

The uneven technological geographies of off-grid solar PV

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Off-grid solar PV supply chains



Source: Julien Potron, Nadji.Bi Senegal (2016)

1. Off grid solar PV, rural electrification and energy access in context

Energy access

- Universal access to low-carbon, affordable, reliable and modern energy services by 2030: key target of SDG7, SEforAll Initiative, and 2015 Paris agreement.
- 80 per cent of people without access to electricity (600 million are in SSA)
- Majority of people lacking access to electricity live in hard to reach, rural, remote, or conflict-affected areas.
- Many households included in electricity connection stats have unreliable and poorly functioning supply (Ulsrud 2020).
- Off-grid solar promoted as an easily deployed, cost-effective solution for pre-electrification.
- Creating entirely new areas of provision... as well as replacing traditional sources of basic energy access such as wood fuel, animal dung, paraffin stoves, candles. Also, diesel generators.
- The most distributed off-grid solar PV product is either a solar lamp or an SHS between Tier 1 and Tier 3
- SHSs: unique supply chains and business models.



World Bank multi-tier electricity access framework

	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Indicated minimum technology or system	Pico-products e.g solar lamp and lantern; nano-grid; micro-grids; entry level SHS.	Basic to medium capacity SHSs,	Medium to high capacity SHSs, with lead acid or lithium-ion battery; Micro grids.	Mini grids	Mini grids, or central grid
Power capacity ratings in Watt	Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW-10 MW
Power capacity ratings in daily Watt hours	Min 12 Wh	200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
Availability hours per day	Min 4 hours	Min 4 hours	Min 8 hours	Min 16 hours	Min 23 hours
Availability hours per evening	Min 1 hour	Min 2 hours	Min 3 hours	Min 4 hours	Min 4 hours
Examples of appliances connected	2 lights, mobile phone charging	4 lights, mobile phone, radio	4 lights, phone, radio, TV, sewing machine, fridge, fan, computer	High-load appliances e.g washing machine, microwave	Water heater, electric cooker, air con

Renewable electricity systems at multiple scales.

1. Utility-scale (10 MW and upwards): connects to the transmission grid
2. Mini-grid (few kW to several MW): standalone and/or connects to the distribution grid
3. Micro-grid/off-grid (below 50 kW): isolated from main grid

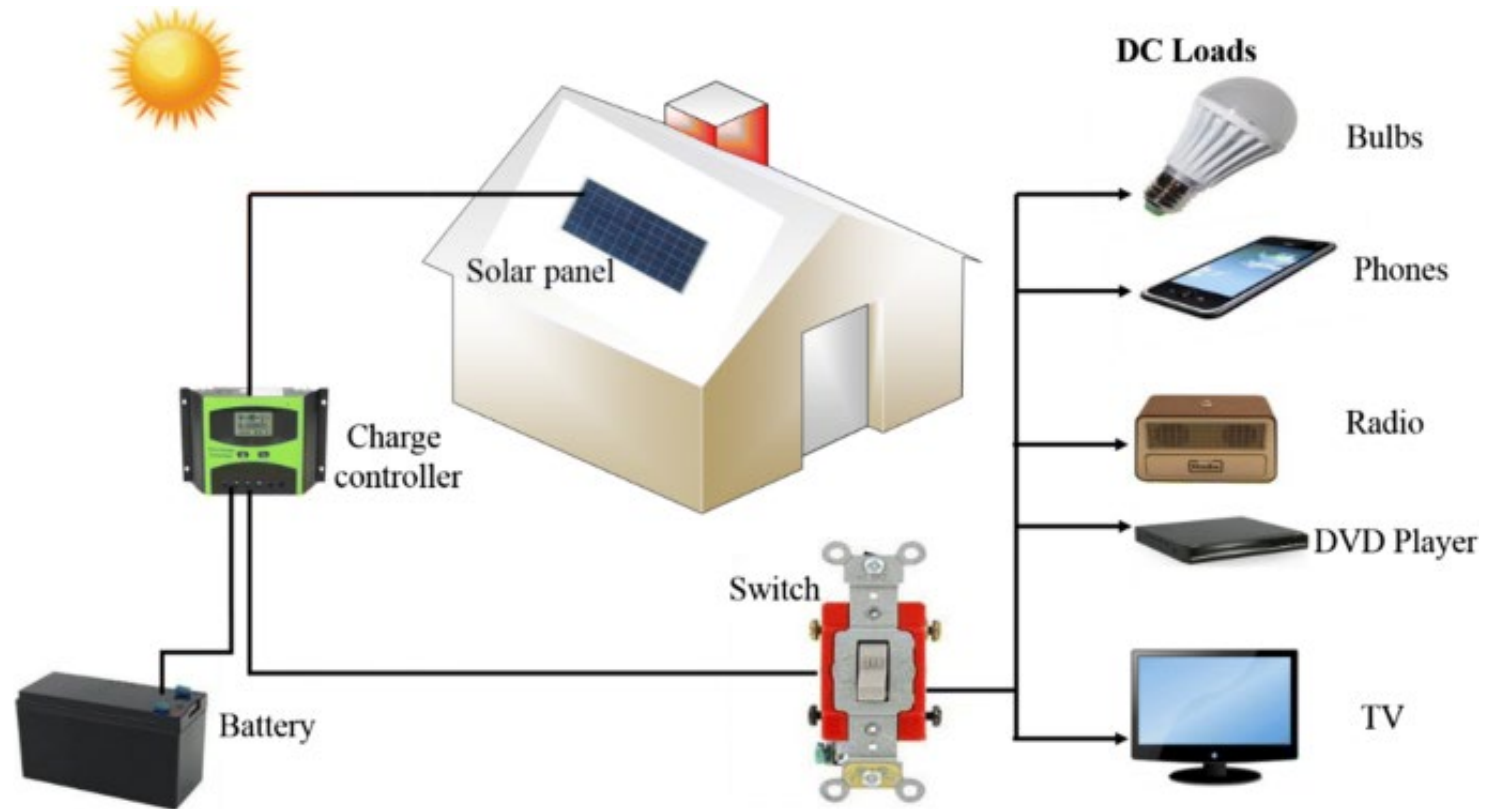


Of money, mobiles and off-grid solar: solar home systems

- 'Pre-electrification': part of rural electrification policies but also under the radar and unregulated
- Sale of the kit rather than an electricity supply or connection.
- PAYGO: Small-scale standalone system, electricity to consumers who pay using mobile money.
- PAYGO SHS contract: customer needs a mobile banking account, an ID card and upfront payment of 10-20% of total equipment price.
- Users make small, regular top up payments in local currency.
- If payment not made, consumer is disconnected.
- Many SHSs are lease-to-own model: when cost of system has been repaid device is permanently unlocked, and ownership granted to consumer (IRENA 2020).



Solar home system



Source: Adwek et al 2020

Of money, mobiles and off-grid solar: solar home systems

- PAYGO SHS credited with enabling low-income users to: *“afford a SHS that they could not previously pay for in cash”*.
- Technologically possible by widespread diffusion of mobile telephones to areas beyond landlines, and introduction of mobile money into previously cash economies.
- Smart remotely controlled software monitors use, collects payments, disconnects.
- **Digitisation** at the intersection of these relationships.
- Formation/ co-evolution of new institutions, processes and actors. And new monopolies.



Between energy access and localisation

- Off-grid solar PV: ownership captured by an increasingly consolidated group of companies, mostly headquartered in global North and/or with offshore listings.
- Employment and manufacturing largely held by in China (ESMAP et al 2024).
- Long-standing tension between priorities of local economic development v. import of technologies that have been designed, manufactured and pre-assembled elsewhere at the least cost.
- Key industry actors argue that importing least cost equipment is most effective way to accelerate energy access, improve affordability and achieve economies of scale and competitiveness.
- But increasing recognition by some that local assembly and manufacturing, skills development and repair are fundamental to long-term sustainability.

2. Uneven technological geographies of off-grid solar PV

Uneven technological geographies

- Far-reaching implications of power imbalances inherent within global supply chains are generally overlooked (Sokona et al 2023).
- Long-standing inequalities in trade and global supply chains: African countries exporting basic commodities, importing finished goods. No technological transfer (Bell and Albu 1999).
- Transfer of physical assets alone insufficient to ensure development and acquisition of necessary knowhow to reproduce, maintain and repair, techno hardware (Lema et al. 2015).
- Bell and Pavitt (1993): technological localisation ranges from basic production capabilities to more advanced innovation capabilities.
- Blurred boundaries between manufacturing and assembly. Manufacturing: transformation of raw or semi-finished materials into final product. Assembly: the final stage of production in which components or partially completed units are put together (ACE-TAF 2021).

Uneven technological geographies

- Energy access industry: delivery of technological hardware at the lowest cost.
- Low-income energy users framed as passive recipients.
- Sole focus on hardware financing and distribution by a globalised private sector is unlikely to meet the needs of low-income users (Lema et al 2021).
- Behuria (2020:126) “...countries that fail to integrate a strategic focus on manufacturing in their renewable energy expansion strategies from the onset may remain dependent on foreign imports... in the long-term”.
- Gaiya et al (2025): development of technological capabilities requires long term and complex strategic coordination across multiple sectors and policy domains e.g energy and rural electrification; telecommunications and digital payment systems; fiscal incentives such as tax, trade and import tariffs; and labour and education.
- But often challenges of national and local politics, e.g disputes between ministries, unequal resource allocation, misunderstanding of technologies.

3. The global off-grid solar PV supply chain

Sector ownership: the 'big seven'

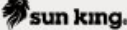
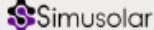
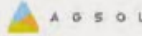
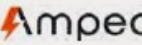
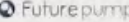
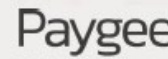
- In 2022: 72% of industry investment directed to seven companies, with the remaining 26% directed to the other 150 companies in a start up phase (Lighting Africa 2022). Further acquisitions anticipated.



the solar revolution



Annex 2: OGS Company segmentation (non-exhaustive)

	Large global companies	Mid-size regional companies	Small domestic companies
	Footprint: 5+ countries	Footprint: 1 – 5 countries	Footprint: 1 country
Vertically-integrated	     	  	 
Distributors		        	      
Manufacturers ²⁰⁵		      	
Service providers		   	There is a long tail of local service providers (including those providing business data and analytics, online storefront software and digital payment collection)

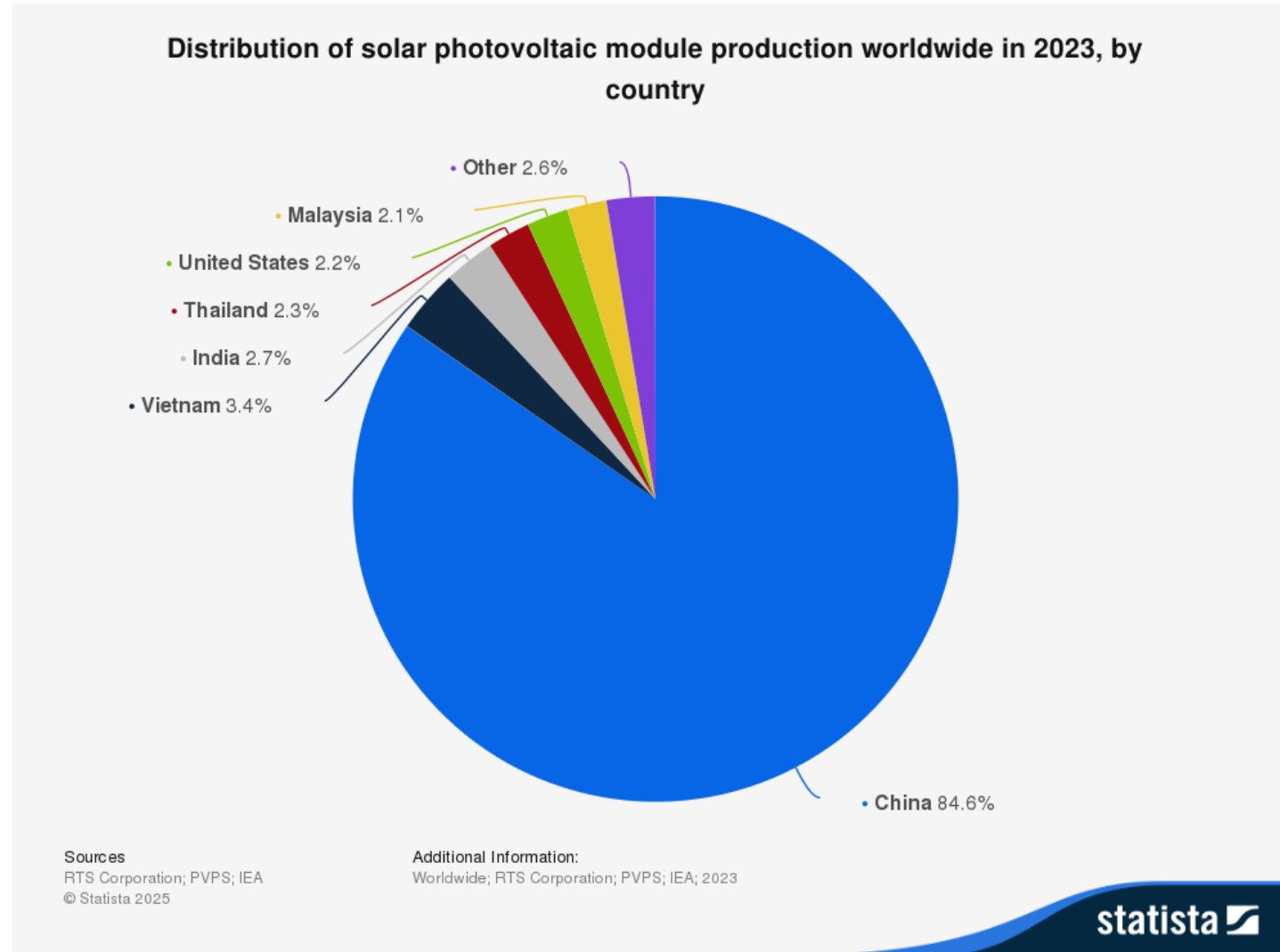
Source: ESMAP et al (2024: 105)

Solar PV manufacturing

Increasingly consolidated group of Chinese companies now account for nearly 85 per cent of global solar PV manufacturing, including polysilicon, ingots, wafers, cells, modules and panels (IEA 2022, ACE-TAF 2021).



Distribution of solar PV module production worldwide in 2023 by country



Global verification system of off-grid solar PV

- Off-grid solar PV supply chain shaped by global verification system.
- Began in 2007, part of the **World Bank-IFC's Lighting Africa** programme.
- 2012: Establishment of Global Association for the Off-Grid Solar Energy Industry (**GOGLA**).
- GOGLA (200 member companies) has significant discursive and policy influence over the sector.
- 2020: Lighting Global Quality Standards adopted by the International Electrotechnical Commission for pico-solar products and SHSs with PV modules up to 350 watts (IEC Technical Specification 62257-9-5) (ACE-TAF 2020:3, VeraSol 2021:1).
- 2020: Lighting Global changed name to VeraSol. Remit extended to include higher-power appliances and productive use equipment.
- International verification system makes local design and manufacturing challenging. Absence of local testing facilities.



Challenges to localisation

- Interoperability between products made by different manufacturers is limited or non-existent.
- No formal requirement for companies to provide instructions for repair, servicing or spare parts (Cross and Neumark 2021).
- Products are based on tamper-proof designs and proprietary screws and seals that are intended to prevent third party access. Component parts are difficult or impossible to source locally (Munro et al 2023).
- *“Often with products if you open them up and start tampering you void the warranty”* (interviewee March 2023).
- Many imported off-grid solar PV systems are generic: not been designed with the unique characteristics of location in mind and are often incompatible with the level of heat, dust, wind and sand.
- System distributor (in interview, February 2023) : *“Lithium and/or lead iron batteries don't sit well in storage, especially in the African context where it's hot, it's humid and some places it's dry”*.
- Need to bulk buy stock on receipt of project funding in the interests of affordability: *“... but then demand can be unpredictable... We can only do our best to predict what the season's going to be like”*.

The afterlives of small scale solar: collection, re-use, recycling

- Off-grid solar PV has an average lifespan of approximately 5 years (espec battery).
- Much harder to collect and identify off-grid than large-scale solar PV.
- Supply chains and business models based on abandonment of the technological systems: 'make-take-dispose'.
- Proprietary systems. Limited interoperability.
- Limited warranties.
- International verification system makes local design and manufacturing challenging.
- Lots of voluntary commitment to repair/ reuse/ recycling but limited national strategies and requirement.
- Lack of local capacity for recycling.



Source: <https://www.ace-taf.org/how-important-is-it-to-understanding-how-to-handle-e-waste-in-the-stand-alone-solar-sector/>

The afterlives of off-grid solar

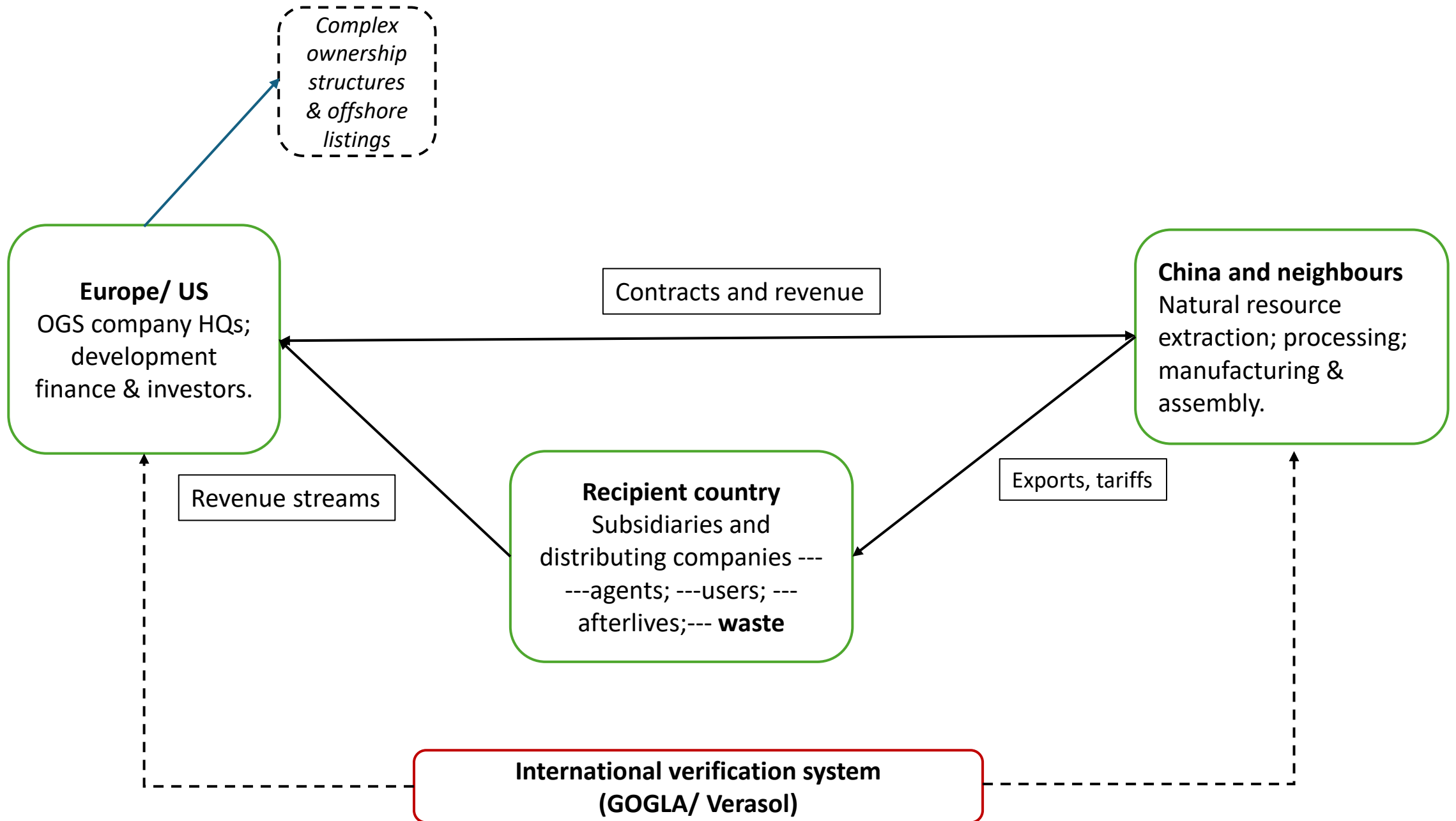
“There is a cost and human resource issue of repossession, for the customer, for us and for the agent. Plus, you can’t generally repurpose the repossessed kits. They aren’t necessarily usable or sellable again, especially if people were disconnected some time ago and the products have been sitting around in a house. Moreover, they may have been tampered with. So, is it worth repossessing something you can’t use?”

(SHS PAYGO company, Senegal in interview, January 2023).

Between energy access and localisation in Senegal

- History of national and regional support for solar technologies.
- Influence of regional institutions over tax, trade, customs, and energy policies e.g ECOWAS & West African Economic and Monetary Union.
- May 2020: Senegalese interministerial order + list of RE components to be exempt from normal 18 per cent of VAT.
- For off-grid solar PV, exemptions for panels, inverters, lighting kits, streetlamps, water pumps, batteries, and various solar thermal components.
- Act granted VAT exemptions to local *manufacturers* of off-grid solar PV technologies but did not exempt *components* used in manufacturing/ assembly.
- Solar panels also exempt from import duties thereby advantaging imported panels.
- A measure that aimed to accelerate rural electrification discouraged local manufacturing and assembly (Potron 2024).
- GOGLA advocated for removal of VAT and import tariffs on imported solar PV modules: local manufacturing unlikely to create significant employment and would increase cost of local products that would be unable to compete with imports (GOGLA 2018:41, GOGLA 2022).
- Prioritisation of imported technologies at lowest cost v development of local technological capabilities.

4. Concluding thoughts



Source: Baker et al, *forthcoming*

How can energy technologies be more rooted in local contexts ?

- Without development of local capacity and production, off-grid solar businesses may remain one of the most ineffective development programmes ever initiated by international organisations (Malima et al 2024).
- What political, economic and technological conditions are needed to realistically achieve localisation within a global supply chain whose ownership and manufacturing is at once increasingly monopolised and geographically and socially dislocated from its users?
- Behuria (2019): there may be little opportunity and little point in trying to find an entry point in more established parts of the supply chain.
- Creation of more opportunities e.g “on designing products that are fit for the local conditions in the country or region they are about to be employed (robust, affordable, where demand is nearby and strong) rather than for global markets” (Get Invest 2024).
- Creation of durable products designed with the cultural practices of the place of use, the nature of the popular economy and related sectors such as productive use in agriculture.
- A more flexible certification system that doesn't privilege well-resourced global players.

Conclusions

- The ability to make replacement parts locally to ensure that they are readily available, the manufacture of what may be seen as less appealing products such as clamps and fasteners, plugs and cables, and the investment in human capacity and training.
- Regulation which penalises the abandonment of the systems.
- Pay far greater attention to the informal economy/ the popular economy that go beyond the initiatives and scrutiny of the verified affiliate sector. Local innovation may be happening, but unregulated and possibly unsafe.

Selected references

Baker, L.H. (2022) 'New frontiers of electricity capital: energy access in sub-Saharan Africa', *New Political Economy*, 28(2), 206–222

Baker, L.H., Potron, J. and Kerr, D. (*forthcoming*) 'The uneven technological geographies of off-grid solar PV', *Under review*

Behuria, P. (2025) 'The injustice of just transitions: How the neglect of the green division of labour cements African dependencies', *Energy Research & Social Science*, 122

Potron J. (2024) 'Challenges to local manufacturing in Senegal's off-grid solar sector: experiences of a forerunner enterprise. Baker, L. and Kerr, D. (eds) *Sustainability, Inclusiveness and Governance of Mini-Grids in Africa* (SIGMA) Project Report, Working Paper 8

Gaiya, A. Samuel, B., Okoroafor, G. P. et al (2025) 'A Whole-of-State Approach to Renewable Energy Mini-Grid Development in Africa' [available at <https://ssrn.com/abstract=5173300>]

Thank you and discussion