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State Fragility initiative

POLICY TOOLKIT

Scaling solar mini grids in fragile contexts: An overview of key findings

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Distributed renewable energy technologies, and solar mini grids in particular, offer significant promise in expanding energy access in low-income and fragile settings. This toolkit summarises key findings from a broader set of work covering different aspects of solar mini grid development in fragile contexts and the challenges and potential solutions that exist for governments and other stakeholders in deploying solar mini grids in these settings.

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List of abbreviations

Abbreviation	Meaning
ACLED	Armed Conflict Location and Event Data
AECF	Africa Enterprise Challenge Fund
DFI	Development finance institution
DRC	Democratic Republic of Congo
DRE	Distributed renewable energy
EEE	Electrical and electronic equipment
EoL	End of life
ESMAP	Energy Sector Management Assistance Program
FCS	Fragile and conflict-affected settings
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
kW	kilo Watt
kWh	kilo Watt hour
MTF	Multi-Tier Framework
PAYGo	Pay-as-you-go
P-REC	Peace Renewable Energy Credit
PUE	Productive use of energy
PV	Photovoltaic
REACT SSA	Renewable Energy and Climate Adaptation Technologies – sub-Saharan Africa
SHS	Solar home system
WTP	Willingness to pay

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1. Introduction

More than a billion people reside in fragile and conflict-affected settings (FCS) globally and it is expected that FCS will account for more than two-thirds of the world's poor by 2030.[1] According to the most recent estimates available, an average of 58% of the population in FCS have access to electricity, with figures being notably lower for rural areas, at around 36% access.[2] These figures hide significant variations across FCS, with some countries having far lower electrification rates.

People without access to electricity today in FCS are unlikely to gain energy access through the extension of national grids. Rather, **distributed renewable energy (DRE)** technologies are a more feasible solution, providing electricity services at the local level, including in rural areas. Renewable energy technologies, and solar mini grids in particular, are an **increasingly competitive and financially viable option** to meet the significant energy deficits in FCS. This is driven in large part by notable **cost reductions** in solar technology, with solar solutions already outperforming fossil fuel options on price. Many FCS have abundant solar resources, making it critical to explore scaling up of deployment of solar mini grids in FCS.

A typical solar mini grid has a capacity of 50-200 kW and is comprised of a set of solar panels connected to a distribution network connecting around 200 households and 20 or so small businesses. Some backup system is needed to provide power outside of generating hours, either through batteries to store solar power or a diesel generator. Which backup option is more appropriate depends on the context and project dynamics. On the one hand, greater reliance on diesel generators may be challenging in situations lacking reliable and affordable fuel supply and the use of diesel reduces the renewable energy component of the system, which may be problematic if financing conditions require a high renewable energy share. On the other hand, reliance on batteries preserves the renewable energy share but can add significantly to overall equipment and maintenance costs.

Solar mini grids have the potential to play an important role in igniting economic growth and its subsequent benefits, such as reducing poverty, enabling higher productivity, and supporting environmental sustainability – as well as potentially increasing state legitimacy, security, and gender empowerment in the long-term.[3] Solar mini grids are also particularly well suited for FCS due to their ability to be modular and easy to roll out, their low dependence on government capacity, and their decentralised nature means any damage incurred to a mini grid has an isolated impact on that system only.[4]

1 The list of FCS referred to in this policy toolkit is based on the list of countries classified by the World Bank as facing situations of fragility and conflict. The World Banks updates this list annually, and the latest version is attached in Table 1.
2 World Development Indicators, 2022.
3 Logan & Sacchetto, 2021.
4 Bazilian & Logan, 2020.

However, progress on scaling up the deployment of solar mini grids has been slow to date, particularly in FCS. There is a myriad of reasons why mini grid expansion has been hindered in FCS, spanning challenges around insufficient financing, inadequate regulatory frameworks, low energy demand and ability to pay for energy services, undeveloped supply chains and skilled workforces, and the greater difficulties of rolling out mini grids in remote or insecure regions. These factors combine to **lower the financial viability** of mini grids, despite them being a good technology fit to the energy access challenge. Revenues generated from solar mini grids servicing rural communities are simply not sufficient to provide the return sought by private investors. How to make mini grids more financially viable is a central challenge.

The obstacles to deploying solar mini grids – and potential ways in which these obstacles can be addressed – have been covered in detail through a series of **policy toolkits** that aim to support policymakers of FCS in decision-making around key aspects of solar mini grid development in their countries. As increasing energy access requires the coordinated efforts of a number of different stakeholders, including solar mini grid developers, distributors of productive use of energy appliances, international energy organisations, donors and development partners, private investors, and local communities, it is hoped that findings from these policy toolkits will be useful for these actors, too.

This roadmap toolkit aims to summarise key findings from this series of policy toolkits and direct readers to which toolkits provide more detailed information on these topics. The toolkits in this series are:

- *Financing and de-risking tools and approaches for solar mini grid projects in fragile contexts*
- *Legal and regulatory framework: Facilitating an enabling environment for solar mini grids in fragile contexts*
- *Improving the supply side for solar mini grids in fragile contexts*
- *Demand-side factors: Tools to measure, incentivise, and sustain demand for solar mini grids in fragile contexts*
- *Driving productive use of energy in fragile contexts*
- *Data and technology: Challenges and opportunities for solar mini grids in fragile contexts*
- *E-waste management: Strategies and policies in fragile contexts*

philou1000,
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These toolkits are also accompanied by **six case studies** that provide real world examples of initiatives that are working to address some of the challenges to scaling up deployment of solar mini grids in fragile contexts. These initiatives have the potential to be replicated in other FCS and offer valuable lessons in this regard. The case studies in this series are:

- *Blended finance in fragile settings: P-RECs and the P-REC Aggregation Facility*
- *Harnessing capacity building to improve leverage: AECF and REACT SSA Somaliland*
- *Concessions: Nuru's experience in the DRC's electricity sector*
- *EnerGrow: Providing asset financing for productive use of energy products in Uganda*
- *Energy Access Explorer: An open access tool to enable data-driven energy planning*
- *E-waste management programme in Cox's Bazar refugee camps*

2. The concepts of FCS and conflict sensitivity

Before delving into the key findings from these toolkits, it is first necessary to clarify what is meant by **'fragile and conflict-affected settings'** in the context of considering how to scale up solar mini grid deployment. Although the causes of fragility and conflict differ across different settings, common characteristics of fragility include "the lack of basic security, inadequate government capacity, the absence of a properly functioning private sector, and the presence of divided societies."[5] Increasingly, environmental destruction and climate change are drivers of fragility, particularly in low-income countries.[6]

Importantly, fragility does not follow national boundaries – sub-national regions within a country may experience fragility that does not affect the whole country, and fragility and conflict within a country may change locations and vary in intensity over time. The use of 'settings' rather than 'states' is intended to emphasise that fragility is frequently a **sub-national phenomenon** and that challenges of fragility should not necessarily label whole countries.

Nonetheless, data is needed to be able to track patterns of fragility and conflict and trends of energy access over time and, since data is primarily collected and reported on the country level, this requires some reference to a set of countries considered to be affected by fragility and conflict. To this end, the World Bank publishes an annual list of countries classified as experiencing fragility and conflict. The 2024 list is outlined in **Table 1** and includes two sets of countries:

- Those with high levels of **institutional and social fragility** – these countries are identified based on indicators that measure the quality of policy and institutions and manifestations of fragility.
- Those affected by **violent conflict** – these countries are identified based on a threshold number of conflict-related deaths relative to the population.[7]

5 LSE-Oxford Commission on State Fragility, Growth and Development, 2018, p. 4.
6 Logan & Sacchetto, 2021.
7 World Bank, n.d.

Table 1 The World Bank's 2024 list of fragile and conflict-affected situations[8]

Conflict	Institutional and social fragility
Afghanistan	Burundi
Burkina Faso	Chad
Cameroon	Comoros
Central African Republic	Congo, Republic of
Congo, Democratic Republic of	Eritrea
Ethiopia	Guinea-Bissau
Haiti	Kiribati
Iraq	Kosovo
Lebanon	Libya
Mali	Marshall Islands
Mozambique	Micronesia, Federated States of
Myanmar	Papua New Guinea
Niger	Sao Tome and Principe
Nigeria	Solomon Islands
Somalia	Timor-Leste
South Sudan	Tuvalu
Sudan	Venezuela, RB
Syrian Arab Republic	Zimbabwe
Ukraine	
West Bank and Gaza	
Yemen, Republic of	

The World Bank's list of fragile and conflict-affected situations is used throughout this series of toolkits to ensure a standardised approach to data pertaining to fragility and energy access.

The evolving dynamics and multidimensional nature of fragility and conflict complicates decision-making around projects – including the deployment of solar mini grids –in affected settings. There is a growing recognition that DRE projects must be implemented in a **conflict sensitive manner** to ensure that they do not have unintentional negative impacts. Potential negative impacts include "reinforcing existing inequalities, violating human rights, exacerbating community grievances, and worsening local conflict dynamics."[9]

There have, unfortunately, been a number of instances of DRE projects aggravating local conflict dynamics, including large-scale solar projects in the Western Sahara (e.g., the Aftissat (Boujdour) project) and Ashegoda and Adama wind farms in Ethiopia. These experiences have highlighted the need for greater care to be taken in the design and implementation of DRE projects in situations experiencing fragility or conflict if they are to either 'do no harm' or go further and contribute positively to peace in the local context. Factors that can be incorporated into a conflict sensitive approach are summarised in **Box 1**.

8 World Bank, 2024.
9 Logan et al., 2023.

BOX 1 WAYS IN WHICH CONFLICT SENSITIVITY CAN BE INCORPORATED INTO DRE PROJECTS[10]

DRE project developers could incorporate conflict sensitivity into the design and implementation of their DRE projects in the following ways:

1. **Undertake a conflict assessment** to understand local conflict drivers and how the project may interact with local dynamics. Use these findings to inform design and implementation of the project. Identify opportunities for DRE projects to make a positive impact on local communities and any entry points for contributions to peacebuilding or reconciliation efforts. Update the conflict assessment regularly to capture changes.
2. **Engage continuously and meaningfully with affected communities** to build trust, generate public and political acceptance of the project and understand the perspectives of those affected by it. Develop an effective communication mechanism to convey project information and updates to the local community and develop a grievance mechanism where concerns can be lodged and addressed.
3. **Develop a comprehensive risk mitigation and management framework** to identify measures to address risks to both the project and the local context. This can offer protection against both conflict-related and regular project risks and can form an entry point for regular discussions with relevant stakeholders to help inform adjustments where needed.
4. **Establish a robust monitoring and evaluation framework** to track progress, measure the effectiveness of different project efforts, and identify where adjustments may be needed. Incorporate mechanisms for community feedback.

10 This box draws extensively from Logan et al., 2023.

3. Key findings and policy recommendations

The key findings and policy recommendations identified in the policy toolkits were developed by conducting **extensive literature reviews** and undertaking a large number of **interviews with practitioners** who have worked on different aspects of energy access across a variety of contexts, including settings experiencing fragility or conflict. Lessons and examples have been taken from countries that are either classified by the World Bank as FCS themselves or are only a few years ahead of most FCS in establishing their solar mini grid sectors, thereby providing realistic models that fragile contexts can feasibly follow in their own efforts.

This section summarises key findings and recommendations included in the toolkits.

3.1. Legal and regulatory environment

Governments are able to create more conducive regulatory environments by streamlining licensing processes, enhancing quality standards, and ensuring protection for both consumers and investors. These developments would notably contribute to removing the barriers that hinder solar mini grid deployment in FCS.

The regulatory landscape in FCS is fraught with complexities that hinder the deployment of mini grids. These challenges include:

- **Unclear and lengthy licensing procedures** – Inconsistent or complex licensing requirements often result in delays and increased project development costs, which deters private sector investment.
- **Weak institutional capacity** – Regulatory bodies in FCS often lack the capacity to oversee and enforce energy regulations effectively. This institutional weakness results in poor coordination among stakeholders and inconsistent application of existing laws, further impeding the development of mini grid projects.
- **Security and political risks** – Operating in FCS involves significant security concerns, with political uncertainties and risks like currency volatility affecting the viability of mini grid projects and investor confidence.
- **Grid arrival uncertainty** – The potential extension of the national grid into areas served by mini grids presents a risk for investors. Without clear regulations to govern this scenario, mini grid operators face the threat of losing their investments if the main grid arrives.
- **Limited consumer and investor protection** – A lack of robust protections for consumers and investors undermines trust in mini grid systems. This gap can result in predatory practices, consumer dissatisfaction, and a reluctance from investors to engage in mini grid projects in FCS.

There are several key strategies that policymakers, regulators, private sector operators, and donor agencies can implement to establish a more favourable environment for mini grid deployment, including:

- **Streamlining licensing processes** – Simplifying and expediting licensing procedures is essential to reduce administrative delays and lower project development costs. This can be achieved by adopting digital platforms for licensing applications, introducing provisional or bulk licenses, and creating a more flexible and transparent regulatory environment.

- **Implementing quality assurance frameworks** – Adhering to internationally recognised technical and safety standards is crucial for ensuring the reliability and sustainability of mini grid systems. Governments should establish and enforce clear standards for equipment, service quality, and environmental impact, ensuring that mini grid projects meet these benchmarks consistently.

- **Strengthening consumer and investor protection** – To promote trust and confidence in mini grid systems, robust consumer protection principles must be established. This includes ensuring transparency in service agreements, safeguarding consumer data, and providing accessible complaint resolution mechanisms. On the investor side, governments should implement transparent compensation mechanisms, offer political risk insurance, and establish dispute resolution frameworks to protect investments.

- **Facilitating grid integration** – As the national grid expands, clear contingency plans are needed to protect the investments made in mini grids. Policymakers should develop regulations that allow mini grid operators to either transition into becoming small power producers or small power distributors once the main grid arrives. Alternatively, compensation mechanisms should be in place to reimburse developers for their infrastructure.

- **Leveraging fiscal incentives** – Governments can incentivise private sector engagement by offering tax breaks, import duty exemptions, VAT relief, and loan guarantees. These measures reduce the financial burden on mini grid developers, making projects more economically viable in fragile environments.

- **Capacity building for regulators** – Investing in training and capacity building for government officials is essential to ensure that regulations are effectively developed, monitored, and enforced. By enhancing the technical and institutional capacity of regulatory bodies, governments can foster a more stable and predictable regulatory environment that encourages long-term investments.

Achieving energy access in FCS requires coordinated efforts from multiple stakeholders. Policymakers and regulators must work to create a regulatory framework that is flexible, transparent, and responsive to the needs of these challenging contexts. The private sector needs to adopt best practices in mini grid development while remaining agile to navigate the complex challenges in FCS. Donor agencies and development partners play a critical role in supporting capacity-building initiatives and providing financial instruments such as risk insurance to mitigate investment risks.

See the policy toolkit *Legal and regulatory framework: Facilitating an enabling environment for solar mini grids in fragile contexts* for more information on this topic.

3.2. Financing and de-risking

The financing needed to extend electricity access to the over 685 million people worldwide who currently lack electricity access is considerable, with financing challenges being particularly high in FCS, where a vast majority of people without electricity access live.[11] Despite the huge potential of wide-ranging DRE technologies, financial commitments in off-grid solutions in countries with the largest energy access gaps remains staggeringly low.

Public financial flows to developing countries for clean energy started decreasing before the COVID-19 pandemic and continued to decline until 2021. These financial flows amounted to USD 10.8 billion in 2021, being only 40% of the 2017 peak of USD 26.4 billion.[12] They increased to USD 15.4 billion in 2022.[13] Development finance institutions (DFIs) collectively provided around USD 5.5 billion annually for wind and solar projects in the 2013-2022 period, with 80% of this in the form of debt.[14] These figures portray a dire situation in terms of financing for renewable energy projects in the countries with the greatest energy deficits, many of which are FCS.

Financing DRE development in FCS is not straightforward. Making mini grids viable in rural, sparsely populated areas or contexts affected by fragility and conflict will require **leveraging innovative financing mechanisms and de-risking tools** to reach customers who would otherwise not be able to afford solar products or services. Certain types of investments offer particular value in FCS, where the **higher costs and risks of investing** necessitate financing that is **flexible, patient, and risk tolerant**. This would include:

- **Grants and highly concessional loans** comprising a significant portion of project funding to enable overall returns that satisfy private investors. Concessional funding would involve the use of subsidies in instances where a public economics case exists, i.e., when a project has the potential to achieve development impact but the returns to society exceed the private returns on investment.[15]

- **Greater equity participation** (and a reduction in reliance on loans), which will require raising the risk tolerance of lenders. Equity financing allows for longer investment time horizons, pursuit of higher growth strategies, and more sustained engagement through the inevitable cycles of volatility in FCS.[16]

11 IEA et al., 2024. Figure is for 2022, the most recent year for which figures are available.
12 IEA et al., 2023.
13 IEA et al., 2024. Figure is for 2022, the most recent year for which figures are available.
14 Kim & Tam, 2024.
15 Carter, 2021.
16 Collier et al., 2021.

- **Working with local intermediaries**, such as local financial institutions, provides a route to enable financing of projects in local currency, allows foreign lenders to achieve deeper contextual understanding of local markets, and strengthens local financial institutions and local financial markets more broadly. This is essential to support sustainable scale up of mini grid financing in FCS.[17]

In addition to conventional sources of financing (grants, equity, and commercial and concessional loans), there are a number of **innovative and emerging funding sources** that can be leveraged for mini grid development in FCS, including:

- **Impact investments and impact bonds**, which support the use of investment capital to achieve positive social or environmental results (which align with investors' preferences), as well as a financial return.

- **Structured financing**, which aims to standardise project documentation, aggregate small-scale projects together, and securitise renewable energy assets to enable trading in capital markets, thereby freeing up capital for investment and lowering the cost of financing.

- **Diaspora finance**, which draws on diaspora populations of FCS as a source of finance, as well as technical expertise and valuable tacit knowledge of local markets in home countries.

A number of tools and approaches can be used to de-risk investments in FCS, serving as critical complementary mechanisms alongside financing sources. De-risking tools **strategically allocate risk** across the public and private financiers of a project and may also use public finance to **de-risk investments and crowd-in private finance**. However, the rhetoric around leveraging public finance to crowd-in private finance does not yet reflect reality in FCS. With continual developments and more initiatives demonstrating success with different tools and approaches, it is anticipated that there will be more progress in coming years. Some of the most notable de-risking tools and approaches include:

- **Grants** provided by DFIs, bilateral donors, or philanthropic funders to mitigate risks, particularly costs associated with early-stage project development.

- **Blended finance**, which combines concessional public finance with commercial private finance for projects intended to attain developmental or social impact. Public finance is used to absorb risks or provide guarantees to enable private investors to participate on de-risked terms, thereby achieving overall returns in line with market expectations.

- **Results-based financing** schemes provide a financing mechanism enabling pre-agreed financial incentives and rewards to be paid to mini grid developers if they achieve pre-agreed results. Achievement of outcomes generally needs to be independently verified.

17 Ibid.

- **Guarantees** involve a third party agreeing to compensate lenders in the event that a borrower (a mini grid developer) defaults on its loan repayment obligations, thereby absorbing (at least part of) the loss that the lender may otherwise bear.

- **Local currency financing** is critical in FCS to avoid borrowers having to bear currency risk in contexts often characterised by macroeconomic instability and local currency depreciation, as this imperils the financial health of projects, developers, and potentially whole renewable energy sectors of FCS economies. A shift towards more local currency financing will be integral to any sustainable scale up of investments in FCS, including in mini grid development, and collaboration across DFIs (and other impact-driven lenders) on joint solutions is necessary for more affordable options to be scaled up.

- **Concessions** can also be used to facilitate private sector participation in mini grid projects in FCS. They provide strong incentives for improved performance and autonomy over delivery and are particularly effective when they cover both electricity generation and distribution elements of electricity provision.

- **Collaborations between DFIs and humanitarian organisations** are emerging with the aim of jointly mobilising investments in contexts affected by fragility, conflict, and displacement through drawing on their complementary expertise and resources.

As much as conventional and emerging sources of financing and de-risking tools and approaches are critical for financing mini grid project development and initial operations, developing a **business model based on market fundamentals** is essential for successful mini grid operation, profitability, and sustainability.[18] Acquisition of enough customers who are willing and able to pay for electricity consumption; collection of sufficient, stable revenues; and attaining 100% utilisation rates as quickly as possible after projects become operational are all vital.

Ultimately, moving the needle on investing in solar mini grids in FCS at scale will require governments to establish **more conducive investment environments**. Responsibility also rests on government to enable financing and de-risking mechanisms, such as by:

- Establishing principles to guide the use of concessions in a coherent and consistent manner.

- Integrating DRE into national electrification plans and developing policy and regulatory frameworks to enable private sector participation in the sector.

See the policy toolkit *Financing and de-risking tools and approaches for solar mini grid projects in fragile contexts* for more information on this topic.

See also the case studies *Blended finance in fragile settings: P-RECs and the P-REC Aggregation Facility and Harnessing capacity building to improve leverage: AECF and REACT SSA Somaliland* for examples of blended finance being used for solar mini grid development in FCS.

18 Interview with Nuru on July 15, 2022; interview with MIT Energy Initiative on June 17, 2022.

3.3. Supply-side factors

The supply side of solar mini grid development is concerned primarily with factors that encourage or hinder investments and decisions of mini grid developers and investors to enter a market. Conducive legal and regulatory environments and adequate financing are critical for scaling up the deployment of solar mini grids in FCS. In addition, the following factors impact developers' decisions around whether to enter a market:

- **Economic dynamics** – FCS were disproportionately affected by the economic impact of the COVID-19 pandemic, with per capita incomes not expected to recover to their 2019 levels even by 2024, and with the share of the population living in extreme poverty in these countries increasing to 38% during this period.

- **Doing business environments** - While all the FCS for which data was available allow the private sector to own or operate solar mini grids, the business environment in these countries is less than conducive, with a majority of FCS ranking in the bottom quarter of the World Bank Doing Business index in 2020.[19]

- **Availability of financing** – Domestic financing is not easy to access in FCS as local banks often lack sufficient liquidity, international banks may be reluctant establish relationships with local banks where they are not sufficiently reassured that local banks are able to adhere to anti-money laundering and combatting the financing of terrorism (AML/CFT) requirements or where economic sanctions or targeted sanctions against named individuals and entities may be in place. These negative macro dynamics lower consumers' ability to pay for electricity, thereby extending the period needed for developers and investors to recoup their initial investments.

- **Supply chains** – Solar mini grids depend on well-functioning supply chains for their equipment and end-user appliances (both household and productive use), as well as for maintenance, repair, and replacement of equipment and appliances. In turn, these supply chains are dependent on raw materials (especially critical minerals), key semi-finished components (such as semi-conductors), and finished products (including solar photovoltaics (PV)), the value chains of which have become highly concentrated in a few countries, notably China. Establishing and maintaining functioning supply chains is a significant challenge in FCS: during times of unrest, there may be site access problems, labour shortages, and unavailability of equipment and spare parts, which tend to increase construction and repair times.

- **Solar equipment costs** – A promising development for FCS is that the costs of deploying solar mini grids have been declining. According to the Energy Sector Management Assistance Program (ESMAP), the levelized cost of energy which captures capital and operating costs per kilo-watt hour (kWh) decreased by 31% between 2018 and 2021. This cost reduction has been driven by many factors: the declining costs of key components (such as solar PV), technological

19 The most recent Doing Business index is for 2020.

innovations (including in batteries and adoption of smart meters), increased usage of geospatial planning tools, and greater economies of scale in manufacturing. Unfortunately, FCS may not fully benefit from these cost reductions unless persisting structural issues are effectively addressed.

- **Enabling and complementary sectors** – There are several important complementary sectors that are key to enabling the deployment of solar mini grids. Availability of transport infrastructure such as roads, railways, bridges, and ports are crucial for transporting solar mini grid equipment and replacement parts to electrification sites, as well as energy efficient products and appliances needed to support productive use of energy. Financial inclusion of end-users is key to improving their access to finance. Digital technologies that assist in sensing and data collection and provide communication, digital platforms, and analytics have proven to be transformative in reducing the cost and increasing the reliability of electricity provision.

- **Labour market capabilities and capacity building** – In many instances, FCS governments experience weak institutional capacity and the inability to provide quality education and skills development opportunities for their citizens, resulting in a gap between existing skills and capabilities of the population and the needs and opportunities of the labour market. It is necessary that detailed capacity needs assessments are undertaken in these contexts to understand existing capacity and the capacity gaps. Capacity gaps can be present at the policy, project, and community levels and targeted interventions will be needed to enable the capacity building required to successfully implement solar mini grid projects that offer quality electricity services.

Potential interventions that governments of FCS, development partners, and mini grid developers operating in FCS could undertake to ease supply-side factors include:

- Governments should establish relevant policies and regulations that **enhance the ease of doing business** and provide clear guidance for developers to navigate the process of setting up mini grid projects. This will also require proactively building the capacity of policymakers to effectively design and implement policies and regulations relevant to the solar mini grid sector, including integrating solar mini grids into national electrification plans and setting fair, cost-reflective tariffs.

- Governments should work with development partners to **invest in enabling and complementary sectors** that will ensure that electrification will have a transformative impact on people's lives. These sectors include transport infrastructure, financial inclusion, and digital technologies.

- Governments should work with development partners and mini grid developers to undertake a capacity needs assessment for their solar mini grid sector and to **develop capacity building initiatives** that respond to local needs and are sensitive to the local context.

- Both mini grid developers and government technical staff need to **proactively build their expertise on emerging technologies** in the solar mini grid sector, particularly those that can help with cost reduction, such as geospatial planning tools.

- Development partners should support the establishment and scaling-up of initiatives that can lower capital expenditure or operational expenditure costs of mini grid developers operating in FCS, such as **providing concessional or grant funding** to enable them to enter more hard-to-reach areas and facilitating bulk procurement where this is possible.

See the policy toolkit *Improving the supply side for solar mini grids in fragile contexts* for more information on this topic.

3.4. Demand-side considerations

The demand side looks at the perspective of energy consumers, with sustainable energy access in FCS requiring a customer-centric approach that focuses on understanding and stimulating energy demand. Strategies and mechanisms to measure, incentivise, and sustain energy demand for DRE systems, such as solar mini grids, is needed to help ensure long-term economic viability and scalability in challenging environments.

Energy demand in FCS is often suppressed due to weak governance, poor infrastructure, low appliance ownership, and limited financial capacity. These factors, combined with volatile economic and political conditions, create significant barriers for mini grid providers aiming to achieve financial viability. Some of the critical challenges include:

- **Low willingness and ability to pay** – Household and small business incomes in fragile settings are often depressed, leading to reduced willingness and ability to pay for energy services provided by solar mini grids. Consumers are often credit-constrained, lack access to financial products, and are wary of spending due to the uncertainty of their environments.

- **Market and infrastructure gaps** – Poor infrastructure, such as weak transportation networks, unreliable supply chains, and limited market development, complicate the deployment and maintenance of solar mini grids. These gaps can also increase operational costs and make energy services less affordable for low-income populations.

- **Knowledge and awareness deficits** – Communities in fragile settings often lack awareness of the benefits of energy access, which can limit demand for energy. In many cases, consumers are not fully informed about how electricity can improve livelihoods.

Having relatively accurate measurements of **energy demand** is critical for ensuring that mini grids can be made to be economically viable. Various tools can be used to estimate and analyse energy demand, thereby helping developers design systems that match customer needs. These tools include:

- **Willingness to Pay (WTP) surveys** – These surveys capture data on how much customers are willing and able to spend on energy services, offering insights into potential demand and allowing developers to tailor their projects accordingly.
- **Geospatial analysis** – These leverage satellite imagery and machine-learning algorithms in order to assess market potential and identify suitable locations for mini grid deployment, particularly in underserved areas.
- **Multi-Tier Framework (MTF)** – This comprehensive framework measures different levels of energy access and identifies the barriers limiting electricity usage, enabling stakeholders to implement solutions that directly address the needs of specific communities.

There are several strategies that can help **sustain energy demand** in fragile contexts by targeting households and small businesses, as well as broader market systems, including:

- **Financial support and products** – End-user subsidies (e.g., cash transfers, vouchers) and innovative financial products (e.g., mobile money, micro-loans) can help bridge the affordability gap for low-income households, thereby increasing uptake of energy services.
- **Promoting the productive use of energy (PUE)** – Encouraging the use of electricity for income-generating activities (such as agriculture, small-scale manufacturing, and commercial services) can improve livelihoods, raise incomes, and increase energy consumption.
- **Raising awareness** – Effective community engagement and communication are essential to change perceptions and encourage the adoption of mini grid systems. Public awareness campaigns and education initiatives can inform communities about the long-term socio-economic benefits of electrification.

Ensuring financial sustainability in fragile contexts requires **innovative approaches to billing, metering, and payment collection**. Key solutions include:

- **Smart metering technologies** – Smart meters provide real-time data on energy consumption, enabling users to monitor and manage their electricity usage effectively. These technologies also help mini grid operators optimise systems and reduce operational costs.
- **Pay-as-you-go (PAYGo) models** – PAYGo systems offer flexible payment plans, allowing consumers to pay for energy in smaller, more manageable instalments. This reduces the risk of default and makes energy services more accessible to lower-income households. Mobile money integration further enhances the accessibility of these models in remote and conflict-affected settings.

Scaling DRE systems in FCS requires a holistic approach that prioritises customer needs, promotes productive use of energy, and provides financial and technological innovations.

See the policy toolkit *Demand-side factors: Tools to measure, incentivise, and sustain demand for solar mini grids in fragile contexts* for more information on this topic.

3.5. Stimulating the productive use of energy

Access to energy alone is not sufficient to change lives or lift people out of poverty – rather, productive use of energy (PUE) is vital to ensure that energy access has a transformative impact and increases people's income-generating capabilities and wellbeing. PUE is also key to enabling the financial viability of solar mini grid projects, as customers' higher incomes increases their ability to pay for electricity usage and raises their demand for energy over time.

PUE uptake is not automatic after an electricity connection has been established, however, and concerted efforts are needed to stimulate PUE uptake. This is particularly so in fragile settings and rural and remote areas with fragile economic conditions, weak market linkages, and lack of natural resources.[20] The most effective approach is to ensure that electrification efforts specifically **target livelihoods and income generation** to support the expansion of economic activities among connected communities.[21] It is critical that specific efforts are made to reach women and other marginalised groups for PUE awareness, financing, and continued adoption, which necessitates special efforts along gender and other dimensions.

Most of the focus of PUE is on increased mechanisation in agriculture, value-added processing, storage, transport, and lighting, cooling and processing equipment for businesses and households. Most PUE appliances can be run off the grid or mini grids, while some of the larger PUE appliances are stand-alone products with their own solar PV cells and batteries. Some off-grid appliances are relatively well established now, such as solar lanterns and SHSs that support lighting, phone charging, televisions, radios and a few other appliances, depending on system size. Other PUE appliances are still emerging, such as solar water pumps, solar refrigeration units, and agri-processing equipment such as grain mills and crop drying equipment.[22]

PUE has the potential to increase the socio-economic impact of electrification, magnifying the opportunities presented by energy access. It enables improved service provision, reduces manual workloads and time required to complete tasks, creates income-generating opportunities for households and small businesses, and supports greater resilience and sustainability. However, significant complementary investments are needed to realise these improved outcomes, including ensuring that teachers and health care workers are paid on time, road and communication infrastructure is sufficiently built out, and that people gain the access to markets needed to procure improved agricultural inputs and sell excess crops, for example. PUE by itself cannot raise incomes unless the complementary investments are in place to allow PUE users to effectively leverage their appliance usage.

20 World Bank, 2023.
21 ESMAP, 2008.
22 GOGLA, 2023.

Despite the evident socio-economic benefits of expanded PUE, a number of challenges hinder the full-scale deployment of PUE products and appliances. These challenges are particularly pronounced in settings of fragility and displacement and span both the demand side and supply side, requiring complex coordination between a range of stakeholders to overcome these constraints. These include:

- On the **demand side**, affordability and lack of consumer awareness are among the most notable constraints.
  - **Different financing models** have been developed to increase affordability for consumers, including PAYGo and payment in kind arrangements.
  - **Raising consumer awareness** around energy access and PUE appliances requires targeted efforts, including roadshows, demonstrations and pilots, and product fairs, taking into account local dynamics and gender-based differences. Specific attention needs to be paid to how to reach different groups of potential consumers, including women and other marginalised groups, and how to ensure that they're able to participate in awareness and training activities.
  - **Business support services** have been seen to be important in ensuring that customers are able to make maximum use of their PUE appliance to grow their economic activities.
- The **supply side** is affected by the investment climate in a country, renewable energy sector dynamics (such as the design and implementation of policies and regulations that support the uptake of PUE), and the presence and reach of PUE appliance distributors, who play a key role in driving uptake.
  - **Distribution** is affected a number of factors, such as distribution networks (including those in rural and remote areas) and the working capital constraints of distributors (which determines whether they can provide in-house consumer financing or not).
  - **Sales and after-sales support** requires trained technical personnel and knowledgeable sales agents, who are needed to ensure that customers purchase the right PUE appliances.
  - **Broader regulatory issues** include the need for effective regulatory frameworks that can support the uptake of PUE, including licensing regimes, quality standards, and adoption and implementation of tax and duty regimes that encourage PUE investment, among other things.
  - **Supply-side financing instruments** have been developed to ensure that appliance distributors are better able to finance their activities and growth, including results-based financing and several instruments using concessional financing. Additionally, government policies that waive or lower taxes or duties on PUE appliances lower cost and therefore raise affordability for customers and financial viability of appliance distributors.

Integrating PUE promotion into market systems development can help achieve maximum impact for households, farmers, and small businesses, while also improving the financial viability of mini grid operators. In rural areas, PUE adoption should be part of an integrated rural development strategy. If consumers are not able to generate greater incomes from their adoption of PUE appliances and, for example, the greater crop yields achieved as a result, then their PUE investment will not be worthwhile. Therefore, complementary investments are needed to ensure that gains from electricity connection and PUE adoption can be attained, such as road and bridge construction and transport and logistics services that enable market access and the sale of agricultural outputs in urban areas.

Mini grid development should better integrate productive use of energy activities and be sized appropriately to cater for the level and nature of existing and future local PUE demand, in addition to estimated household usage. PUE plays a key role in ensuring that mini grids are financially viable, with PUE users contributing a notable proportion of mini grid revenues despite normally comprising only around 15% of mini grid customers. Mini grid developers need to balance how much electricity they're providing with how much consumers are using, making good use of PUE use during daylight hours (when the cost of solar energy generation is marginal). This approach balances the needs of customers and increases the capacity utilisation of mini grids.

Support is also needed for governments, particularly those that experience capacity constraints, to assist in development of PUE regulations and keeping them abreast of sector developments. Cross-sectoral and inter-ministerial collaboration is needed to cover key sectors (including energy, agriculture, health, water, vocational training, infrastructure development, and rural development) and coordinate a large number of different actors (including local governments, mini grid operators, appliance distributors, local communities, donors and development partners) and all aspects of the PUE ecosystem (including licensing, quality standards for appliances, tax and duty regimes, etc).

Although the challenges around stimulating PUE adoption in low capacity and fragile environments are considerable, mechanisms developed to overcome these challenges are being innovated and improved continuously. More public and private finance needs to be mobilised to enable these efforts to scale up. Greater recognition of the critical importance of PUE to mini grid viability and improved integration of financing of mini grids and PUE is needed to ensure that PUE distribution can be scaled up in line with efforts to scale up mini grid development as part of efforts to expand energy access.

See the policy toolkit *Driving productive use of energy in fragile contexts* for more information on this topic.

See also the case study *EnerGrow: Providing asset financing for productive use of energy products in Uganda* for an example of an asset financing company driving uptake of productive use of energy appliances.

3.6. Data and technology

One of the key challenges in expanding electricity access is the limited availability and accessibility of quality data in many low-income countries, especially FCS. Both the World Bank and the International Energy Agency (IEA) measure energy access in a binary manner, i.e., either a household is connected, or it is not. Essential data on electricity consumption trends, affordability and reliability of electricity supply, and its contribution to the quality of life have not traditionally been tracked, although these are crucial to understanding the existing gaps for better targeting.

The lack of granular data hinders accurate identification of unelectrified communities and their energy needs and impedes energy planning. On-the-ground surveys to collect this data are prohibitively expensive and can be too dangerous to undertake in situations of fragility and conflict. New geospatial technologies have emerged as promising solutions to fill this gap, enabling national planners and mini grid developers to optimise electrification strategies.

Geospatial technologies can pool datasets collected from a range of sources, including:

- Open-source databases, e.g., energydata.info and OpenStreetMap
- Proprietary databases for more granular remote sensing and satellite imagery (e.g., Maxar's building footprint)
- International organisations, e.g., World Bank, IEA, and the International Renewable Energy Agency (IRENA)
- National and sub-national government departments, e.g., census bureau, statistics department, and ministries of electricity and energy.

They integrate data on both energy demand and supply, as well as location-specific information – data often covers demographics (e.g., population number and distribution, poverty rates, urbanisation rates), social and productive uses of energy (e.g., education and health facilities, agricultural crops, location of markets and mines), energy resources (solar irradiance, hydro resources, wind speed), and infrastructure (roads, electricity transmission and distribution lines).

Geospatial tools can reduce costs, increase transparency, and can be used to identify high-potential sites for solar mini grids. However, least-cost electrification plans in FCS must also take into account aspects of fragility and conflict to ensure that proposed plans are viable in these settings. For example, WAYA Energy's tool incorporates data from ACLED on frequency and intensity of conflict incidents in specific areas.

Another major challenge for FCS is the complexity of implementing smart and digitalised mini grids. These grids, equipped with advanced hardware like smart meters and inverters, and supported by software solutions, can greatly optimise energy generation and storage, particularly with intermittent solar power. They can also significantly improve monitoring and control of mini grids, including remotely, which is critical for FCS where travel may be difficult or risky. This digitalisation promises to enhance the efficiency and sustainability of mini grids, while reducing operational costs. Yet, implementing these smart technologies in FCS remains difficult due to high costs, limited local capacity, and poor internet and mobile network penetration.

For FCS specifically, the combination of challenges around accessing reliable data and deploying digitalised mini grid technologies requires flexible, context-specific solutions that balance technological innovation with the realities of fragile environments. Some of the ways in which policymakers, mini grid developers, and other actors can navigate the challenges posed by FCS include:

- International organisations tasked with monitoring progress towards SDG 7 should establish a **common framework** and **build consensus on data sources, collection methods, and assumptions**. This is necessary to enable improved measurement of electricity access data.
- Governments should develop **technology-neutral national electrification plans** that go beyond the usual least-cost electrification thinking and are sensitive to the inherent risks prevalent in FCS. Engaging private sector actors in developing electrification plans can assist with better integration of on-the-ground realities and experiences and can assist planners with setting realistic timelines to achieve national electrification targets.
- When geospatial electrification plans are developed by third parties (as is often the case), governments should require that these third parties **build the capacity of the government counterparts** who will be responsible for maintaining the database and the electrification model.
- Within the confines of established ethical standards, governments, mini grid developers, and development partners should endeavour to **share more data** with each other to foster more evidence-based decision-making. Data that can be shared should be shared with peers to foster learning within the mini grid community, with partners where there is a legitimate business need, and with the general public for awareness where possible.

See the policy toolkit *Data and technology: Challenges and opportunities for solar mini grids in fragile contexts* for more information on this topic.

See also the case study *Energy Access Explorer: An open access tool to enable data-driven energy planning* for an example of a geospatial tool that can be used by a range of stakeholders for energy planning.

3.7. E-waste management

The World Bank estimates that in 2021, 19,000 solar mini grids were installed and another 30,000 were planned across over 130 countries. To reach universal electricity access by 2030 would require the development of a total of 210,000 mini grids.[23] The roll-out of mini grids is inevitably followed by the increased penetration of electrical and electronic equipment (EEE) within a country.

Increased access to EEE within countries raises the question of what should happen to this equipment once it reaches its end-of-life (EoL). An estimated 5.5-6 million metric tonnes of solar panels are expected to be decommissioned by 2050. E-waste is the fastest growing waste stream in the world, with 62 million tonnes of waste generated in 2022 and expectations that it will reach 82 million tonnes by 2030.[24] Less than a quarter of e-waste is recorded as collected and recycled through formal channels. Instead, a large portion of e-waste is dumped in landfills, burned, or buried, with the informal sector repurposing what valuable materials they can find using crude recycling methods.

Improper disposal of e-waste creates a considerable threat to communities living near e-waste disposal sites. E-waste has been found to contain lead, mercury, cadmium, and nickel, as well as brominated flame retardants, all of which have detrimental impacts on human health. Lead is particularly hazardous for children, causing neurodevelopmental and behavioural challenges.

However, setting up the infrastructure and regulations needed to ensure the safe disposal of e-waste is a considerable challenge in FCS. Difficulties include:

- **Lack of financial incentives** – Disposing of e-waste properly is generally too costly even when valuable raw materials can be extracted. The high cost involved in picking up the used parts from remote areas and sending them to appropriate facilities where they can be recycled, together with the low volumes involved, means that it is generally prohibitively costly to do.
- **Insufficient infrastructure** – Many countries still lack solid waste management infrastructure, let alone facilities to recycle solar panels, circuit boards, and batteries. There is also a lack of collection points and storage facilities that are accessible for households and businesses to dispose of their e-waste. This is compounded by a lack of reliable road infrastructure in some countries, especially to more remote areas, making the transportation of e-waste more costly.
- **Undeveloped regulations** – Without government regulations, no stakeholder bears the legal responsibility to finance and operate e-waste management activities. Only three countries (Ukraine, Cameroon, and Nigeria) out of the 39 countries categorised as FCS by the World Bank have e-waste regulations in place. These regulations can be hard to establish, as there are several actors involved in the creation of e-waste (producers of each component, developers, and

23 ESMAP, 2022.
24 UNITAR, 2024.

consumers in the case of mini grids). Even if regulations are adopted, they are hard to enforce as governments require capacity to set targets and monitor recycling value chains.

- **Lack of awareness** – Consumers generally lack awareness of the environmental and health problems caused by e-waste. They are also unaware of the best way to dispose of e-waste and where to find the facilities to do so.

- **Poor maintenance and repair** – Solar mini grids require consistent maintenance and repair to ensure that they reach their expected lifespan. This is costly to do, especially in remote areas or conflict zones. Obtaining spare parts is expensive, with most parts needing to be imported. Specialised labour is needed to ensure proper maintenance and repair, and the local labour force often lacks the necessary technical training.

- **Low quality and suitability of the solar mini grid** – Many solar panels break down before their EoL. Solar mini grids are sometimes built using cheap, ill-adapted, or second-hand components, leading to their premature EoL. Matching demand to supply is also crucial in ensuring the sustainability of the mini grid. If the demand is too low, the fees paid by the existing customers may not be enough to cover the maintenance and repair costs. If the demand is too high, the grid will be overloaded, which can lead to its premature wear.

- **Inadequate data** – Many governments lack robust data on the quantity of e-waste in their countries and its composition, making it difficult for them to design policies and regulations that effectively tackle the issue.

In FCS, this is compounded by security issues which increase the cost of collecting e-waste and maintaining the grid. Exchange rate fluctuations and depreciation of the local currency can make it more expensive (in local currency terms) to import the spare parts necessary for repair. Finally, poor governance and resource constraints mean that it is difficult for governments to build the infrastructure and regulations necessary to safely dispose of e-waste. Given the myriad of priorities facing FCS governments, building e-waste infrastructure seldom features on governments' agendas but, as the quantity of e-waste in a country rises, it will become an increasingly important issue.

There are several pathways that FCS can adopt to tackle the rising challenge that e-waste poses, including:

- **Emphasise prevention** – As much as possible, governments and mini grid developers should minimise the e-waste generated by the grid and other EEE. E-waste prevention can take many forms: ensuring correct sizing of mini grids to ensure that they are not under- or over-used, designing the grid in such a way that it can be easily repaired, and undertaking regular maintenance of the grid to avoid premature failures. The quality of the grid needs to be high enough to avoid early dysfunction, which can often happen when the components are of poor quality or second hand.

- **Build basic recycling infrastructure for the most hazardous components** – Governments and developers can collaborate to start building basic recycling infrastructure: collection points, storage and transportation systems, and dismantling sites. This can be initially restricted to the most hazardous components (such as lead-acid batteries) or to components that are easier to recycle (such as copper cables).

- **Build on the informal recycling sector** – Most countries have an informal recycling sector that collects e-waste and recovers its most valuable parts. This is often done in a rudimentary way, endangering workers and communities alike. However, instead of suppressing this sector, governments can work with international actors and EEE manufacturers, to use the informal sector and its network to collect higher volumes of e-waste. Training can be delivered to informal recyclers to increase their safety standards and protective equipment can be distributed. Financial incentives can be offered to informal recyclers to bring back the e-waste collected to proper treatment facilities. Over time, governments can start formalising these operations.

- **Collect data on e-waste** – Data is required to start regulating e-waste and building key infrastructure, but this is often missing in FCS. Governments can work with international organisations such as UNITAR to start building a database on e-waste within their country. Generally, this requires inputting import data into a lifecycle model to assess when EEE will reach their EoL. Capacity should be built within governments to start collecting data.

- **Start regulating as capacity increases** – To ensure that a sizable fraction of e-waste is safely disposed of, governments will eventually need to regulate it. This is generally done through an Extended Producer Responsibility (EPR) policy. This type of regulation puts the financial and sometimes operational responsibility for the safe disposal of e-waste on producers of EEE. This type of regulation takes time to be drafted and adopted, with many different public and private stakeholders needing to collaborate to ensure that each has a clear and accepted role to play. It also requires building the capacity of governments to monitor and enforce the policy. Governments can work towards this by mapping stakeholders, current regulations on hazardous waste, and projects on e-waste. As capacity builds over time, governments can then start drafting e-waste regulations with the help of international organisations.

See the policy toolkit *E-waste management: Strategies and policies in fragile contexts* for more information on this topic.

See also the case study *E-waste management programme in Cox's Bazar refugee camps* for an example of how e-waste repair and disposal programmes can be established in challenging environments.

4. Further research is needed

Review of the existing evidence base has shown that there is very little evidence available on scaling up mini grids and driving uptake of productive use of energy appliances in fragile and conflict-affected settings specifically, although considerable knowledge exists among practitioners working on these topics. To strengthen the evidence base on what works and does not work to support mini grid deployment in FCS, more primary research and documenting of case studies are needed to better understand the dynamics that may be specific to these settings and how they may impact and be impacted by fragility and conflict.

An example of specific aspects that were highlighted during the course of this project as needing research include the following:

- How the financing for mini grids, on the one hand, and productive use of energy appliances, on the other hand, can best be brought together in projects (rather than persistence of the largely siloed financing approach that persists today).
- How emerging data technologies can help generate more data on energy supply and demand factors, willingness and ability to pay, etc. in fragile situations where on-the-ground data collection is less feasible.
- How geospatial planning tools can be tailored to increase their application to contexts of fragility and conflict.
- Experimentation is needed around what payment terms for productive use of energy appliance loans work best in different low-income and fragile settings. This could include mechanisms to protect consumers in situations of evolving fragility and economic shocks.
- How gender can be more integrated into efforts to roll out mini grids and productive use of energy appliances, ensuring that specific measures are taken for projects to be inclusive of women and other marginalised groups.
- How mini grid projects can be designed and implemented in more conflict sensitive ways to ensure they don't aggravate existing tensions and divides in fragile settings, and what measures are needed in different contexts to enable these projects to make positive contributions to peace in local contexts (recognising these measures will vary across contexts).
- What facilities for e-waste recycling and safe disposal can feasibly be developed in low-income and fragile settings, including how to build on existing informal activities with provision of training, protection equipment, incentives to bring e-waste into the formal sector, etc.

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State Fragility initiative

IGC

The **State Fragility initiative** (SFi) is an International Growth Centre (IGC) initiative that aims to work with national, regional, and international actors to catalyse new thinking, develop more effective approaches to addressing state fragility, and support collaborative efforts to take emerging consensus into practice. SFi brings together robust evidence and practical insight to produce and promote actionable, policy-focused guidance in the following areas: state legitimacy, state effectiveness, private sector development, and conflict and security. SFi also serves as the Secretariat for the Council on State Fragility.

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