance, in Germany, the wind energy sector faced financial issues created by the lack of coordination between incentive policies and the adaptation of the infrastructure,[123] while in Brazil the development bank attached national content requirements to the offer of interest rates lower than the market rate for solar energy projects and promoted the construction of domestic industry, but the trade policy made it cheaper to import the final panels than their separate parts to assemble it in the country.[124]

Notwithstanding the need for policy alignment, different government organisations often have distinct priorities. In the renewable energy sector, there might be a trade-off between ensuring faster and cheaper deployment of projects and developing a national industry since the latter entails additional costs (at least temporarily).[125] This trade-off reflects a contradiction inherent to industrial policies targeting green sectors. One way of measuring its success is to analyse the amount of clean energy produced; another way focuses on traditional industrial policy measures, like jobs created and the international competitiveness of supported industries, among others. However, the fastest way of expanding renewable energy production is to rely on imported goods and suppliers, which conflicts with the creation of domestic industries.[126] Consequently, the priority level given to each of these goals leads to different policy designs and, thus, different industrial outcomes.[127] In South Africa, for example, while the National Treasury prioritises energy deployment at a low cost, the Department of Trade and Industry (DTI) emphasises the development of local manufacturing and job creation. The DTI is responsible for drafting local content requirements, but the National Treasury governs the Renewable Energy Independent Power Producers' Procurement Programme (RE IPPPP). This results in some missed opportunities to push forward the national industry. The fourth round of RE IPPPP did not, for instance, include any requirement for the local lamination of solar PV modules as a bidding requirement, which could have resulted in job creation and spin-off activities that benefited local industries.[128]

Source: UNCTAD.

Select and adapt to local circumstances

Policy instruments need to be selected according to the intended goal. In sectors characterized by domestic market opportunities, the selection of policy instruments for market stimulation, for example, through feed-in tariffs or national auction systems, needs to be carefully designed and implemented.

Policies also need to be adapted to local needs. Box III-6 describes two renewable energy support mechanisms: feed-in-tariffs and auctions, showing their advantages and disadvantages.

The Mexican and South African national auctions for renewable energy show how they can work differently in diverse contexts. In Mexico, for example, the priority was low-cost deployment, while in South Africa the objective was to establish a domestic renewable energy value chain. This led to different micro level policies and produced different outcomes.[129]

Box III 6

Renewable energy support mechanisms

Feed-in tariffs

These are fixed electricity prices paid to renewable energy (RE) producers for each unit of energy produced and injected into the electricity grid. The feed-in-tariff (FIT) usually varies between technologies to reflect the differences in generation costs as well as between the size of installed capacity, reflecting the higher generation costs of small- and medium-scale RE projects. A third differentiation is according RE resource quality, such as the average wind speed at different project locations. The FIT for is higher for sites with lower RE potential.

FITs are relatively simple policy instruments that can be fine-tuned to different policy objectives – such as innovation, climate protection, and regional development. For investors, FITs combined with long-term contracts guaranteed by the government, provide transparency, predictability and security, and therefore contribute to reducing investment risks and financing costs.

The main challenge with FITs is to define levels of remuneration that are neither too low to be attractive for investors nor too high as to result in over-paying. This requires good information on project costs along with effective monitoring.

Auctions and tendering schemes

These are competitive mechanisms for allocating financial support to RE projects, usually based on the cost of electricity production. Public authorities are responsible for preparing the tender documents, the publication of the tender, the evaluation of the bids and the selection of the winning bids. They specify the capacity (kW) or the electricity generation (kWh). They can also specify the technology such as solar PV or wind energy, or they can be technologically neutral. Sometimes they indicate the location. Project developers can then submit a bid, outlining their proposal and stating the price per unit of electricity they will be able to realize.

Auctions and tendering schemes stimulate competition between different operators, locations and technologies, reveal the actual costs of RE technologies, and prevent overcompensation.

Auctions can help control the development of renewable energy projects because they require public authorities to define the required additions to capacity. This enables central planning and coordination of renewable energy development.

However, for the bidders, there are certain costs and risks – which also tend to discourage the involvement of small and medium investors and can lead to more expensive offers.

The main difference between FITs and auctions is the mechanism for price discovery. In FITs, the price is fixed by the policymakers. In auctions, the industry determines the price through competitive bidding. If a country lacks experience and does not have cost data available, auctions are a useful way of discovering the true cost of the technology. However, for auctions to be successful, they need to be competitive, which means there needs to be enough interest amongst project developers.

Source: UNCTAD based on energypedia.info.

Combine policy instruments

Policymakers will need to use a combination of measures. In China, for example, creating the domestic market for solar energy was combined with subsidies for developers of off-grid and grid-connected projects, covering up to 70 per cent of the costs of installations as part of the Golden Sun Demonstration Program. There were also public investments in grid infrastructure and in poverty alleviation programs of installation of solar PV panels for poor households.[130] There was also mandatory purchasing of electricity generated from renewable energy.

Find the finance

For building up solar PV production the China Development Bank and other state and commercial banks provided credit to PV producers when most Western solar manufacturers had difficulty accessing credit due to the financial crisis.[131]

Other developing countries will be unable to finance renewable energy projects from national sources, but they should be able to get concessional external finance. Morocco, for example, identified CSP as the best option, and for CSP installations was supported by the Climate Investment Fund, the World Bank, the African Development Bank and other EU financing institutions.

Establish demonstration programs

Nascent industries such as CSP and green hydrogen need to be built up through constant experimentation and steady improvement. For CSP, China, for example, built knowledge and experience within domestic firms through “megaprojects of science-research”, experimenting with different technical designs on the ground.[132] Similarly, in Chile, with the support of international investors, the National Development Agency established several green hydrogen pilot projects.

2. ASSESS AND SUSTAIN SECTORAL SYSTEMS

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.

Evaluate existing conditions

Successful exploitation of green windows naturally depends on pre-existing conditions in the sectoral system. Dynamic conditions will unfold and develop in an emergent trajectory. Both public and private preconditions are essential. Public preconditions involve both overall state capacity and governance capability in the relevant areas, such as the strength of relevant public agencies in the regulation field, the extension support system, and the provision of public-goods services. A lead agency within government should mobilize resources and convene stakeholders to assess overall state capacity as well as the strengths of public agencies, particularly for regulation, and extension support systems, and for providing public services. Without a lead agency it can be hard to ensure experience sharing and interactive learning between stakeholders. Kenya, for example, found it difficult to take advantage of wind power in the absence of a national agency to assemble expertise, enable systematic learning and allow for transfer of knowledge between projects.[133]

For each technology, tailored strategies should be developed and adjusted along with the necessary support systems, knowledge infrastructures and design and engineering capabilities – identifying activities that local firms can feasibly undertake.

In industries where the technology is 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.[134] These need to be carefully examined because some policy instruments rely on private sector capacity; there is little point for example in stipulating local content requirements if local companies lack the capacity to deliver.[135]

Governments need to assess at various stages where and how production and innovation must be strengthened and changed.[136, 137] 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.

Access external knowledge

Building domestic production typically means learning from other countries. In China, for solar PV for example, firms were encouraged to carry out research with international partners.[138]

Invest in domestic R&D

Nascent green technologies are usually biased towards capital and the use of high-skill labour, and 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 (Box III-7).

Public R&D investments are also needed in process improvements and complementary technologies.[139] And when technologies are rapidly evolving, as in the wind industry, this investment will need to be continuous. China, for example, did not provide sufficient support for its shift from onshore to offshore turbine technology.[140]

In the early stages, when the domestic market cannot support a competitive industry, governments can set up demonstration projects, as happened with CSP in China and green hydrogen in Chile.

Box III 7
Promoting R&D in green areas

Oman - Innovation Park Muscat is an initiative under the Ministry of Higher Education, Research & Innovation that encourages scientific research, innovation, and collaboration between various sectors. It provides access to various facilities and services to create an environment that motivates innovators, entrepreneurs, and companies to develop ideas in energy, food and biotechnology, health, water, and environment sectors.

Philippines – The Department of Science and Technology (DOST) supports R&D projects in line with green technology and innovation. Topics covered include Machinery for Decontaminating Rice Hull as Litter Floor for Broiler Breeder Production; Black Soldier Fly farming for agricultural productivity and waste management; Development of nano fertilizer from poultry waste biogas digestate; and Extraction of Phytohormones from Waste Coconut Water using Biochar Derived from Agricultural Residues. The DOST is pushing for the passage of the Science for Change Bill, which provides programmes for establishing R&D centres and collaborative R&D between academia and industry. This initiative bolsters the productivity and competitiveness of industry players and drives R&D on renewable forms of energy and green technologies. Also in the Philippines, the "Niche Centers in the Regions for R&D" will focus on sectors related to health and industry, energy, and emerging technology. This initiative will allow the country's academic and R&D institutions to upgrade their research facilities, develop policies, transfer technologies, and ramp up regional initiatives and efforts toward a competitive innovation ecosystem. Through these R&D centres, the DOST cultivates the innovation landscape in various sectors to ensure no one is left behind in R&D progress.

Switzerland – The Swiss Federal Office of Energy (SFOE) subsidizes research projects that correspond to the priorities of the current energy research concept of the SFOE 2021-2024. The focus is on application-oriented and development-related research projects. The SFOE's energy research programmes cover the entire spectrum of energy research and all major technology fields in renewable energies and energy efficiency. There is also a socio-economic research programme and a programme on the social aspects of dealing with radioactive waste.

Türkiye – The Scientific and Technological Research Council of Türkiye (TÜBİTAK) designs its R&D support for compliance with the European Green Deal and for mobilizing R&D and innovation accumulation within the scope of co-creation models. Programmes include the 1501 Industrial R&D Projects Grant Programme and the 1507 SME R&D Start-up Support Programme. Also, the TÜBİTAK 1512 Entrepreneurship Support Programme's 2021 call targeted R&D and innovation topics within the scope of the European Green Deal Agreement. The 1512 Entrepreneurship Support Programme's 2022 call also targets green growth. In TÜBİTAK's new call for proposals for the "High Technology Platforms Support" and "Industry Innovation Networks Mechanism (SAYEM)", areas focusing on sustainable solutions to mitigate and adapt to climate change attracted significant attention.

Source: UNCTAD based on contributions to the Commission on Science and Technology for Development from the Governments of Oman, the Philippines, Switzerland and Türkiye.

Build domestic capabilities along the value chain

To absorb, adapt, and eventually develop, renewable energy industries, countries need to accumulate local expertise – scientific, technological, managerial, and organizational. Governments can offer support through public procurement, by stipulating local content requirements and by offering tax incentives targeted at specific energy facilities, production projects, or types of companies such as joint ventures.[141] In South Africa, for example, efforts to promote local tower and blade manufacturers failed because global multinational companies preferred to operate through long-standing relations with international first-tier suppliers. The industry need not necessarily focus only on the manufacturing phase. In wind energy, for example, there are opportunities for efficient domestic service providers to collaborate with lead firms.[142]

It is also important to build the capacity of SMEs – and particularly to tap the potential of women entrepreneurs. UNIDO research in Cambodia, Peru, Senegal and South Africa found that women entrepreneurs were particularly interested in green industries where they believed they had more opportunities.[143] Policymakers can publicise the options for women, while increasing access to technical vocational education and training, and investing capacity-building. They can also present successful women entrepreneurs as role models.

Invest in human capital

Dedicated training programmes may be needed to build local specialized scientific, technological, managerial and organizational capabilities. In Thailand, for example, this happens through universities and research centres.[144] In China, in 2008, the Government launched the “Thousands of Talents Plan” which offered full-time positions in research institutes and universities with good salaries and benefits. This attracted many Chinese researchers from western universities who had contributed to fields such as PV cell technologies.[145]

Skills are also acquired through learning-by-doing and on-the-job training. In China, for the biomass industry, state-owned design institutes diffuse technical knowledge and must be involved when constructing biomass power plants. Often the institutes have learned from pioneer companies and then disseminated the knowledge to others.[146]

Collaborate internationally

Participation with international organizations, along with collaboration with other national governments, and non-governmental organizations will provide valuable information for developing more diverse and more affordable energy technologies. International collaboration is more common in new industries such as CSP and green hydrogen – as has happened, for example, between Germany and African countries.

Another example of multilevel collaboration is the Africa- EU Energy Partnership – a forum for political dialogue, knowledge sharing and peer connection between EU and African stakeholders in renewable energies.[147] At the global level, in 2021, UNIDO launched a global programme for the green hydrogen industry with the support of the International Hydrogen Energy Centre in Beijing.[148]

A key area for international cooperation is setting and harmonizing international standards and technical norms that are then incorporated into national regulations. For green hydrogen, for example, this would include guarantees of origin, hydrogen purity, equipment specifications, and blending into the gas grid.[149] Establishing standards requires extensive consultation with stakeholders, public and private, from advanced and developing countries.

Reform intellectual property regimes

It will also be important to reform global intellectual property (IP) regimes so as to allow developing countries ready access to frontier technologies. This involves striking a balance between the disadvantages and advantages of IP rights. Weaker IP protection may enable companies to take up new ideas, but it could also discourage innovation. One recent study of 59 countries concluded that on balance stronger IP protection helps propagate the deployment of renewable energy technologies.[150] However, this area needs more robust empirical research on issues such as novelty requirements, compulsory licensing, and the length of patent protection.

Diffuse knowledge in the domestic ecosystem

Knowledge gained by leading pioneer companies should be diffused to other enterprises to encourage broader development. For the Chinese biomass industry, for example, the State encouraged information spillover to other domestic firms. This was enabled by weak enforcement of intellectual property rights, which smoothed copying and imitation by domestic competitors. Knowledge flows were also mediated by State-owned design institutes.[151]

Another example is the wind industry in Ethiopia, where the Government has asked national universities to submit proposals to act as consultants for wind projects. The Ministry of Water, Irrigation, and Electricity has liaised with several domestic universities to engage them in projects and apply their experience.[152]

1 Hausmann and Hidalgo, 2011

2 Malerba, 2002

3 Data are from IRENA. 1 GW is equal to 1000 MW.

4 Shubbak, 2019

5 Shubbak, 2019; Binz et al., 2020

6 Binz et al., 2020

7 Shubbak, 2019

8 Shubbak, 2019

9 Xinhua News Agency, 2020 http://www.xinhuanet.com/nzzt/135/

10 CGTN, 2021

11 For a detailed description about how a national auction works see Box 1 in Section 5.

12 Matsuo and Schmidt, 2019

13 Matsuo and Schmidt, 2019

14 Baker and Sovacool, 2017

15 Johnson, 2016; Sahoo and Shrimali, 2013

16 BOS components refer to all components of a PV system other than the modules. These includes wirings, inverters, switches, and battery chargers and other elements involved in the 'deployment chain' (as opposed to the core technology manufacturing chain) of solar energy (Lema et al., 2018).

17 Do et al., 2021

18 Mekong River Commission, 2022

19 Ngan, 2021

20 Kitchlu,Rahul, 2021

21 Vietnam News, 2022

22 Brown, 2019

23 Weatherby, 2021

24 Asian Development Bank, 2018, 2020

25 Weatherby, 2021

26 Bloomberg, 2021a

27 Bhamidipati et al., 2021

28 Bhamidipati et al., 2021

29 Gorjian et al., 2019placing it among the world's top ten greenhouse gas (GHG

30 The export volume of biodiesel in India was around 50 million litres in 2021 (Statista, 2022a). In 2020, ethanol fuel exports from Brazil amounted to 2.68 million cubic meters, out of which 37 % went into the U.S., and 34 % to South Korea.

31 See, for instance, Antwi-Bediako et al. (2019), Romijn and Caniëls (2011), and Nygaard and Bolwig (2018).

32 Antwi-Bediako et al., 2019; Romijn and Caniëls, 2011; Nygaard and Bolwig, 2018

33 Antwi-Bediako et al., 2019

34 Figueiredo, 2017; Andersen, 2015; Dos Santos e Silva et al., 2019

35 Scientific American, 2013

36 Hira and de Oliveira, 2009

37 Duque Marquez, 2007.

38 Lema et al., 2015

39 Furtado et al., 2011

40 Perez-Aleman and Alves, 2016; Andersen, 2015; Furtado et al., 2011

41 Pereira and De Paula, 2018

42 Landini et al., 2020

43 Nygaard and Bolwig, 2018

44 Ahmed et al., 2017

45 The CDM is a 'project-based' mechanism under the Kyoto Protocol devised to encourage production of emission reductions in developing countries. To stimulate sustainable development, CDM facilitates low-carbon technology transfer from advanced to developing economies in connection with implementation of emission reduction projects (Clean Development Mechanism, 2022).

46 Nygaard and Bolwig, 2018

47 Benti et al., 2021

48 Yimam, 2022

49 Arora et al., 2014

50 In contract farming, an out-grower is a farmer who commits to supplying a buyer and to meet certain requirements. In return, the buyer agrees to make the purchase, sometimes at a pre-agreed price, and the buyer may provide other support.

51 Arora et al., 2014

52 Biodiesel in India: The Jatropha fiasco, 2018.

53 Methane reacts with steam under pressure the presence of a catalyst to produce hydrogen, carbon monoxide, and a small amount of CO_2.

54 Fernando and Jackson, 2020

55 UNIDO Industrial Analytics Platform, 2022

56 Cammeraat et al., 2022

57 McKinsey & Company, 2020

58 Biogradlija, 2022

59 IRENA, 2019

60 MME, 2021

61 Governo do Estado do Ceará, 2022

62 Michal, 2021

63 *Bloomberg*, 2021

64 Hydrogen Council and McKinsey & Company, 2020

65 UNIDO, 2022

66 Hydrogen valleys are characterized by a) large scale projects, beyond mere demonstration activities; b) a clearly defined geographic scope; c) the presence of multiple phases in the hydrogen value chain production; d) the supply to various end sectors (Weichenhain et al., 2022).

67 Department of Science and Innovation, 2021b

68 Load shedding is a way to distribute demand for electricity to keep the proper operation of the primary energy source when demand is greater than the primary power source can supply.

69 City of Johannesburg, 2022

70 Trace, 2020

71 Department of Science and Innovation, 2021a

72 Engineerinng News, 2021

73 Development Bank of Southern Africa, 2020

74 Huegemann and Oldenbroek, 2019

75 Executive Summary – Harambee Prosperity Plan II, 2022

76 Hyphen Hydrogen Energy, 2022

77 The H2Atlas-Africa project is a joint initiative of the German Federal Ministry of Education and Research and African partners in the Sub-Saharan region to explore the potentials of hydrogen production from the renewable energy sources within the sub-regions (H2Atlas-Africa, 2022).

78 *BBC*, 2021

79 Friedrich-Ebert-Stiftung, 2020

80 *Frontier Economics, 2021*

81 *The Guardian*, 2021

82 African Hydrogen Trade Partnership, 2022

83 Huegemann and Oldenbroek, 2019

84 Hansen and Hansen, 2020

85 Zhang et al., 2015

86 Gosens et al., 2020

87 Furtado et al., 2011

88 Lema et al., 2015

89 Malerba et al., 2021; Landini et al., 2020

90 Chowdhury et al., 2020

91 Fritzsche et al., 2011

92 Vidican, 2015

93 Lema et al., 2013

94 Dai et al., 2020

95 Reinauer and Hansen, 2021

96 International Climate Initiative, 2022

97 Gregersen and Gregersen, 2021

98 Gregersen, 2020

99 Gregersen and Gregersen, 2021

100 Gregersen and Gregersen, 2021

101 E. J. Ordoñez-Frías et al., 2020

102 Yaqoob et al., 2021

103 Gosens et al., 2021

104 Geels, 2002

105 ∑ Total Patent Applications 2000-2021 - ∑ Total Forward Citations 2000-2021 / ∑ Total Patent Applications 2000-2021

106 UNCTAD, 2018a; Agrawal et al., 2018

107 *Forbes*, 2021b

108 Lee and Park, 2006

109 Landini et al., 2020

110 Mazzucato, 2018

111 Lema et al., 2020

112 Landini et al., 2020

113 Suwanasri et al., 2015

114 Bwalya et al., 2009; Te Velde and Whitfield, 2013

115 Criscuolo et al., 2022

116 Evans, 1995

117 Meckling and Nahm, 2018

118 Johnstone et al., 2010; Palage et al., 2019; Pitelis, 2018

119 Jaffe and Palmer, 1997; Nesta et al., 2014

120 Jamasb and Pollitt, 2008; Nesta et al., 2014

121 Nesta et al., 2014; Palage et al., 2019; Pitelis, 2018; Zhang et al., 2013

122 Zhang et al., 2013

123 Schmitz et al., 2015

124 da Silva, 2015

125 Dos Santos e Silva et al., 2019

126 Hochstetler, 2020

127 Matsuo and Schmidt, 2019

128 Baker and Sovacool, 2017

129 Matsuo and Schmidt, 2019

130 Shubbak, 2019

[131] Shubbak, 2019

[132] Lilliestam et al., 2021

[133] Gregersen, 2020; Schmitz et al., 2015; Lema et al., 2021

[134] Matsuo and Schmidt, 2019

[135] Baker and Sovacool, 2017

[136] Participatory methods of assessment involve: (a) Policymakers (especially those closely related to innovation in Ministries of Science, Technology and Innovation, Trade, Industry, and Education) have broad decision-making power and the ability to design and implement public policies to increase national STI capacity and effectively support systems of innovation; (2) Private sector actors have an understanding of the challenges faced in building firm-level technology and innovation capacity, the local knowledge of the business environment and of the effects of policies in place as well as clear ideas on actions needed for upgrading and innovating; (3) Academic and research institutions have knowledge of specific technologies and R&D capacity; (4) Civil society organization have knowledge of the concerns and priorities of marginalized groups, and ability to voice these concerns and increase awareness in public institutions.

[137] Ministerial Declaration of the Group of 77 and China to UNCTAD XV.

[138] Shubbak, 2019

[139] Shubbak, 2019

[140] Dai et al., 2020

[141] Matsuo and Schmidt, 2019

[142] Morris et al., 2022

[143] UNIDO, 2021

[144] Suwanasri et al., 2015

[145] Shubbak, 2019

[146] Hansen and Hansen, 2020

[147] More information is available at https://africa-eu-energy-partnership.org/.

[148] More information is available at https://www.unido.org/green-hydrogen.

[149] Cammeraat et al., 2022

[150] Tee et al., 2021

[151] Hansen and Hansen, 2020

[152] Lema et al., 2021