Green Windows of Opportunity: Catching up in Sustainable Global Value Chains

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How developing countries can harness the full potential of green frontier technologies?

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Green windows of opportunity: latecomer development in the age of transformation toward sustainability

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Abstract

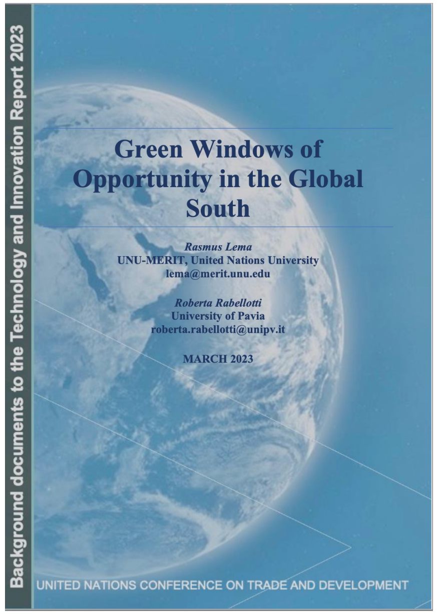
The world is in the early stages of a paradigm transition toward a global green economy. In this article, we propose the notion of green windows of opportunity, highlighting the importance of institutional changes in the creation of new opportunities for latecomer development. We emphasize how demand and mission-guided technical change influence the directionality of latecomer development and highlight the important role emerging economies may attain in the global green transformation. We provide important insights regarding opportunities for green development in emerging economies, how these opportunities emerge in different renewable energy sectors and their implications for the global green economy.

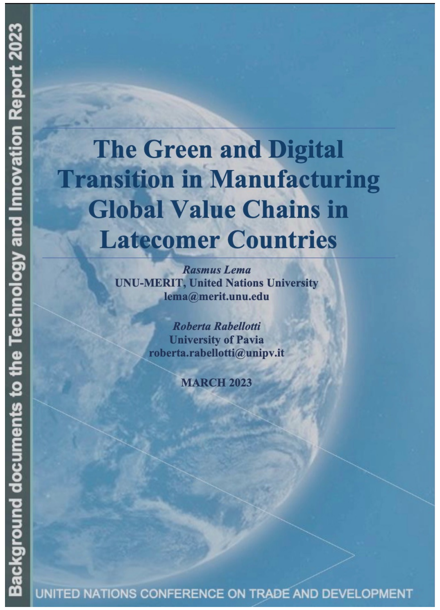
JEL classification: L10, L50, O10, O20, O30, Q20, Q40

1. Introduction

Although the transformation toward a global green economy is still in its early stages, there is little doubt that a major disruption in the capitalist world economy is under way. As popular pressure increases in line with the mounting global effects of climate change, the transformation agenda and associated investments in the green economy are likely to accelerate (Mazzucato and Perez, 2015; Roberts and Geels, 2019; Schmitz and Scoones, 2019).

Until recently, the idea of green growth was limited to the advanced economies, with developing countries reluctant to take up the challenge of sustainability. Today, the dichotomic relationship between green transformation and latecomer development, inherent in the environmental Kuznets curve (Stern, 2004), has been turned on its head. The "clean up later" model where developing countries wait for the environmental Kuznets curve to set in (Altenburg and Pegels, 2020) is being replaced by a leapfrog strategy, which offers an alternative way to bypass the high pollution models of growth. Countries such as China, India, Brazil, and South Africa, are not only reacting to the paradigm change but also are actively contributing to the green transformation, adopting environmental transformation policies and supporting the emergence of domestic sustainability-oriented industries (Mathews, 2013; Harrison *et al.*, 2017).





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Do green foreign direct investments increase the innovative capability of MNE subsidiaries?

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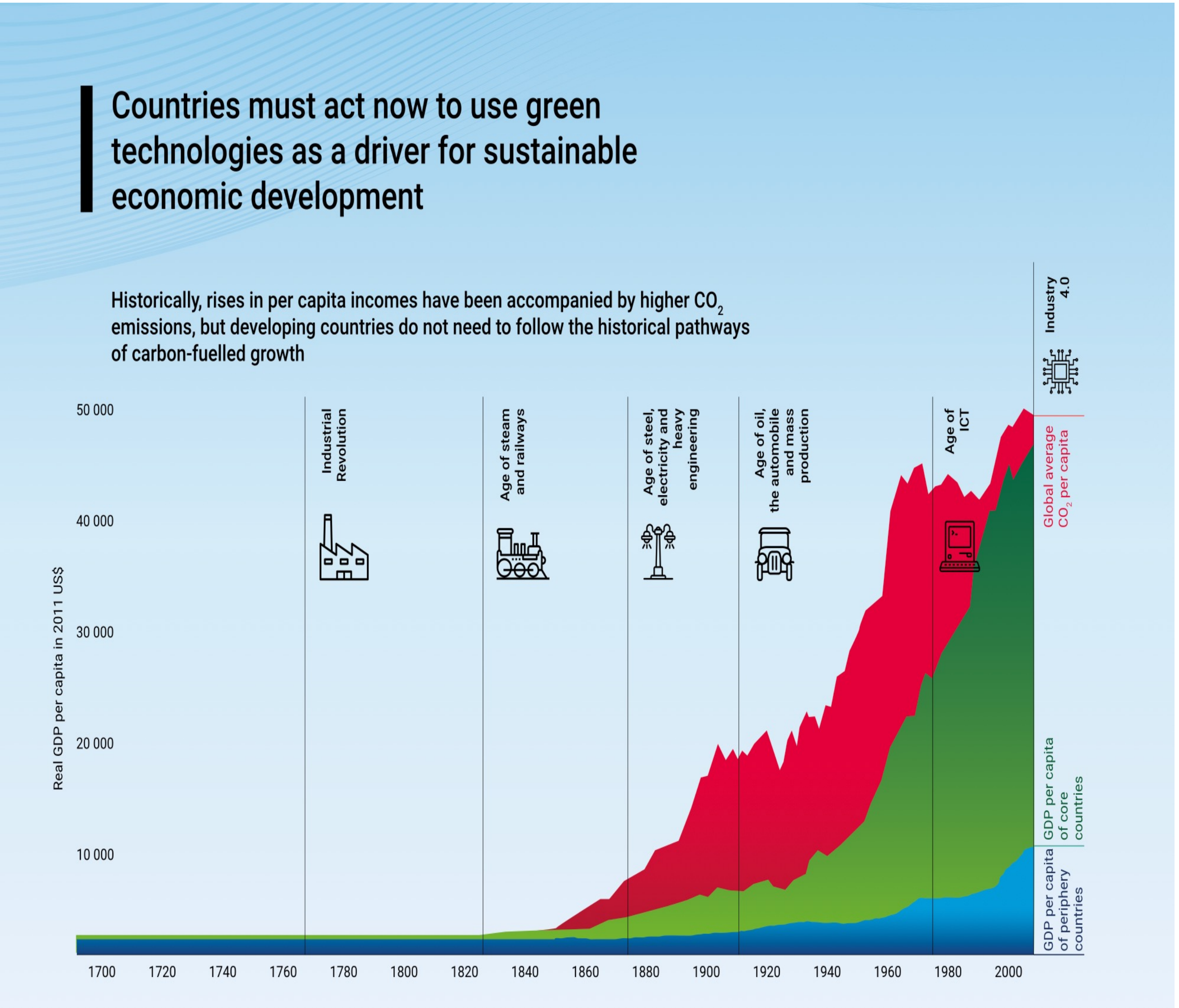
ABSTRACT

Technologies to mitigate climate change may diffuse from lead markets to the rest of the world through several mechanisms and make important contributions to the global green transformation. In this paper, we explore the role played by multinational enterprises (MNEs) in transferring knowledge and innovative capabilities in green technologies to their global subsidiaries. We posit that the degree of green knowledge transfer and innovative capability development in subsidiaries depend on: (i) the host country characteristics, (ii) the specific technology in question, and (iii) the mode of entry. The empirical analysis combines data on foreign direct investments with patent analysis. The results suggest that being a subsidiary of a green MNE has a positive impact on the number and quality of green patents produced locally. This green innovative advantage vis-à-vis domestic companies is larger in less developed countries and in those that are less reliant on oil rents, in particular if they already possess higher levels of relevant domestic innovative capacity. Furthermore, firm and sectoral characteristics also matter. The analysis suggests that green FDIs are more effective when technologies are characterized by low tradability and tacit knowledge. Finally, cross-border acquisitions are more efficient at strengthening green innovative capabilities than subsidiaries established with greenfield investments.

Developing countries must catch the green technological revolution early

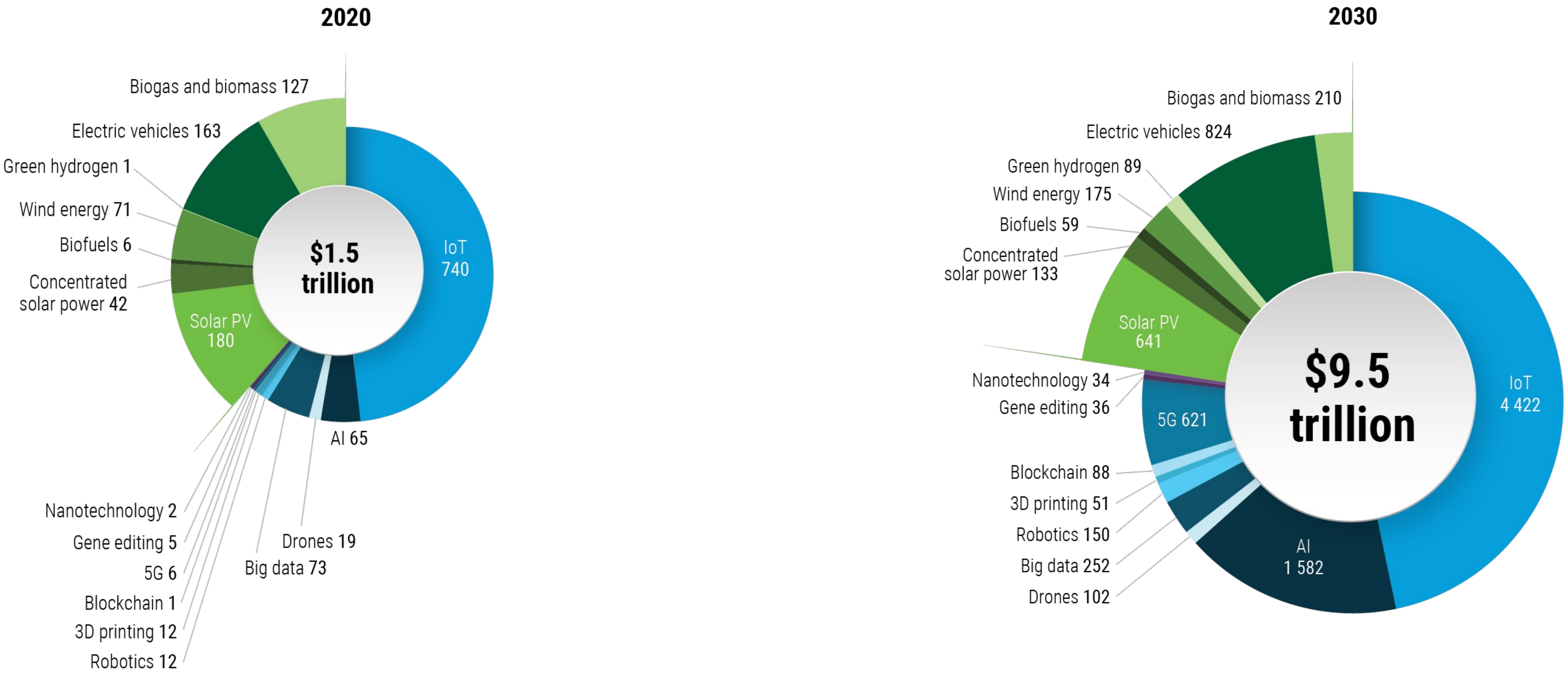


Latecomers should from the outset develop differently rather than catch up along established pathways

Grow first and clean up later models are not viable!

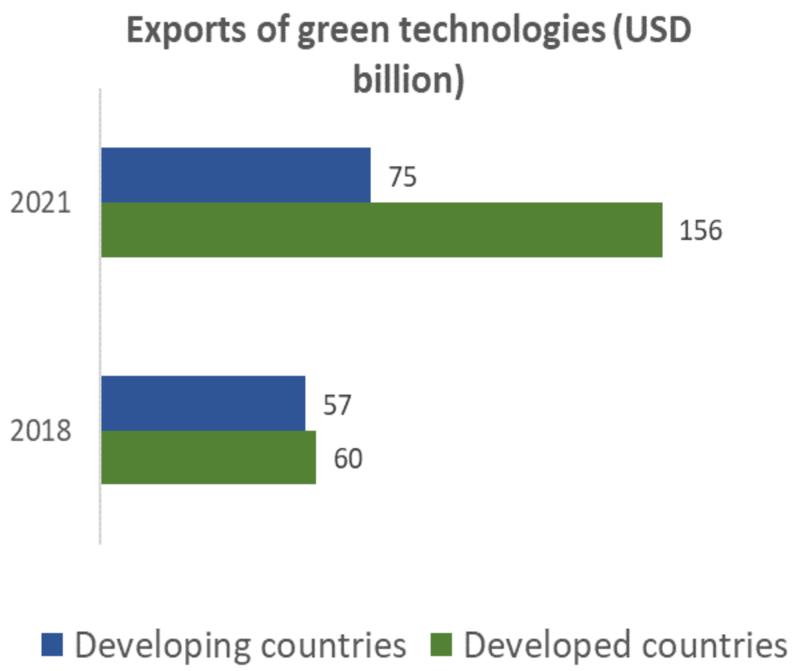
There are enormous opportunities in the development of green frontier technologies

Market size estimates of frontier technologies, $ billion



Source: UNCTAD based on various estimates.

But so far, developed economies are seizing most of the opportunities



Top green frontier technology providers

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 Chemi-cals	Volkswagen		Envitech Biogas
Wilmar international		Guangdong Nation-Synergy Hydro-gen Power Technologies	Renault-Nissan-Mitsubishi Alliance		Weltec Biopower

Source: UNCTAD based on various sources.

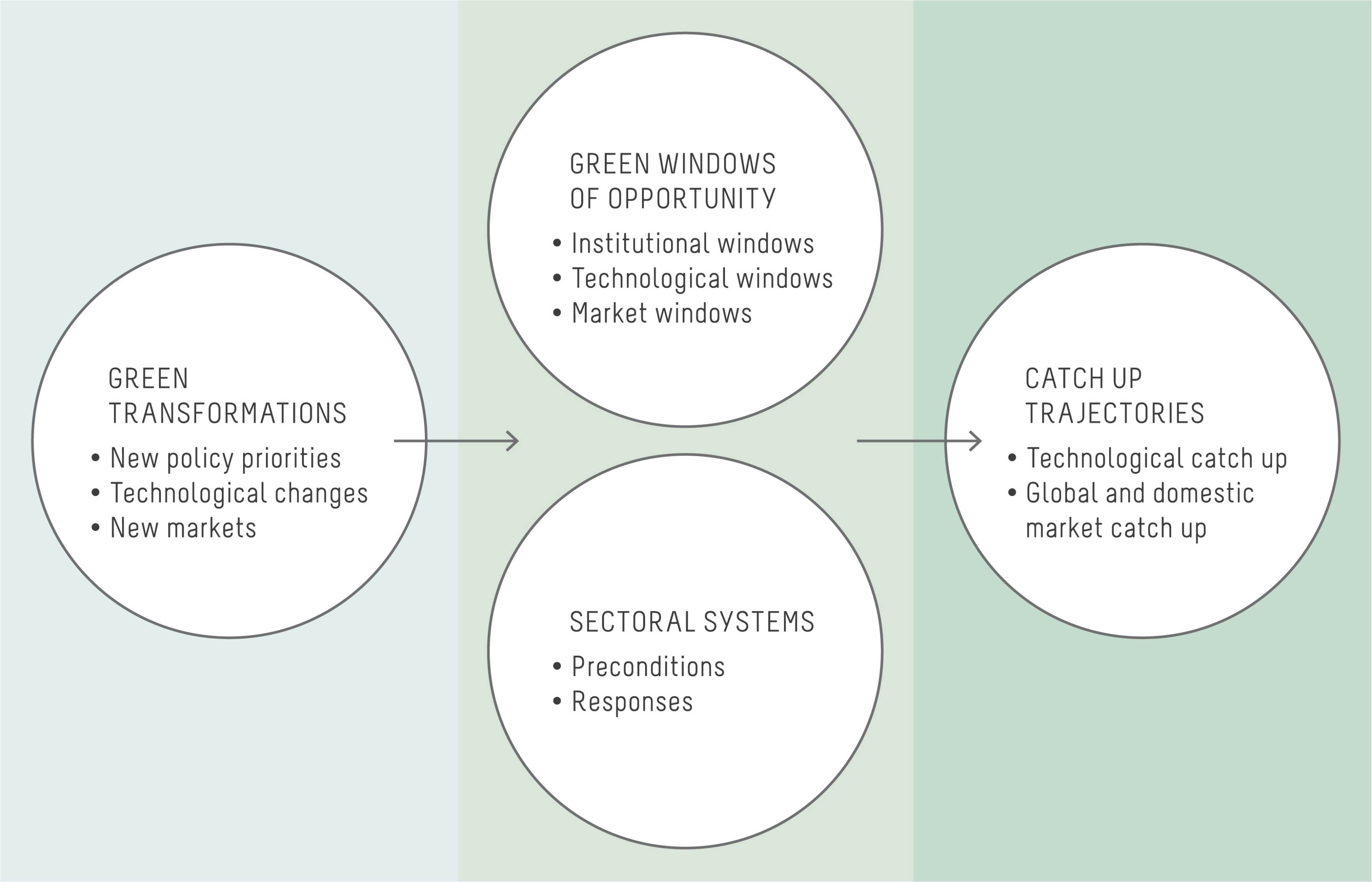
Notes: American companies in dark blue, Chinese companies in orange, others from developed economies in light blue and developing economies in yellow.

To harness the full potential of green frontier technologies, developing countries have to move fast.

Research questions

- Does the green economy offer opportunities for latecomer catch-up in developing countries?
- What characterises the capacity of developing countries to seize these opportunities?
  - *What are the prospects for joining green tech GVCs and upgrading within them for developing countries?*
  - *What is the role of FDI in increasing the green innovative capabilities of their subsidiaries?*
- What policy options can support developing countries in their efforts to take advantage of GWOs?

The GWO framework



1. Green Windows of opportunities
2. Sectoral system of production and innovation: preconditions and responses of public and private actors
3. Catch up trajectories resulting from the interactions of GWO with stakeholders' actions

Windows of opportunity

- As suggested by Perez & Soete (1988), development paths are prompted by different windows of opportunity.
  - **Technological windows:** e.g., in the electronic industry the shift from analog to digital technologies provided an opportunity for Korean s firms to seize control of the market from the incumbent Japanese firms;
  - **Demand windows**: a new type of demand (e.g., demand for low-cost car in emerging countries), rise of new consumers (e.g., wine industry) or a change in the business cycle;
  - **Institutional windows:** the establishment of public R&D programs that affect the learning process and the accumulation of capabilities of domestic firms or the provision of subsidies, tax reduction, export support, regulations, and public standards (e.g., renewable energies).

When a WoO opens up

- Latecomers respond depending on their learning processes, their level of capabilities, organisation and strategies as well as the level of development of their innovation systems;
- Incumbents also respond but they may be subject to "incumbent traps";
- Different windows and different responses from incumbents and latecomers determine the successive catch-up trajectories.

What is different in the green techno-economic paradigm

Catching up with green innovation

Experimentation
Higher degree of experimentation and novelty: Limited opportunities for a path-following catch-up

Public goods
Driven by social value and the provision of climate-related public goods

Directed development
Social drive implies directed development: High levels of policy

Global agendas
Influenced by global agendas

Source: UNCTAD.

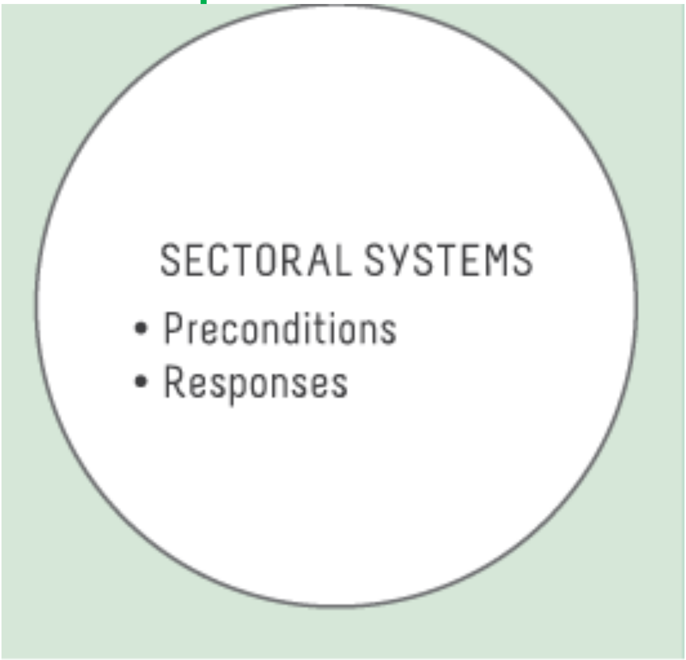
Green windows of opportunity

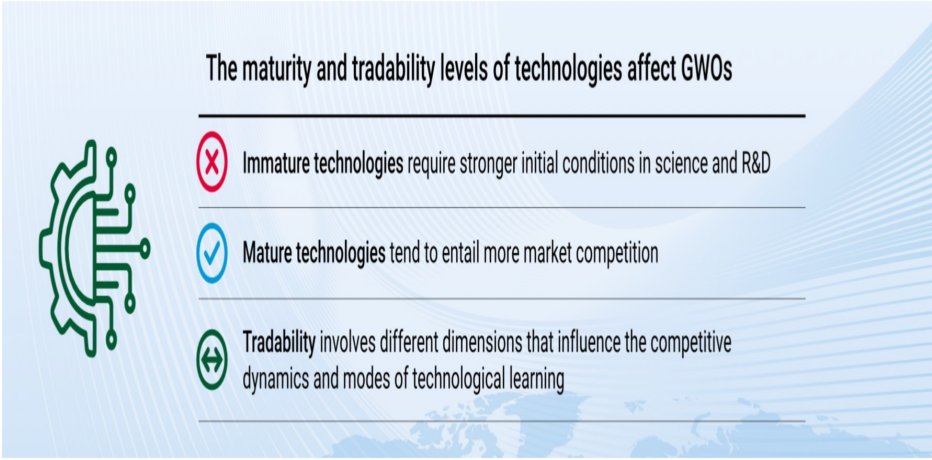
- In green sectors, there are local, national, and international efforts to create and scale up new technologies.
- GWO are mainly endogenous, created by governments and influenced by national and global environmental and industrial policies;

- Examples are:
  - **China**:2006 Renewable Energy Promotion Law; Golden Sun Demonstration Program; Ride the Wind Program.
  - **Brazil**: Sugarcane-based ethanol fuel program.
  - **India**:2020 National Electric Mobility Mission Plan.
  - **Brazil, Chile, Uruguay, Viet Nam, Turkey, Morocco, Namibia and South Africa**: existing or forthcoming green hydrogen national strategies.

Sectoral systems: preconditions & responses

- The ability to take advantage of GWOs in developing countries differs across green technologies and countries.
- To investigate and understand how they differ, we focus on two components of the sectoral system:
  - preconditions to take advantage of the opportunity
  - strategic responses of public and private actors for seizing the GWOs
- Responses to GWOs differ depending on technological maturity and tradability of the industries





Seizing GWOs: four 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.

Scenario 1: Windows open
Example: Renewables in China

- Preconditions:
    - large internal market,
    - diversified industrial structure
    - well-developed related capabilities such as, for example, design and engineering capabilities for biomass plant construction.
- Responses:
    - Co-design of environmental and industrial policies.
    - Diffusion of knowledge among firms and institutions, such as government stimulation of knowledge spillovers with loose enforcement of property rights and diffusion through state-owned design institutes in biomass.
    - Acquisition of foreign technology through licensing activity and cross-border acquisitions of foreign firms in solar PV and biomass.
    - Public R&D experimentation in CSP.

Scenario 2: Windows to be open

Example: **Solar in India and Biogas in Bangladesh**

- **India: National Solar Mission** prioritised deployment at low costs above domestic manufacturing, and this resulted in a high dependency on imports.
  - Insufficient attention paid to training, promotion of linkages with domestic companies and R&D to boost domestic competitiveness.
  - When local content requirements were introduced, there were not enough domestic capabilities to effectively mitigate import dependence due to the lack of domestic business creation in the early stages.

- **Bangladesh**: R&D investments in **biogas energy projects** was not complemented with the strengthening of the production system.
  - No appropriate incentives to encourage biogas plant installations.
  - Very little has been done to increase awareness among farmers about the potential of correct waste management

Scenario 3: Windows within reach

Example: Biogas in Thailand

- Preconditions: Limited initial experience, absence of domestic firms and fragmentation of actors
  - Factories (e.g. of casava starch) were not interested to invest in biogas production due to high investment costs
  - Pilot projects supplied by foreign firms (no domestic suppliers in the 1990s/2000s)

- Responses: Proactive strategy of the Minister of Energy to attract private investors to the biogas industry
  - Financial subsidies for the construction and design of biogas production plants, tax incentives for firms involved in waste transformation;
  - Small Power Purchase Tariff program for increasing the proportion of electricity generation from biogas;
  - Enforcement of an environmental law taxing companies producing pollution;
  - Support for the strengthening of the sectoral innovation system.

The wind sector

Preconditions Responses	**Strong**	**Weak**
Strong	1. Effective GWO seizing • China (2010)	2. Missed opportunity • China (2020) • (India, for now)
Weak	3 . Active Approach • Ethiopia	4. Distant opportunity • Kenya

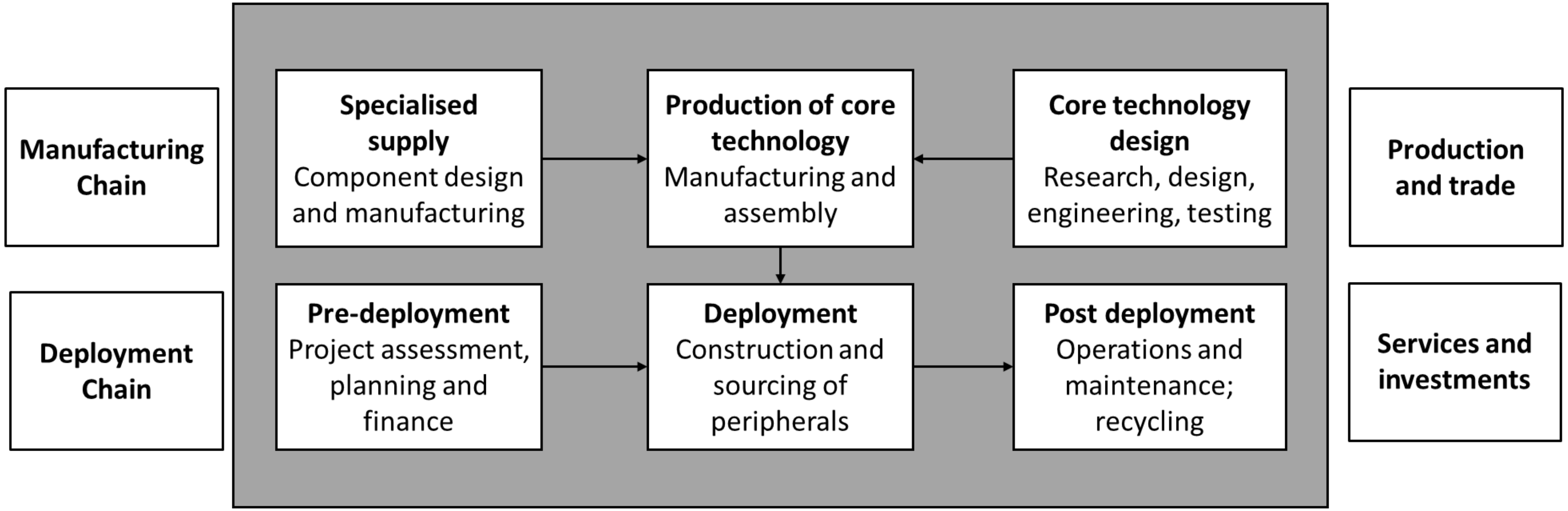
China	Ethiopia	Kenya
• Active industrial policy • Active approach by firm: licensing and co-design • Catching up close to frontier in 2010 • Now falling behind in post-turbine technology due to insufficient IS response => Missed opportunity	• Wind part of energy policy and planning • Active role in designing wind projects to guarantee maximum local learning • Still limited industrial outcome but local learning secured => Active approach	• Driven largely by external funds and support • Ad-hoc project approval with no industrial conditionalities attached • Virtually zero local content and learning • Small number of local jobs in O&M => Distant opportunity

GWOs & GVCs

- This is the next step of our research project to be developed in a book on **Green Windows of Opportunity. Sustainable Global Value Chains and Latecomer Development;**
- Our scenarios get more complex if we consider how RE GVCs are organised because both preconditions and responses are influenced by GVCs characteristics.

Renewable energy GVCs

- **Manufacturing chain**: manufacturing of energy-generating equipment. It is led by OEMs and networks of suppliers;
- **Deployment chain**: distribution of renewable energy, i.e. services activities lead by engineering, procurement and construction (EPC) firms.



The main leading actors in the two chains

- **OEMs** are the lead firms in trade-centred global value chains. Manufacturing of core technology is often based in the exporting country (home economy) but may also sometimes be undertaken in the importing country (host economy).
  - The technology provider and its networks of component suppliers manufacture and assembly either offsite (exports) or onsite at the destination (FDI and follow sourcing).
- **EPC firms** lead the deployment chain by bringing together a range of actors, including financiers and specialised service providers, whose location is typically tied to the site of installation.

Solar PV GVC

Governance

- Low transportation costs, high tradability and standardised products.
- Significant power exerted by lead firms which have traditionally been OEMs.
- Economies of scale are important.

Market-based governance with low switching costs throughout the chain

Upgrading

- China: functional expansion strategy (starting from modules) to gain lead-firm status
- ROW: High entry barriers in the manufacturing chain (e.g., lock-in in India despite NSM)
- Opportunities mainly confined to the deployment chain
- GVC-learning constrained due to market-based governance

Who Controls the Solar Panel Supply Chain?

The Manufacturing Process for Solar PV Panels

POLYSILICON — The primary material for solar PV manufacturing which is melted and cast into ingots.

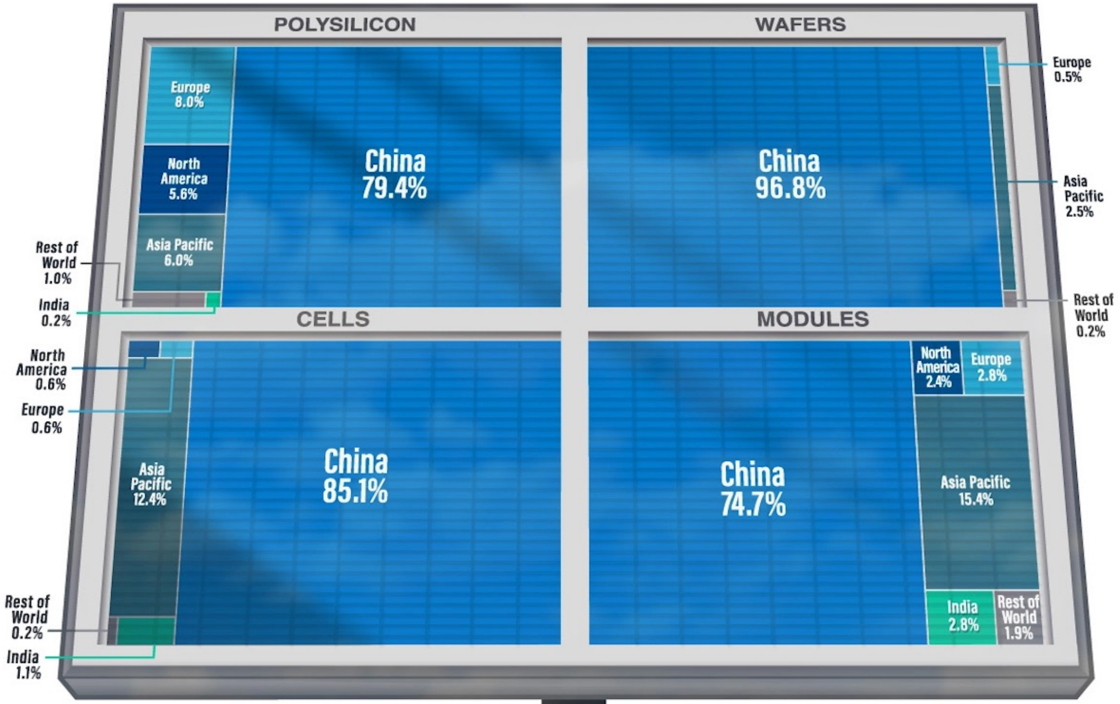
INGOT — Polysilicon ingots are sliced into thin wafer sheets ranging from 150-280 micrometers in thickness.

WAFER — The wafer is then cleaned and doped to manufacture a crystalline solar cell.

CELL — Multiple cells are wired together and laminated to form modules, before being connected to panels.

MODULE / PANEL

Share of Manufacturing Capacity by Country/Region in 2021



China made up **55%** of global solar panel manufacturing capacity in 2010, with its share rising to **84%** in 2021.

The total value of global solar PV related trade increased by more than **70%** YoY to reach over **$40B** in 2021.

Wind GVC

Governance

- Top leading companies are Vestas, Siemens-Gamesa (Europe), GE Wind (North America) Goldwind and Envision (China).
- High transportation costs.
- Significant localisation of production in (sizeable) end markets and widespread follow-sourcing there.

Co-existence of modular and relational governance (between project developers, OEMs and suppliers but switching costs are decreasing)

Upgrading

- China: expanding backward from deployment (licenses and foreign suppliers are key)
- India: initially less success with lead-firm strategy (Suzlon)
- Chile: blade production enabled by lead-firm learning (close interaction)
- ROW: mainly simple components such as towers and foundations

Biomass GVC

Governance

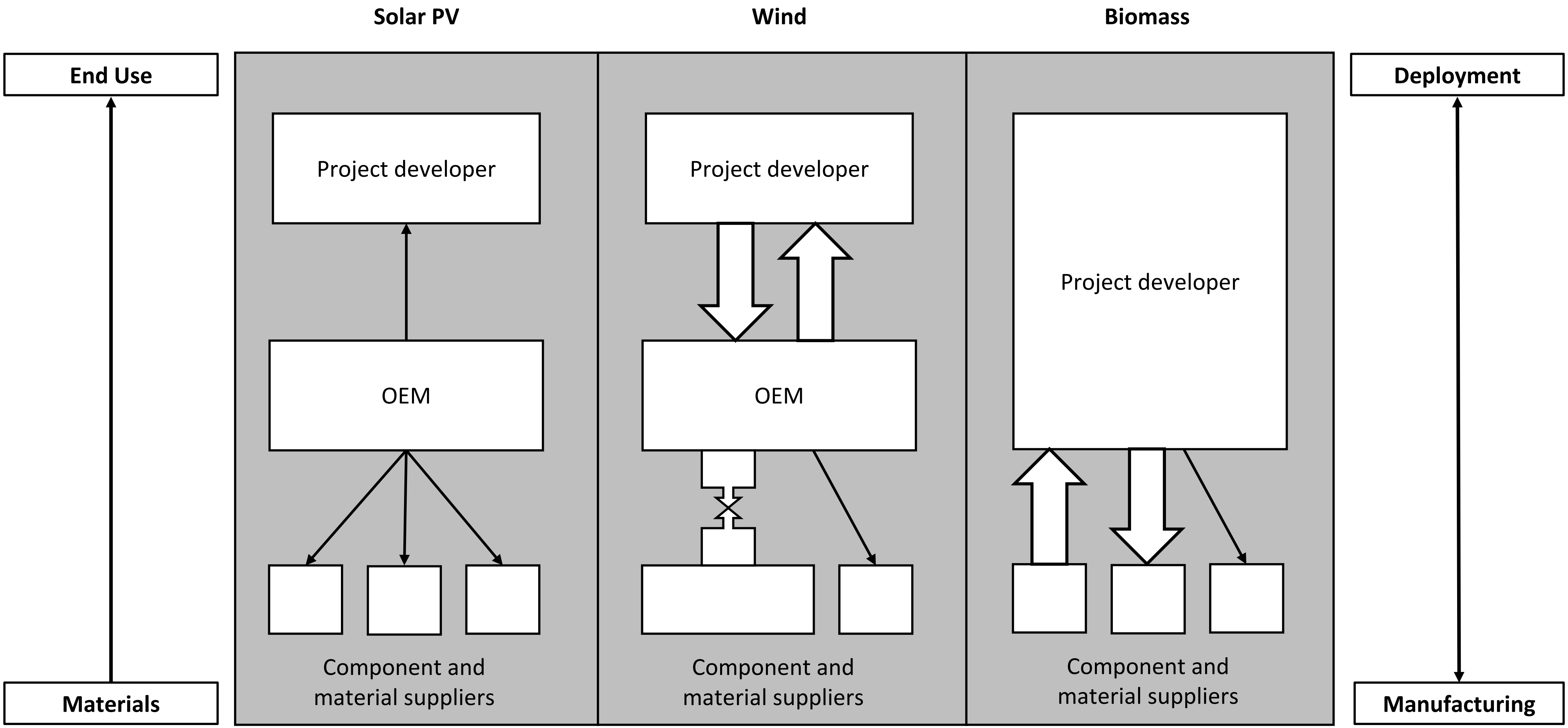
- Very low tradability and integral product architecture.
- Customised solutions depending on feedstock (e.g. cassava or corn residue).
- High importance of design and organisational capabilities.
- Both specialised and generic suppliers.

Vertical governance with integrated EPC lead firms

Upgrading

- China: starting from deployment with firm acquisitions and local diffusion of designs.
- Thailand: feedstock processing firms acquired design capabilities from foreign EPCs and consultants.
- India: Strong indigenous EPC as well as specialised technology suppliers.
- ROW: relatively low entry barriers but tacit knowledge is key.

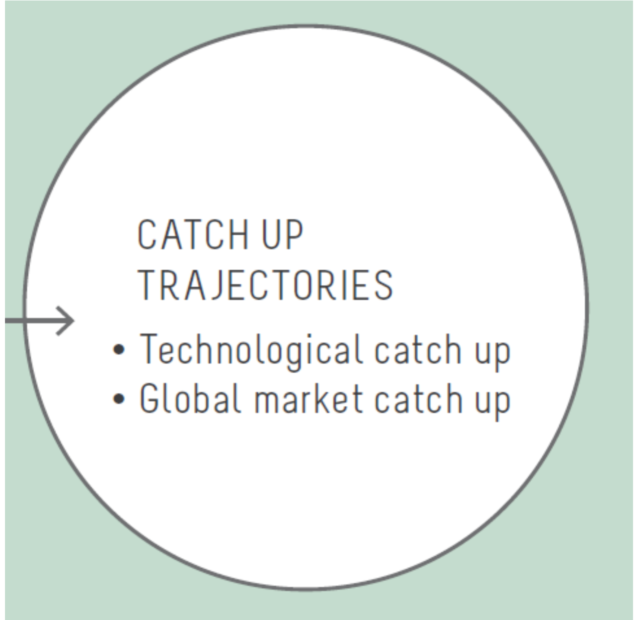
	Solar PV	Wind	Biomass
Governance	Market	Relational/ modular	Vertically integrated
Separation between manufacturing and deployment	High	Medium	Low
Entry barriers in manufacturing	High	Medium	Low
Entry barriers in deployment	Medium	High	
Upgrading opportunities	• Few opportunities in core technology • High entry barriers due to economies of scale by incumbents • Possibilities in the deployment GVC • Opportunities to create manufacturing capabilities in peripheral GVCs such as batteries, inverters, racking solutions etc.	• Upgrading opportunities in core technology • Possibility of moving from domestic market to regional exports of key components • High transportation costs combined with standard designs favour local manufacturing of blades and towers • Competent domestic EPCs may facilitate domestic sourcing	• Key opportunities arise from the significant economic activity necessarily tied to the point of end-use • Domestic firms involved in feedstock processing may upgrade functionally in the value chain, learning from project participation

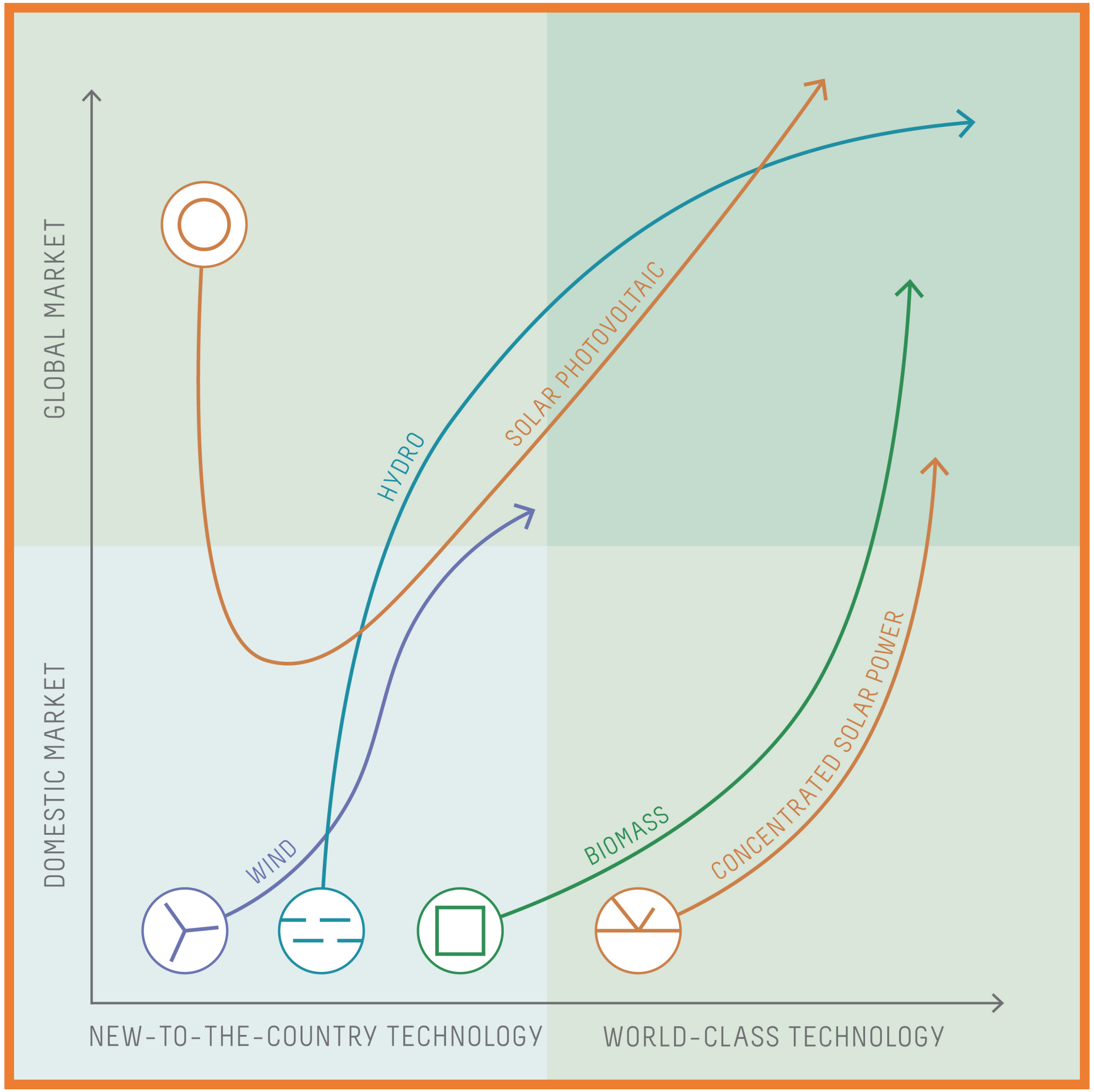

Solar PV
Wind
Biomass
End Use
Materials
Deployment
Manufacturing
Project developer
OEM
Component and material suppliers
Project developer
OEM
Component and material suppliers
Project developer
Component and material suppliers

GWOs & GVCs: the complexity

- Many variables to consider:
  - GVCs: governance and upgrading opportunities
  - Industry specificity: technological maturity and tradability
- All these different variables impact on preconditions and responses and influence our scenarios, which become more complex…
- To be done……

Catch-up trajectories

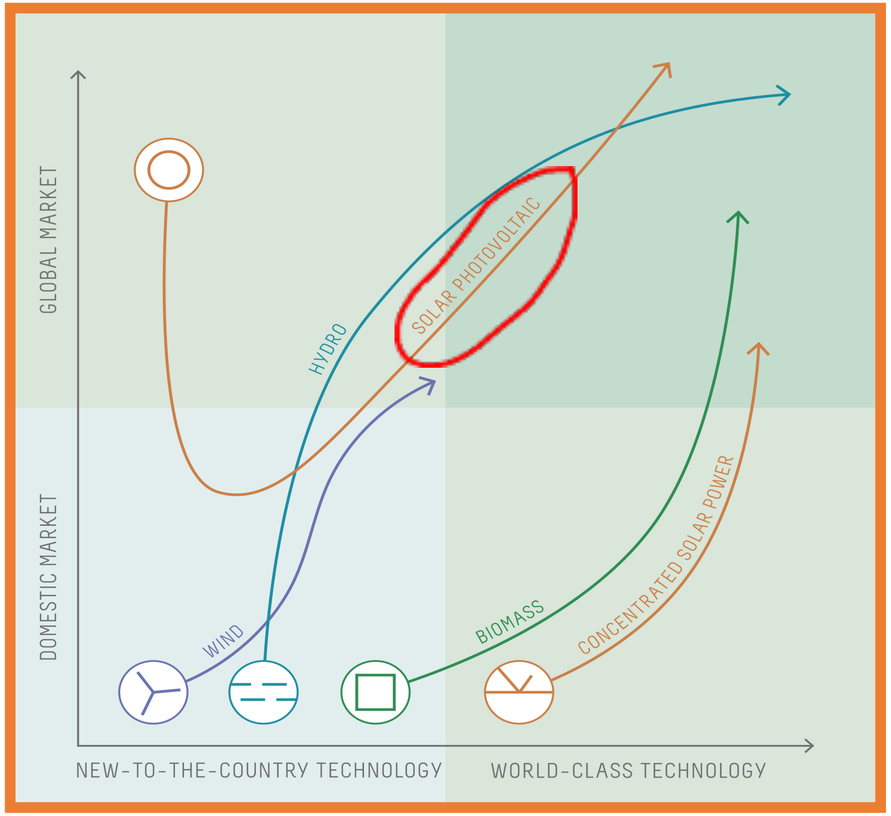




Trajectory #1
From learning from exporting to domestic strengthening and then to global leadership

Chinese Solar PV Industry

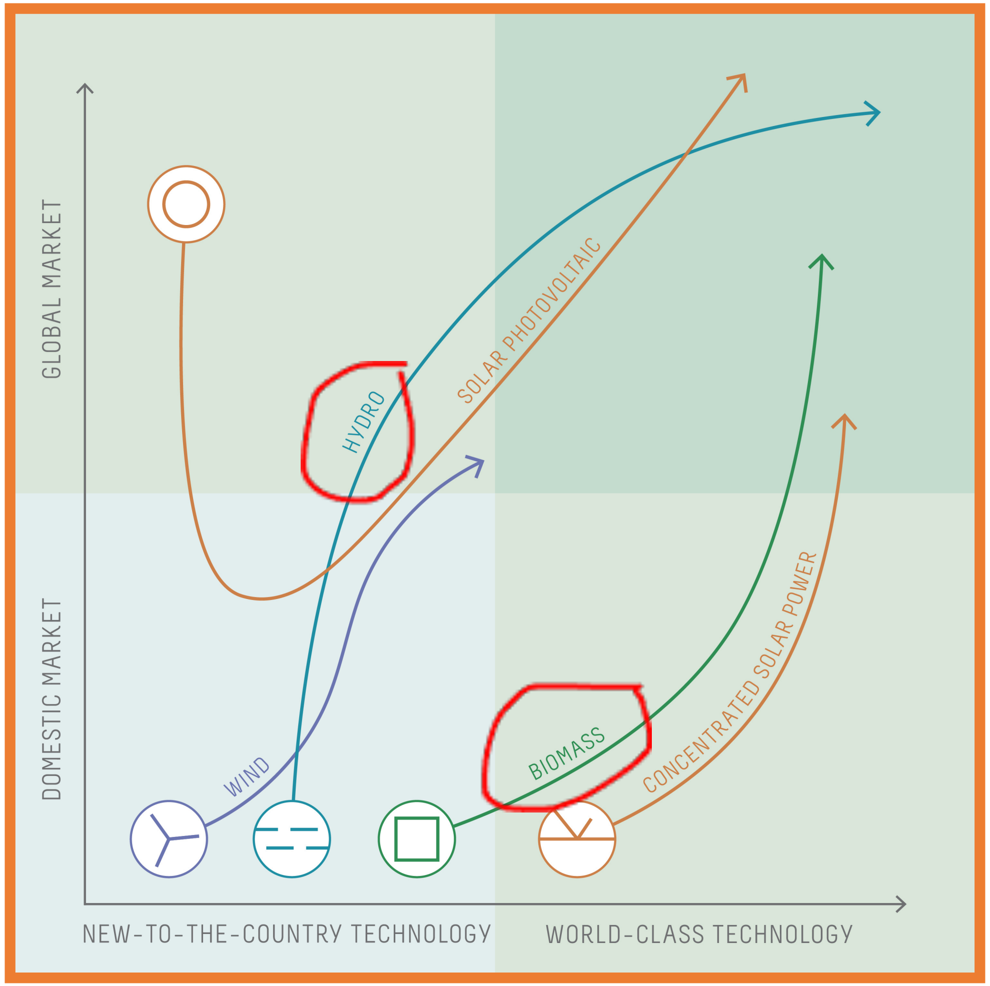
- ❖ Learning from export started in the global market exporting solar panels made with imported technology
- ❖ Substitution of international demand with domestic demand, after a fall in the global market, thanks to the incentives created by public policy
- ❖ Huge investments in building domestic technological capacity and the whole solar value chain
- ❖ Back to international markets as technological and market leaders.



Trajectory #2
From domestic imitation to global leadership

Chinese Biomas & Hydropwer Industry

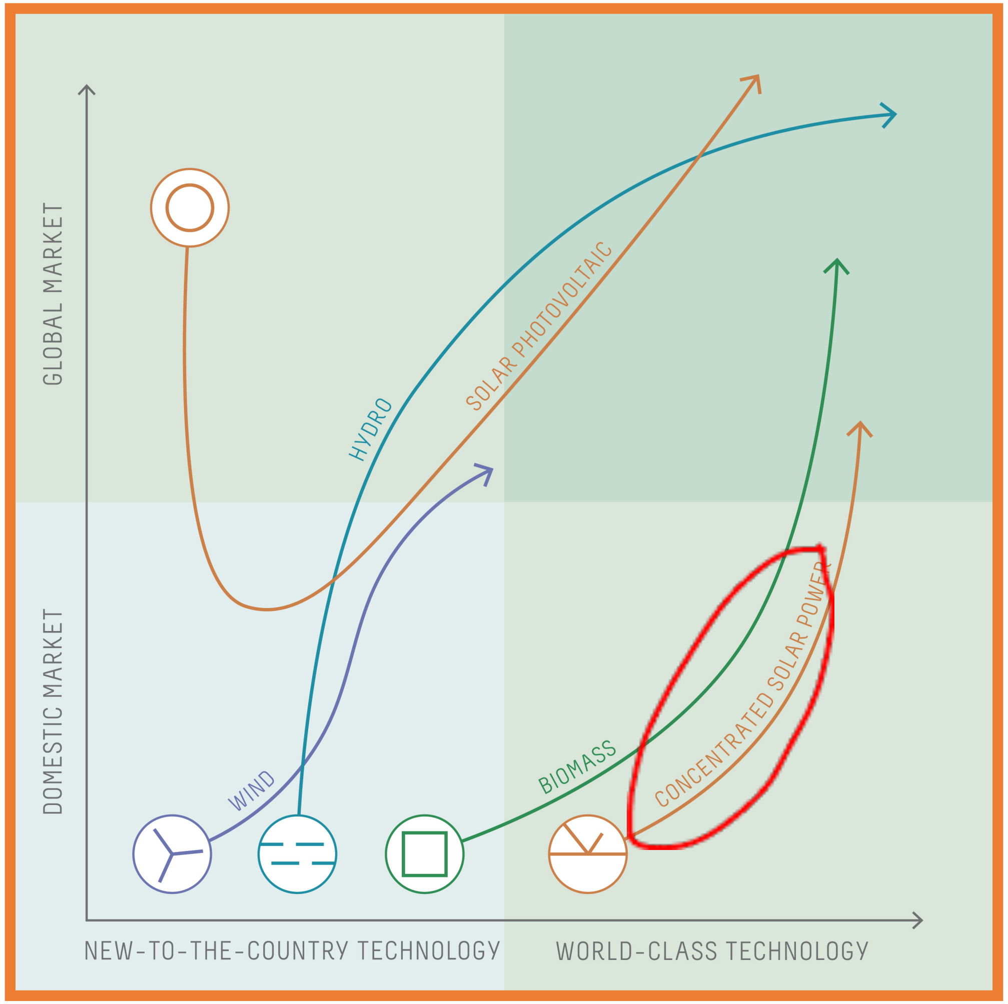
- ❖Stable technologies
- ❖China has initially relied on technology transfer and then with public support has built a domestic technological capability at the frontier.



Trajectory #3
From world-class technology to limited global market progression

Chinese Concentrated Solar Power Industry

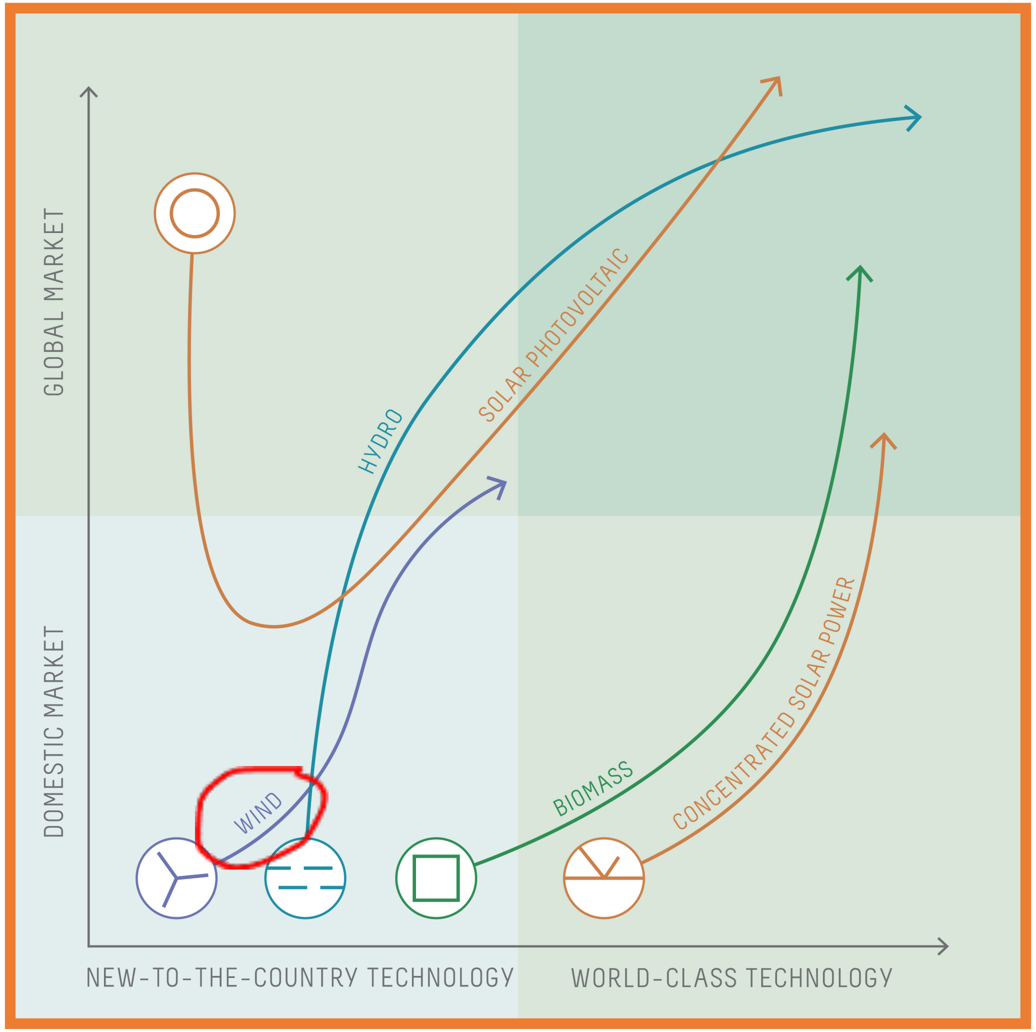
- ❖Rather immature industry
- ❖Significant investments in domestic demonstration projects
- ❖Technological development at the frontier
- ❖Technological uncertainty and competing on standards.



Trajectory #4
From domestic imitation to limited global progression

Chinese Wind Industry

- ❖Complex and rapidly evolving technology regimes
- ❖Increasing role of digital technologies and hybrid-digital technologies
- ❖Technology gap and limited exports



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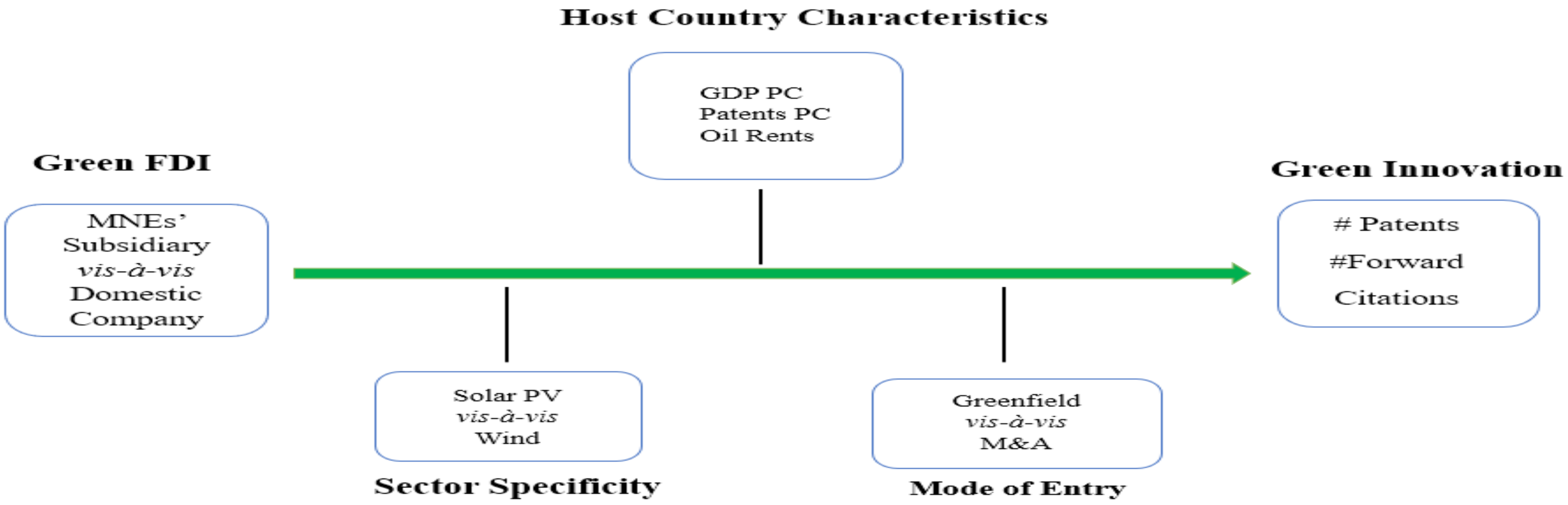
Research question

To what extent are MNEs contributing to increase the green innovative capabilities of their subsidiaries vis-à-vis domestic companies?



DATASET

Green FDIs are investments undertaken by MNEs with at least one patent in **renewable energy technologies** (subset of Y20E: **geothermal, hydro, marine, solar thermal, solar PV, solar thermal-PV hybrid, wind, biofuels, fuel from waste**).

- Subsidiaries' main business activities focus on production/distribution of renewable energy.

- # GREEN FDIs 1,055 (73% GREENFIELD INVESTMENTS and 27% M&As)
- Patents are attributed to subsidiaries if at least one inventor is from the same country of the subsidiary (Stiebale, 2016): **1,410 SUBSIDIARIES' PATENTS IN RE**
- **Counter sample:** 6,276 DOMESTIC COMPANIES (in the same sectors/countries of the subsidiaries)
- Period of the analysis: 2003-2015

METHODOLOGY

- **Negative binomial model** (Piperopoulos et. al., 2018)
- **Output variables**
  - # of green patents (DOCDB families) up to 5 years after the investment
  - # forward citations (average) to green patents up to 5 years after the investment
- **Main independent variable:** Dummy 1= MNE subsidiary 0 = domestic company
- **Moderating factors:** Host country-specific characteristics (GDP per capita; # of patents per capita in the country; oil rents %GDP)
- **Controls:** SIZE, AGE, PRE-DEAL KNOWLEDGE BASE
- **Fixed effects:** NACE 2-digit sector and deal year
- **Subsamples**
  - ➢ Wind & Solar (vs. domestic companies)
  - ➢ Greenfield investments & M&As (vs. domestic companies)

Table 2
Full sample.

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−0.859*** (0.262)	−0.049 (0.262)	0.188 (0.249)	0.377 (0.263)	0.705*** (0.245)	0.552** (0.274)	1.167*** (0.375)	1.154*** (0.352)	1.202*** (0.399)	1.510*** (0.361)	2.115*** (0.357)	2.187*** (0.376)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.690** (0.306)	−0.614*** (0.171)	−0.626*** (0.211)	−0.145 (0.144)	−0.518** (0.208)	−0.172 (0.166)	−1.029*** (0.187)	−1.056*** (0.167)	−1.099*** (0.260)	−1.049*** (0.365)	−1.026*** (0.234)	−0.666*** (0.257)
AGE (LN)	−0.314*** (0.071)	−0.249*** (0.071)	−0.189*** (0.072)	−0.244*** (0.074)	−0.087 (0.072)	−0.156* (0.086)	−0.072 (0.085)	−0.414*** (0.077)	−0.281*** (0.087)	−0.226** (0.090)	−0.125 (0.092)	−0.003 (0.097)
MIDDLE SIZE	0.093 (0.165)	0.173 (0.182)	0.066 (0.169)	0.138 (0.181)	0.105 (0.208)	0.934*** (0.221)	−0.127 (0.204)	−0.150 (0.214)	0.021 (0.230)	−0.040 (0.249)	0.015 (0.244)	0.815*** (0.264)
LARGE_SIZE	0.350* (0.188)	0.088 (0.200)	0.308 (0.199)	0.398** (0.193)	0.405** (0.206)	1.064*** (0.241)	−0.313 (0.232)	0.067 (0.241)	−0.487** (0.230)	−0.154 (0.280)	0.507** (0.250)	0.741** (0.345)
COUNTRY GDP PC (LN)	0.106 (0.068)	0.010 (0.063)	0.029 (0.069)	0.150* (0.077)	−0.004 (0.072)	−0.081 (0.074)	0.250*** (0.083)	0.305*** (0.083)	0.255*** (0.089)	0.458*** (0.104)	0.360*** (0.083)	0.228** (0.092)
COUNTRY PATENT PC (LN)	0.131 (0.148)	0.466*** (0.154)	0.265 (0.166)	0.422** (0.170)	0.764*** (0.195)	1.062*** (0.206)	0.384* (0.202)	−0.032 (0.218)	0.242 (0.248)	−0.165 (0.196)	0.353 (0.242)	0.921*** (0.260)
OIL RENTS (% GDP)	−0.049 (0.043)	−0.061 (0.038)	−0.082* (0.042)	−0.063 (0.053)	−0.023 (0.038)	0.011 (0.055)	−0.145*** (0.046)	−0.074* (0.043)	−0.156*** (0.050)	−0.012 (0.068)	−0.064 (0.043)	0.192 (0.133)
INDUSTRY FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−19.082	−20.876*** (1.222)	−21.553 .	−22.229 .	−20.192*** (0.858)	−20.596*** (1.914)	−21.540*** (1.409)	−27.152 (9090.162)	−36.194 (8447873.262)	−31.572 .	−23.094*** (0.613)	−27.666 (125.124)
LNALPHA	2.462*** (0.164)	2.838*** (0.101)	2.788*** (0.107)	2.870*** (0.113)	2.983*** (0.112)	3.171*** (0.110)	4.048*** (0.071)	4.087*** (0.072)	4.148*** (0.081)	3.996*** (0.082)	4.044*** (0.084)	4.177*** (0.097)
OBSERVATIONS	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331

FDI subsidiaries = 1,055. # Domestic companies = 6,276. Robust standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$″.

RESULTS - FULL SAMPLE

- Subsidiaries **outperform comparable domestic companies** with respect to # of green patents & # of forward citations.

→Subsidiaries have a green innovation advantage with respect to domestic companies

Table 3
Interaction terms (full sample).

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t (1)	t + 1 (2)	t + 2 (3)	t + 3 (4)	t + 4 (5)	t + 5 (6)	t (7)	t + 1 (8)	t + 2 (9)	t + 3 (10)	t + 4 (11)	t + 5 (12)
FDI SUBSIDIARY	−2.042** (0.864)	−1.498* (0.845)	−1.182 (1.202)	0.017 (0.734)	0.143 (0.574)	0.242 (0.593)	1.730** (0.789)	2.486*** (0.818)	2.081** (0.922)	3.302*** (0.791)	3.251*** (0.686)	2.770*** (0.650)
PATENT PORTFOLIO STOCK LAG 1 (LN)	−0.728** (0.293)	−0.746*** (0.194)	−0.699*** (0.242)	−0.169 (0.150)	−0.575*** (0.215)	−0.255 (0.178)	−0.978*** (0.181)	−1.018*** (0.171)	−1.030*** (0.265)	−0.986*** (0.311)	−1.343*** (0.247)	−0.826*** (0.237)
AGE (LN)	−0.323*** (0.070)	−0.254*** (0.075)	−0.187** (0.077)	−0.239*** (0.073)	−0.087 (0.071)	−0.175** (0.085)	−0.077 (0.084)	−0.419*** (0.077)	−0.297*** (0.087)	−0.252*** (0.090)	−0.211** (0.093)	−0.042 (0.097)
MIDDLE SIZE	0.094 (0.163)	0.153 (0.180)	0.036 (0.165)	0.123 (0.181)	0.073 (0.204)	0.945*** (0.219)	−0.104 (0.205)	−0.122 (0.210)	0.037 (0.232)	−0.087 (0.246)	0.145 (0.240)	0.848*** (0.269)
LARGE SIZE	0.368** (0.186)	0.121 (0.202)	0.331* (0.200)	0.403** (0.193)	0.435** (0.208)	1.162*** (0.240)	−0.298 (0.235)	0.139 (0.246)	−0.461** (0.230)	−0.136 (0.278)	0.634** (0.255)	0.895*** (0.339)
COUNTRY GDP PC (LN)	0.062 (0.068)	−0.035 (0.061)	−0.030 (0.064)	0.115 (0.075)	−0.028 (0.078)	−0.070 (0.083)	0.331*** (0.087)	0.403*** (0.088)	0.324*** (0.098)	0.496*** (0.119)	0.577*** (0.093)	0.440*** (0.117)
COUNTRY PATENT PC (LN)	0.101 (0.148)	0.360** (0.156)	0.192 (0.168)	0.395** (0.174)	0.648*** (0.200)	0.892*** (0.211)	0.301 (0.199)	−0.157 (0.219)	0.166 (0.250)	−0.084 (0.202)	0.070 (0.246)	0.491* (0.262)
OIL RENTS (%GDP)	−0.037 (0.043)	−0.050 (0.039)	−0.079* (0.045)	−0.054 (0.055)	−0.038 (0.042)	0.003 (0.056)	−0.153*** (0.049)	−0.049 (0.044)	−0.143*** (0.053)	0.006 (0.070)	−0.079 (0.048)	0.139 (0.171)
FDI SUBSIDIARY * COUNTRY GDP PC	**0.334** **(0.288)**	**0.254** **(0.240)**	**0.277** **(0.344)**	**0.083** **(0.221)**	**−0.079** **(0.180)**	**−0.263** **(0.179)**	**−0.390*** **(0.224)**	**−0.660***** **(0.219)**	**−0.445*** **(0.249)**	**−0.233** **(0.241)**	**−1.292***** **(0.220)**	**−0.966***** **(0.189)**
FDI SUBSIDIARY * COUNTRY PATENT PC	**0.471** **(0.925)**	**2.111**** **(0.900)**	**1.530*** **(0.896)**	**0.548** **(0.770)**	**2.030**** **(0.844)**	**2.918***** **(0.869)**	**1.286** **(1.156)**	**2.467**** **(1.123)**	**1.403** **(1.261)**	**−1.777** **(1.091)**	**6.497***** **(1.076)**	**5.463***** **(1.137)**
FDI SUBSIDIARY * COUNTRY OIL RENTS	**−0.070** **(0.115)**	**−0.086** **(0.127)**	**−0.024** **(0.138)**	**−0.109** **(0.120)**	**0.074** **(0.099)**	**−0.071** **(0.147)**	**−0.070** **(0.206)**	**−0.604***** **(0.204)**	**−0.253** **(0.190)**	**−0.858***** **(0.247)**	**−0.064** **(0.168)**	**−0.193** **(0.237)**
INDUSTRY FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
DEAL YEAR FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
CONSTANT	−20.379 .	−21.262*** (2.125)	−19.904*** (1.223)	−21.323** (9.381)	−20.276*** (0.975)	−20.766 .	−22.385*** (3.576)	−24.177 .	−35.701 .	−19.287*** (0.834)	−24.453*** (0.987)	−32.564 (7659.261)
LNALPHA	2.456*** (0.160)	2.816*** (0.097)	2.766*** (0.111)	2.865*** (0.115)	2.977*** (0.112)	3.160*** (0.110)	4.043*** (0.071)	4.072*** (0.072)	4.139*** (0.080)	3.985*** (0.082)	3.991*** (0.082)	4.120*** (0.098)
OBSERVATIONS	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331	7331

FDI subsidiaries = 1,055. # Domestic companies = 6,276. Robust standard errors are in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01″.

RESULTS - INTERACTION TERMS

- **GDP per capita**
  - Relative to domestic companies **the subsidiaries of multinationals are more innovative** when the GDP per capita is lower.
    - In less developed countries being a subsidiary it really makes a difference!
- **Patents per capita**
  - The advantage of being a subsidiary is larger in more innovative countries → better absorptive capacity
- **Oil Rents (% GDP)**
  - In oil-reliant countries, subsidiaries engage less in green innovative activity → the resource curse hypothesis.

Wind

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t	t+1	t+2	t+3	t+4	t+5	t	t+1	t+2	t+3	t+4	t+5
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
FDI SUBSIDIARY	-0.197	0.986***	1.888***	1.503***	2.309***	2.410***	3.827***	3.742***	5.139***	3.731***	4.654***	3.288***

Solar

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t	t+1	t+2	t+3	t+4	t+5	t	t+1	t+2	t+3	t+4	t+5
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
FDI SUBSIDIARY	-0.079	-0.717	0.078	-0.169	-0.167	1.440***	3.491***	2.985***	2.933***	1.688**	2.908***	3.561***

RESULTS: SECTOR SPECIFICITY

- **Wind** subsidiaries outperform domestic companies in both outputs;
- **Solar** subsidiaries outperform domestic companies only in forward citations;
  - **The subsidiaries' advantage in terms of patent quality is larger in wind than in solar PV.**

➢ Knowledge is more tacit in wind and more codified in solar!

Greenfield FDI

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t	t+1	t+2	t+3	t+4	t+5	t	t+1	t+2	t+3	t+4	t+5
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
FDI SUBSIDIARY	-1.134***	-0.133	-0.027	0.408	0.443	0.728*	1.119**	0.869**	0.397	1.920***	1.356***	1.895***

M&As

	OUTPUT: # green patents						OUTPUT: # forward citations to green patents					
	t	t+1	t+2	t+3	t+4	t+5	t	t+1	t+2	t+3	t+4	t+5
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
FDI SUBSIDIARY	0.536	2.331*	2.244**	2.020	3.708***	3.416***	7.262***	7.417***	6.490***	7.227***	7.566***	6.646***

RESULTS: MODE OF ENTRY

- **Greenfield investments** outperform domestic companies in terms of forward citations, but not in terms of # of patents.
- **M&A** perform better in terms of both output variables, i.e., the amount and quality of innovation.
  - **The gap between subsidiaries and domestic companies in terms of innovative capability is larger in case of acquisitions than in greenfield investments.**
  - Greenfield subsidiaries rely mostly on foreign investors' knowledge;
  - Acquired companies combine parent's knowledge with an easier access to local knowledge.

Opening green windows

Set the direction towards green technologies and innovation

- Align environmental and industrial policies
- Prioritise investments in green sectors
- Incentives and infrastructure to shift demand towards greener goods and encourage recycling and the circular economy

Build green productive and innovative capacities

- Invest in R&D, in particular in nascent green technology
- Develop digital infrastructure and skills

International cooperation

Trade rules should permit developing countries to protect infant green industries through tariffs, subsidies and public procurement

Consistency between international agreements on trade, intellectual property and climate change is critical for green technology revolution

Intellectual property should have greater flexibilities for developing countries with regard to green technologies

To address the financial constraint the role of international cooperation should be key but so far the resources made available have been insufficient.

Better coordination between public and private actors, and also between domestic and international actors, is needed to reduce systemic redundancies and maximize the impact of investments.

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The role of digital technologies in RE GVCs

- The digital and green transformations have developed largely in parallel, with their own trajectories and with separate drivers and policy domains.
- This is now beginning to change.
  - Digital technologies can help accelerate progress towards the green transition
  - The twin - green and digital - goals are increasingly seen to complement each other, and digital technologies such as AI, cloud computing, IoT are expected to help the economy become greener.

Some examples from RE GVCs in latecomer countries

- Mobile sensors in harvesting and logging equipment provide precise information on tree species, biodiversity counts, or illegal logging (Gale et al, 2017).
- Data collected from online-connected sensors and GPS tracking systems in logistics.
- 3D printing instead of traditional production methods with substantial material savings.

- Blockchain
  - Provide information to buyers on the origin of products and guarantee about the authenticity of the information;
  - Track faulty products or components;
  - Increase traceability along the GVC.
- Artificial intelligence
  - Reduce energy consumption and optimize green energy use in smart grids.
  - In agriculture, to plan shipping and delivery of perishable goods

Challenges for digitalization in latecomer countries

- Import and adoption of advanced digital technologies is still limited to a small number of emerging economies
- Production is limited to an even smaller set of advanced economies plus China
- Heterogeneity also exists within countries at firm level, with only a minority of (larger) companies adopting digital technologies, while the majority is still involved only in industry 2.0 technologies.
- There is a large digital capability gap between the leading most digitalized companies and their suppliers.
- Large gap existing between urban and rural areas, where very often digital infrastructures are lacking, making it impossible to spread digital technologies.

In latecomer countries the digital and green transitions may not yet be twins, but rather related through the extended family!

Greening the Green GVCs

- Renewable energy technologies are critical to address the climate crisis, but they are not exempt from **impacts on the environment**:
  - some of the inputs used in their value chains can be harmful or scarce in supply,
  - there are possible negative influences on biodiversity
  - there are large amounts of waste produced by the decommissioning of the obsolete systems (e.g., wind turbines)
- A **circular approach to renewable energies** implies several dimensions:
  - the application of eco-design to reduce resource use
  - the development of high-standard maintenance and reuse procedures
  - the adoption of remanufacturing and retrofit practices
  - the improvement of recyclability and reusability of materials.

The environmental impact of the solar PV industry

- Recycling of PV modules:
  - in developing countries there are high recycling costs and lack of specific infrastructure for this type of waste. Only the EU and a few other countries have set up specific protocols for PV waste, while most countries do not have specific regulations.
- Key role played by SMEs in the repair, as well as the disassembly and remanufacturing of end-of-life solar PV panels. The adoption of a circular economy approach will open market opportunity for the provision of services such as repair, maintenance, recycling, and remanufacturing.
- In developing countries, and mainly in Africa and South Asia, there is a rapid and significant diffusion of the so called off-grid solar devices, including PV-based solar lanterns, solar charges, and solar home systems. The increasing amount of waste is accelerated by the short lifetime of these products due to poor product quality, affordability constraints, low level of technical expertise in system design and installation and low access to maintenance and repair services.

KEY Takeaways

1. Subsidiaries of green MNEs are more innovative than domestic firms with similar characteristics.
2. This green innovative advantage is larger in less developed countries (and in those that are less reliant on oil rents), in particular if they already possess higher levels of relevant domestic innovative activity, as exemplified by the cases of China and India.
3. Firm-level and sectoral characteristics also matter.
   - Green FDI is more effective when technologies are characterized by low tradability and uncodified knowledge, as in wind compared to solar PV industries.
   - Cross-border acquisitions are more efficient at establishing green innovative capabilities than newly established greenfield subsidiaries.

POLICY IMPLICATIONS

- Countries can **attract green FDI** to enhance their green innovative capacities.

- Policies attracting green FDI should go hand in hand with measures **encouraging knowledge spillovers from MNE subsidiaries to domestic companies**, such as policies including local content requirements and training of the local workforce.

- Green technology transfer should take a more central role in the WTO around the TRIMS agreement, accounting for the public goods nature of green technologies, to support their global diffusion through FDI.

- International organizations, such as the UNFCCC, should direct **more attention to FDI as a key channel for green technology transfer**.

We don’t measure knowledge spillovers in the host economies!

- Numerous studies have shown that, although the extent of spillover may vary, it is likely that some degree of spillover will inevitably occur due to various mechanisms.

- Case-study research shows that knowledge spillovers from green FDI take place across various RE technologies and developing countries (e.g. Hansen and Ockwell, 2014 on biomass power technologies in Malaysia and Hansen and Hansen, 2020 on China; Lema et al., 2018; Baker and Sovacool, 2017; Davy et al., 2021 on wind and solar in Kenya and South Africa).

- Two possible, complementary, analyses:
  - On backward citations of green patents in the host economies, exploring whether domestic green patents are more likely to cite investors’ patents after the investments (see Branstetter, 2006);
  - On number and quality of green technologies co-patented by MNEs subsidiaries and domestic companies (see de Araújo et al., 2019).

The environmental impact of the wind industry

- Use of rare earths for the manufacturing of permanent magnets for the turbine generators
- Waste management is a huge problem given that for instance, blades, commonly made from glass or carbon fibres cannot be recycled and offshore structures are made on steel which is a high polluting industry
- This implies a huge amount of materials to be recycled and it would require a wide range of recycling options.
- New lighter green materials can be introduced in the production of wind-turbine generator structures with a longer lifespan.