Barriers to Inclusivity in the Solar Value Chain: Africa, Asia and the Indo-Pacific Region

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TEA@SUNRISE is enabling sustainable, affordable, next-generation solar photovoltaics to be manufactured locally in countries in Africa, Asia, and the Indo-Pacific. The project is part of the Transforming Energy Access platform funded by UK aid from the UK Government to support the technologies, business models, and skills needed to enable an inclusive, clean energy transition.

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Table of Contents

Executive summary

This report examines barriers to inclusivity across the solar photovoltaic (PV) value chain in Africa, Asia, and the Indo-Pacific regions, using available literature and in consultation with various stakeholders who are part of the TEA (Transforming Energy Access) network. It analyses how structural inequalities – often rooted in colonialism, patriarchy, and capital flows – shape who benefits from, and who is excluded from, renewable energy transitions. We maintain that deliberate attention and awareness to these dynamics is needed through the lens of a Gender Equality Disability and Inclusion (GEDSI) approach, otherwise current approaches might risk reinforcing historical patterns of inequality and marginalization under the guise of climate action. While the urgency of the energy transition demands rapid progress, it is equally critical that this does not come at the expense of justice, inclusivity, and getting the transition right. Our vision is of a just, equitable, and sustainable energy transition through the development of next-generation photovoltaics.

Key findings and concepts

Key findings which are explored in this report include:

- **Gender as a system of power:** Understanding barriers to women's participation requires analysing how patriarchy intersects with race, class, caste, indigeneity, and colonial history to create compounded exclusions. Our understanding of gender in TEA@SUNRISE recognises that it is not merely a demographic variable but a dynamic system of power relations, historically shaped. We maintain that such patterns persist in areas of the contemporary solar value chain (SVC).

- **Value chain geography reflects colonial divisions:** The most profitable segments – technology development and manufacturing – remain concentrated in the Global North and China, while the Global South provides raw materials, land, and low-skilled labour and this often perpetuates colonial legacies. Many African countries, for example, capture minimal value despite hosting solar projects and providing critical minerals, perpetuating technological dependency and limiting opportunities for local industrial

development. The aim of TEA@SUNRISE, through the network and associated activities, is to develop sustainable, affordable, next-generation solar photovoltaics to be manufactured locally in countries in Africa, Asia, and the Indo-Pacific.

- **Upstream extraction reproduces dispossession:** Current research and reporting has uncovered how silica mining for solar panels displaces forest-dependent communities in India, with women, children, and marginalized castes bearing the greatest burdens through loss of livelihoods, environmental destruction, and hazardous working conditions. The documented use of Uyghur forced labour in China in polysilicon and metallurgical grade silicon production – affecting up to 97% of global solar panel supply – represents a profound ethical crisis that threatens the legitimacy of clean energy transitions.

- **Midstream and downstream exclusions:** Despite promises of job creation, employment in solar projects predominantly goes to external, male workers. Large-scale solar parks often fail to provide electricity to surrounding communities, creating "energy unfreedoms" where local populations bear costs without receiving benefits. Gender segmentation restricts women to lower-paid assembly work even when they possess technical training, reflecting socio-cultural assumptions rather than actual capabilities.

Research informing this report also points to systemic barriers that cascade throughout the chain:

- **Education and skills gaps:** Women and marginalized groups face barriers beginning in secondary education, where they are steered away from STEM subjects due to discriminatory counselling, hostile environments, and patriarchal expectations.

- **Financial exclusion:** Women's lack of land ownership, limited assets, and exclusion from formal employment create compounded barriers to accessing credit. Even innovative financing like pay-as-you-go systems exclude women through gender-blind credit algorithms that privilege formal employment patterns more common among men.

- **Decision-making marginalization:** Women are excluded from household energy decisions and community consultations about solar projects, which typically engage only male landowners. This procedural injustice appears to perpetuate colonial governance that bypassed indigenous decision-making systems to empower male collaborators.

- **Masculine workplace cultures:** Solar sector employment across manufacturing, installation, and maintenance is characterized by cultures that actively exclude women through assumptions about physical strength, safety concerns used to justify exclusion, sexual harassment, and male-dominated networks.

In addition, solar energy infrastructure investments tend to concentrate in areas with existing grid connectivity and economic activity, often bypassing remote and marginalized communities that could benefit most from distributed renewable energy. This perpetuates entrenched systemic and geographical inequalities rooted in colonial-era infrastructure planning that connected resource extraction sites to ports and urban centres while neglecting rural development.

International finance mechanisms for solar projects also typically require institutional capacities, credit histories, and collateral that favour large-scale developers and multinational corporations over community-based organizations, cooperatives, and small enterprises. Women and marginalized groups face additional barriers in accessing finance due to discriminatory lending practices, lack of formal land titles, and limited business networks. These financial architectures echo historical patterns where capital flows remained controlled by Global North institutions.

Many national renewable energy policies lack explicit provisions for gender equality, community participation, or benefit-sharing with affected populations. Environmental and social impact assessments frequently fail to adequately consult women and marginalized groups or address differentiated impacts. Where policies do exist, implementation mechanisms and accountability structures are often weak, allowing exclusionary practices to continue.

Fundamentally, technical knowledge, research agendas, and standards in the solar sector remain predominantly defined by institutions in the Global North and China. This limits opportunities for locally led innovation, context-appropriate technology development, and capacity retention in the Global South. Women's exclusion from technical education and research leadership compounds these inequalities, and our work through all the TEA@SUNRISE activities aims to develop a strong network which highlights these issues and provides a positive platform to develop a more just and sustainable PV future.

Critical implications

Simply adding women to existing solar value chains is insufficient and may reinforce underlying injustices. Achieving genuinely just transitions requires further awareness of the intersectional issues: not just training more women engineers but transforming masculine workplace cultures; not just providing women with micro-loans but challenging financial systems that privilege male property ownership; not just consulting communities but redistributing decision-making power.

The climate crisis creates pressure for rapid solar deployment, yet this urgency is weaponized to override justice concerns. Much of the research for this report point to how speed prioritization reproduces the extractive logics of land grabbing, labour exploitation, community exclusion, or patterns that echo earlier models of unequal development. Advancing climate justice requires rejecting false choices between speed and justice, instead building transitions that centre human rights, inclusion and ecological care.

Undoubtedly, Western technical knowledge still dominates solar R&D and policy, while Indigenous and local knowledge – particularly women's ecological expertise – is systematically devalued. Decolonizing solar transitions requires not just including diverse researchers but fundamentally rethinking whose knowledge counts, whose priorities shape innovation, and whether Global North development models should be universally imposed.

It is often the case that countries rich in minerals for solar technologies risk experiencing a "resource curse" where wealth generates corruption and environmental destruction rather than development. This echoes how colonial extraction impoverished resource-rich colonies while enriching imperial centres. Without transformed governance ensuring local value capture, African countries providing lithium and cobalt may enable wealthy countries' energy transitions while their own populations lack energy access.

The barriers documented throughout this report are not natural, neutral, or inevitable. Ultimately, just solar transitions require a vision that goes beyond market-based inclusion, seeing renewable energy not as an end in itself but as part of broader struggles for human dignity. Addressing these struggles requires a commitment to transformative action for a just and sustainable transition, a core aim of TEA@SUNRISE. A companion paper to this report (*Opportunities for Inclusivity in the Solar Value Chain*) looks at positive examples where we have encountered areas

of good practice around GEDSI in Africa, Asia and the Indo-Pacific region through our own TEA@SUNRISE network and activities, and beyond.

Introduction

Access to affordable, reliable, sustainable and clean energy plays a fundamental role in advancing both global climate commitments and broader sustainable development goals. At the heart of this agenda lies the concept of a "just energy transition", a framework that should ensure the shift to renewable energy is inclusive, equitable, and responsive to the needs of all communities, especially those historically underserved (UN, 2015).

However, recent reports suggest that only 2.8% of multilateral climate finance for mitigation has gone towards supporting just transitions over the last decade - just over US$630 million - meaning that barely any climate finance is going to support workers and communities to undertake just transitions (ActionAid, 2025). Achieving genuine justice in energy transitions requires moving beyond technical solutions and market-based reforms to recognise that there are deeply embedded power structures that continue to shape who benefits from – and who is exploited by – renewable energy systems. This approach is gaining traction globally, as it inherently links climate action with social and economic development, embedding the dual goals of decarbonisation and energy access within a broader development narrative.

Yet we note that the urgency to meet climate targets risks reproducing the very patterns of extraction and dispossession that characterize colonial and capitalist systems. Achieving the targets set by the Paris Agreement (UNFCC, 2016), which aims to keep global temperature increase well below 2°C (ideally 1.5°C) above pre-industrial levels, necessitates a rapid transformation of energy systems away from fossil fuels. Alarmingly, the 1.5°C threshold is already nearly reached, almost 70 years ahead of schedule (WMO, 2025), underscoring the urgency of action. However, this urgency can create tensions between the goals of speed and justice in low-carbon transitions (Newell et al. 2022), potentially reinforcing historical patterns where the costs of development fall disproportionately on marginalized communities, while benefits accrue to dominant groups.

Solar photovoltaics (PV) have emerged as one of the most cost-effective and impactful energy technologies worldwide for addressing the climate crisis (IPCC, 2022). In 2023, solar PV installations constituted approximately 75% of all new renewable power capacity added globally (IEA, 2024). Next-generation solar PV technologies, such as perovskite solar cells and integrated PV solutions, potentially offer new pathways not only for accelerating decarbonisation, but also for advancing energy justice if designed and deployed with deliberate attention to power relations and wider economic development centred on truly sustainable development. These innovations could enhance efficiency, lower installation and maintenance costs, and enable flexible applications in diverse environments, including off-grid and underserved areas. However, without critical examination of whose knowledge shapes these technologies, whose labour produces them, and whose lands host them, solar expansion risks becoming what some scholars term "green colonialism": a continuation of extractive relationships under the guise of climate action.

Aims of this report

This report sets out to explore and present the key persistent and emerging barriers to inclusivity throughout the solar energy chain, with a focus on Africa, Asia and Indo-Pacific regions, analysed through the critical framework outlined above and in the following sections. The report draws on case studies provided by our network, on academic and grey literature, and on insights from experts in the field. We examine who is being adversely impacted, who is being left behind, why systemic exclusions persist, and how future (next generation) solar technologies may either help overcome or reinforce these inequalities. The report recognizes that these barriers are not natural, neutral, or inevitable, but are products of specific histories and contexts.

What follows is not an in-depth systematic review of barriers throughout the entire global solar PV innovation landscape. We aim to survey the main barriers to inclusion throughout the solar value chain, while maintaining critical attention to how these barriers might reflect and reproduce inequitable outcomes. We also begin to consider what can be done to facilitate genuinely equitable and transformative practices, with considerations on how next-generation solar technologies can address these structural inequalities. We argue that achieving energy justice requires deep scrutiny of present systems and raising awareness about the importance of inclusivity at all levels.

A Gender, Equality, Disability and Social Inclusion (GEDSI) Lens

As noted, without deliberate attention to who benefits and who is excluded, clean energy transitions risk reinforcing existing inequalities. This is particularly relevant to the rollout of new solar technologies, where design and deployment choices can either reduce or exacerbate barriers to access. A GEDSI lens is essential to understanding and addressing these barriers, but it must be grounded in structural analysis that moves beyond adding marginalized groups into existing structures and recognizing the systems of power that create exclusion in the first place.

Gender here is not simply a demographic category or a matter of biological sex. Through a postcolonial and intersectional lens, gender emerges as a dynamic system of socially constructed power relations that has been historically shaped, often by colonial and expansionist projects, but also by pre-existing patriarchal structures. Globally, various historical colonial systems often created, reinforced or exploited divisions between public (political, male-dominated) and private (domestic, feminized) spheres, devaluing feminized bodies and reproductive labour.

Current patterns of exclusion in the solar value chain, such as women's restriction to low-skilled assembly work, their absence from decision-making roles, their lack of land ownership, their limited access to financing are not merely cultural preferences or capacity gaps. Rather, these patterns reflect intersecting inequalities that continue to structure who is valued, who is heard, and who controls resources. Across the SVC – from research and design through to installation, ownership, and end use – women, people with disabilities, youth, older people, and communities marginalized through these intersecting systems are systematically underrepresented and excluded from decision-making, training, employment, and benefit-sharing. An intersectional GEDSI approach helps reveal how overlapping identities compound such exclusion and disadvantage.

For example, women from Scheduled Tribes and Castes in India's mining sector face exploitation not simply because they are women, but because their gendered experiences are shaped by caste-based discrimination, Indigenous dispossession, and economic marginalization—all rooted in colonial and pre-colonial hierarchies that were codified and intensified under British rule. Similarly, young women entrepreneurs face barriers that reflect not just gender bias but age-

based discrimination, limited access to family land due to patrilineal inheritance systems reinforced during colonialism, and digital exclusion shaped by infrastructural inequalities.

The critical questions raised here are: Whose knowledge counts when designing solar energy systems? Who defines what constitutes "appropriate" roles for women in the energy sector? Why do renewable energy projects so often reproduce the spatial patterns that prioritize and serve urban and industrial centres while extracting resources from rural and Indigenous lands? These questions often also reveal what feminist philosopher Miranda Fricker terms 'epistemic injustice' (2007): the systematic devaluation of knowledge produced by subaltern peoples, particularly women and Indigenous communities in the Global South, whose lived experiences and traditional ecological knowledge are often excluded from energy planning and policy. Indigenous theories of justice further identify settler colonialism as a root cause of current environmental and social crises, highlighting how renewable energy development on Indigenous lands can perpetuate rather than remedy historical injustices.

Failing to incorporate a transformative GEDSI approach, one that moves beyond tokenistic inclusion, not only reinforces existing inequalities but also limits the transformative potential of decentralized solar energy systems. If inclusivity is considered from the outset across material sourcing, PV design, manufacturing, and deployment, then next-generation solar can open opportunities for local production, skills development, and community ownership.

Gender Equality, Disability and Social Inclusion Statement

At TEA@SUNRISE, we believe that an equitable energy transition can only happen when it includes the voices and contributions of those most impacted by inequality. By prioritising gender equality, disability, and social inclusion (GEDSI), we aim to create solutions that are not only technically sound but also socially just. This commitment ensures that throughout our activities we will consider potential benefits and harms for all community members, particularly underrepresented groups (i.e. those who are often excluded from decision-making processes). By embedding GEDSI into our work, we aim to build a more inclusive energy future that leaves no one behind, fostering economic resilience and equitable growth for everyone.

TEA@SUNRISE Project Aims

1. **Technology transfer**: Facilitate the sustainable, low-cost manufacturing of next generation photovoltaic energy solutions in sub-Saharan Africa and the Asia-Pacific region.

2. **Green supply chains and circular economy**: Develop local supply chains using environmentally sustainable materials. The circular economy approach ensures that products, such as solar technologies, are designed for reuse, recycling, and minimal waste at the end of their life cycle, creating a closed-loop system that reduces environmental impact and promotes resource efficiency.

3. **Business models**: Create locally owned business models focused on reuse and circular economy principles for solar technology.

The ethical imperative

The climate transition hinges on solar energy, but it must not come at the cost of human rights or reproduce historical patterns of exploitation. Serious ethical challenges exist within solar supply chains, including documented use of forced labour in polysilicon production, which threatens the legitimacy of climate action and can impede solar deployment and decarbonisation efforts (Cockayne et al., 2022; Murphy & Elimä, 2021, 2023). Additionally, concerns have been raised about whether renewable energy aid and investment maintain geostrategic control over critical minerals and manufacturing capacity in the Global South, fitting older patterns of colonial extraction (Sovacool & Stock, 2024). These issues, explored in detail in the Upstream section of this report, raise urgent questions about whether current solar transitions genuinely serve the energy needs and sovereignty of communities in Africa, Asia, and the Indo-Pacific, or primarily serve the decarbonization goals and economic interests of the Global North. A just transition requires not only eliminating forced labour but transforming the economic structures that make such exploitation profitable and challenging the power asymmetries that risk turning solar expansion into what Indigenous scholars call "energy colonialism".

[1]The Solar Value Chain

The Solar Value Chain (SVC) is a complex system encompassing all the necessary activities involved in bringing solar PV products or services from their initial conception through to their end-of-life management. It is defined as the full range of activities undertaken from raw material sourcing, through production/manufacturing, distribution, end customer use, and finally to end-of-life management, leading to circular economy considerations (Fig 1 schematic).

[1] Note on Terminology: In conversations with network members and colleagues across the wider Energy Access field, it became clear that terminology is not always understood or used consistently. To support clearer communication within TEA@SUNRISE – especially in relation to next-generation PV – this report uses a consistent set of terms and definitions that reflect efforts to standardize how we discuss inclusion, innovation, and solar transitions while maintaining critical awareness of how language itself can reproduce or challenge power relations. (Please refer to our Glossary for additional terms and definitions.)

However, understanding the SVC requires more than mapping technical processes and economic flows. The solar value chain must be analysed as a spatial and political geography of power, one that often mirrors historical patterns of colonial extraction, where raw materials flow from the Global South to manufacturing centres in the Global North and emerging economies, and where the most profitable segments remain concentrated among actors who inherited advantages from colonial-era industrialization. The diagram below serves as a tool to understand at what points and how different stakeholders can interact to create and sustain value across the solar energy sector or, conversely, be adversely impacted or systematically excluded during the process. Yet this representation itself risks naturalizing what are actually contingent power relations shaped by histories of domination.

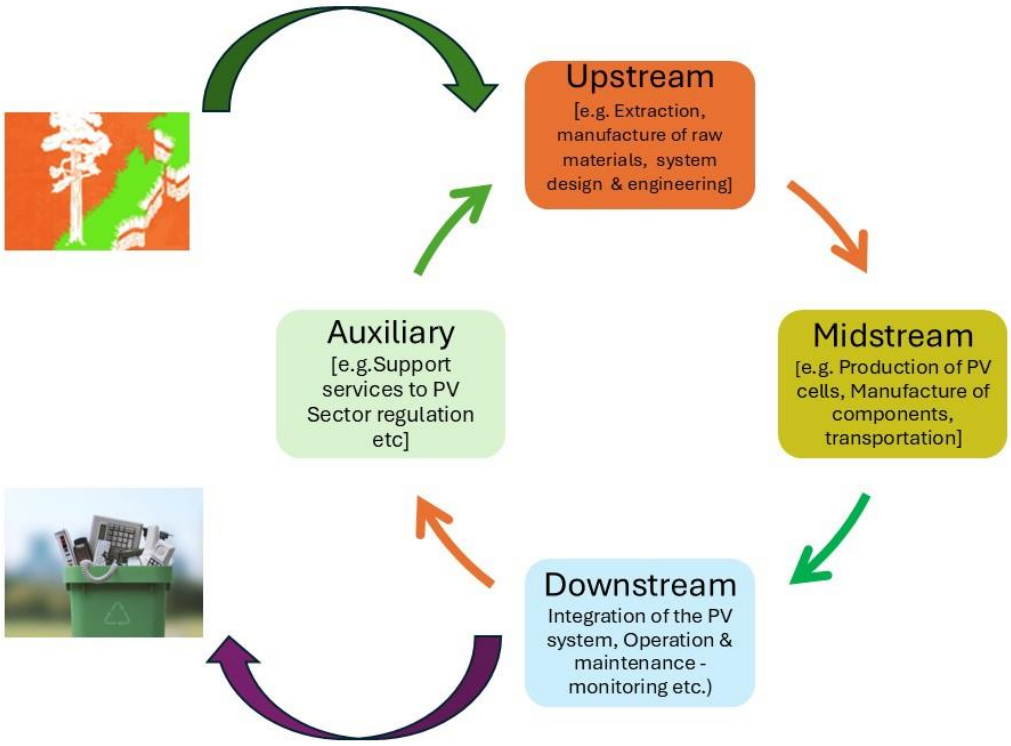

Figure 1: Solar Value Chain schematic (adapted from source: www.eucolight.org)
As we examine each stage of the value chain, we must remain attentive to how gender intersects with race, class, caste, indigeneity, and colonial history to structure patterns of inclusion and exclusion that reflect specific choices about how to organize energy systems and distribute their benefits and burdens.

Steps in the SVC and identified barriers

The value chain for distributed solar energy is typically divided into four main parts: **upstream, midstream, downstream,** and **auxiliary/ancillary** or supporting activities. While this division

provides analytical clarity, it is important to recognize that barriers to justice are not isolated to individual stages but rather cascade through the entire system, with injustices at one stage enabling and reinforcing injustices elsewhere.

Upstream

This sector involves the initial stages for the formation of the photovoltaic cell and the extraction and manufacturing of raw materials for the structural part of the module and includes:

- Raw material extraction (i.e. silica, silver, and other essential materials)
- Production of ingots and wafers (processing raw materials into wafers, assembling cells, and creating PV modules)
- Manufacturing raw materials like steel, aluminium, glass, and encapsulating film
- System Design & Engineering: Customizing PV systems for specific applications

This part of the SVC generally requires both specific knowledge and high technological capacity and is thus associated with creating greater added value and typically obtaining the highest profits within the global photovoltaic industry (Garlet et al., 2020). However, this concentration of profit and technological control in the hands of a few actors – predominantly in China, Europe, and North America – reflects historical patterns where colonial powers monopolized industrial capacity while extracting raw materials from colonized territories. The current geography of the solar value chain, where Africa and much of Asia provide materials and labour but capture minimal value, continues this asymmetrical relationship.

Barriers to inclusivity in the upstream SVC

Evidence from recent research, including work by Ryan Stock and others (Sovacool & Stock, 2024; Stock & Sovacool, 2024; Sud, 2023) alongside a variety of reports from Public Benefit Organizations (PBOs) and various think tanks (Action Sustainability, n.d.; Cockayne, Huerta, & Burcu, 2022; Sheffield Hallam University, 2021, 2023), highlight significant social and environmental injustices in the upstream stages of the solar photovoltaic (PV) value chain. These injustices pose considerable barriers to inclusivity and equity, particularly for marginalized communities in resource-rich but politically and economically vulnerable regions. Critically, these

are not unfortunate side effects of otherwise beneficial development, but rather structural features of how global solar supply chains have been organized to prioritize speed and profit over justice and human rights. The following points indicate areas of profound concern regarding systemic exclusions:

Resource extraction impacts

The extraction of silica, a key input in solar panel production, exemplifies how renewable energy transitions can reproduce patterns of dispossession and exploitation. Extraction is often marked by exploitative practices and displacement of people linked to silica mining in Southeast Asia. Land-use changes due to mining destabilize traditional livelihoods and agriculture, especially for forest-dependent tribes like the Kols in Uttar Pradesh, India, exacerbating their economic and energy poverty (Sovacool & Stock, 2024; Stock & Sovacool, 2024).

This is not simply environmental damage but a continuation of colonial land seizure that disrupts Indigenous and peasant communities' relationships with land – relationships that are often deeply gendered, with women holding specific ecological knowledge and responsibilities for gathering forest resources. When mining destroys these ecosystems, women bear additional time burdens traveling further for water, fuel, and food, while losing their traditional sources of livelihood and autonomy (Sovacool & Stock, 2024). This gendered impact reflects how colonial systems constructed divisions of labour that made women's subsistence work invisible and expendable.

Sovacool and Stock (2024) reveal how weak governance and the dominance of criminal networks or "sand mafias" control extraction through corruption and illegal practices. These networks exploit regulatory gaps and political protection to mine sand in broad daylight, often with devastating environmental consequences (Taylor, 2024). However, framing this as simply "weak governance" risks obscuring how such arrangements reflect legacies of colonial administration that concentrated power in elite hands, created extractive institutions designed to benefit external actors, and systematically excluded local communities from resource governance. Post-independence states in many cases inherited and perpetuated these exclusionary structures.

Women, children, and adolescents form a particularly vulnerable segment of the precarious labour force in India's silica mining sector. They are routinely exposed to hazardous working

conditions that jeopardize their health. For children and youth, this exploitation also disrupts access to education, severely undermining their long-term well-being and life trajectories (Stock & Sovacool, 2024). This mirrors historical patterns of colonial labour systems that relied on the hyper-exploitation of racialized and gendered bodies deemed "expendable" – a logic that persists in contemporary supply chains that treat certain lives as more disposable than others. The intersection of gender, age, caste, and indigeneity creates compounded vulnerabilities where young girls from marginalized communities face the most severe exploitation, reflecting how multiple systems of oppression operate simultaneously.

Land acquisition and the reinforcement of inequalities

Large-scale solar development frequently involves land acquisition processes that replicate patterns of enclosure and dispossession. Decisions to develop solar energy parks in India have been shown to maintain fossil-era inequalities and discourage decentralized systems that might be more inclusive for women and marginalized communities (Martin et al., 2024). This type of centralized land acquisition privileges utility-scale projects that generate profits for large developers and investors while displacing smallholder farmers, pastoralists, and forest-dependent communities whose land tenure is often informal or communal, and with a tendency to individual titling that typically benefits men.

The gendered dimensions of land dispossession are profound. In many contexts, women's land rights are mediated through male relatives, and customary tenure systems provide inadequate protection when land is acquired for solar parks. Women lose not only agricultural plots but also common property resources crucial for subsistence, while compensation schemes typically channel payments to male household heads, reinforcing patriarchal control over resources. This pattern of large-scale land acquisition for solar development thus operates as what scholars term "green grabbing": the appropriation of land for environmental purposes that nonetheless dispossesses marginalized communities, particularly women and Indigenous peoples, in ways that echo colonial land seizures.

Moreover, the prioritization of utility-scale solar parks over decentralized systems reflects epistemic injustices that discourage smaller-scale, more inclusive systems which could empower women and marginalized groups through community ownership models.

Manufacturing raw materials: Forced labour and ethical supply chains

The upstream solar supply chain faces a profound ethical crisis that demands urgent attention: the extensive use of forced labour, particularly of Uyghur people, in the production of polysilicon – a critical component of most solar panels. This issue was documented in the landmark 2021 report "In Broad Daylight: Uyghur Forced Labour and Global Solar Supply Chains" by Murphy and Elimä at Sheffield Hallam University's Helena Kennedy Centre for International Justice and further detailed in their 2023 follow-up report "OVEREXPOSED: Uyghur Region Exposure Assessment for Solar Industry Sourcing."

"Laboring for light: energy unfreedoms and freedom dreams of solar labor in Ghana," Stock (2025)

The paper explores the complex social and environmental impacts of large-scale solar power development in Ghana, specifically focusing on the Kaleo Lawra solar plant. It argues that while solar projects aim to mitigate climate change and alleviate energy poverty, they inadvertently create “energy unfreedoms" through gendered and racialised dispossession of land and resources.

Local communities in Lawra and Kaleo (particularly women reliant on forest resources) feel excluded from the benefits of the solar project including energy access or jobs. Most jobs created were temporary, with higher-paid, skilled positions going to non-local men. Concerns have been raised about gendered inequalities and elite capture in hiring practices.

According to Murphy and Elimä (2021), at the time of their initial investigation, 40-45% of the world's polysilicon (the refined silicon used in solar panels) came from the Xinjiang Uyghur Autonomous Region in China. However, their research suggests that the contamination of solar supply chains is far more extensive: as much as 97% of the global supply of solar PV panels may contain components tainted by forced labour (Murphy & Elimä, 2021). This shocking figure reflects how deeply integrated Xinjiang's polysilicon production has become in global supply chains, with the region's production often mixed with materials from other sources, making it virtually impossible to guarantee forced labour-free panels without comprehensive supply chain transparency and traceability.

The 2023 "OVEREXPOSED" report (Sheffield Hallam University, 2023) provides even more granular analysis of corporate exposure to forced labour risks, mapping how major solar manufacturers source from the Uyghur region and assessing the adequacy of their due diligence measures. The report reveals that many companies claiming to have "clean" supply chains lack sufficient evidence to support these claims, and that the complexity and opacity of solar supply chains make verification extremely challenging. This systematic exploitation occurs within a broader context of state-sponsored forced labour transfer programs targeting Uyghur and other Turkic Muslim populations, involving mass surveillance, detention, and coercive labour arrangements that violate international law (Murphy & Elimä, 2021, 2023; Cockayne et al., 2022). The extent to which this report has faced concerted efforts to be suppressed has only recently come to public attention.

Understanding this crisis through a postcolonial lens reveals disturbing parallels to historical patterns of racialized labour exploitation. The targeting of Uyghur Muslims for forced labour reflects how racial and religious difference has long been used to justify the super-exploitation of particular groups, from plantation slavery to indentured labour systems established under colonialism. The fact that this exploitation produces materials for "clean energy" – enabling the Global North's decarbonization while Western companies and consumers benefit from artificially cheap solar panels – echoes extraction patterns where colonized peoples' labour produced wealth for imperial centres. As Cockayne and colleagues (2022) argue, we must confront the question: what is the true cost of the pursuit of clean energy in terms of human freedom?

The forced labour in Xinjiang also has profound gender dimensions that are often obscured in technical discussions of supply chain ethics. Uyghur women face specific forms of coercion including forced sterilization, separation from children sent to state institutions, and assignment to factory work under surveillance (Murphy & Elimä, 2021). This represents a gendered form of violence that intersects with ethnic and religious persecution, a reminder that systems of oppression are always intersectional and that just energy transitions must account for how different forms of domination compound one another.

The inadequacy of industry responses to date reveals deeper governance failures. Despite mounting evidence documented in "In Broad Daylight" and "OVEREXPOSED," many solar manufacturers and purchasing companies have been slow to implement robust due diligence, often citing supply chain complexity as justification for inaction (Sheffield Hallam University,

2023; Action Sustainability, n.d.). This reflects how global capitalism's drive for cheap inputs creates incentives to ignore labour abuses, particularly when those being exploited are racialized and geographically distant from consumer markets. Addressing modern slavery in solar supply chains is not merely an ethical imperative but is essential for the legitimacy of climate action itself, as failure to do so threatens to deter ethically conscious investors and buyers while undermining the justice claims of the energy transition (Cockayne et al., 2022).

Case Study: Social Injustices in Silica Mining, India

Implications for Inclusive Solar Supply Chains taken from (Sovacool & Stock, 2024)

Context:

Silica mining in Uttar Pradesh, India – an area with rich deposits critical for solar energy – reveals stark inequalities faced by marginalised communities, particularly the Kol tribe. The Government of India pursues increased domestic PV production, and the region is poised to become a key supplier of silica. However, mining operations here reflect deeply problematic patterns of exclusion, harm, and unregulated extraction.

Key Findings:

- **Marginalised labour impacts:** Mechanisation has not led to improved livelihoods but instead displaced large numbers of unskilled and landless workers, compounding local economic vulnerability.
- **Gender and livelihoods:** Both men and women in the community previously engaged in sand and stonework. With the shift to machine-led extraction, women have lost income-generating roles, and families are facing acute livelihood insecurity. Male workforce and masculine labour culture perpetuate gendered power asymmetries
- **Labour exploitation and informality:** The sector remains informal, with little to no enforcement of labour protections. Scheduled Tribes and Castes dominate the most hazardous roles. Workers describe long hours of exhausting physical labour under conditions lacking safety oversight.

Manufacturing and labour conditions: Gender segmentation and masculine workplace cultures

Beyond the crisis of forced labour, the upstream manufacturing sector exhibits additional barriers to inclusion that reflect and reproduce patriarchal and colonial power structures:

- **Skills development and labour segmentation**: High-skilled, high-profit segments of solar manufacturing (e.g., solar cell and module production) are dominated by actors – generally men – with advanced technological capacity (Garlet et al., 2020), while workers marginalized by gender, caste, race, or lack of formal education remain in precarious, low-wage roles with limited access to training or advancement. This segmentation is not a natural result of differential capabilities but reflects how colonial education systems created hierarchies of technical knowledge that privileged certain groups (typically urban, upper-caste or upper-class men) while excluding women and marginalized communities from advanced technical training. Contemporary barriers to inclusive skills development thus perpetuate these legacies, limiting the participation of underrepresented groups, particularly women and marginalized communities, in higher-value roles.

- **Masculine workplace cultures:** Manufacturing and renewable energy sectors sustain masculine workplace cultures that marginalise women and non-binary individuals, reinforcing unequal power relations. These cultures – rooted in assumptions about physical strength, aggressive communication, sexual harassment, and male-dominated networks – are structural elements actively excluding those not conforming to dominant gender norms, reflecting patriarchal systems coding technical and industrial work as masculine.

Stock and Nyantakyi-Frimpong's (2025) research on Ghana's Kaleo-Lawra solar plant illustrates how large-scale solar development produces "energy unfreedoms": local communities, particularly women, face dispossession without promised benefits. Most skilled roles went to non-local men, perpetuating gendered exclusion and colonial spatial patterns where rural communities provide land and low-skilled labour whilst skilled employment and profits flow to urban centres and external actors. Women bore primary dispossession costs whilst being shut out of meaningful participation.

These issues extend across the renewable energy value chain, where women face sexual harassment, discriminatory hiring and promotion, inadequate workplace accommodations, and exclusion from informal decision-making networks. These barriers reflect how the energy sector, inheriting structures from fossil fuel industries, perpetuates patriarchal norms intensified during colonial industrialisation when wage labour became coded as men's work and women's productive labour was rendered invisible.

Midstream

This is the central part of the value chain. Activities in this segment include:

- Production of the photovoltaic cell
- Manufacture of components for the photovoltaic module (such as cables, frames, sealing silicone, and junction box)
- Manufacture of components for balancing the photovoltaic system (including inverters, fastening structures etc.)
- Transporting components and systems to sites

The midstream sector is often characterized by lower entry barriers and high competition, resulting in lower profit margins (Garlet et al., 2020). However, this technical characterization obscures important questions about who actually captures even these diminished profits, where manufacturing facilities are located, and whose labour produces these components under what conditions. While lower entry barriers theoretically could enable greater participation by local firms and entrepreneurs in the Global South, in practice the midstream sector often remains dominated by established manufacturers with access to capital, supply networks, and technical expertise, advantages that reflect historical patterns of industrial concentration in former colonial powers and emerging economies.

Barriers to inclusivity in the midstream SVC

The illusion of job creation

Despite the potential for solar PV to create new jobs, particularly in the midstream section where module production is labour-intensive, actual employment for local communities, especially women, is often severely limited. This gap between promise and reality reveals how solar development can reproduce existing patterns where local populations provide land and resources but capture minimal economic benefit.

Stock and Nyantakyi-Frimpong's (2025) detailed research on the Kaleo-Lawra solar plant in Ghana illustrates this dynamic powerfully. In that project, most jobs were temporary, concentrated during land preparation and construction phases, and disappeared once operations began. The few women who found work were typically confined to low-status, stereotypically feminized roles such as cooking and selling food to (male) workers or cleaning buildings. This pattern reflects deep gender segmentation where women are systematically excluded from technical, skilled, and permanent positions while being channelled into precarious, low-paid service work that reinforces rather than challenges patriarchal divisions of labour.

This gendered exclusion from meaningful employment reflects how energy projects continue to be designed within existing power structures that assume men are the primary workers and beneficiaries. The result is that women benefit the least from job creation in solar projects, even in labour-intensive phases. Moreover, this exclusion compounds other injustices: when women are denied employment opportunities, their economic dependence on male household members increases, reinforcing patriarchal control over resources and decision-making. The intersection of gender with other marginalized identities – such as lower caste status, ethnic minority identity, or rural location – creates even more severe barriers to employment, as hiring practices often favour urban, higher-caste, or ethnically dominant men who have social connections to project managers and contractors.

The temporary nature of construction employment, followed by minimal operational jobs, also reflects how utility-scale solar projects are often designed to minimize ongoing labour costs through automation and centralized control, rather than to maximize local employment and skill development. This mirrors long-established extractive industries, educational and training infrastructure where local populations provide disposable labour during initial development but are excluded from skilled, permanent positions and management roles. In utility-scale solar

projects, the majority of economic benefits typically flow to private investors, developers, utility companies, and large landowners, while local communities – especially marginalized groups – are frequently excluded from both the energy produced and the employment opportunities created (Martin et al., 2024).

Distributional injustice and elite capture

The midstream and broader solar value chain frequently exhibits what scholars term "distributional injustice": the unequal distribution of both the benefits and burdens of energy systems. Certain communities or marginalized groups are excluded from decision-making and disproportionately burdened by the negative impacts of energy production, such as localized environmental degradation, loss of land access, and social disruption from large-scale solar projects, while simultaneously being excluded from both the "green jobs" these projects ostensibly create and the energy they generate (Alda-Vidal et al., 2023; Stock & Sareen, 2024).

The case of the Bhadla Solar Park in India, examined by Stock and Sovacool (2024), exemplifies this dynamic. Despite being internationally lauded as a success story and a model for large-scale solar deployment, the park generates considerable profits for its developer and companies operating within the park, while local revenues flow elsewhere, actually worsening Bhadla's economic precarity. The local community experiences the burdens – land loss, environmental impacts, disrupted livelihoods – without meaningful compensation through employment, energy access, or revenue sharing. This represents a continuation of extractive relationships where rural and marginalized communities provide the spatial and material foundations for development projects that enrich external actors.

The gendered dimensions of this distributional injustice are profound. When solar parks displace agriculture or enclose common lands, women who depend on these resources for subsistence and livelihood activities, such as gathering fuel, grazing animals, growing food, might lose crucial sources of autonomy and economic security. Yet compensation schemes typically recognize only formal land titles, which are predominantly held by men, leaving women's use rights invisible and uncompensated. Moreover, when household income declines due to lost livelihoods, women often bear increased domestic burdens, including traveling further for resources, while having less say in how remaining resources are allocated.

Reinforcing colonial spatial patterns

The concentration of midstream manufacturing in certain regions, now primarily China, but also Southeast Asia, Europe, and North America, while raw materials are extracted from other regions and finished products are exported globally, reproduces colonial spatial divisions of labour. The Global South, particularly Africa, provides materials and sometimes low-skilled assembly labour, but captures minimal value from manufacturing activities. Many African countries have extremely limited domestic capacity for manufacturing and assembly of solar PV systems, meaning employment is concentrated in distribution, installation, and operation and maintenance, with economic benefits from higher-value manufacturing accruing elsewhere (Goldthau et al., 2020).

This geography of production reflects historical legacies where colonial powers deliberately prevented industrialization in colonized territories to maintain them as sources of raw materials and markets for manufactured goods. Post-independence, this pattern has been reinforced through structural adjustment policies, unequal trade agreements, and the concentration of technological capacity in the Global North and emerging economies like China. The result is that even as solar deployment expands in Africa and South Asia, the most profitable segments of the value chain remain concentrated in a few manufacturing hubs, perpetuating technological dependency and limiting opportunities for local firms and workers to move up the value chain.

Transportation and supply chain control

The midstream activity of transporting components and systems to sites also reflects and reinforces global inequalities. Long-distance supply chains – where polysilicon from Xinjiang, cells manufactured in Vietnam or Malaysia, modules assembled in China, and inverters produced in Germany are shipped to installation sites in Africa or South Asia – create dependencies and vulnerabilities for countries in the Global South. These extended supply chains mean that local solar deployment is vulnerable to disruptions in global logistics, price volatility, and decisions made by distant corporations and governments.

The control of supply chains by multinational corporations and large trading companies also limits opportunities for local and regional manufacturing networks to develop. Small and medium enterprises in the Global South face difficulties competing with established global supply chains that benefit from economies of scale, established relationships with installers and distributors, and often preferential financing terms. This perpetuates dependency on external actors and

limits the potential for solar industrialization to contribute to broader economic transformation in the Global South.

Gender and intersectional dimensions in midstream employment

Where midstream manufacturing does occur in the Global South, it frequently exhibits stark gender segmentation. Women may be employed in assembly work, seen as suited to "women's nimble fingers" and patience for repetitive task, but are systematically excluded from technical, supervisory, and managerial roles.

Research from various contexts shows that even when women receive training in technical skills, they are often deployed only in assembly roles due to socio-cultural assumptions about appropriate work for women, physical capabilities, and mobility restrictions (a pattern explored further in the systemic barriers section). This represents a profound waste of human potential and perpetuates economic inequalities between men and women. It also reflects epistemic injustices where women's technical knowledge and capabilities are systematically undervalued and overlooked.

The intersection of gender with other marginalized identities creates compounded exclusions. In manufacturing contexts, women from lower castes, ethnic minorities, or rural backgrounds face multiple barriers to accessing even the limited employment opportunities available. They may lack the social networks to learn about job openings, face discrimination in hiring, lack the educational credentials required (due to earlier exclusions from education), or be unable to migrate to manufacturing centres due to family responsibilities or safety concerns. The result is that the already limited benefits of solar manufacturing employment flow disproportionately to more privileged groups, while the most marginalized remain excluded.

Lack of local ownership and control

A critical barrier in the midstream sector is the limited participation of locally owned firms, particularly those owned by women and marginalized entrepreneurs, in component manufacturing and system integration. The capital requirements, technical expertise, and supply chain access needed to compete in component manufacturing create high barriers to entry. Additionally, procurement practices by large solar developers and international development

programmes often favour established manufacturers, sometimes explicitly requiring international certifications or partnerships that effectively exclude local firms.

This exclusion perpetuates a pattern where solar deployment in the Global South enriches external corporations and investors rather than building local industrial capacity and entrepreneurship, a continuation of economic structures designed to extract value for the benefit of external actors. Supporting local and locally-owned manufacturing, for example through preferential procurement, technology transfer, financing mechanisms, and capacity building, is essential for ensuring that solar transitions contribute to economic sovereignty and transformation rather than reinforcing dependency.

We maintain that the gender dimensions are particularly acute, and contemporary efforts to support women-owned businesses in the solar sector must address these structural barriers rather than simply offering training programmes that do not adequately challenge the underlying systems of exclusion.

Downstream

This segment encompasses activities more directly linked to the final consumer. Key activities include:

- Integration of the photovoltaic system, including project development and installation
- Operation and maintenance of the system (monitoring, cleaning, repairing to ensure optimal performance)
- Deactivation of the system, including dismantling
- Disposal of waste and recycling of materials at the end of the product's lifespan, including reintegrating them into the production cycle

Similar to the midstream sector, the downstream sector presents relatively low entry barriers and intense price competition. In this sector, non-market strategies are crucial due to strong price competition. Policies that promote awareness, lower costs, and improve inclusive consumer access to solar technology help companies gain consumer support, which in turn strengthens their businesses and increases market share (Garlet et al., 2020). However, from a justice

perspective, these market-based framings often obscure questions about whose needs are prioritized in system design, who benefits from downstream activities, and how power relations shape access to and control over solar systems.

Barriers to inclusivity in the downstream SVC

Installation: Gender segmentation and mobility restrictions

The installation phase of solar deployment reveals particularly stark patterns of gender segmentation that reflect deep socio-cultural assumptions about appropriate work for women and men. Despite women sometimes receiving training that covers installation alongside other technical skills, they are systematically channelled away from installation work and confined to other roles deemed more "suitable." Research from Kenya found that male staff predominantly carried out installations for both grid-connected and private systems, with women typically confined to office-based administrative roles, with security concerns cited as justification (Majale et al., 2024).

However, this framing itself reflects patriarchal constructions of women as vulnerable and in need of protection, while obscuring how masculine workplace cultures and lack of safety protocols create genuinely unsafe conditions for women. Women's exclusion is justified through multiple, mutually reinforcing rationales – assumptions about physical capability, socio-cultural norms about women's mobility, and perceptions about customer preferences – each naturalizing what are socially constructed barriers that could be challenged and transformed. The result is that installation work, often better paid than assembly or administrative work and providing opportunities for skill development, customer interaction, and potential entrepreneurship, remains overwhelmingly male-dominated, perpetuating economic inequalities between men and women and denying women access to one of the most visible and empowering aspects of solar work.

Operation and maintenance: Devalued labour and precarity

Operation and maintenance (O&M) activities (e.g. monitoring system performance, cleaning panels, troubleshooting issues, and conducting repairs) are essential for ensuring that solar installations deliver their promised benefits over their 20-25 year lifespan. However, O&M

work is frequently undervalued, poorly compensated, and characterized by precarious employment conditions.

This devaluation reflects broader patterns in how different types of technical work are gendered and racialized. Installation work, often seen as requiring strength and technical skill, is coded as masculine and relatively well-compensated. In contrast, maintenance work, especially routine tasks like cleaning panels, is often coded as less skilled, even menial, and therefore appropriate for lower wages and more precarious employment. When women do find employment in solar O&M, it is often in these devalued maintenance roles rather than in diagnostic troubleshooting or repair work that requires (and builds) deeper technical expertise.

The lack of technical expertise in O&M is likely to be more pronounced in the unregulated solar home system (SHS) sector, where installation, maintenance, and repairs may be conducted by minimally trained technicians or users themselves (Kinally et al., 2022). This creates sustainability challenges for off-grid solar systems and limits the development of local technical capacity. Though there are notable exceptions which we will explore in a further paper, from a gender perspective, the absence of structured training and career pathways in O&M means that even when women express interest in technical work, they lack access to the education and mentorship needed to develop expertise.

Moreover, O&M work is frequently organized through informal, short-term contracts or on-call arrangements rather than permanent employment with benefits and job security. This precarity reflects the broader trend toward casualization of labour under neoliberal capitalism, where employers minimize costs by avoiding permanent employment relationships. Women and marginalized workers are disproportionately concentrated in these precarious positions, lacking the social capital and bargaining power to demand better conditions. The intersection with other marginalized identities – particularly caste, ethnicity, and rural location – means that the most marginalized workers face the most severe precarity and exploitation in O&M roles.

Energy access and affordability: Who benefits?

The downstream sector brings into sharp focus fundamental questions about energy access and justice: who actually benefits from solar deployment, and whose energy needs are prioritized in system design and distribution?

Even when solar systems are designed for local energy access – such as mini-grids or solar home systems – affordability barriers often exclude the poorest and most marginalized. Multiple solar mini-grid projects in Zambia face both financial and technical sustainability challenges, with tariffs needed to cover capital and operational expenses being unaffordable for low-income rural residents (Chanda et al., 2025). Similarly, limited financial schemes for solar PV investments are a key constraint in Kenya, alongside high capital, installation, and maintenance costs, and long payback periods (Mutuku & Mbatia, 2020).

Chanda and colleagues (2025) highlight a significant lack of research on how existing Solar PV products align with the specific needs of rural communities in Africa. This research gap itself reflects epistemic injustices where the knowledge needs and priorities of marginalized communities are not considered worthy of systematic investigation. Solar systems are often designed based on assumptions about energy needs developed in the Global North or urban contexts, failing to account for the actual productive uses, seasonal variations, and cultural practices of rural users.

The gendered dimensions of affordability and access are profound. Women in sub-Saharan Africa (SSA), for example, frequently do not own land, have limited assets, less education and mobility than men, which limits their financial credibility and access to funding (Durga et al., 2024). Even innovative financing models like pay-as-you-go (PAYGO), which eliminate the need for large upfront payments, often exclude women through biased credit-scoring systems. These systems are typically gender-blind, failing to account for women's income sources (which may be from informal work, off-farm activities, or collective income-generating activities) and instead privileging the types of formal employment and asset ownership more common among men (Durga et al., 2024).

Women are often marginalized in energy-related decision-making within households, lacking control over resources and frequently requiring permission from male household heads for acquiring energy devices (Alda-Vidal et al., 2023; Winther et al., 2017). This means that even when solar systems could significantly benefit women's productive activities – reducing time spent on energy-intensive tasks like cooking, grinding, or water pumping – women may be unable to access these technologies because household energy decisions are controlled by men who prioritize other uses of limited household resources. This reflects broader patriarchal control over household resources and decision-making that solar interventions often fail to challenge or even acknowledge.

Radley and Lehmann-Grube's (2022) review of off-grid solar energy and economic development in the Global South found decidedly mixed results. While many studies suggest that solar access can improve household income or savings, others show that such outcomes are not guaranteed. Evidence from Fiji, India, Nepal, Kenya, and Malawi points to little or no measurable economic improvement from solar adoption. Some researchers argue that market-based solar models risk reinforcing existing socio-economic inequalities rather than challenging them (Samarakoon, 2020). A major barrier is the high cost of maintaining and repairing off-grid solar systems, which often exceeds what poor rural households can afford, leading to system abandonment and the reproduction of energy poverty despite initial solar access.

This sobering finding challenges more techno-optimist narratives about solar energy automatically delivering development benefits and highlights how market-based approaches may simply create new forms of dependency and debt for poor households, particularly when systems are designed without adequate attention to local economic realities, repair infrastructure, and genuine community needs.

End-of-life management: environmental justice and labour exploitation

Solar electronic waste holds significant economic value due to the materials that can be recovered – silicon, silver, aluminium, glass, and other components. However, the recycling and disposal phase of the solar value chain reveals stark environmental and labour justice issues that mirror broader patterns of waste colonialism, where hazardous materials from the Global North are exported to the Global South for disposal or recycling under conditions that would be illegal in their countries of origin.

Stock and Sareen (2024) document how labourers in the solar waste chain experience profoundly unequal treatment depending on whether they work in formal recycling systems with safety protections and fair wages, or in informal and often hazardous dismantling and disposal sectors. Disparities shaped by social hierarchies – including caste, class, gender, ethnicity, and citizenship status – and weak regulatory enforcement result in marginalized communities being overrepresented in the informal sector and thus facing severe health and economic risks. This raises urgent concerns about safety, justice, regulation, and inclusion in this critical but overlooked part of the SVC.

The health hazards of informal solar waste recycling include exposure to toxic materials, respiratory damage from burning components to extract metals, injuries from unsafe dismantling practices, and long-term health impacts from accumulation of heavy metals and other contaminants. Workers in informal recycling – often including women and children from the most marginalized communities – lack protective equipment, health monitoring, or compensation for occupational injuries and illnesses. This represents a form of environmental racism and classism where certain lives are deemed expendable in the pursuit of profit from waste recovery.

The gendered dimensions of waste work also reflect broader patterns of labour segmentation and exploitation. Women may be involved in sorting, cleaning, and preliminary processing of waste material i.e. work that is lower-paid and exposes them to toxin, while men engage in the more lucrative (though also dangerous) work of extracting valuable metals. Women waste workers also face specific vulnerabilities including sexual harassment, lack of sanitation facilities, and the challenge of combining waste work with care responsibilities for children and elderly family members.

The concentration of informal waste recycling in marginalized communities reflects how pollution and environmental hazards are systematically displaced onto those with the least political power to resist. This pattern connects contemporary environmental injustices to colonial and postcolonial spatial planning that relegated marginalized groups to the least desirable lands and exposed them to the greatest environmental hazards. The fact that solar panels, the very symbols of clean energy, generate waste streams that poison marginalized workers reveals the profound contradictions of energy transitions that fail to centre justice at every stage of the value chain.

The implementation of robust recycling processes for end-of-life panels is important not only for resource recovery and circular economy principles but for ensuring that this is done with dignity, safety, and fair compensation for workers. However, current governance frameworks and corporate practices largely fail to ensure justice in solar waste management. Extended producer responsibility schemes, where manufacturers are responsible for end-of-life management of their products, remain weak or non-existent in many contexts, allowing companies to profit from solar sales while externalizing the costs and risks of disposal onto marginalized communities and informal workers.

Procedural exclusion in downstream planning and implementation

Many marginalized groups are also excluded from meetings and decision-making processes related to the development of solar projects and installations and affiliated corporate social responsibility schemes (Joshi & Yenneti, 2020; Stock & Sareen, 2024). Communities near solar park developments in India reported that consultation processes were inadequate, not inclusive, or unfair, and that they were not invited to participate in meetings about projects that would fundamentally transform their landscapes and livelihoods (Stock & Sovacool, 2024).

This procedural injustice reflects broader patterns where development is done to communities rather than with them, replicating governance models where local populations were subjects of administration rather than participants in decision-making. The exclusion is often explicitly gendered: even when community consultations occur, they typically engage male community leaders or landowners, excluding women whose voices are deemed less important or who face barriers attending public meetings (such as care responsibilities, mobility restrictions, or social norms against women speaking in mixed gatherings).

The consequences of this exclusion are profound. Solar projects are designed without understanding actual community energy needs, priorities, or concerns. Benefit-sharing arrangements are negotiated without input from those most affected. Mitigation measures for negative impacts are inadequate because the full range of impacts, particularly those falling on women and marginalized groups, are never aired in consultation processes dominated by privileged voices. The result is that solar projects fail to deliver promised benefits, generate community opposition, and reproduce rather than transform unjust power relations.

One way to promote greater inclusivity in the downstream value chain is by supporting women-owned businesses that deliver essential services across installation, O&M, and system integration (Parshotam, 2018b), and we will be highlighting such cases in subsequent papers. Given the decentralized nature of solar PV, enabling women's participation requires policies that remove gender-specific barriers such as limited access to finance, asset ownership, skills, and training (Mutuku & Mbatia, 2020). However, this must go beyond simply creating opportunities for a few women entrepreneurs to succeed within existing systems and instead must challenge deeper structural barriers that make women's entrepreneurship so difficult. Supporting women-owned businesses should be part of a broader transformative agenda that redistributes power and resources, but ultimately not a substitute for structural change.

Auxiliary chain

In addition to the main value chain activities, there is an auxiliary chain composed of firms and organisations essential for the photovoltaic sector's development, including:

- Research and technological development (R&D)
- Marketing and sales services
- After-sales service
- Human resources management and training
- Transportation and logistics
- Commissioning services
- Provision of financing by financial institutions
- Government incentives for photovoltaic generation
- Sector regulation
- Associations and organisations linked to the photovoltaic sector

While often treated as secondary, the auxiliary chain is critical for determining who participates in and benefits from solar transitions. These functions – particularly R&D, financing, regulation, and training – are sites where power is exercised and where inclusion or exclusion is actively produced. Their concentration in the Global North and among privileged actors within the Global South reflects and perpetuates historical legacies of knowledge production, capital accumulation, and governance structures.

Barriers to inclusivity in the auxiliary chain

Research and development: Epistemic injustice

Research and technological development in solar PV is highly concentrated in universities, research institutions, and corporate R&D facilities in the Global North, China, and a few emerging economies, reflecting historical patterns where scientific capacity was concentrated in industrial centres whilst other territories served as resource extraction sites.

This creates profound epistemic injustices. Research agendas are shaped by wealthy countries' priorities rather than Global South communities' needs. R&D prioritises grid-scale systems and efficiency improvements serving industrial applications, whilst innovations addressing off-grid rural needs – systems optimised for grinding, refrigeration, or water pumping – receive less attention.

Women and marginalised groups are severely underrepresented in solar R&D, reflecting barriers beginning in secondary and tertiary education where girls and marginalised students often lack STEM opportunities (Parshotam, 2018a). Universities have critical roles in building inclusive energy professionals, yet persistent gender imbalances in STEM limit women's participation and the transformative potential of decentralised renewable energy (Pailman & de Groot, 2022). When women are excluded from energy research, resulting technologies fail to account for women's knowledge, needs, and perspectives.

Indigenous peoples' underrepresentation means Indigenous knowledge systems, often embodying sophisticated understandings of local ecosystems, seasonal patterns, and sustainable resource use, are excluded from technology design, perpetuating patterns where Western scientific knowledge is valorised as the only legitimate expertise.

Financing: Gatekeeping and structural exclusion

Access to capital determines who can participate in solar value chains as developers, installers, entrepreneurs, and consumers. However, financing systems systematically exclude marginalised groups through multiple mechanisms. For example, farmers, small groups, and women-owned businesses face enormous challenges securing affordable credit (Durga et al., 2024; Mutuku & Mbatia, 2020). There are a lack of targeted funding instruments and streamlined processes, leading to significant entry barriers; loan applications require documentation, business plans, and collateral that marginalised entrepreneurs lack. Even supposedly neutral credit-scoring algorithms systematically disadvantage women and marginalised groups.

Women in sub-Saharan Africa frequently don't own land, have limited assets, less education and restricted mobility, undermining their financial credibility (Durga et al., 2024). Collateral requirements exclude women historically denied property ownership through patriarchal inheritance systems and discriminatory land policies. This is the product of specific histories that financial systems continue enforcing. Even pay-as-you-go (PAYGO) systems reproduce

gendered exclusions through credit-scoring that privileges formal employment and asset ownership patterns common amongst men whilst failing to account for women's income from informal work, agriculture, or collective activities (Durga et al., 2024).

International financing for Global South solar projects depends heavily on Global North economic cycles, creating vulnerabilities and hindering local wealth generation (Goldthau et al., 2020). This mirrors historical patterns where capital flowed from industrial centres to resource-providing regions on favourable terms, extracting profits whilst limiting local accumulation.

Training, marketing, and regulation

Human resources management and training determine who accesses employment opportunities. However, training systems exhibit gaps reflecting broader exclusion patterns. There is fundamental disconnect between industry demand and available skills (Ukoba et al., 2024). Whilst demand exists for specialised knowledge with well-paid jobs, this creates entry barriers for lower-income, rural populations and marginalised groups. Skills gaps mean locals lose higher-paying roles to external actors.

Inadequate training institutions represent critical barriers (Durga et al., 2024; Goldthau et al., 2020; Mutuku & Mbatia, 2020). Where programmes exist, they suffer from inadequate funding, outdated equipment, and disconnected curricula. Women face multiple barriers: urban-located programmes requiring mobility; schedules conflicting with care responsibilities; hostile masculine training environments; and social norms discouraging women from technical education.

Marketing and sales frequently operate on gendered assumptions excluding women as both agents and consumers. Energy professionals assume men are primary household decision-makers, reinforcing patriarchal dynamics (Alda-Vidal et al., 2023). Women's potential as effective sales agents is systematically undervalued.

Leadership in solar sector organisations is overwhelmingly male, urban, and privileged, shaping whose perspectives inform advocacy and whose networks facilitate opportunities. Rural communities, Indigenous peoples, and marginalised groups lack effective representation.

Government incentives and regulation represent critical sites where policy can challenge or reinforce inequalities. However, policies are often "gender-blind," risking inequality

exacerbation (Winther et al., 2017). Gender neutrality obscures how neutral policies favour privileged groups, and these might include solar subsidies requiring property ownership exclude women lacking land titles; formal business registration requirements favour men; daytime training excludes women with care responsibilities.

Regulatory frameworks often fail to address ethical challenges in global supply chains. Despite extensive research documenting forced and child labour links in solar technology production (Cockayne et al., 2022; Murphy & Elimä, 2021, 2023), responses remain inadequate, reflecting power asymmetries where corporate interests outweigh human rights commitments.

Systemic barriers throughout the Solar Value Chain

Several core barriers hinder inclusivity throughout the SVC, particularly impacting communities marginalised through intersecting systems of patriarchy, racism, historical inequalities, and capitalism. These barriers manifest across value chain segments from raw material extraction to end-of-life management. Critically, these are not isolated problems requiring discrete technical fixes, but interconnected manifestations of deeper structural injustices requiring systemic solutions.

As Stock and Sareen (2024) argue, employment and participation across the SVC mirror and reproduce patriarchal and hierarchical structures of societies in which solar initiatives are embedded. Even well-intentioned projects inadvertently reproduce existing inequalities unless deliberate, transformative strategies are implemented. The task is not simply including marginalised groups in existing systems but fundamentally transforming those systems to dismantle intersecting oppressions that structure them.

Regional variations and global inequalities

The solar value chain structure differs significantly by country and region, reflecting and perpetuating historical global divisions of labour. Developed economies have integrated value chains with strong manufacturing, R&D, and recycling capabilities, capturing value at multiple stages and possessing the financial, technical, and institutional capacity to set standards and

shape global markets. Conversely, most Global South countries have truncated value chains, relying heavily on imports and focusing on downstream activities with lower profit margins. China's dominance in solar manufacturing – producing the majority of global polysilicon, wafers, cells, and modules – has shifted economic geography but hasn't fundamentally altered patterns where few centres dominate technological production whilst the rest depends on imports, creating new dependencies for Global South countries without building local innovation capacity.

Countries rich in critical minerals – lithium, cobalt, rare earth elements – may not benefit if renewable energy sectors aren't well-governed, potentially creating a new "resource curse" where mineral wealth generates corruption, conflict, and environmental destruction rather than development (Goldthau et al., 2020). Foreign capital availability for Global South renewable energy investment remains heavily dependent on Global North economic cycles, hindering local wealth generation and limiting the sovereignty of governments and communities to determine their own energy futures.

Stakeholder involvement: Participation or tokenism?

Multiple stakeholder roles and interactions exist across the solar PV supply chain, from extraction communities to suppliers, manufacturers, consumers, recyclers, government, and researchers. All are crucial for sector development. However, ineffective collaboration or lack of meaningful contribution from marginalised communities hinders just transition strategies. The inclusion of various stakeholders faces numerous complex barriers (Arıöz et al., 2025), and holistic analyses accounting for multiple stakeholder roles across entire system lifecycles are profoundly lacking (Franco & Groesser, 2021).

Fundamentally, "stakeholder participation" risks becoming tokenistic if not addressing underlying power asymmetries. When marginalised communities are invited to participate in processes where agendas, frameworks, and decisions have been largely predetermined by powerful actors, participation becomes performative rather than transformative. Genuine participation requires not just including marginalised voices but redistributing power, giving communities meaningful control over decisions affecting their lands, resources, and futures, including power to refuse projects serving external interests.

Stock and Sovacool (2024) used whole systems approaches exploring multidimensional and intersectional inequities across SVC steps in India, highlighting inequities, exclusionary practices, lack of public participation and governance failures. These range from: marginalised groups' exposure to environmental and occupational hazards resulting in exclusion from longer-term profitable SVC aspects; loss of livelihoods, land, and resources; ecosystem contamination causing habitat destruction and agricultural land loss; and additional time burdens on marginalised resource-dependent groups, particularly women travelling further to gather wood, water, and necessities due to mining and large-scale solar development environmental destruction (Sovacool & Stock, 2024).

Similar patterns occur throughout Africa, Asia, and the Indo-Pacific, suggesting these are systematic features of how solar value chains currently operate rather than isolated incidents. Pattern consistency across contexts reveals they are structural rather than accidental, requiring systemic transformation rather than incremental reform.

Gender perspectives, segmentation, and socio-cultural barriers

Energy access is often framed either as gender-neutral, leading to policies overlooking inequality, or as a tool for gender empowerment, resulting in overly technocentric solutions failing to address root causes of women's disempowerment. Feminist approaches challenge both framings by addressing systemic power imbalances – including those based on gender, race, class, caste, and historical inequalities – across all energy system levels, from infrastructure to household dynamics (Alda-Vidal et al., 2023).

Alda-Vidal et al. (2023) synthesised "gender imaginaries" within the energy sector across sub-Saharan Africa and the Global South, revealing gender barriers deeply embedded in socio-cultural norms and institutional mindsets. Their study identified two main, overlapping frameworks:

1. **Gender-Neutral Grid Imaginary (GNGI)**: Assumes providing energy access helps everyone equally without considering how gender or social differences affect who benefits most – it is "gender blind." This treats electricity systems as inherently equalising, masking intersectional disparities and leading to policies that, whilst claiming neutrality, actually favour those already privileged by patriarchal, class, and racial hierarchies.

2. **Gender-Aware Decentralised Development Imaginary (GADDI)**: Recognises people have different energy needs and experiences based on gender and other social factors, supporting more local, flexible energy solutions aiming to reduce inequality. However, this can be problematic if essentialising women's roles or becoming technocratic fixes providing women solar lanterns for domestic tasks without challenging gendered labour divisions or women's exclusion from productive economic opportunities and decision-making power.

Alda-Vidal et al. (2023) critique both imaginaries: the centralised model (GNGI) for treating electricity systems as inherently equalising whilst actually reproducing male dominance, and the decentralised model (GADDI) for potentially trapping women in domesticity unless explicitly linked to transformative goals. They advocate for shifts towards inclusive, justice-oriented energy transitions recognising and actively addressing structural inequalities rather than assuming technology alone delivers empowerment.

From postcolonial feminist perspectives, both imaginaries risk reproducing frameworks failing to question whose knowledge shapes energy systems, challenge Eurocentric assumptions about development and gender roles, or centre lived experiences and self-defined priorities of women and marginalised communities in the Global South.

Gender segmentation in practice

As discussed, the solar value chain exhibits stark gender segmentation, where women are restricted to certain, often lower-skilled roles even when trained for wider activities. This reflects socio-cultural perceptions and assumptions about physical capabilities or appropriate social roles rather than women's actual desires and abilities (Hemson & Peek, 2017).

Hemson and Peek's (2017) investigation of a USAID-funded project in Bangladesh provides a revealing case study. Despite women training in skills covering production, assembly, and servicing across different SHS value chain parts, women employees were almost exclusively deployed in assembly, not in marketing, sales, distribution, installation, or service segments. The value chain was rigidly gender-segmented: 91% of SHS component assembly undertaken by women whilst 91% of installation undertaken by men.

Qualitative interviews revealed persistent gender biases where managers viewed women as physically and culturally unsuited for installation work. One male manager felt batteries were too heavy for women to lift and considered it inappropriate in Bangladesh's socio-cultural context for women to travel from their village or attempt rooftop solar panel installation. However, other managers recognised women's potential as effective household agents, highlighting ongoing contestation and gender rigidities.

This case illustrates critical points. First, the problem isn't women's lack of skills – they received training and demonstrated competence – but rather patriarchal assumptions overriding women's qualifications. Second, exclusion justifications shift depending on convenience: women deemed too weak for installation but apparently strong enough for repetitive assembly work; considered inappropriate for customer-facing roles requiring mobility but acceptable when confined to factories. Third, programmes ostensibly designed to empower women can actually reinforce gender segregation without explicitly challenging structural barriers channelling women into least-valued roles.

This pattern isn't unique to Bangladesh. In Kenya, male staff predominantly carried out installations whilst women typically worked in offices due to stated security concerns (Majale et al., 2024). Across contexts, similar justifications – physical strength, cultural appropriateness, safety – are invoked to exclude women from installation, maintenance, sales, and other roles offering better pay, skill development, visibility, and potential entrepreneurship opportunities. Gender segmentation must be understood not as neutral worker sorting based on aptitude, but as active exclusion processes maintaining male privilege in the energy sector. It devalues women's labour by concentrating them in lower-paid positions, denies advancement and skill acquisition opportunities, and reinforces patriarchal norms about appropriate women's work.

Intersectionality: Compounded exclusions

Gender intersects with other social categories – age, geographical location, income, class, disability, ethnicity, race, caste, family status – leading to vastly varied energy experiences and profoundly unequal SVC access (Alda-Vidal et al., 2023; Ojong, 2021). Despite growing intersectionality acknowledgment, genuinely deeper understanding of how multiple oppression forms compound one another is urgently required within specific solar sector institutional and infrastructural contexts.

A young Scheduled Caste woman in rural India seeking solar installation employment faces barriers that cannot be understood through gender alone, or caste alone, or youth alone, or rural location alone. Rather, these identities interact creating unique discrimination and exclusion forms: she may be excluded from training programmes because of caste, unable to travel to urban training centres because of gendered mobility restrictions and family expectations, denied employment because of age-based assumptions about reliability or marriage/children plans, and face sexual harassment and caste-based abuse if entering male-dominated and upper-caste-dominated workplaces.

Similarly, an older woman with a disability in a remote rural areas faces compounded barriers accessing solar energy: lacking income to afford even subsidised systems, unable to navigate financing application processes due to literacy barriers, excluded from community meetings about solar projects due to mobility limitations and social marginalisation of people with disabilities, and finding solar products not designed to accommodate her specific needs.

Intersectional analysis reveals how oppression systems are not additive (gender + caste + disability = three separate problems) but rather multiplicative and mutually constitutive, creating unique marginalisation experiences un-addressable by targeting any single identity axis. It also reveals how solar interventions addressing only one inequality dimension – for example, programmes supporting "women" without accounting for how different women are positioned by class, caste, race, ethnicity, and other identities – risk primarily benefiting relatively privileged women whilst leaving the most marginalised behind.

From postcolonial perspectives, intersectionality must be understood within historical contexts of how power systems created, codified, and intensified hierarchies of race, gender, and caste. Historical regimes racialised populations to justify exploitation, imposed rigid gender binaries and patriarchal family structures onto societies with more fluid gender systems, codified caste and ethnic hierarchies into legal and administrative frameworks, and created land tenure and labour systems compounding multiple disadvantage forms. Contemporary intersectional inequalities in solar value chains are thus not simply cultural traditions or unfortunate prejudices, but ongoing operation of structures continuing to determine who has access to resources, knowledge, and power.

Policy and governance gaps

The solar value chain is increasingly recognised as vulnerable to governance failures risking entrenched systemic inequalities rather than challenging them. Governance – encompassing policy frameworks, regulatory systems, institutional arrangements, and decision-making processes – determines who has power over solar transitions, whose interests are prioritised, and whether solar deployment serves justice or reproduces exploitation. Contemporary governance failures often reflect persistence of administrative structures and power relations designed to facilitate extraction and control rather than serve local populations' self-determined development.

A key barrier is lack of collective action and co-design amongst stakeholders, especially in upstream production. This absence of inclusive governance undermines efforts ensuring ethical sourcing and sustainable production, systematically excluding producer communities – particularly marginalised groups within those communities – reinforcing exploitative practices (Cockayne et al., 2022). When governance is top-down, technocratic, and dominated by powerful actors (governments, multinational corporations, international financial institutions), it becomes a mechanism for imposing agendas rather than facilitating genuine participation and self-determination.

Gender-blind policies and intersectionality

Policies that are "gender-blind" – claiming neutrality but actually favouring men – don't adequately consider intersectional vulnerabilities or local realities, thereby risking inequality exacerbation and marginalising Indigenous entrepreneurs and communities. Policies adopting supposedly "gender-neutral" approaches tend in practice to result in male-dominated systems overlooking women's specific needs and potential productive electricity uses (Winther et al., 2017).

Gender neutrality fiction serves to naturalise and render invisible ways policies systematically advantage men. Solar subsidies structured around property ownership automatically exclude most women lacking land titles due to patriarchal inheritance systems and discriminatory land policies. Procurement policies requiring certain business certifications favour formal, established firms typically owned by men, excluding women entrepreneurs operating informally due to business registration access barriers. Training programmes scheduled during daytime hours

without childcare provision exclude women with care responsibilities. Each of these policies appears neutral on face value but has profoundly gendered effects because it operates within – and fails to challenge – existing patriarchal structures.

Moreover, policies recognising gender but failing to account for intersectionality risk benefiting relatively privileged women whilst leaving the most marginalised behind. A policy supporting "women entrepreneurs" without addressing how race, caste, class, disability, and other identities intersect with gender may primarily benefit urban, educated, upper-caste or upper-class women who face gender discrimination but possess other privilege forms. Meanwhile, poor rural women from marginalised castes or ethnic groups – facing compounded discrimination – remain excluded. Genuine gender justice requires intersectional policy frameworks addressing how multiple oppression systems interact.

Governance frameworks and human rights

Governance frameworks in the solar value chain must confront ethical challenges embedded in global supply chains. Extensive research, including from the University of Nottingham's Rights Lab (Cockayne et al., 2022) and Sheffield Hallam University's "In Broad Daylight" and "OVEREXPOSED" reports (Murphy & Elimä, 2021, 2023), has documented how key solar technology production is linked to forced and child labour, particularly involving Uyghur people in Xinjiang, China. This raises an unresolved critical dilemma: what is the true cost of pursuing clean energy in terms of human freedom?

Despite mounting evidence, governance responses remain inadequate. Most countries lack effective import controls preventing solar products made with forced labour from entering their markets. Corporate due diligence remains largely voluntary and often superficial. International coordination is fragmented, with some jurisdictions implementing restrictions whilst others continue business as usual, allowing companies to redirect tainted products to less regulated markets.

This governance failure reflects deeper power asymmetries in the global political economy. Multinational corporations have enormous influence over national governments, particularly in the Global South where countries compete to attract investment. International trade rules prioritise free flow of goods over human rights protections. The geopolitical dimensions of solar supply chains – with China dominating production and Western countries dependent on Chinese

manufactures for their climate goals – create reluctance to impose restrictions that might disrupt supply chains or increase costs.

The new resource curse and lack of whole systems approach

Countries rich in critical minerals – lithium, cobalt, copper, rare earth elements – may paradoxically fail to benefit from this resource wealth if renewable energy sectors aren't well-governed, creating potential for a new "resource curse" where mineral abundance generates corruption, environmental degradation, conflict, and continued poverty rather than sustainable development (Goldthau et al., 2020). This mirrors historical patterns where resource-rich regions remained impoverished whilst their minerals enriched industrial centres.

Foreign capital availability for Global South renewable energy investment is heavily dependent on Global North economic cycles, creating vulnerabilities and hindering local wealth generation and economic autonomy (Goldthau et al., 2020). This dependency relationship gives external actors enormous power over Global South solar transition pace and direction, limiting sovereignty of Global South governments and communities to determine their own energy futures.

A critical governance failure is absence of holistic, systems-thinking approaches integrating socio-cultural dimensions with economic, technical, and environmental considerations. Whilst solar scholarship increasingly examines social and environmental injustices globally, policies and policy-making processes at multiple governance scales still insufficiently regulate whole solar energy deployment systems (Martin et al., 2024). Governance tends to be fragmented across different agencies and scales – one ministry handles mining regulation, another manufacturing incentives, another energy access programmes, another environmental protection – with limited coordination and no institution responsible for ensuring justice across the entire value chain.

There is also a limited availability of disaggregated data, especially around labour markets and community-level impacts, which hampers effective planning and policy design. Without data disaggregated by gender, caste, ethnicity, disability, age, and other identity categories, policymakers cannot identify who is being excluded or design targeted interventions. The data lack itself reflects governance failures where marginalised groups' experiences aren't considered worth documenting systematically.

Even when governance institutions exist, they frequently operate in ways excluding marginalised communities from meaningful participation. Large-scale solar developments often reproduce deep-rooted procedural injustices through inadequate or exclusionary consultation processes. Stock and Sovacool (2024) document how communities near solar park developments in India reported consultation processes were inadequate, not inclusive, or unfair, and many weren't invited to participate in meetings about projects fundamentally affecting their lands and livelihoods. When consultations do occur, they're often perfunctory exercises designed to satisfy regulatory requirements rather than genuine efforts to understand community concerns, incorporate local knowledge, or ensure free, prior, and informed consent.

Summary and way forward

The most profitable solar value chain segment – technology development – is dominated by the Global North and major emerging economies, severely restricting the Global South's ability to move up the chain and capture value. Many countries in Africa, Asia, and the Indo-Pacific lack robust domestic manufacturing and R&D capabilities, relying heavily on imports and foreign firms for technology, finance, and infrastructure. This dependency perpetuates trade imbalances and market dominance by large multinational corporations, making it profoundly difficult for local firms and entrepreneurs to maximise value chain benefits. This pattern reflects ongoing operation of historical global labour divisions that positioned the Global South as raw materials and labour provider whilst concentrating high-value activities in industrial centres and emerging powers.

Solar PV value chain expansion in the Global South is constrained by deep-rooted structural barriers limiting equitable participation and local value capture. A key challenge is dependency on external actors for capital, technology, expertise, and market access, perpetuating relationships where the Global South's energy transitions serve primarily external actors' interests rather than local communities' self-determined development priorities.

Compounding this is absence of holistic, systems-thinking approaches integrating socio-cultural dimensions with economic, technical, and environmental considerations. Severely limited availability of disaggregated data, especially around labour markets and community-level

impacts, hampers effective planning and policy design, ensuring proposed interventions remain fragmented and exclusionary. Without data showing who is actually participating in and benefiting from solar value chains, inequalities remain invisible and unaddressed.

These systemic issues are further reinforced by practical and procedural exclusions. Large-scale solar developments often reproduce deep-rooted social and environmental inequalities, such as public lands and commons enclosure, leading to marginalised communities' dispossession. This especially affects smallholder farmers, pastoralists, forest-dependent peoples, and women, reinforcing gendered and capitalist systems where certain bodies, labour, and lands are deemed expendable in "development" pursuit. Procedural injustices, disempowering development schemes, and loss of access to vital resources disproportionately affect women and marginalised groups whose voices are systematically excluded from decision-making processes.

Together, these interwoven barriers create a landscape where those already facing socio-economic disadvantages are least likely to benefit from, or meaningfully contribute to, solar PV sector growth. Addressing these challenges requires coordinated action encompassing inclusive policies, transformed governance structures, and substantial investment in local capabilities. However, more fundamentally, it requires confronting and dismantling intersecting systems of patriarchy, racism, historical inequalities, and capitalism that structure current solar value chains.

A critical barrier to inclusivity lies in ethical dimensions of solar energy production. Ethical concerns, particularly modern slavery in solar supply chains documented in the "In Broad Daylight" and "OVEREXPOSED" reports, pose major barriers to inclusive solar energy adoption. These human rights issues threaten energy transition legitimacy and may deter buyers, investors, and insurers facing reputational, legal, and ethical risks. Critically, poorly designed responses to these concerns could slow deployment and exacerbate climate change, creating false choices between justice and climate action. What is needed instead is systemic transformation of supply chains and global governance to ensure solar transitions are both rapid and just.

Towards a just solar transition

To ensure truly just and inclusive energy transitions, governance frameworks must embrace system-level interventions prioritising transparency, genuine local participation and control, and intersectional equity. This includes strengthening regulatory oversight with enforcement capacity

and accountability to affected communities; supporting community-led initiatives and community ownership models keeping value local; and embedding justice principles – including recognition of Indigenous sovereignty, respect for subaltern knowledge, redistribution of power and resources, and procedural inclusion of marginalised voices – at every solar value chain stage.

However, these interventions will remain insufficient if occurring within unchanged power structures. Achieving genuinely just solar transitions requires not simply including marginalised groups in existing systems but fundamentally transforming those systems. It means centring knowledge, sovereignty, lived experiences, and self-defined priorities of marginalised and subaltern communities rather than imposing solutions designed by and for dominant groups. Such a pluralistic vision for energy transition means seeing renewable energy not as an end in itself but as part of broader struggles for justice, economic sovereignty, and human dignity.

Looking forward: Opportunities in next-generation solar

Whilst this report has necessarily focused on identifying and analysing barriers to inclusivity in current solar value chains, it is important to recognise that these challenges are not insurmountable. The emerging field of next-generation solar technologies – including perovskites, organic photovoltaics, and other innovations – presents significant opportunities to reimagine solar value chains in ways prioritising justice, local manufacturing, and inclusive participation from the outset.

A companion paper explores some of these opportunities, drawing on case studies and insights from the global TEA@SUNRISE network, which currently comprises over 300 researchers, practitioners, policymakers, and community partners across multiple continents. This network is actively developing and fostering an inclusive and interdisciplinary approach which will help us identify and deliver opportunities for next-generation PV. This paper foregrounds inclusion opportunities and highlights case studies which have emerged from the network and beyond, giving examples of successful interventions and practices which demonstrate how solar transitions can advance both climate and justice goals.

By understanding barriers documented in this report alongside opportunities explored in the forthcoming paper, stakeholders across the Transforming Energy Access network and beyond

will be better positioned to design interventions that genuinely transform – rather than merely reform – solar value chains in service of just and sustainable energy transitions.

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