Partnerships for Power

Unlocking Scale for Interconnected Minigrids in Nigeria

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RMI

About RMI

Rocky Mountain Institute (RMI) is an independent, nonpartisan nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to secure a prosperous, resilient, clean energy future for all. In collaboration with businesses, policymakers, funders, communities, and other partners, RMI drives investment to scale clean energy solutions, reduce energy waste, and boost access to affordable clean energy in ways that enhance security, strengthen the economy, and improve people's livelihoods. RMI is active in over 60 countries.

Global Energy Alliance for People and Planet
GEAPP

About GEAPP

The Global Energy Alliance for People and Planet (GEAPP) is an alliance of philanthropy, governments in emerging and developed economies, and technology, policy, and financing partners. Our common mission is to enable LMIC's shift to a clean energy, pro-growth model that accelerates universal energy access and inclusive economic growth, while supporting the global community to meet critical climate goals during the next decade. As an alliance, we aim to reduce four gigatons of future carbon emissions, expand clean energy access to one billion people, and enable 150 million new jobs. With philanthropic partners, IKEA Foundation, The Rockefeller Foundation, and Bezos Earth Fund, GEAPP works to build the enabling environment, capacity, and market conditions for private sector solutions, catalyze new business models through innovation and entrepreneurship, and deploy high-risk capital to encourage private sector solutions and assist just transition solutions. For more information, please visit www.energyalliance.org.

Acronyms

ACPU	average consumption per user
AEDC	Abuja Electricity Distribution PLC
ATC&C	aggregate technical, commercial, and collection
AVR	automatic voltage regulator
BESS	battery energy storage system
capex	capital expenditure
CO_2	carbon dioxide
DARES	Distributed Access to Renewable Energy Scale-Up
DER	distributed energy resources
DisCo	distribution company
DUOS	distribution use of system
EPC	engineering, procurement, and construction
GEAPP	Global Energy Alliance for People and Planet
GVE	Green Village Energy
GW	gigawatt
IDEC	import duty exemption certificate
IE	Ikeja Electric
IMAS	Interconnected Minigrid Acceleration Scheme
IMG	interconnected minigrid
KEDCO	Kano Electricity Distribution Company
kV	kilovolt
kVA	kilovolt-amperes
kW	kilowatt
kWh	kilowatt-hour
kWp	kilowatt peak
LCOE	levelized cost of electricity
MVA	megavolt-amperes
MW	megawatt
MWh	megawatt-hour
MWp	megawatt peak
O&M	operations and maintenance
OEM	original equipment manufacturer
NEMSA	Nigerian Electricity Management Services Agency
NERC	Nigerian Electricity Regulatory Commission
opex	operating expenditure
POI	point of interconnection
PUE	productive use of electricity
PV	photovoltaic
REA	Rural Electrification Agency
SMEs	small-to-medium enterprises
V	volt

Contents

Executive Summary

Interconnected minigrids (IMGs) are a transformative solution for improving power availability and reliability, expanding energy access, and strengthening distribution networks across Africa. By fostering collaboration between developers and utilities through a win-win-win business model,[i] IMGs bridge the last-mile electricity gap and integrate renewable energy generation at the distribution level.

In Nigeria, the first four operational IMGs have added 3 megawatts (MW) of solar photovoltaic (PV) capacity and 3 megawatt-hours (MWh) of battery storage, have retrofitted and expanded the existing distribution network, and now serve approximately 6,300 connections in urban and peri-urban areas (see Exhibit ES1).[ii] These pioneering projects offer critical insights to accelerate future IMG developments — making them faster, more cost-effective, and scalable. This report distills key lessons, presents data-driven insights, and offers actionable recommendations to drive the next phase of IMG expansion in Nigeria and beyond.

Exhibit ES1 IMG pilot projects fact sheet supported under RMI and GEAPP IMG acceleration program

	Unit	Toto	Zawaciki	Robinyan	Wuse
Distribution company (DisCo) service territory		AEDC	KEDCO	IE	AEDC
Developer		PowerGen	Bagaja	Darway Coast	GVE
Project status		Operational	Operational	Operational	Testing
Solar PV capacity	kW	352	1,000	500	1,000
Battery Li-ion capacity	kWh	972	N/A	625	1,200
Interconnection voltage	kV	33	33	11	11
Connections	No.	1,756	1,039	1,400	2,166
Distribution network	km	19	5	13	N/A
Total capex	US$, Million	3	2.5	1.3	2.4
Average hours of supply	hours/day	16	18	15	13
DisCo supply hours	hours/day	3	16	8	7
Monthly DisCo revenues	NGN, Million	0.6	5.2	0.4	4.8
Average end-user tariff	NGN/kWh (US$/kWh)	450 (US$0.28)	150 (US$0.09)	209 (US$0.13)	215 (US$0.13)

Note: US$ to NGN exchange rate: NGN 1,600/US$1.

RMI Graphic. Source: RMI analysis of IMG pilot data

i For utilities, developers, and customers.

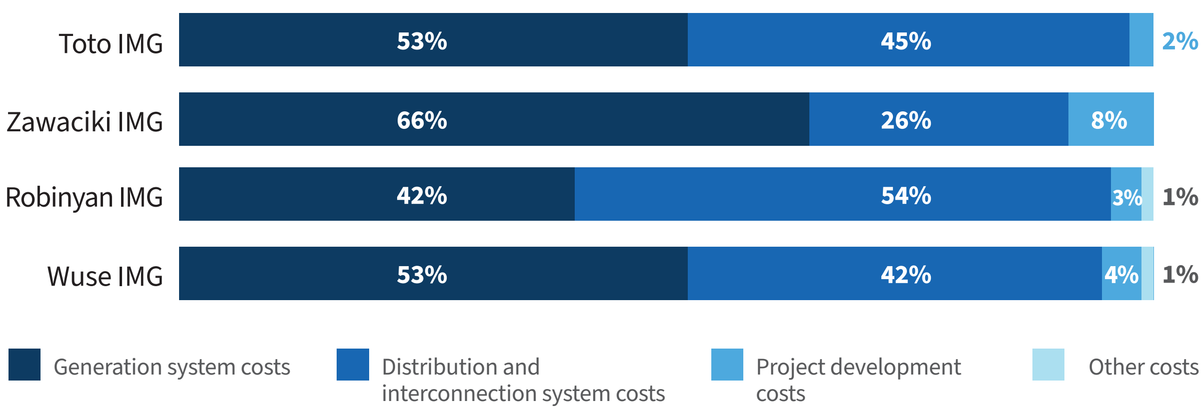
ii As of March 2025, only Wuse IMG (1 MW) was still under testing; the rest of the IMG pilot projects were operational.

IMG pilot project distribution and interconnection costs represent about 50% of total capital expenditure (capex) due to pioneering collaboration, while generation costs remained higher than global averages.

Across the four IMG pilots executed by different IMG developers, **distribution and interconnection capex accounted for nearly half of the total project costs**, often exceeding initial budgets. The aging and inadequate distribution networks, coupled with poor bulk grid power quality, required IMG developers to make substantial investments in distribution and interconnection equipment. Generation assets' capex prices (i.e., solar PV, battery energy storage system [BESS], and power conversion) were 47% higher than industry benchmarks with a **total median aggregated cost of US$2,547 per kilowatt (kW) or US$1,323 per connection** (see Exhibit ES2). For the most part, developers did not use aggregation procurement platforms.

Exhibit ES2 High-level overview of IMG pilot projects cost

IMG cost by category



Category	Unit	Median	Range
1. Generation system	US$/kWp	1,425	1,103–4,460
2. Interconnection system	US$/project	73,087	15,017–120,626
	US$/kWp	86	30–248
3. Distribution system	US$/connection	503	216–725
4. Total capex	US$/kWp	2,547	1,781–8,360
	US$/connection	1,323	894–1,743

Note: Including batteries, a full description of the generation components accounted for in the first line is listed in *Appendix B*.

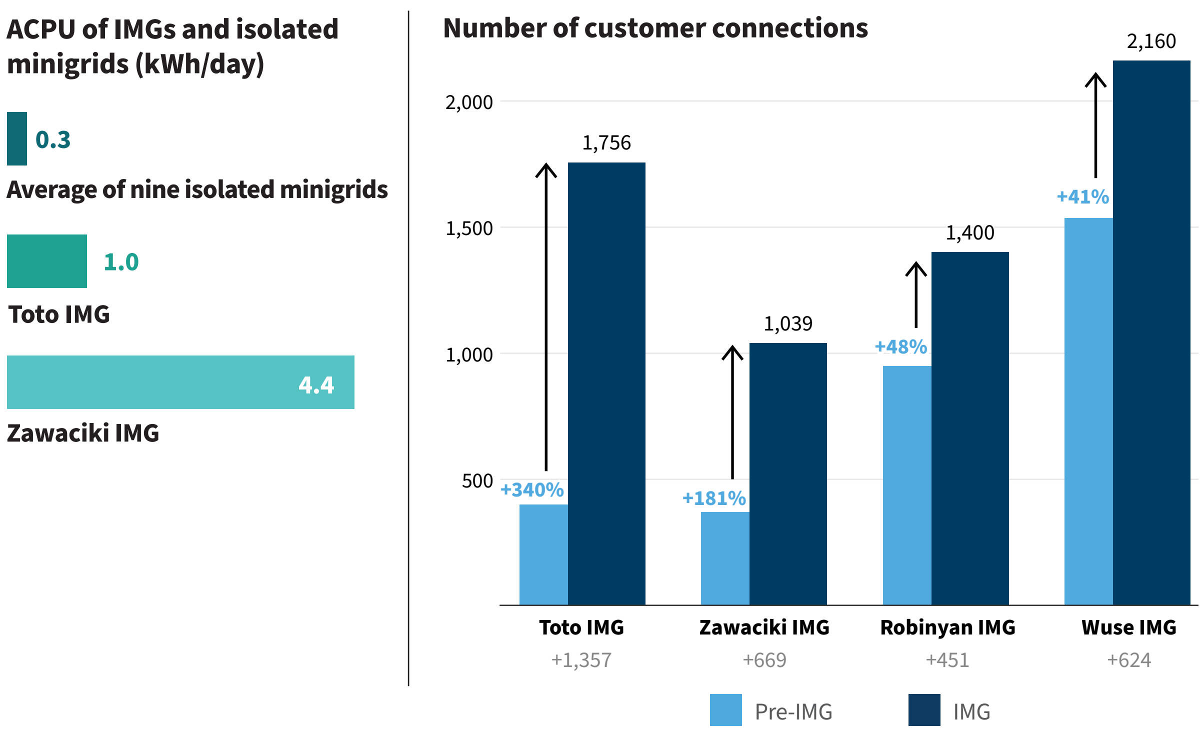
RMI Graphic. Source: RMI analysis of IMG pilot data

All four supported pilot projects experienced significant delays, with an **average completion time of four years**. These delays stemmed from prolonged negotiations of project agreements, challenges in equipment procurement, importation and logistics, and extended approval processes for construction and government inspection. Additionally, the **absence of standardized interconnection architecture** and clearly defined roles and responsibilities further complicated project execution. These challenges highlight the urgent need for greater standardization to streamline development and accelerate implementation.

IMG pilot projects resulted in a 95% increase in connections, and a 15-fold increase in average consumption per user (ACPU) compared to their peer-isolated minigrids (see Exhibit ES3).

The operational data presented in this report primarily draws from the Toto and Zawaciki IMGs, which had been operating for over a year as of March 2025. **Both IMG communities have experienced significant improvements in energy supply and reliability, alongside a notable increase in connections and metering rates.** These communities are also reporting higher energy consumption (higher ACPU) compared to their isolated minigrid peers, which translates to higher monthly revenues for developers.

Exhibit ES3 Impact of IMGs on number of connections and electricity usage in IMG communities

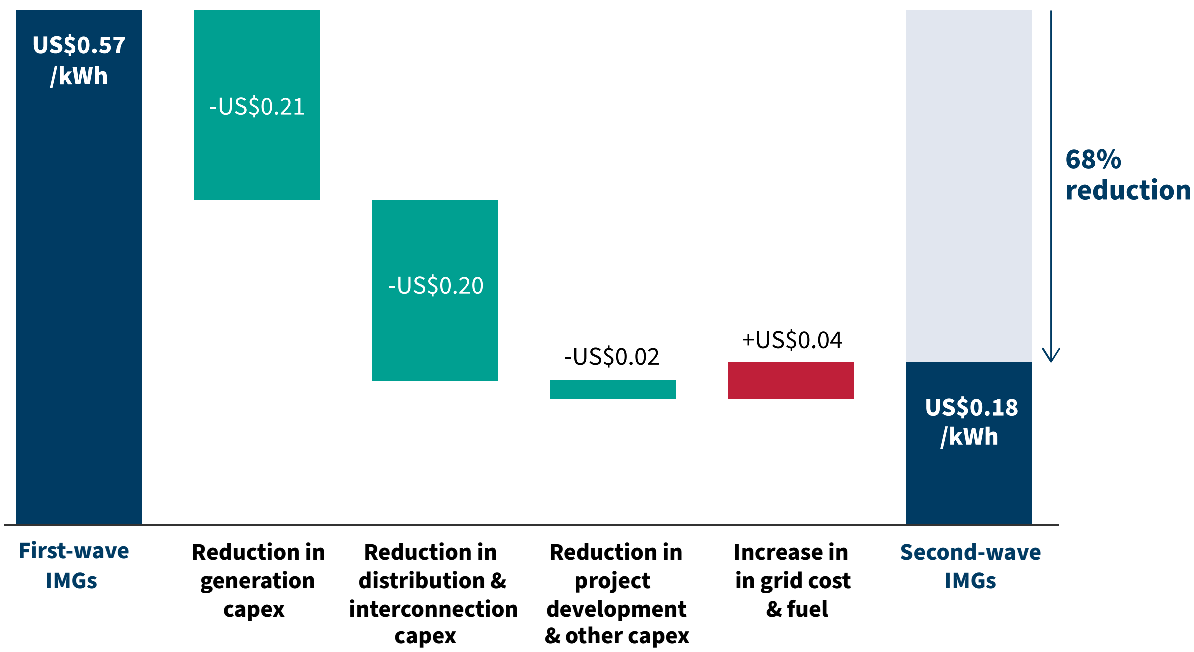


RMI Graphic. Source: RMI analysis of IMG pilot data

Meanwhile, **distribution companies (DisCos)** have significantly reduced losses and increased revenues in these two project locations (Toto and Zawaciki), **achieving a 100% collection rate from previously unprofitable communities**. DisCos are also benefiting from reduced operational costs because those are borne by the developers, which often means a DisCo can divert resources to other areas, potentially alleviating resource constraints elsewhere. However, DisCo supply availability at IMG locations experienced a slow ramp-up period during the first six to eight months; experience reveals that DisCos needed time to prioritize delivering power to IMG locations during agreed-upon supply hours.

In a recent report, RMI unveiled a 22-gigawatt (GW) distributed energy resources (DERs) opportunity across Nigeria that could translate into 4,000–8,000 IMGs across service territories.[1] As scaling efforts and DER regulatory targets strengthen market support, we have identified three key cost reduction strategies that could lower costs to US$0.18/kilowatt-hour (kWh), representing a **68% decrease** from the average levelized cost of energy (LCOE) across the first wave of IMGs (see Exhibit ES4).

Exhibit ES4 **IMG cost of service reduction opportunities**



RMI Graphic. Source: RMI analysis of IMG pilot data

To achieve this level of cost reduction and drive projects at faster and larger rates, the sector must transition into a more mature market with specialized actors across the value chain, alongside increased public sector support.

RMI's critical path recommendations for scaling IMGs are categorized around five thematic areas:[iii]

1. Project preparation, design, and execution

- Harmonized site selection criteria for win-win. Developers and DisCos should select locations with moderate distribution network refurbishment needs that improve service to existing underserved customers while expanding it to unserved ones.

- DisCos should align their network investments and plans (upgrades, digitization, and metering program efforts) with IMG and DER opportunities to maximize value and reduce developers' distribution capex. DisCos should prioritize network investments to ensure high grid availability for IMG locations.

- DisCos should define clear roles and responsibilities in project agreements. Developers, on the other hand, need to build stronger collaboration with DisCos.

- DisCos should develop a substantial pipeline of IMG projects, tender them in lots, and utilize competitive procurement to achieve the least-cost development. DisCos should ensure data availability to facilitate IMG project preparation and reduce data collection lead time.

2. Cost optimization and financing

- Developers should build larger projects and portfolios to benefit from economies of scale. Developers should leverage DisCo feeders and corridors with existing IMGs to build more IMGs and DERs that serve multiple demand hubs. DisCos should concession larger areas or entire feeders to developers to build IMG portfolios and reduce distribution and operations costs per project.

- Developers should outsource specialized project life-cycle components that require external expertise, such as detailed engineering, construction or operations and maintenance, to avoid delays and cost overruns witnessed during the first wave of projects.

- Government and policymakers should allocate public financing to support network upgrades, last-mile connections, and interconnections.

3. Grid infrastructure and development

- Developers should hire DisCo-approved contractors for distribution network upgrades, adhere to DisCo distribution network technical specifications, and coordinate implementation closely with DisCos for efficiency.

- DisCos should provide smart meters at the interconnection points of all DER customers for better visibility and reconciliation.

- Developers should prioritize data-driven asset management to reduce network losses, prevent theft, and improve revenue monitoring.

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iii Additional recommendations are provided in Section 5 of this report.

Electric sewing machine in a tailor shop at Robinyan.

4. Regulatory and enabling framework

- Government and policymakers should expand the allowable installed capacity for larger IMGs.[iv]
- Government and policymakers should adapt minigrid regulations for IMGs, addressing key challenges such as grid supply tariffs, distribution use of system (DUOS), and legacy debt.
- Government and policymakers should monitor and report key operational improvements from existing projects, enforce performance standards, and share learnings.

5. Institutional and workforce development

- Developers should improve governance and grow senior leadership teams to enhance operational effectiveness.
- DisCos should create and support dedicated DER units to drive the implementation of IMGs.
- Financiers and donors should include and prioritize workforce development to build the energy transition workforce needed for project development.

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iv Distributed Access to Renewable Energy Scale-Up (DARES) Phase 1 is in advanced conversations with the Nigerian Electricity Regulatory Commission (NERC) for a capacity waiver from 1 to 10 MW of installed capacity for the 40 selected sites.

1. Transforming Nigeria's Electricity Sector: The Case for Interconnected Minigrids

In Nigeria, an estimated 150 million people — 75% of the population — have no or unreliable access to electricity.[2] The national grid only meets 20% of the country's electricity demand, forcing residential, institutional, and commercial customers to rely on petrol- and diesel-powered generators that cost over 600 NGN/kWh (US$0.40/kWh) just for fuel to operate.[3] This fossil fuel dependency comes at a steep cost: households and small-to-medium enterprises (SMEs) collectively spend $12 billion annually on purchasing and operating generators, while manufacturers allocate up to 40% of their operating costs to energy expenses.[4]

> **Nigeria is recognized as one of the leaders in isolated minigrid development on the continent, creating a favorable regulatory environment, providing subsidies, and integrating these solutions into national development strategies.**

DERs, particularly solar energy solutions, are widely recognized as a significant part of the solution to Nigeria's energy deficit.[5] Isolated solar minigrids are recognized as one of the least-cost options for customers not connected to the main grid. Over the past decade, the Nigerian Rural Electrification Agency (REA) and private energy developers have expanded the sector, deploying 176 minigrids and over 11 MW of solar PV capacity under the World Bank–sponsored Nigerian Electrification Project (NEP).[6] Nigeria is recognized as one of the leaders in isolated minigrid development on the continent, creating a favorable regulatory environment, providing subsidies, and integrating these solutions into national development strategies.

However, isolated minigrids have faced some limitations in scaling. The very rural sites where distribution companies (DisCos) typically allow isolated minigrid deployment are small and have limited productive use of energy.[v] This typically leads to low utilization of the minigrid assets, with customers spending less than US$2 monthly on electricity and using only a fraction of available supply.[7, vi] Low utilization means that sales revenues for the minigrid operator are typically inadequate to cover the operational expenses needed to maintain infrastructure and service quality to provide an adequate level of reliability to commercial and productive use of electricity (PUE) users, with 40% of this customer class finding minigrid power insufficient.[8] Finally, isolated minigrids often have a high LCOE due to high up-front costs, large battery systems, and maintenance expenses.

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v Nigerian distribution utilities are commonly known as DisCos. "Utilities" and "DisCos" are used interchangeably in this report.

vi Data is from a subset of 11 Nigerian rural minigrids.

Despite the progress made with isolated minigrids, tens of millions of Nigerians continue to lack reliable electricity access. This underscores the urgent need for scalable complementary solutions to accelerate service delivery and close Nigeria's energy gap. Interconnected minigrids (IMGs) — minigrids that leverage existing grid infrastructure and receive power from the main grid — provide underserved customers with improved electricity supply by combining electricity from the main grid along with DERs that are part of the IMG solution and situated near consumption. IMGs result in reliability improvements at a lower cost than existing fossil fuel solutions.

IMGs are implemented in urban, peri-urban, and rural areas where DisCos already serve customers, although unsatisfactorily. Typically, these areas have large populations and robust economic activities, leading to substantial existing energy demand. High energy demand combined with power purchase from the main grid means IMGs achieve higher energy consumption and revenues compared to greenfield locations that are newly electrified at lower LCOE than isolated minigrids.[vii]

IMGs boost energy sales and reduce losses for the DisCo, incentivizing the DisCo to collaborate in more viable and urban locations. The DisCo saves on operational costs covered by the developer, allowing it to reallocate resources and alleviate constraints elsewhere. Furthermore, the DisCo will benefit significantly after the IMG contract terms end, as it resumes operations in an improved service territory with local generation assets, a more resilient distribution network with prepaid meters, and better customer energy consumption and payment habits. Exhibit 1 summarizes the "win-win-win" value proposition for all parties involved in an IMG.

Exhibit 1 **The value proposition of IMGs**

DisCo	Community	Developer
Increased energy sales and revenue	Increased electricity supply availability and reliability	Higher consumption and revenues than isolated minigrid
Reduced financial losses and operational constraints	Reduced levelized cost of energy	Lower LCOE and smaller BESS than isolated minigrid
Compliance with regulatory targets	Less reliance on polluting and expensive alternatives	Access to DisCo customers and opportunity for project expansion and scaling across DisCo territory
Improved distribution network		

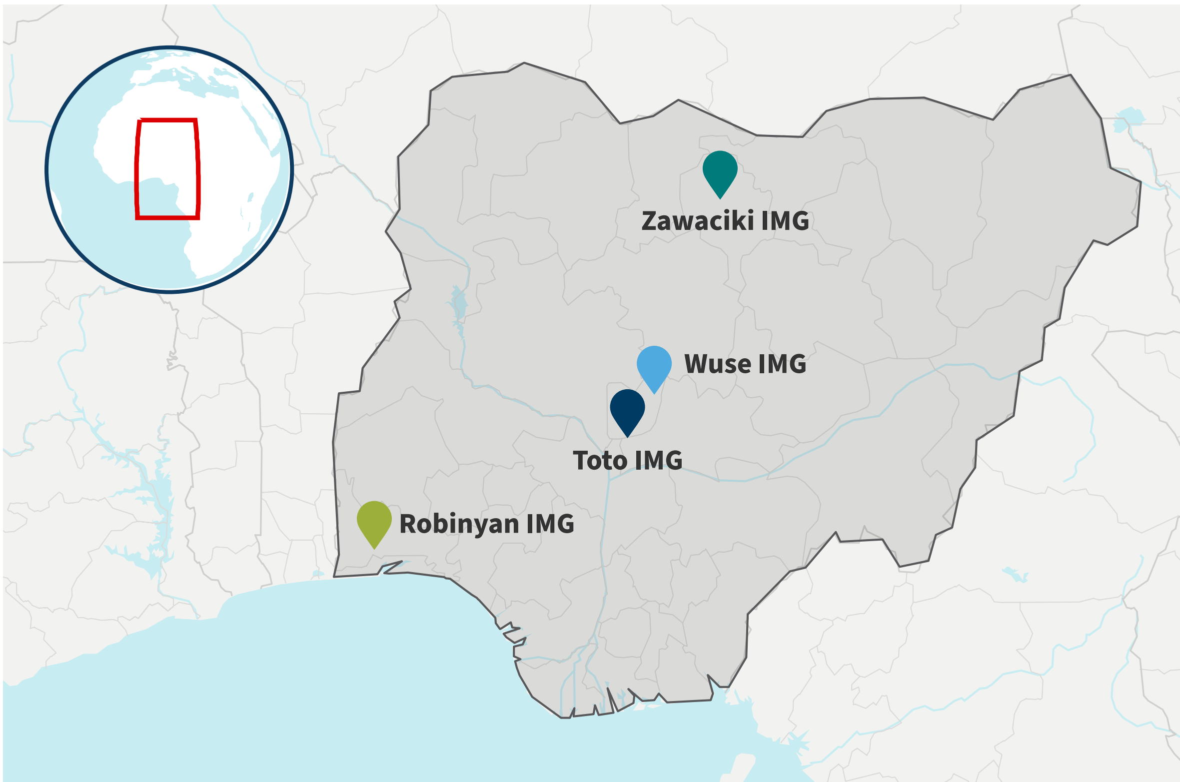
RMI Graphic. Source: RMI analysis

RMI, with support from the Global Energy Alliance for People and Planet (GEAPP), has supported the acceleration of four IMGs in Nigeria (see Exhibit 2). From October 2022 to April 2025, GEAPP and RMI supported these pioneering projects with grant financing, technical assistance, and project management support. Additionally, to facilitate project implementation, we supported the establishment of DER

vii RMI and GEAPP assumed that IMGs have a lower LCOE than isolated minigrids when supporting the four showcased IMGs. This report presents valuable learnings and insights on this assumption.

departments by placing key staff within the DisCos in whose territory these IMGs were built to provide targeted assistance to these projects, as well as to increase awareness and understanding of these solutions at the DisCo level.

Exhibit 2 Map of IMG pilot projects supported by GEAPP and RMI and analyzed in this report



Toto IMG | 2023
PV: 352 kW | BESS: 973 kWh | 1,700+ customers

Robinyan IMG | 2025
PV: 500 kW | BESS: 675 kWh | 1,400+ customers

Zawaciki IMG | 2024
PV: 1 MW | 1,000+ customers

Wuse IMG | 2025
PV: 1 MW | BESS: 1.2 MWh | 2,100+ customers

RMI Graphic. Source: RMI analysis of IMG pilot data, OpenStreetMap

Backed by data and real-world experiences collected by the developers, DisCos, and RMI, this report presents the key learnings and insights from these pilot projects. Section 1, the introduction, discusses the Nigerian energy deficit, the challenges isolated minigrids face in closing that deficit, and the need for large IMGs. Section 2 provides a summary of the first set of IMG projects supported by RMI and GEAPP. Section 3 summarizes key insights and takeaways on IMG project costs, timelines, construction, and operations. Section 4 includes a forward-looking analysis of what the cost of the next wave of IMG projects will look like, and recommendations for different sector stakeholders to drive scale in the sector are provided in Section 5.

BESS in Wuse IMG.

Past publications to advance minigrid solutions for underserved customers

The challenge of providing reliable electricity to underserved customers — those connected to the main grid but experiencing frequent and prolonged outages — has been widely discussed in the energy access sector. RMI's *Under the Grid* report highlights the difficulties Nigerian DisCos face in serving these communities and demonstrates the potential of undergrid minigrids to benefit DisCos, developers, and consumers alike.[9] The World Bank's *Mini Grid Solutions for Underserved Customers* further explores this opportunity through case studies of non-interconnected undergrid minigrids and IMGs in Nigeria and India.[10] This report builds on those foundations, offering a first-of-its-kind analysis based on real operational data from Nigeria's pioneering IMGs.

2. IMG Pilots Summary

Unlike isolated minigrids, IMGs have been slow to progress in Nigeria. In 2019, RMI supported the Mokoloki minigrid, the country's first undergrid minigrid.[11] This undergrid minigrid, deployed in a record nine months, was meant to interconnect with the distribution grid in the second phase of the project but has encountered several delays. Similarly, the Interconnected Minigrid Acceleration Scheme (IMAS) program launched between 2019 and 2020, with the grant agreements signed in February 2022 between the REA and eight local minigrid developers. The initiative supported development of up to 19 minigrid projects, of which 13 projects were planned to be interconnected. However, as of March 2025, these projects are yet to receive electricity from the main grid, presenting an opportunity for future operational interconnection.[viii]

Exhibit 3 illustrates how the typical IMG business model operates. The IMG developer finances and constructs the project, which includes the solar hybrid generation system, upgrades to the distribution network, and end-user meters. Customers within the IMG community pay a blended energy tariff to the IMG developer, who then reimburses the DisCo for the grid electricity supplied to the area as well as DUOS charges.

In 2022, RMI and GEAPP set out to demonstrate the sustainability of IMGs to improve the accessibility and affordability of electricity in underserved Nigerian regions. We selected advanced projects with tripartite agreements in place and significant execution progress, and secured financing. Partnering with experienced developers, RMI supported IMG projects across three different DisCo territories in four states in Nigeria, providing implementation and grant support to bridge affordability gaps.

Minigrid terminology

Isolated minigrid or minigrid: An isolated minigrid is a self-contained electricity generation and distribution system that provides power at the community level. Isolated minigrids are typically developed in rural areas where there is no national grid infrastructure and usually consist of a combination of the following DERs: solar PV, BESS, and a backup diesel generator.

Undergrid minigrid: An undergrid minigrid is a minigrid that is in an area with existing distribution grid infrastructure where the minigrid wheels the locally generated power from DERs through the existing distribution network but does not receive power from the main grid.[12]

Interconnected minigrid: An IMG is a minigrid that receives power from the main grid. The IMG combines electricity from the main grid along with DERs that are part of the IMG solution and situated near consumption.

Tripartite agreement: In an undergrid minigrid or IMG, the developer, DisCo, and the minigrid community will typically enter a tripartite agreement that governs the terms of the minigrid.[ix]

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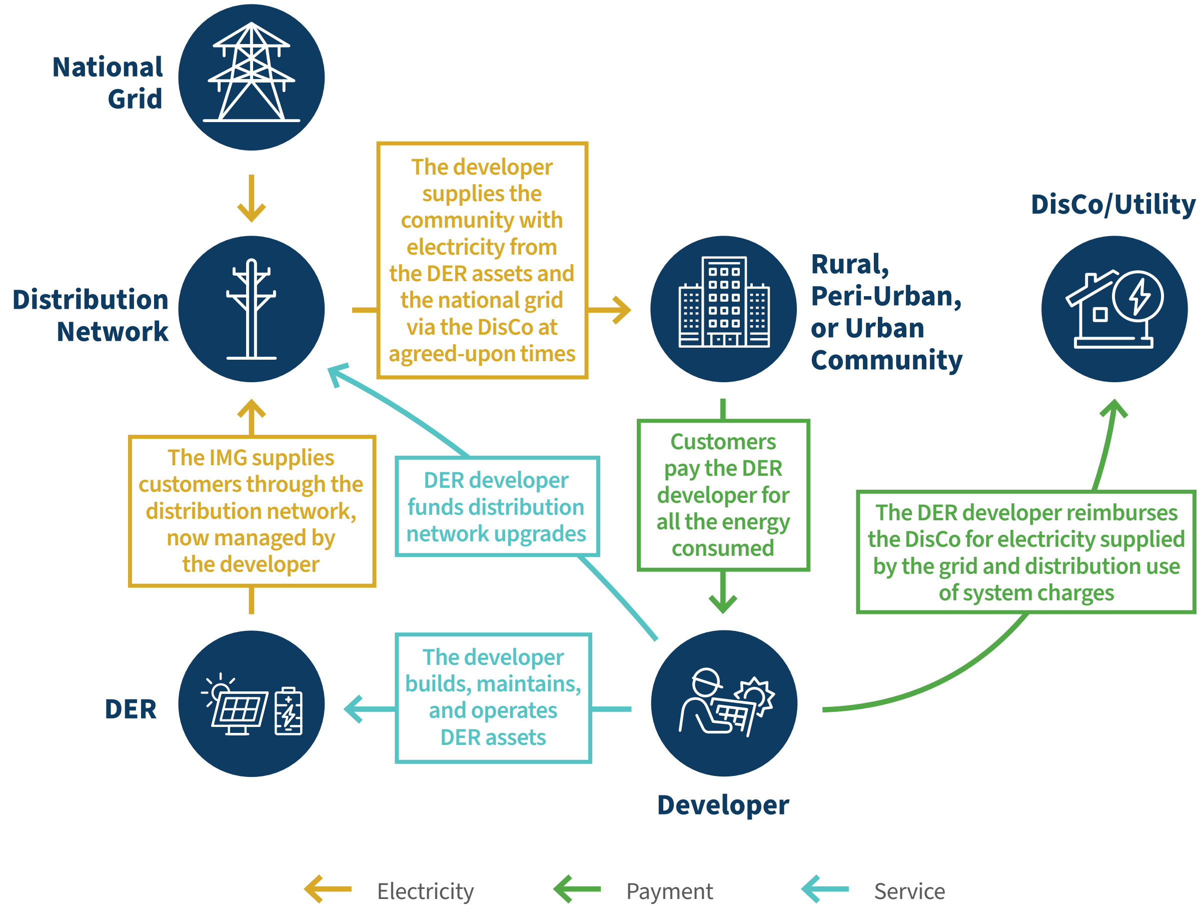
viii The IMAS initiative was supported by the European Union, German Cooperation and GIZ Nigeria Energy Support Programme.

ix RMI has developed a standardized tripartite agreement template for IMGs that defines the key terms and transaction arrangements among communities, DisCos, and developers. This template reflects best practices from these IMG pilots and can be found at **https://rmi.org/utility-enabled-distributed-energy-resources-hub/**.

Exhibit 3 **Summary of the IMG business model**



RMI Graphic. Source: RMI analysis

This section provides a summary of the four IMG pilots supported under RMI and GEAPP's DER Pilot Support Programme (see Exhibit 4). It includes site demographic details, the technical solution's main features, including the interconnection architecture, and a summary of the main roles played by the DisCo and the developer.

Exhibit 4 **Summary of IMG first wave projects supported by RMI and GEAPP**

Project Detail	Unit	Toto IMG	Zawaciki IMG	Robinyan IMG	Wuse IMG
General					
Site description		Large peri-urban residential area with significant PUE	Peri-urban hub with residential, SME, and industrial customers	Large peri-urban residential area with a blend of SMEs	Large enclosed urban market with high daytime load
Location (local government area, state)		Toto, Nasarawa	Kumbotso, Kano	Ifo, Ogun	Abuja Municipal Area Council, Federal Capital Territory
Coordinates	Lat., long.	8.394276, 7.087542	11.9081, 8.44149	6.76066, 3.3167523	9.070064, 7.465320
DisCo		Abuja Electricity Distribution Co. (AEDC)	Kano Electricity Distribution Co. (KEDCO)	Ikeja Electric (IE)	AEDC
DER developer		PowerGen	Bagaja	Darway Coast	GVE Ltd.
Lifetime avoided emissions	tons of CO_2	15,000	11,000	12,000	32,000
Total capex~	US$	3 million	2.5 million	1.3 million	2.4 million
Generation System					
Solar PV capacity	kW	352	1,000	500	1,000
Battery capacity*	kWh	972	N/A	625	1,200
Diesel backup generator	kVA	500	700	500	500
PV mounting solution		Ground-mounted	Ground-mounted	Ground-mounted	Rooftop-mounted
Type of coupling		AC-coupled	AC-coupled	DC-coupled	DC-coupled
IMG supply / DisCo supply†	hours	24/7	16/10	24/8	13/7
Generation capex	US$	1.6 million	1.7 million	0.6 million	1.3 million
Distribution and Interconnection System					
Voltage level	kV	33	33	11	11
Step-down/-up transformers	kVA	1× 500/1× 1,000	2× 500/2× 500	1× 1,000	3× 500/no step-up
Automatic voltage regulator		Yes	No	No	No
DisCo bulk meter‡	No.	1	1	1	3
Other interconnection equipment used		Low-voltage panel with automatic grid voltage sensing	Medium-voltage panel	Advanced recloser controller	Advanced automatic transfer switch
Interconnection capex	US$	90,000	120,000	15,000	56,000
Connections	No.	1,756	1,039	1,400	2,166
Distribution transformers	No.	6	5	3	3
Meter provider		Inhemeter	Kayz	Calin	Inhemeter
Distribution newly built	km	14	3.4	3.2	N/A
Distribution revamped	km	5	1.5	9.8	N/A
Distribution capex	US$	1.3 million	540,000	650,000	960,000§
Operations and Usage‖					
Average hours of supply	hours/day	16	18	15	13
Avg. hours of supply from DisCo	hours/day	3	16	8	7
Monthly DisCo revenues	NGN	580,000	5.2 million	396,000	4.8 million
Average end-user tariff	NGN/kWh	450	150	250	215
ACPU	kWh/day	1	4.4	1	1.8
Energy source split: solar PV / grid / genset	%	75% / 18% / 7%	20% / 72% / 8%	89% / 6% / 5%	69% / 21% / 10%

Note: ~Total CAPEX includes Generation capex, Interconnection capex, Distribution capex, project development and other costs. See *Appendix B* for further detail. *Lithium-ion batteries. †As defined in the tripartite agreement. ‡The DisCo bulk meter is a critical part of an IMG because it allows the DisCo to accurately meter and bill the IMG as a single customer and helps to reduce its losses. §This cost includes smart meters for end customers, substation panels, low-voltage last-mile cabling to customer blocks, and various accessories in the market. All information is self-reported by GVE. ‖ Average from July 2024 to December 2024 for Toto and Zawaciki. For Wuse and Robinyan, estimated values were used.

RMI Graphic. Source: RMI analysis of IMG pilot data

2.1 Toto IMG

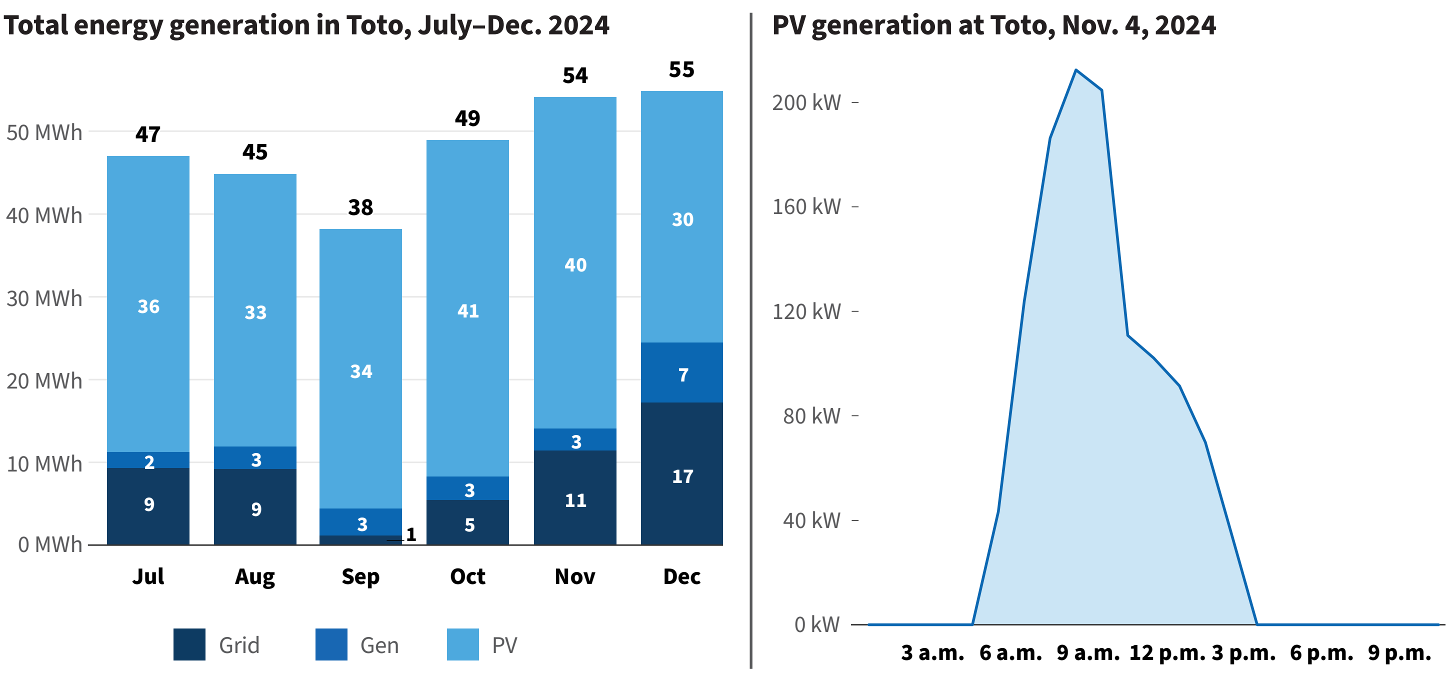
As the first operational IMG in Nigeria, this pioneering project has demonstrated the win-win-win opportunity for DisCos, developers, and peri-urban communities. With four times the ACPU of isolated minigrids, this project serves residential and commercial customers and shows promise in transforming the economics of minigrid business models.

Toto IMG generation plant.

Located about two hours south of Abuja, Toto, a peri-urban community in Nasarawa State, did not receive any grid electricity from 2019 to 2022.[13] The Abuja Electricity Distribution Company (AEDC) was unable to supply electricity to the community due to the high losses it incurred in serving the area. AEDC did not have the funds to invest in and maintain the grid infrastructure in the community. The community was largely unmetered, and AEDC was significantly understaffed in the area and could not collect payments for electricity supply or maintain and clear faults on the feeder. As a result, this community, with over 1,600 households and businesses, including a water packaging and distribution company, a polytechnic, dozens of welders and cold rooms, and the local government office, had to rely on fossil fuel generators for three years, with over 500 generators being used.[14]

In December 2023, PowerGen Interconnected Energy Limited (PowerGen) commissioned an IMG consisting of a 352 kilowatt peak (kWp) PV system, 972 kWh BESS, and a backup 500 kilovolt-ampere (kVA) diesel generator.[x] PowerGen also constructed and rehabilitated over 18 km of distribution network in Toto. This IMG has since provided reliable energy to over 1,600 customers at Toto. Exhibit 5 shows a snapshot of operational data from the Toto IMG. As of December 2024, the project has abated an estimated 800 tons of CO_2 since its inception, reflecting a significant positive environmental impact.[xi]

Exhibit 5 Operational data from Toto IMG



RMI Graphic. Source: RMI analysis of IMG pilot data

Khalid Mustapha, a welder working at his shop at Toto with electricity supplied from the IMG.

x Although Toto kicked off limited operations as an undergrid minigrid in early 2023, it only became a full IMG and received power from the main grid in December 2023.

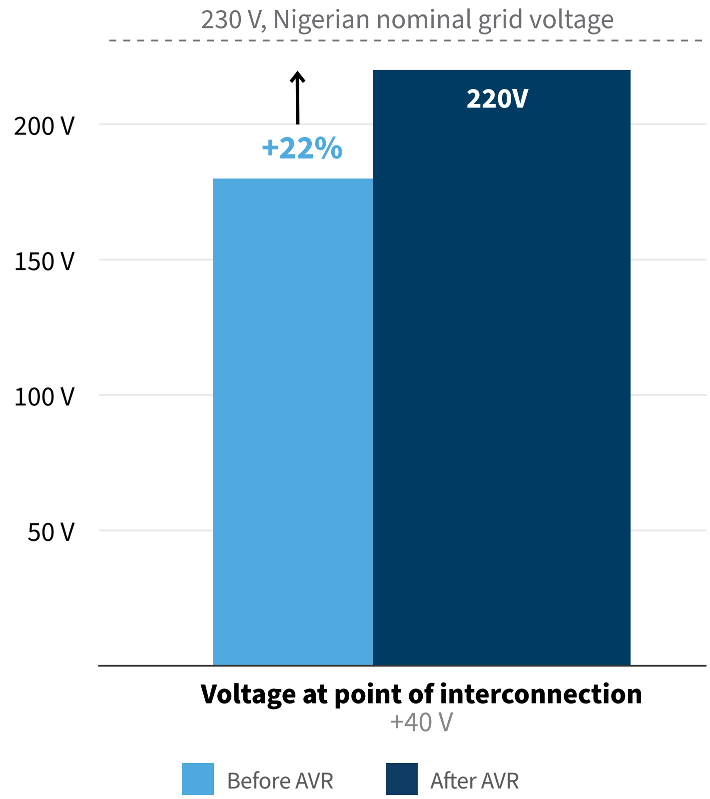
xi Assuming 1 kWh of energy generated from a PV plant avoids 1.7 kg CO_2.

Grid interconnection

The IMG receives grid supply from the Nasarawa Toto 33 kV feeder through a substation that includes a dedicated 500 kVA, 33/0.4 kV step-down transformer, a bulk meter, and protection equipment. The incoming grid supply feeds into a power converter interface where other energy sources from the generation system, such as the PV array, BESS, and the backup diesel generator, are blended with the grid supply. The generation output flows through a 1 MVA, 0.4/11 kV step-up transformer for distribution to the distribution transformers that supply users in Toto. Due to the length of the Nasarawa Toto feeder (approximately 100 km), there is a significant voltage drop at Toto. As a result, PowerGen installed an automatic voltage regulator (AVR) at the point of interconnection (POI) to improve the voltage from the grid.[xii] Exhibit 6 shows how the AVR improved power quality in Toto and Exhibit 7 shows the grid interconnection architecture of the Toto IMG.

Exhibit 6

Grid voltage regulation at Toto IMG before and after AVR installation

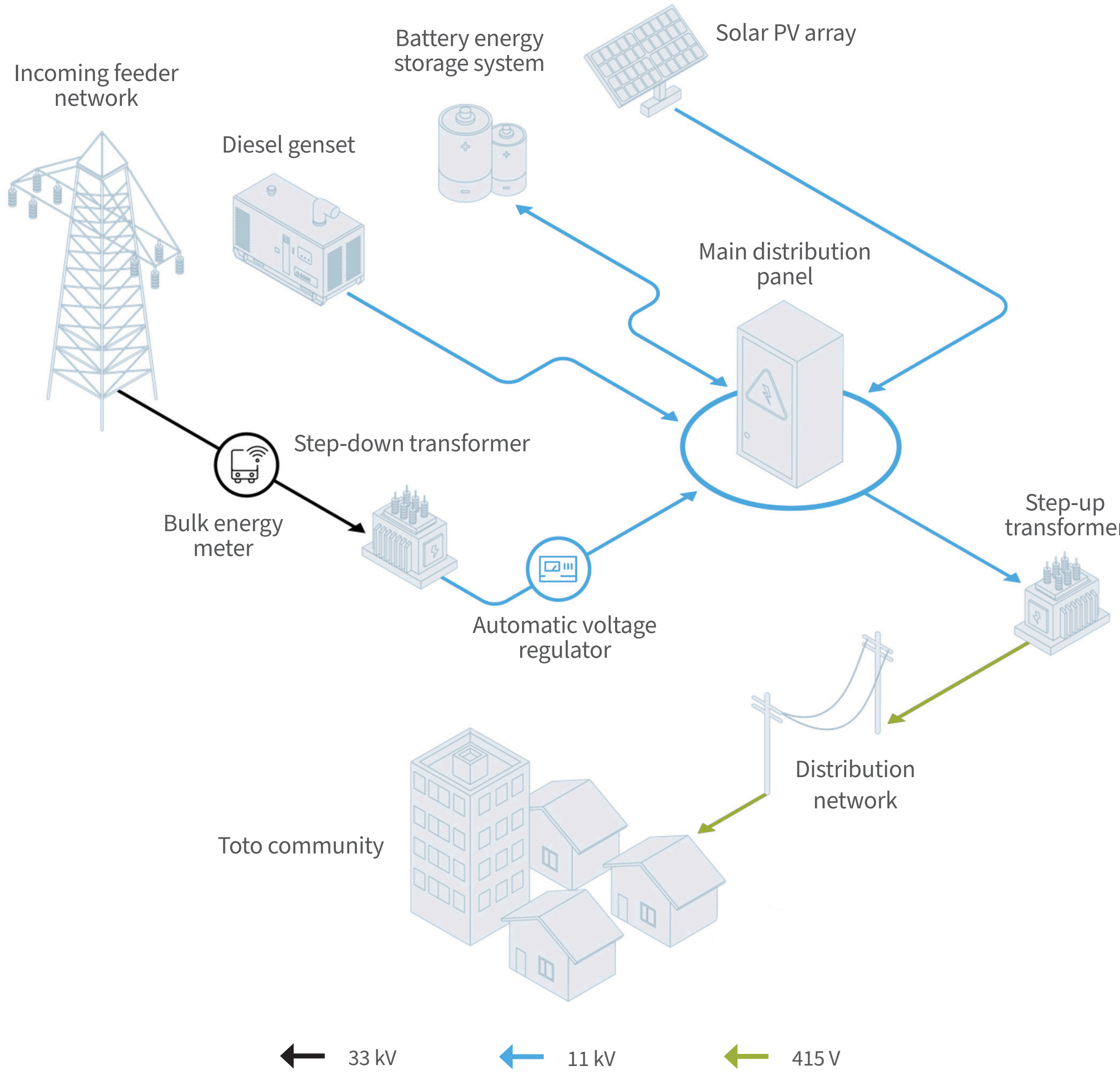


RMI Graphic. Source: RMI analysis of IMG pilot data

Husseini Habib, an internet cafe operator in Toto.

xii Voltage on the Nasarawa Toto feeder at the Toto point of interconnection was as low as 180 volts, which is 20% below the nominal voltage of the Nigerian grid. This voltage was too low for successful power exchange between the grid and the IMG. The installed AVR corrected the voltage drop to within the operational voltage range, allowing for successful power exchange between the grid and the IMG.

Exhibit 7 **Grid interconnection architecture of Toto IMG**



RMI Graphic. Source: RMI analysis of IMG pilot data

Cold drinks store of Maaji Abubakar Maikasuwa, Nasarawa, Toto.

2.2 Zawaciki IMG

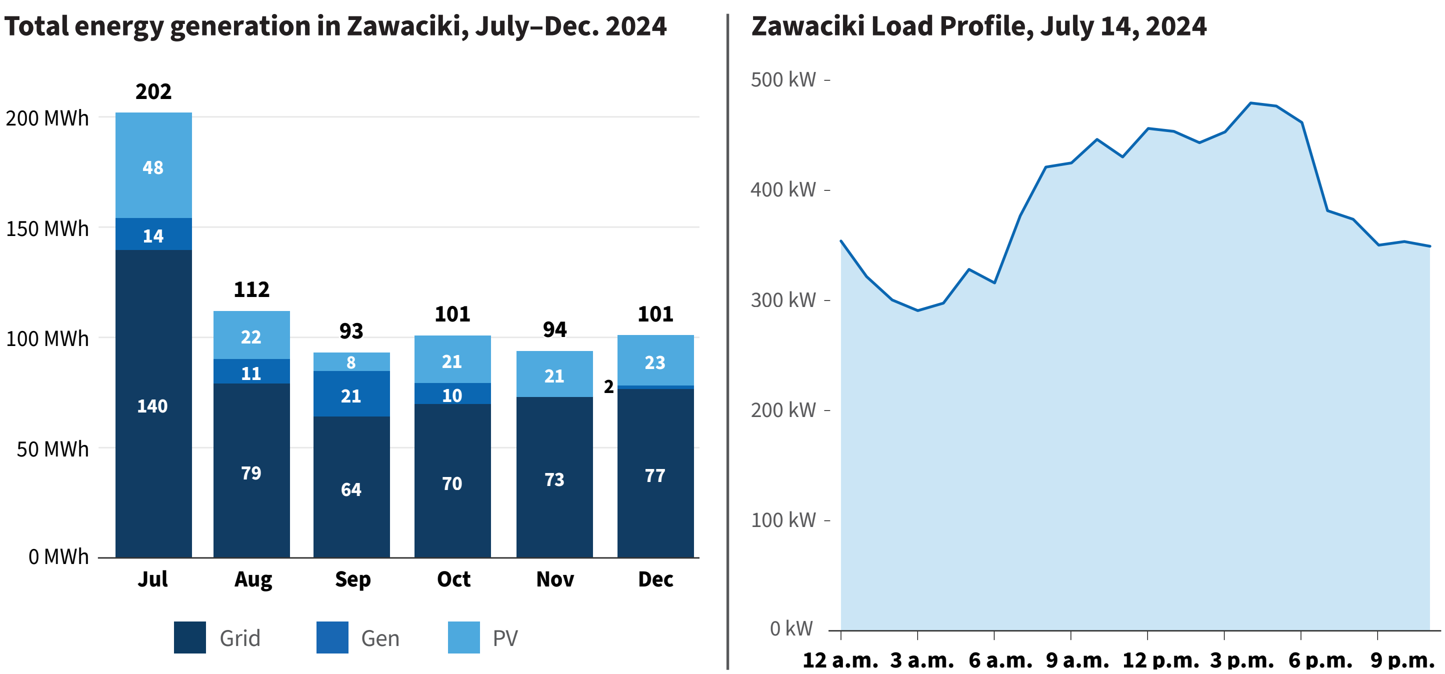
As the largest IMG in the country and the first in northern Nigeria, the Zawaciki IMG capitalizes on the abundant sunshine in the north. Located far from most power generation plants, this pilot project showcases the effectiveness of using IMGs to address the challenges of energy reliability and quality associated with aging transmission and distribution infrastructure.

Gida Dubu is one of the communities within the Zawaciki settlement, a suburb on the outskirts of Kano City. Although primarily a residential community, home to many middle-class residents, the area has a decent amount of commercial activity and is home to many SMEs, a water production factory, the Dala dry port, and the China Civil Engineering Construction Company (CCECC). Kano Electricity Distribution Company (KEDCO) used to provide the community with an average of only four hours of supply from the grid due to limited allocation from the national grid and other technical limitations.[15]

The Zawaciki IMG includes a 1 MWp solar plant developed by Bagaja Renewables in Kano. The plant provides reliable and affordable power to homes, businesses, and industrial customers in the Gida Dubu community. The Zawaciki IMG went live in January 2024, making it the first IMG in northern Nigeria and the second in the country. It has continued to provide an average of over 16 hours of reliable power daily to the cluster. The commercial (including small and large) and industrial customers consume 40% of all energy delivered by the IMG to its customers. Exhibit 8 shows a snapshot of operational data from the Zawaciki IMG. As of December 2024, it has abated an estimated 500 tons of CO_2 since its inception.

Zawaciki IMG generation plant.

Exhibit 8 Operational data from Zawaciki IMG

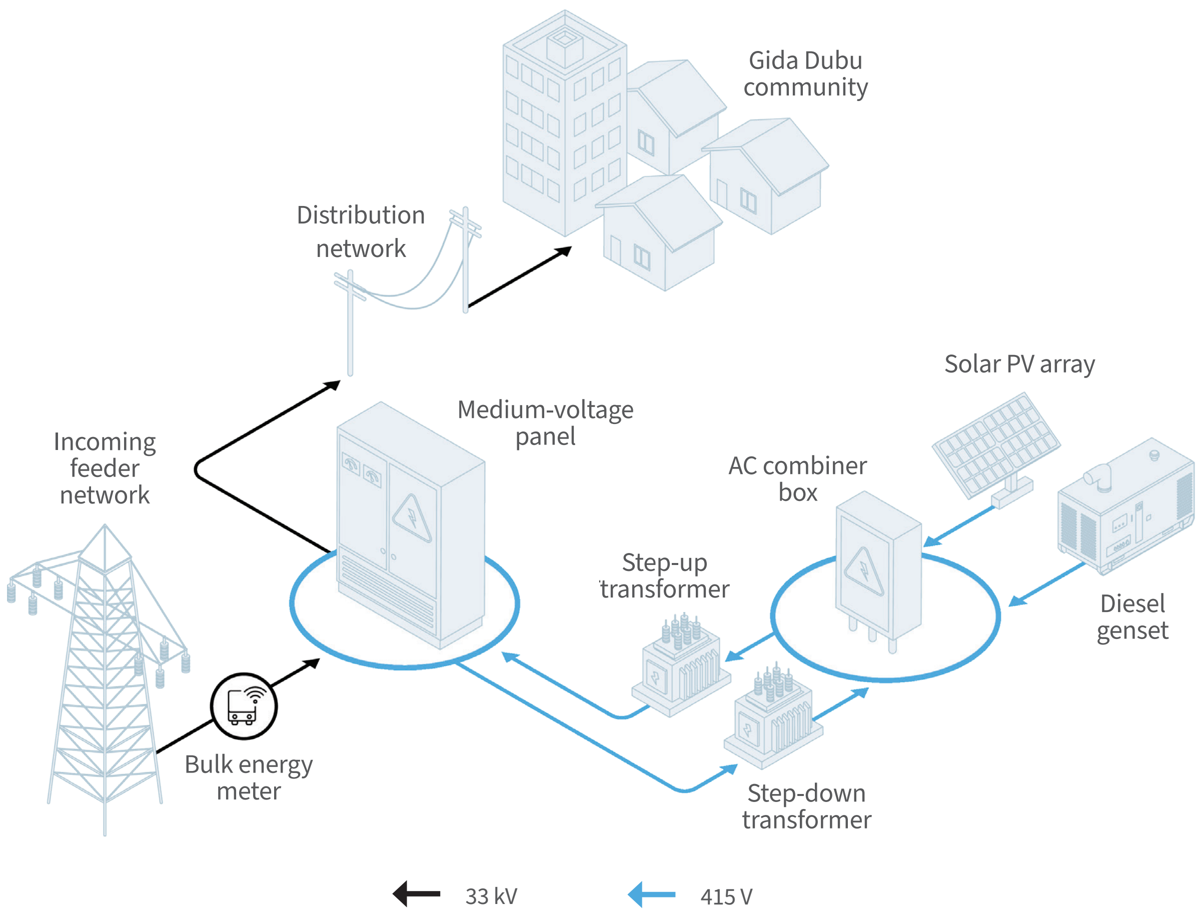


RMI Graphic. Source: RMI analysis of IMG pilot data

Grid interconnection

Grid interconnection is achieved via a branch of the incoming 33 kV Angels feeder line into a medium-voltage (MV) panel that protects, controls, and monitors the incoming and outgoing medium-voltage lines. The metered grid supply is fed into two 500 kVA, 33/0.4 kV step-down transformers. Blended energy from the IMG, which includes solar PV, grid, and backup genset, is fed into two 500 kVA 0.4/33 kV step-up transformers, which then gets routed back to the community through a 33 kV distribution network. Exhibit 9 shows the grid interconnection architecture of the Zawaciki IMG.

Exhibit 9 Grid interconnection architecture of Zawaciki IMG



RMI Graphic. Source: RMI analysis of IMG pilot data

Spotlight on Zawaciki IMG customers

Alhaji Gambo operates a small cold drink shop from his home in Zawaciki. Before the IMG, Gambo recalls that he usually had only about four hours of electricity (which many Nigerians refer to as "light") daily.

"Before the minigrid, we faced difficulties with our work due to poor lighting. At times, we went even two days without any light. Now that we have this minigrid . . . we enjoy at least 16 to 20 hours of light daily," he says.

With consistent power from the IMG, Gambo has grown his business from one fridge to four, providing cold drinks in this hot, arid community.

Meanwhile, Ibrahim Sali, who runs Nifal Limited, a water packaging and distribution company in Zawaciki, has seen significant energy savings since the introduction of the IMG. Sali delivers about 10,000 liters of water to the housing settlement each day. Before the IMG, Sali had to run his diesel generators to power his facilities daily.

"Before now we were not having light very well, but with this [IMG] now there is light and it is helping our business," he explains. "We make more profit now because with the light, I don't use diesel like before."

Alhaji Gambo showing one of the refrigerators out of which he sells cold drinks.

Nifal water distribution facility.

2.3 Robinyan IMG

The Robinyan IMG illustrates how IMGs effectively address energy needs in underserved communities with inadequate grid infrastructure. The project features significant upgrades to the distribution network such as the replacement of undersized line conductors, replacement of makeshift wooden electric poles with standard concrete poles,[xiii] and use of an advanced management system with reclosers and autonomous grid islanding and reconnection.

Robinyan IMG generation plant.

Robinyan is a residential border town situated in Ifo Local Government Area of Ogun State, close to the Lagos State border. Located at the end of a lengthy, overloaded 11 kV feeder, the community has had to crowdfund grid extension and distribution network expansion projects for its use for several years.[xiv] The feeder experiences significant technical and commercial losses, resulting in an average of four hours of daily grid supply.[xv]

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xiii Ikeja Electric specifies concrete poles of lengths 12 and 8.53 m for high tension and low tension poles, respectively, while the line conductor is specified as either AAC or ACSR with a section area of 150 square millimeters.

xiv Feedback from community leaders during a community engagement session.

xv Ikeja Electric Distribution Substation Operator (DSO) interview. Load shedding is done both locally and from the central substation.

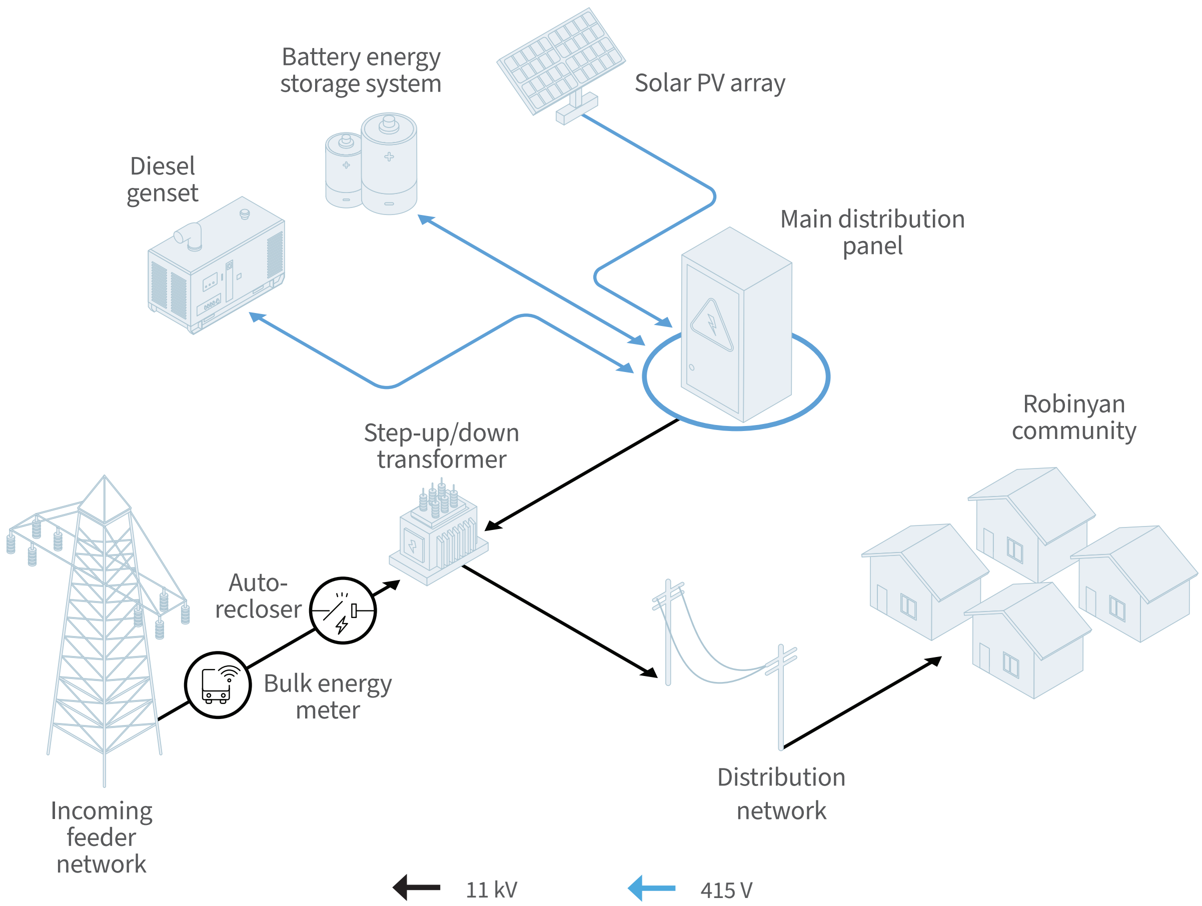
Darway Coast's IMG project at Robinyan is among a portfolio of projects they are embarking on in the area. The 500 kWp/625 kWh IMG is providing the community with increased productivity and improved access to electricity. The IMG includes a 500 kVA backup generator.

A corner shop owner in Robinyan in front of her shop.

Grid interconnection

Interconnection is achieved via an advanced recloser and relay system, which monitors the presence of grid voltage on the incoming 11 kV feeder line. The recloser is able to safely island from the grid when necessary, and a bulk energy meter is used to measure grid energy flowing to the IMG. Power flows from and to the generation plant via a single 1 MVA 0.4/11 kV transformer. Exhibit 10 shows the grid interconnection architecture of the Robinyan IMG.

Exhibit 10 Grid interconnection architecture of Robinyan IMG



RMI Graphic. Source: RMI analysis of IMG pilot data

2.4 Wuse IMG

Wuse IMG is one of Nigeria's earliest conceived IMG projects. The IMG, primarily serving daytime energy consumers at Wuse market, will replace over 2,000 noisy, costly fossil fuel generators used by shop owners during daily grid outages that sometimes last over 24 hours.

Wuse market is one of the largest and busiest markets in Abuja, Nigeria's capital city. Located in the Wuse district, it offers a wide variety of goods, including fresh produce, clothing, electronics, household items, beauty products, and more. There are more than 2,000 shops and stalls in the market. Due to the unreliable supply from the national grid, individual shop owners are forced to rely on expensive and polluting fossil fuel generators.

Green Village Energy (GVE) in collaboration with AEDC is providing a cleaner and more affordable alternative with the Wuse IMG project. The IMG includes a 1 MWp PV system, 1.2 MWh BESS, and a backup 500 kVA diesel generator.

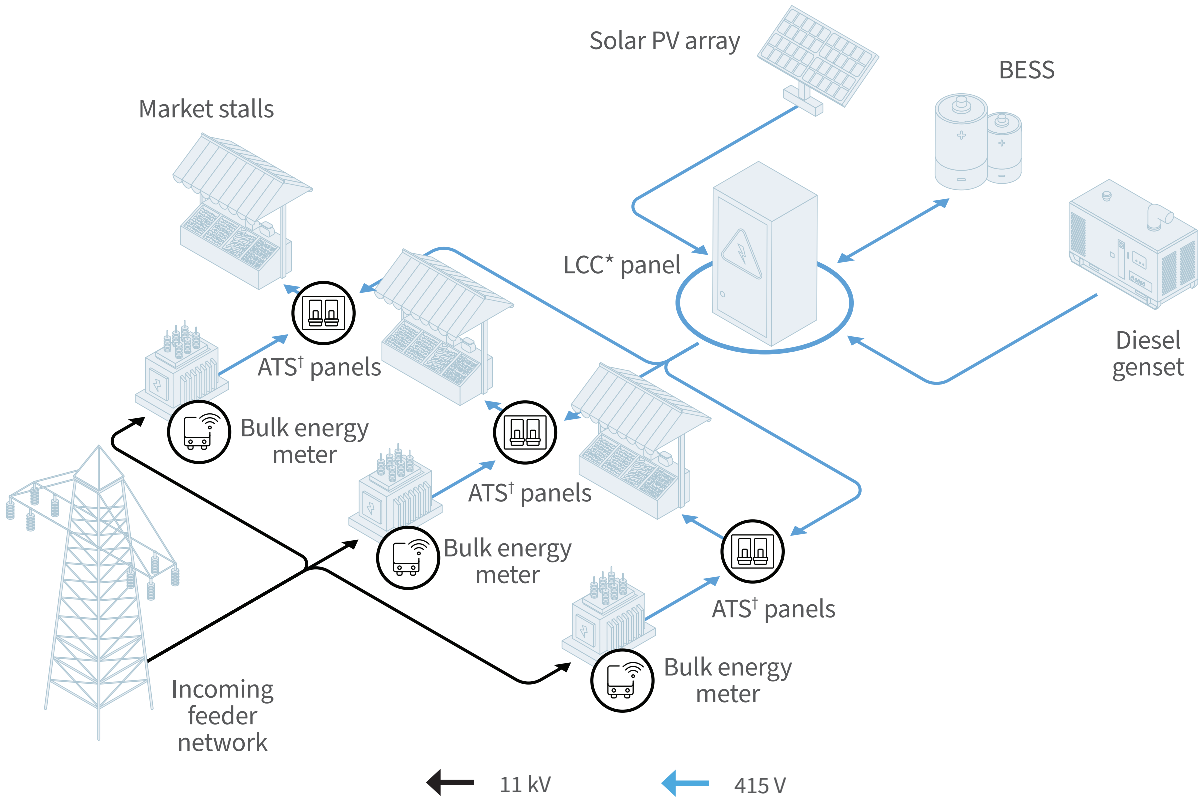
Grid interconnection

Unlike other IMGs, energy from the grid does not blend with that from the local generation plant at Wuse market; instead, they operate independently, supplying three designated distribution substations connected to customer shops. These substations feature a switching mechanism for selecting between the DER and the main grid. The incoming grid medium-voltage supply is directed straight to

PV modules on top of stalls at Wuse IMG.

the corresponding transformers within the market. An automatic transfer switch alternates between the DER and the grid based on availability and a time-of-use policy stated in the tripartite agreement. Exhibit 11 shows the grid interconnection architecture of the Wuse IMG.

Exhibit 11 **Grid interconnection architecture of Wuse IMG**



Note: * LCC is load control cabinet, † ATS is automatic transfer switch.

RMI Graphic. Source: RMI analysis of IMG pilot data

Tailor shop with electric sewing machine in Wuse.

2.5 Summary of DisCo and developer roles

Exhibit 12 presents an overview of the main roles and responsibilities of DisCos and DER project developers during key IMG project phases in the pilots. *Appendix A* contains more details for each project.

Exhibit 12 Summary of DisCo and developer roles and responsibilities for IMG pilots

Phase	Developer role	DisCo role
Initiation	**Selected** IMG project site from DisCo shortlist	**Created** a shortlist of promising communities for IMG
Preparation	**Led** the project preparation including community engagement, technical design, business model design, and source for financing **Negotiated and signed** a tripartite agreement between the community leadership, DisCo, and developer **Conducted** environmental and social management plan and environmental impact assessment studies needed for Nigerian Electricity Regulatory Commission (NERC)'s approval and applied for and received NERC's permit	**Negotiated and signed** a tripartite agreement **Supported** developer in regular community engagement **Provided** preliminary data on distribution network assets, customers, and energy consumption estimates
Construction	**Procured** equipment and constructed the generation and distribution assets, including interconnection equipment like transformers and voltage regulators **Tested** the system and received Nigeria Electricity Management Services Agency (NEMSA)'s approval	**Provided** oversight and quality control of the distribution system work **Provided** bulk electricity meter
Operation	**Operates and maintains** the generation and distribution assets **Ensures** adequate service to the community **Carries** out billing and collection for all energy sales in the IMG community	**Invoices** developer monthly for total grid electricity consumed in the IMG **Establishes** a customer service unit responsible for attending to customer complaints and issue resolution
Project Close	**Has a license** to own and operate the IMG for a set term. After term elapses, developer exits the community	**Resumes** utility operations in IMG community

RMI Graphic. Source: RMI analysis of IMG pilot data

RMI's DER Toolkit

The toolkit provides curated, standardized resources and templates for key documents used in IMG project preparation, development, and implementation. It includes key templates like:

IMG project implementation plans, which include an overview of the main implementation steps, from initiation to execution, including roles and responsibilities of DisCos and developers, as well as the recommended timelines for each step.

IMG financial model templates, which can be used to assess the financial viability of IMG projects; calculate customer tariffs, developer returns, and DisCo cash flows; determine project funding needs; and facilitate negotiation.

IMG tripartite agreement templates and term sheets, which can be adapted to define key terms and transaction arrangements between parties and have been developed to reflect best practices from the IMG pilots.

IMG project procurement templates including request for qualifications, request for proposals , and evaluation templates, which can be used to support competitive IMG project portfolio tenders.

The Toolkit is available at **https://rmi.org/utility-enabled-distributed-energy-resources-hub/**

3. Key Learnings and Insights

This section discusses the key insights and learnings from the team's experience supporting the four IMG pilot projects. It focuses on findings related to capital costs, development and execution timelines, grid interconnection, and early operational data. These insights draw on a combination of qualitative and quantitative data collected through regular engagement with developers and DisCos, monthly surveys conducted by RMI, and performance data from smart meters, inverters, weather stations, and other data collection equipment installed by RMI at the project sites.[xvi]

Across the four pilots, the distribution and interconnection component of the IMG capex made up almost half of the project costs, showing clear opportunities for cost reduction for future projects. The aging and inadequate distribution networks, along with poor bulk grid power quality, required IMG developers to invest heavily in distribution and interconnection equipment.

GVE system engineer checking the readout from a panel at the Wuse Market generation yard.

Projects faced several delays and took at least two and a half years to complete due to lengthy timelines for negotiating project agreements, equipment procurement, logistics, and receiving construction approvals. Similarly, lack of standardization in interconnection architecture, roles, and responsibilities complicated projects and contributed to delays, indicating the need for some standardization.

As of March 2025, only the Toto IMG and Zawaciki IMG have been operational for over 15 months, while Robinyan IMG was only successfully commissioned on March 6, 2025.[16] Consequently, the analysis in Section 3.4 is primarily based on data from the Toto and Zawaciki projects. Both IMG communities have experienced significant improvements in energy supply and reliability, along with a notable increase in connections and metering rates. These communities show higher consumption relative to their isolated minigrid peers, and the DisCos have steadily ramped up supply to the IMG, having witnessed a sharp decline in losses and an increase in revenues from the IMG communities.

xvi RMI partnered with Odyssey Energy Solutions to deploy monitoring devices and other data collection equipment at project sites. The team leveraged the Odyssey analytics platform to gather and analyze data included in this report.

3.1 Key learnings on IMG capital costs

Exhibit 13 summarizes the reported costs for the IMGs analyzed in this report. It includes the range and median costs for major cost items by category.[xvii] Exhibit 14 illustrates the proportion of the total cost that each category represents.

Exhibit 13 **Summary of IMG major cost components**

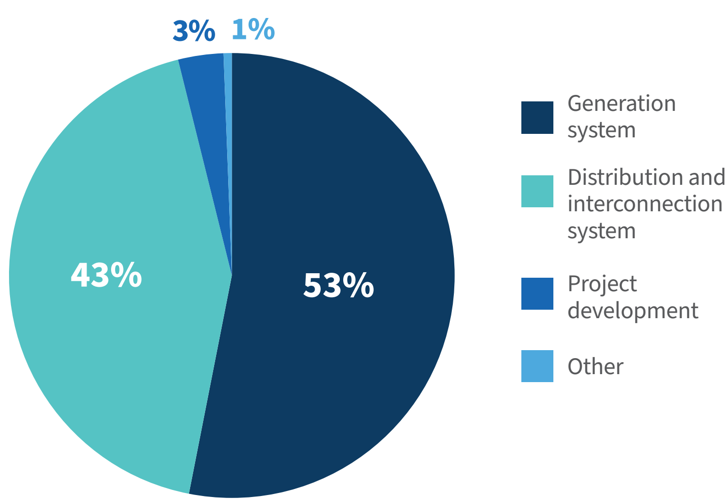
Category	Unit	Median	Range
1. Generation system	US$/kWp	1,425	1,103–4,460
1a. PV modules	US$/kWp	279	110–512
1b. PV inverters*	US$/kWp	53	53*
1c. BESS†	US$/kWh	327	216–600
1d. Genset	US$/kVA	250	91–355
2. Interconnection system	US$/project	73,087	15,017–120,626
	US$/kWp	86	30–248
3. Distribution system	US$/connection	503	216–725
3a. Metering system	US$/connection	167	62–305
4. Total capex‡	US$/kWp	2,547	1,781–8,360
	US$/connection	1,323	894–1,743

Note: *Among the two projects using PV inverters, only one developer listed the inverter cost separately. The other included it under the generation balance of systems cost (see *Appendix B*). †BESS costs include the cost of the battery and an integrated grid-forming inverter. ‡Total CAPEX includes Generation capex, Interconnection capex, Distribution capex, project development and other costs. See *Appendix B* for further detail.

RMI Graphic. Source: RMI analysis of IMG pilot data

Exhibit 14

Average proportion of IMG cost by category



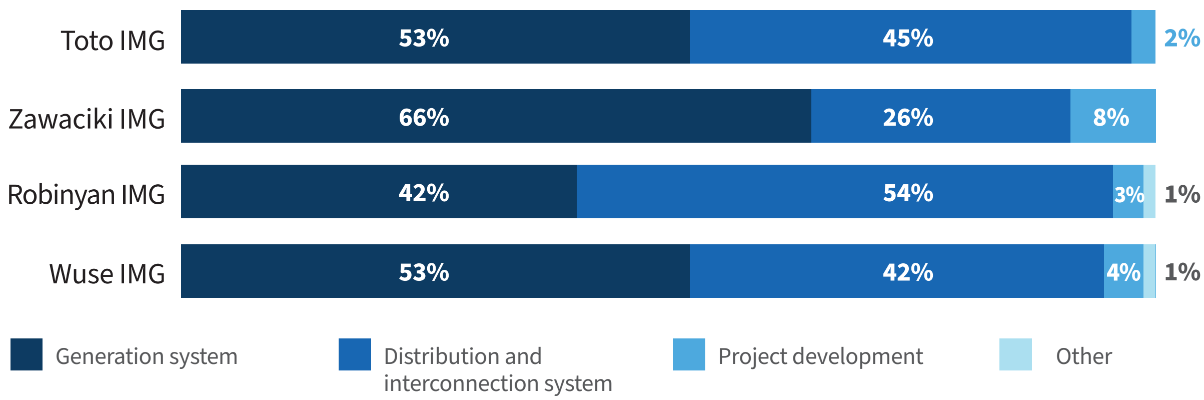
RMI Graphic. Source: RMI analysis of IMG pilot data

xvii Further details on cost categories can be found in *Appendix B*.

Distribution and interconnection represented up to 54% of total IMG capex

The aging and incomplete state of the distribution networks in the IMG pilot projects, coupled with poor power quality on the bulk grid, necessitated significant investments in distribution and interconnection equipment by IMG developers (see Exhibit 15). These investments included transformers and voltage regulators to improve grid power quality, as well as islanding controllers to ensure safe grid interconnection. Additionally, a substantial portion of the total capex was allocated to distribution-related costs, such as repair and replacement of damaged feeder equipment, upgrades of customer connection, and installation of customer end-use meters.

Exhibit 15 **Proportion of IMG cost by category for each pilot project**

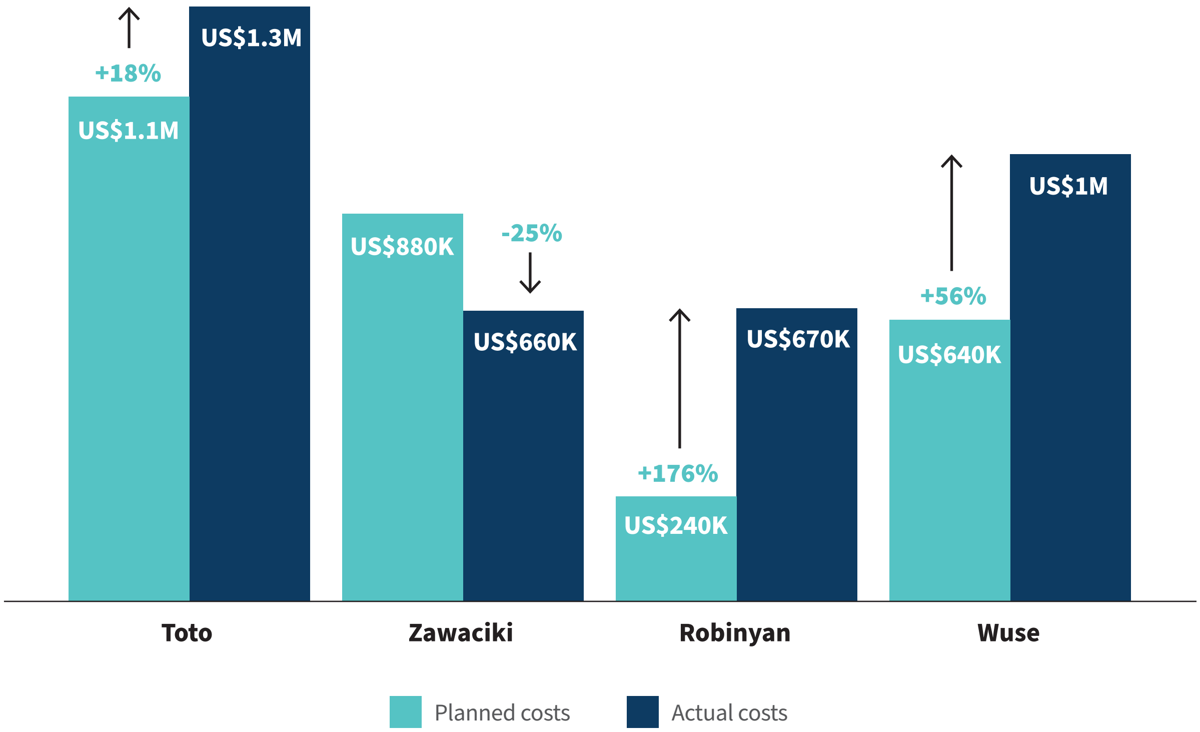


RMI Graphic. Source: RMI analysis of IMG pilot data

Interconnection costs varied widely, with distribution and interconnection cost averaging 60% over budget due to first-of-a-kind collaboration

Distribution and interconnection costs have varied significantly among these four projects, with three out of four projects going over the planned budget in this cost category (see Exhibit 16). These projects have been the first of their kind for many developers, leading to some inefficiencies that could be improved with experience and scale. For instance, many developers underestimated the scope of work required for distribution network upgrades in the area by not thoroughly assessing the existing state of the distribution network and the necessary upgrades, as they lack this expertise. Some developers initially did not use DisCo-approved contractors, resulting in a significant amount of remedial work; unlike isolated minigrids, IMGs require distribution networks to meet DisCo standards. This suboptimal coordination with DisCos prolonged project execution timelines and raised costs. In the Zawaciki IMG, the strong collaboration between Bagaja and KEDCO, along with KEDCO assuming the responsibility and costs of retrofitting the MV lines upstream of the point of interconnection, allowed Bagaja to spend less on distribution and interconnection than planned.

Exhibit 16 IMG distribution and interconnection planned vs. actual costs, showing significantly elevated costs exceeded budget



RMI Graphic. Source: RMI analysis of IMG pilot data

However, even at scale, there is some variability inherent to the distribution and interconnection costs in IMGs, as these costs differ based on the layout and existing condition of the distribution network in the community as well as the choice of interconnection equipment and architecture. Exhibit 17 shows the interconnection system unit costs for each project.

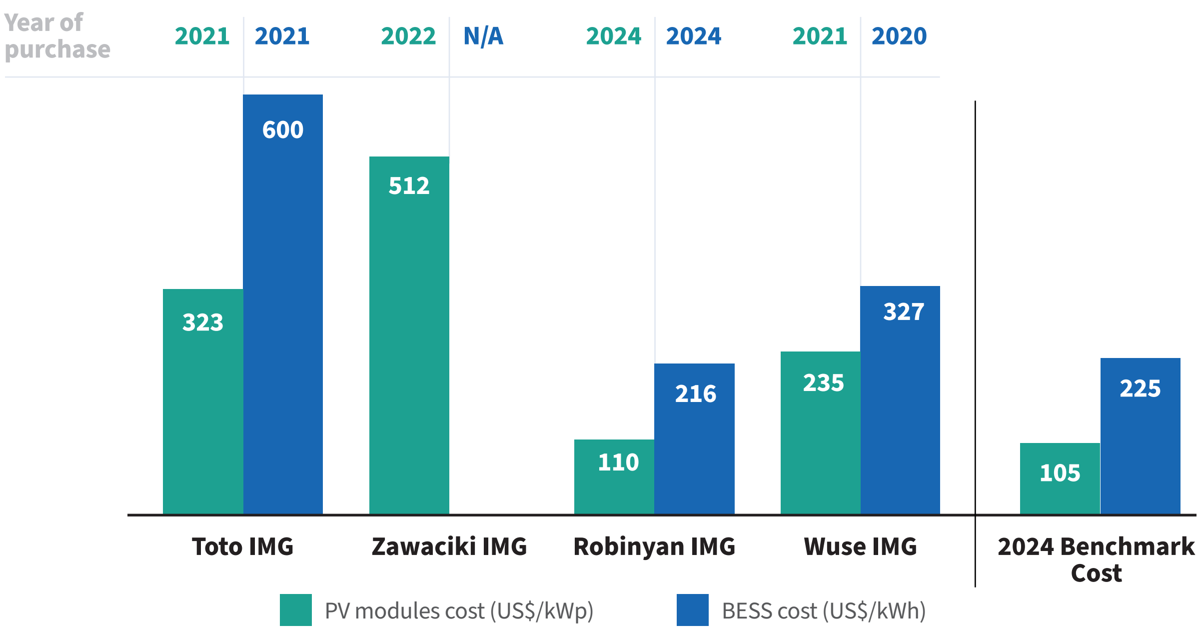
Exhibit 17 Interconnection system unit costs showing significant differences across various projects

RMI Graphic. Source: RMI analysis of IMG pilot data

In contrast, generation costs showed less variability but remained higher than global averages

The global costs of PV modules and BESS have reached a level of maturity evident in the standardization and low variation of unit costs for generation system components. However, these costs were significantly higher than their 2024 benchmark (see Exhibit 18).[xviii] This is for several reasons; many of these components were purchased before 2022 and some as early as 2020, when global unit prices were higher. Additionally, the relatively small system capacity, compared to optimal IMGs (see Section 4) deployed in these projects, prevented developers from taking advantage of larger economies of scale. Finally, some of these developers incurred additional costs by sourcing generation equipment from distributors instead of directly from suppliers and original equipment manufacturers (OEMs).

Exhibit 18 **Generation system unit costs show less variability across various projects**



RMI Graphic. Source: RMI analysis of IMG pilot data

3.2 Key learnings on IMG timelines

Implementing an IMG through an optimal DisCo-led development process could take eight months to complete.[17] However, these groundbreaking projects faced, among other delays, mitigating macroeconomic and external setbacks, including the COVID pandemic.

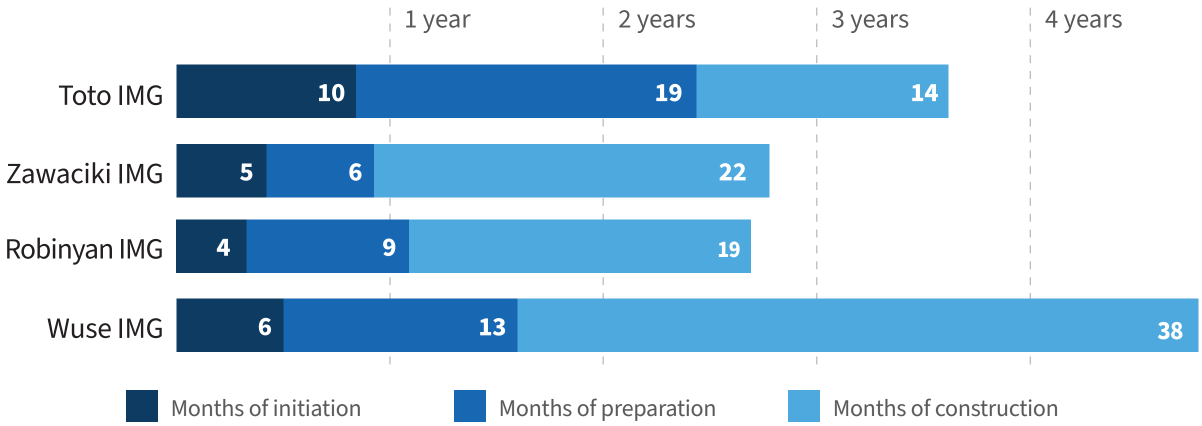
This section summarizes the time taken for each of the pilot projects from initiation through preparation to completion of construction. It also captures some of the common causes of delays and key learnings to help guide the implementation of the next wave of DER projects in Nigeria.

xviii RMI analysis of developer and original equipment manufacturer quotes.

The IMG pilot project timelines varied widely on a project-by-project basis, with construction averaging two and half years

Project timelines vary widely from project to project. Exhibit 19 shows the time taken in months to complete each of the four pilot projects.

Exhibit 19 **IMG project timelines varied widely**



RMI Graphic. Source: RMI analysis of IMG pilot data

Delays in pilot project implementation were primarily concentrated in four key areas

Across the four IMG projects, the project activities and milestones that caused the most delays were 1. Project agreement negotiation, 2. Equipment procurement, 3. Construction supervision and certification, and 4. Interconnection.[xix]

1. Negotiating first-of-a-kind project agreements between DisCos, developers, and communities took time

The IMG brings in the DisCo, a third party to the typical agreement governing an isolated minigrid. Negotiating this tripartite agreement added complication and took a longer time than projected. Customers in urban and peri-urban locations where IMGs were located had more negotiating power than rural isolated communities for various reasons, but primarily because of their experience with DisCos and their energy source alternatives.

Even after the tripartite agreements were signed, the pilot projects faced delays due to the need to renegotiate and sign addendums prompted by shifting macroeconomic conditions; a rapidly changing regulatory landscape — including the introduction of cost-reflective tariffs in Nigeria and state electricity markets; and frequent leadership changes at the DisCos.[18] DisCos also renegotiated terms around DUOS fees and IMG community legacy debt settlement, which further contributed to project delays.

xix Insights on delays due to interconnection are addressed in Section 3.3.

2. Procurement delays often disrupted project timelines

PV modules, BESS, and many other equipment required to build these IMGs were imported. The complicated nuances of importation, duties, shipment, and in-country transportation logistics in Nigeria caused several months of delays for some projects.[xx] Imported equipment arrival in Nigeria faced delays due to slow shipping, **complicated and unpredictable port clearance processes**, and logistical challenges within the country, all of which affected procurement timelines. In Robinyan IMG, for instance, the BESS arrived in Nigeria in March 2024, but was not cleared out of the port until July 2024 due to delays with import duty exemption certificate (IDEC) approval and other statutory fees payments.

3. Construction supervision and inspection by authorities created major setbacks for projects

There were several challenges with obtaining the Nigerian Electricity Management Services Agency (NEMSA) certification needed for IMG commissioning.[xxi] These included:

- **Inspection process timeline:** The inspection and certification process, from initial application to final approval, took considerable time, depending on the workload and availability of inspection teams. For the Robinyan IMG, the application and payment were submitted in November 2024. Following two rounds of inspection and reinspection, the site received approval in February 2025.

- **Statutory inspection fees:** The calculation of statutory fees for IMG certification was often unclear for project developers. The fee structure lacked transparency and was not easily calculable based on a plant's assets and capacity. Exhibit 20 illustrates that the total inspection fees per installed solar capacity varied significantly with over 300% difference between projects.

Exhibit 20

NEMSA inspection fees for the pilot IMG projects per kWp of installed PV capacity showed high variability

RMI Graphic. Source: RMI analysis of IMG pilot data

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xx Nigeria, with a score of 2.6, ranked 88th out of 141 countries in the World Bank's Logistics Performance Index (https://lpi.worldbank.org/international/scorecard/radar/C/NGA/2023).

xxi NEMSA is the body responsible for ensuring all electrical installations conform to standards and regulations. An IMG requires NEMSA certification to supply energy to customers.

- **Construction standards:** Failing a certification inspection resulted in reinspection, which sometimes took several months to complete. Common issues flagged by the inspection team during IMG construction supervision included lack of visible signs, tagging and labeling of assets, undersized equipment, substandard PV ground mount material, noncompliance with functional tests, and poor site sanitation and landscaping.[xxii]

Certification recommendation

Projects face significant delay risks in the inspection and commissioning, and therefore commencement of commercial operations from uncertainty in the regulatory inspection and certification process. The market would benefit from a more transparent certification fee structure and a more streamlined inspection timeline. RMI recommends a simple six-stage inspection and certification process that begins at the permitting stage of the project:

Step 1 Developer submits project artifacts, designs, and configurations to NEMSA.

Step 2 NEMSA reviews these documents and checks for conformance to relevant standards.

Step 3 Developer communicates to NEMSA when the project has reached more than 50% and less than 75% of completion.

Step 4 NEMSA conducts an initial inspection when the project is at 50%–75% completion, providing initial recommendations on areas that may require improvements.

Step 5 NEMSA conducts a final inspection when the project achieves the 100% completion milestone.

Step 6 NEMSA issues certification to applicant if the project meets standards.

With the approach above, snags and nonconformance are identified earlier and corrected, which prevents rework, cost overrun, and commissioning delays.

4. **Misalignment and abscence of standardization in interconnection led to delays.**

   This is discussed in detail in *Section 3.3*.

3.3 Key learnings on interconnection

There is no standard approach to splitting roles and responsibilities necessary for IMG interconnection between the developer and DisCo

Due to the nascent nature of the IMGs, there was often a **lack of clarity and misalignment** between DisCos and developers regarding **which party was responsible for what in the four pilot projects**. Agreeing on the responsibility for providing key components such as bulk energy meters for energy

xxii Further details on these common construction issues can be found in *Appendix C*.

accounting and trading between the grid and the DER **led to over 14 months of project delays** between developers and DisCos. Also, tripartite agreements often did not capture key aspects of the projects, including interconnection roles and responsibilities. Across projects, RMI observed a variety of approaches, from a developer taking all responsibility for interconnection to a more balanced shared responsibility between the developer and the DisCo. Exhibit 21 summarizes how DisCos and developers owned specific interconnection hardware components for the four pilot projects. We expect these roles and responsibilities to become more well-defined as the second wave of IMGs is implemented with learnings from these pilots.

Exhibit 21 Summary of how interconnection hardware roles and responsibilities were split between DisCos and developers

Task at each IMG	Toto	Zawaciki	Robinyan	Wuse
Bulk meter installation	DisCo	DisCo	Developer	DisCo
MV network rehabilitation	Developer	Developer	Developer	DisCo
MV/low voltage (LV) substation rehabilitation	Developer	Developer	Developer	Developer
LV network rehabilitation	Developer	DisCo and Developer	Developer	Developer
Point of interconnection equipment installation	Developer	Developer	Developer	DisCo and Developer

DisCo   Developer   DisCo and Developer

RMI Graphic. Source: RMI analysis of IMG pilot data

Lack of interconnection and technical requirements in tripartite agreements caused delays

Most tripartite agreements for the pilot projects omitted interconnection and technical requirements peculiar to each site. Consequently, deviation in key technical requirements like interconnection voltage levels and power quality at the point of interconnection from the planning stage and the Nigerian distribution code led to project delays and cost overruns as developers had to purchase new transformers and voltage regulators to compensate.[19,xxiii]

Interconnection point of the Zawaciki IMG, showing the incoming 33 kV line with its associated current transformer and energy meter.

xxiii The Nigerian distribution code permits a maximum voltage drop of 5% at the point of interconnection, so grid voltage quality must remain within 5% of nominal voltage levels.

Interconnection is project- and location-specific; however, there are opportunities for standardization

System architecture and choice of equipment for the interconnection of DER to the utility network differed from project to project due to location-specific constraints. The interconnection standard is also undefined in Nigeria by any utility or regulator. In contrast, interconnection approaches in Germany, Japan, the United States, and other mature markets typically follow the IEEE 1547-2018 DER interconnection standard, which defines the interconnection of DERs like solar and BESS to the electric grid. There are, however, minor modifications to IEEE 1547-2018 by utilities and municipalities to address specific objectives such as protection and safety, clean energy prioritization, metering standards, grid reliability, and simplicity of the interconnection process. Exhibit 22 compares the interconnection architecture of each project and opportunities for standardization.

Exhibit 22 **Interconnection architecture for pilot projects showing opportunity for standardization**

	Toto IMG	Zawaciki IMG	Robinyan IMG	Wuse IMG	Opportunity for standardization
Voltage level for bulk metering	MV	MV	MV	MV	Standardize
Island detection	Motorized breaker with grid voltage sensor	Motorized breaker with grid voltage sensor	Grid/recloser relay	N/A	Location-specific
Disconnection switch	Transformer load break switch	MV panel/ring main unit (RMU)	Recloser	Transformer load break switch	Location-specific
Grid input voltage	33 kV	33 kV	11 kV	11 kV	Location-specific
Grid transformer	Step-down	Step-down	Step-down	Step-down	Standardize
DER transformer	Step-up	Step-up	Step-up	N/A	Standardize
DER output voltage	11 kV	33 kV	11 kV	11 kV	Location-specific

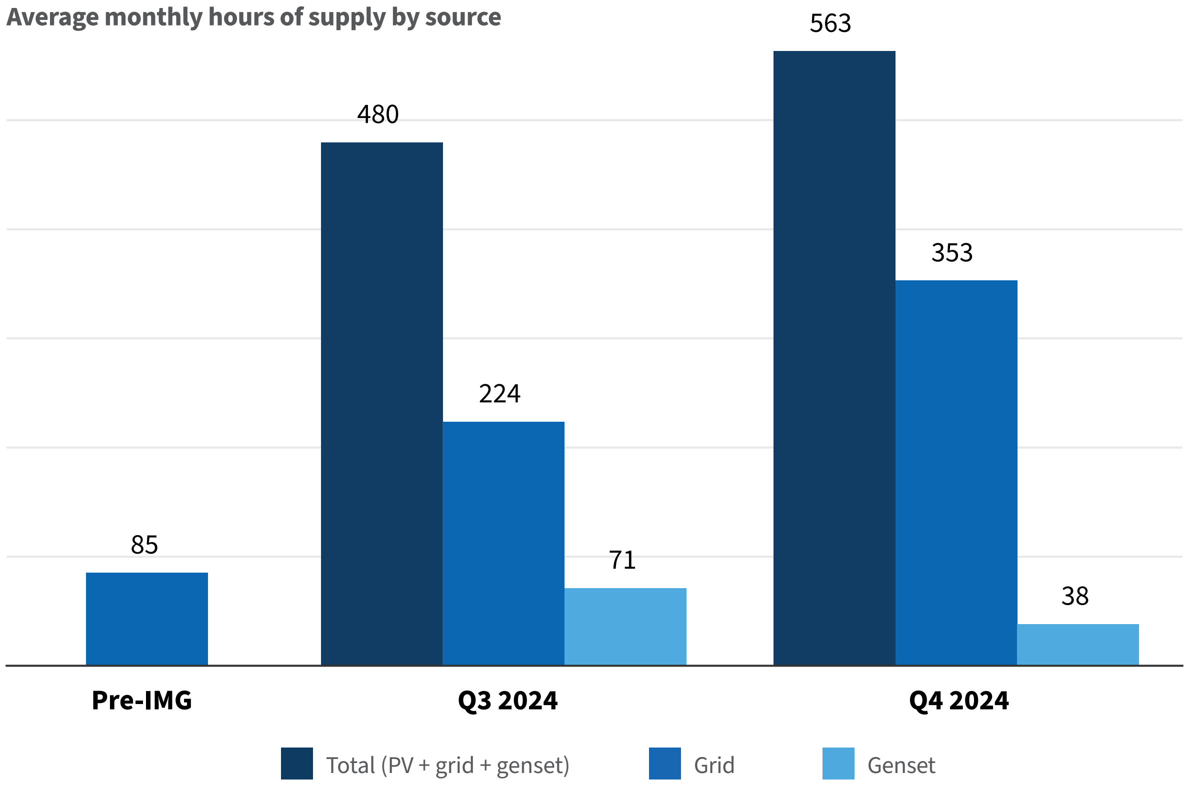
RMI Graphic. Source: RMI analysis of IMG pilot data

3.4 Key learnings on IMG operations

The IMG communities have seen large improvements in energy supply and reliability

IMGs have led to communities seeing a large improvement in their energy supply and reliability. IMG communities went from receiving two to three hours of supply a day to over 18 hours of daily supply by the end of 2024 (see Exhibit 23). The PV plants generate most of the energy supplied to the IMG communities. Additionally, improved energy supply from the grid, resulting from the developers' investment in upgraded grid infrastructure, further boosts energy reliability and availability.

Exhibit 23 IMG communities have seen a fivefold improvement in the availability of power supply

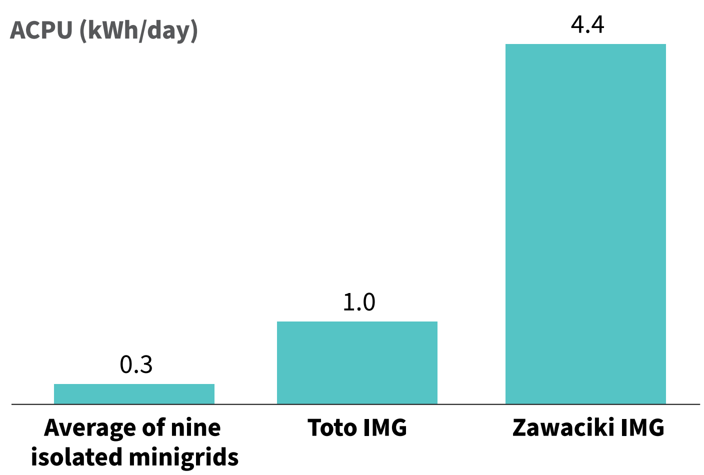


RMI Graphic. Source: RMI analysis of IMG pilot data

The IMGs have shown high consumption relative to their isolated minigrid peers

With more commercial and higher-income residential customers, the IMGs have significantly greater consumption compared with isolated minigrids (see Exhibit 24). In Toto's early operational days, its ACPU reached up to 2 kWh/day, driven largely by the prevalence of higher-income households, PUEs, SMEs, and institutional customers in peri-urban areas, when compared to rural, isolated minigrid communities. Likewise, Zawaciki, being more urban, boasts a greater number of higher-income residential customers and is also home to two large industrial customers.

Exhibit 24 The IMGs have up to 15 times the ACPU of isolated minigrids



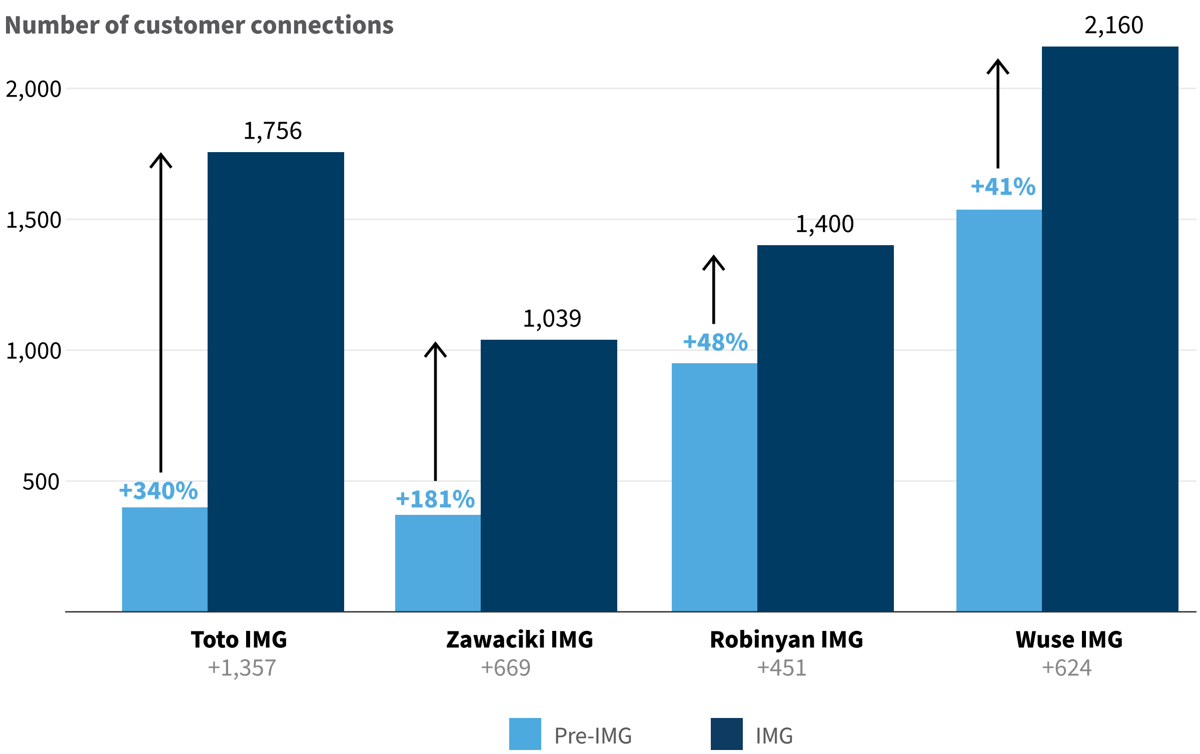
RMI Graphic. Source: RMI analysis of IMG pilot data

The IMGs led to a 95% increase in connections, filling the metering gap, ensuring equitable billing, and reducing commercial losses

More than half of all Nigerian grid-connected customers are unmetered, and in many cases multiple customers share a single meter or are grouped and served as a single connection by the DisCo. The IMG communities were no different. Without a meter, customer electricity consumption cannot be measured, forcing customers to pay arbitrary estimated bills. Sharing a meter or grouping customers as a single DisCo connection also leads to splitting electricity bills among users in an ad hoc manner, which is inequitable and often results in conflicts. DisCos' lack of visibility on customer consumption and poor payment discipline among customers contribute significantly to their losses.

By providing all customers with meters, the IMGs have improved visibility into their customers' usage compared to when DisCos served the communities. Each IMG connection, including new connections and those separated from customer groups, is assigned an individual meter, which addresses the aforementioned issues. When the IMGs' terms end, DisCos inherit this improved operational infrastructure upon resuming utility operations in the community. Exhibit 25 shows the number of connections in each IMG community before and after the IMG.

Exhibit 25 **The IMGs had 95% more connections than when DisCos were serving the areas**



RMI Graphic. Source: RMI analysis of IMG pilot data

DisCos cut their losses and achieved a 100% collection rate from previously loss-making areas

With a bulk metering interface that accurately measures all the energy flowing from the distribution grid to the IMG, and with the IMG community acting as a single customer to the DisCo, DisCos achieved a 100% collection rate from previously loss-making communities and cut their aggregate technical, commercial, and collection (ATC&C) losses significantly (see Exhibit 26).

Additionally, DisCos benefited from reduced operational costs since those were borne by the developers, which often meant the DisCo could divert resources to other areas, potentially alleviating resource constraints elsewhere. IMGs help DisCos in meeting their loss reduction and renewable energy targets, which are key performance indicators set out for them by the regulator.

Exhibit 26

IMGs see significantly lower losses than the business-as-usual portions of the feeders

	Losses (%)
Toto IMG	<10%
Rest of Nasarawa Toto feeder	50%
Zawaciki IMG	<30%
Rest of Angels feeder	57%

Note: ATC&C losses are presented at an aggregate level due to data collection limitations. In future analyses, we will break down these losses into their technical, commercial, and collections components.

RMI Graphic. Source: RMI analysis of IMG pilot data

IMG customers showed only a slight price sensitivity to electricity tariffs despite paying a premium compared to DisCos' bulk grid tariff

Despite tariffs up to twice Band A tariffs, IMG customers still consumed and paid for energy with minimal collection losses.[xxiv] Even when tariffs were increased on the IMGs, customers only slightly reduced their energy consumption (see Exhibit 27).

In Toto, a 131% increase in tariffs resulted in a 26% reduction in consumption, while in Zawaciki, a 50% increase in tariffs resulted in only a 4% reduction in consumption. This is because a lot of this electricity is for productive uses and the tariff is still significantly cheaper than the equivalent tariffs from the use of fossil fuel gensets.[xxv]

xxiv Band A tariffs are the highest tariffs customers pay for grid electricity, determined by the service-based tariffs charged by Nigerian DisCos. Customers in Band A are expected to receive at least 20 hours of electricity supply each day. As of February 2025, Band A tariffs range from 210 to 242 NGN/kWh.

xxv RMI estimates self-generation fuel cost at 600–650 NGN/kWh (US$0.40/kWh–US$0.43/kWh).

Exhibit 27 The IMG customers' electricity usage showed limited sensitivity to electricity tariff variations

	Month of 2024	Tariff (NGN/kWh)	Toto ACPU (kWh/day)
Toto IMG	March	195	1.42
	April–June	450	1.04

	Month of 2024	Tariff (NGN/kWh)	Zawaciki ACPU (kWh/day)
Zawaciki IMG	August–October	100	3.3
	November–December	150	3.2

RMI Graphic. Source: RMI analysis of IMG pilot data

Currency devaluation and minigrid tariffs

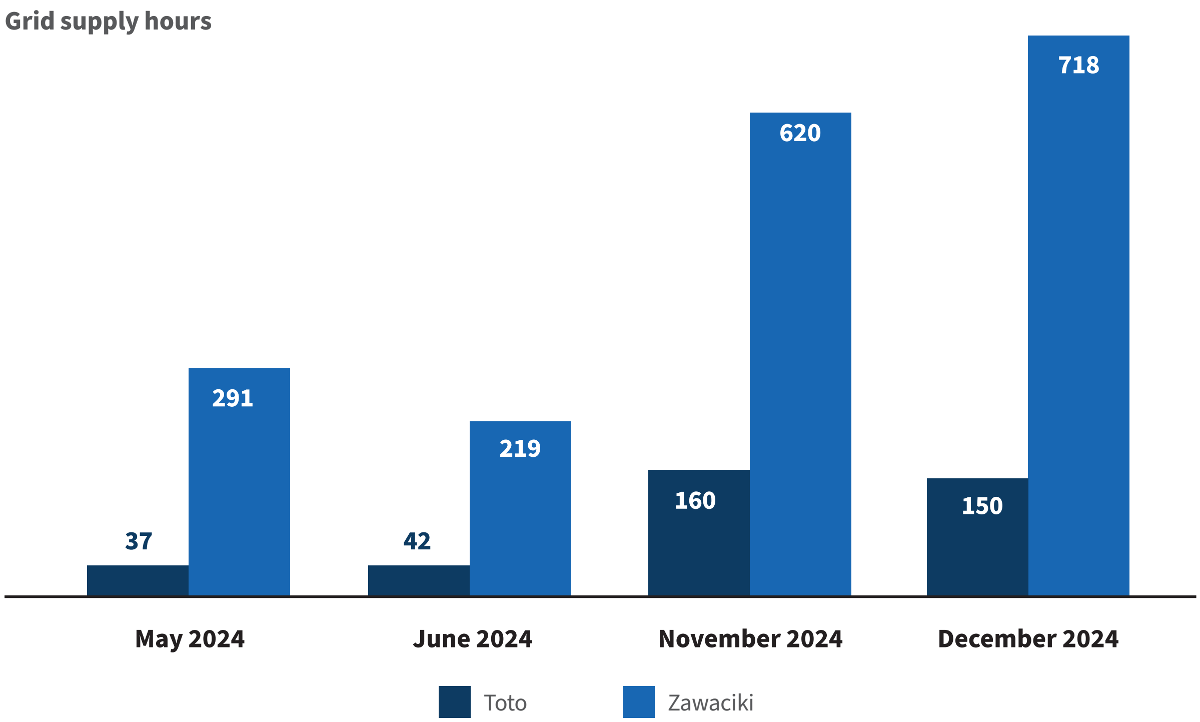
Macroeconomic conditions significantly affect minigrid economics and tariff setting. Since most components in an IMG solution are imported and priced in US dollars, fluctuations in the naira to US dollar exchange rate can greatly impact project viability. For instance, the NGN/US$ exchange rate rose from 420 in April 2022 during the Toto IMG development to 1,600 by March 2024. Consequently, the tariff decreased from US$0.46/kWh to US$0.12/kWh, adversely affecting PowerGen's returns from the IMG. Although the tariff increase in April 2024 from 195 to 450 NGN/kWh was substantial in naira terms, the new tariff equated to US$0.28/kWh, which was 40% lower than PowerGen's projected tariffs during the development phase.

A local business in Toto uses electricity supplied from the IMG.

Grid availability at IMGs had a slow ramp-up

Experience from the two operational IMG pilots shows that it takes a few months after commissioning to achieve the agreed-upon improved grid availability from DisCos in the IMG areas. Grid availability at the Toto and Zawaciki IMGs nearly tripled, increasing from five hours of electricity from the grid in May 2024 to an average of over 14 hours in December 2024 (see Exhibit 28). The average energy supply on the bulk Nigerian grid saw a 5% average increase between May and December in both 2020 and 2021. DisCos need to make technical and operational changes to dispatch more power to a given community, even after the necessary grid upgrades have been implemented. This process could take a few months following commissioning and requires close coordination and management from the developer.

Exhibit 28 **Grid availability tripled from May–December 2024**

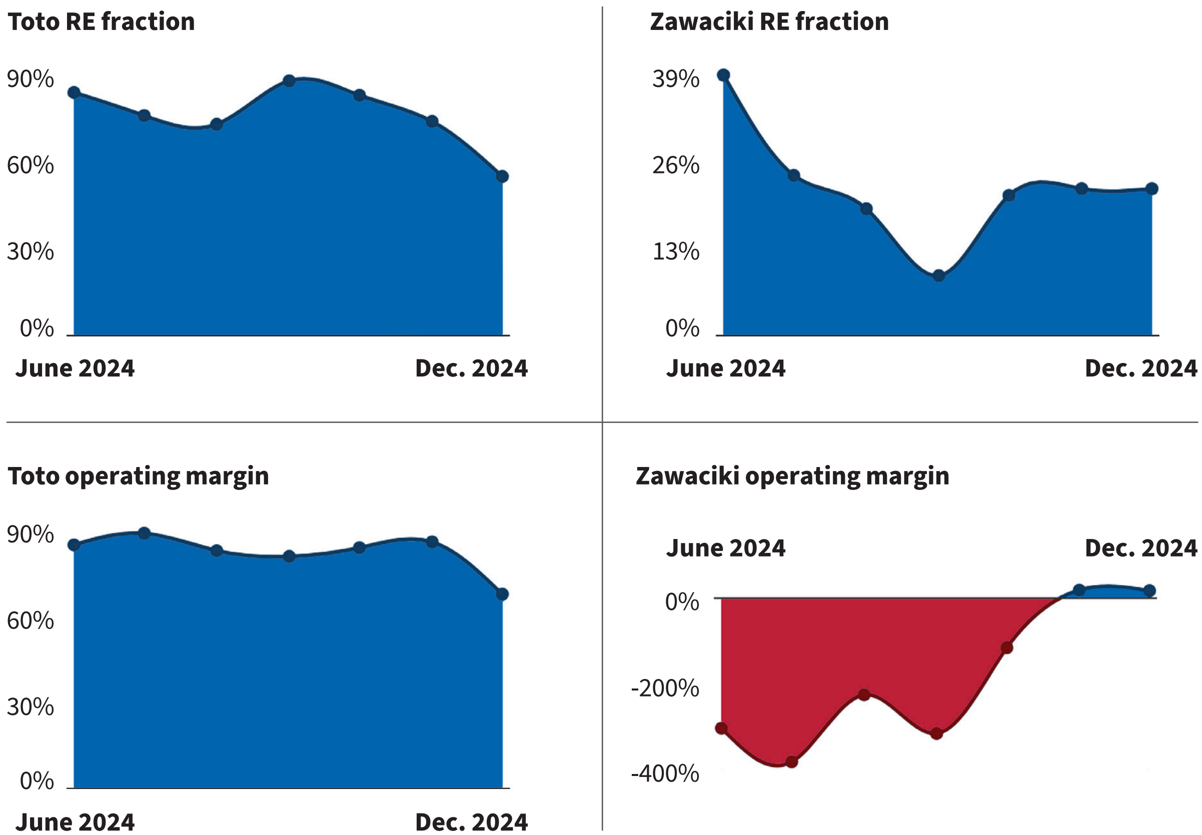


RMI Graphic. Source: RMI analysis of IMG pilot data

High renewable energy fraction due to high solar PV penetration supported by a BESS is critical to profitability

The two operational IMGs are experiencing contrasting fortunes in profitability, partly due to the lack of storage in one of the pilots. While a solar PV and BESS system can supply energy to an IMG on its own, a generation plant without storage requires either the grid or a fossil fuel generator to evacuate power from the solar PV assets. In the case of the Zawaciki IMG, without a BESS component, energy that could be supplied by the PV modules otherwise is curtailed to meet the minimum loading conditions of the generator (i.e., approximately 30% minimum of rated power) in the absence of grid power during the day. This leads to increased fossil fuel consumption and significantly affects operational expenses and profitability as seen on the right of Exhibit 29. On the other hand, the Toto IMG averaged a renewable energy fraction of 76% from June to December 2024 and had an operating margin of 81% in the same time frame.[xxvi]

Exhibit 29 **Relationship between renewable energy fraction and profitability**



RMI Graphic. Source: RMI analysis of IMG pilot data

xxvi Renewable fraction is the percentage of energy consumption in the IMG community from solar PV modules. The operating margin is the percentage of revenue (community payment for electricity sales) that remains after subtracting all operating expenses, including staff wages, grid electricity costs, and fuel for the backup genset.

4. Scaling IMGs in Nigeria: The Next Wave of Projects

The first wave of IMG projects has demonstrated that developers and DisCos can successfully collaborate to achieve mutually beneficial outcomes while improving and providing access to electricity to thousands of underserved and unserved customers. IMG developers are already accessing site locations with higher consumption and revenues compared to isolated minigrids, and DisCos are benefiting from reduced losses and increased energy sales through IMGs.

Learnings from the first wave of projects show that there are opportunities for improvement in the initiation, procurement, construction, and operation of these projects. To achieve faster project execution timelines, reduce uncertainty, and lower costs, the sector must recognize challenges and resolve them. Some of these major challenges include:

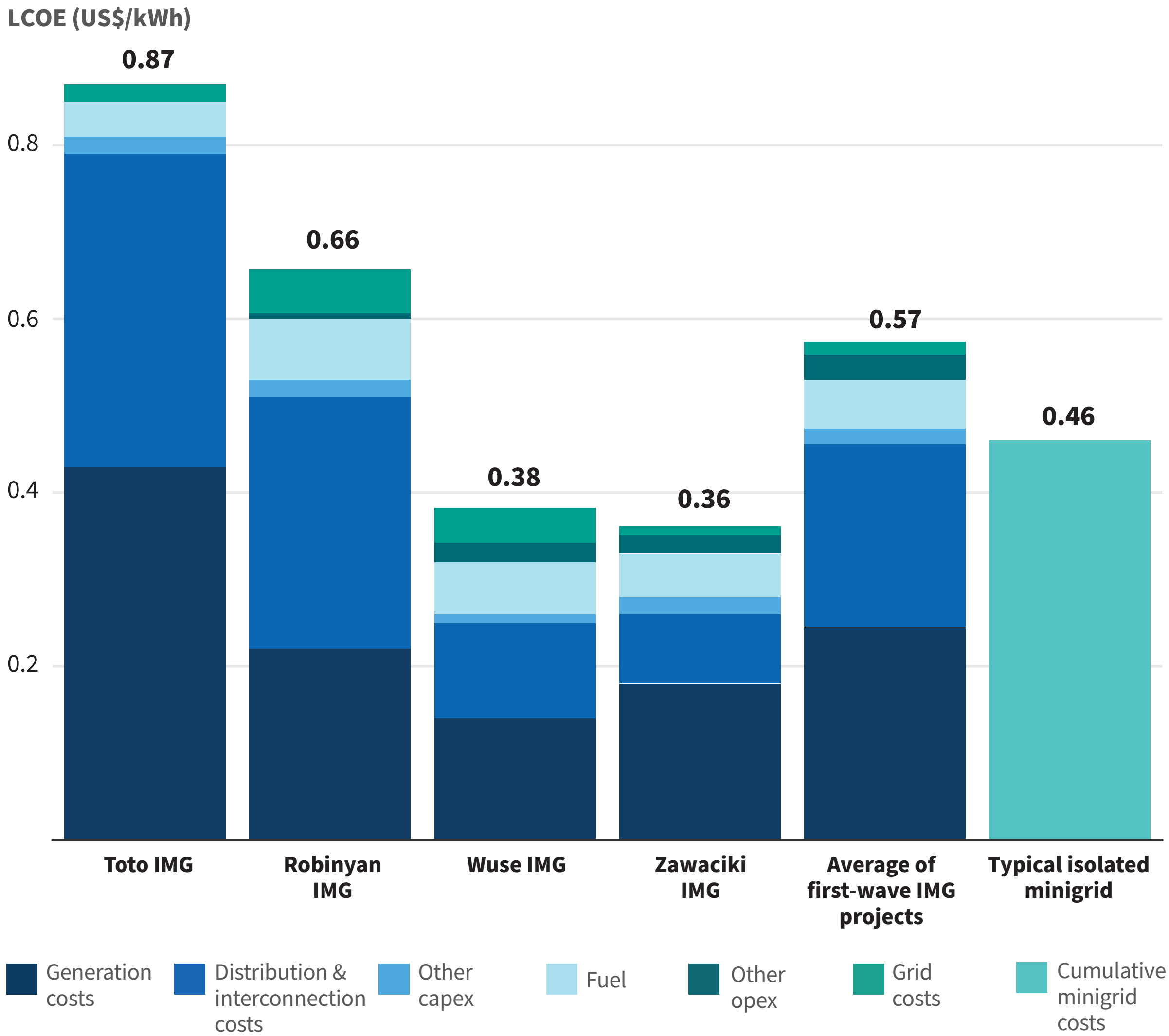
- **Capex**
  - High up-front generation costs
  - High and widely fluctuating interconnection and distribution network costs
- **Schedule**
  - Prolonged delays in project development, procurement, and construction
  - Extended delays in interconnection and certification
- **Misalignment**
  - Including interconnection expectations, requirements, processes, roles, and responsibilities among developers and DisCos
- **Low DisCo grid supply hours**
  - That result in higher operating expenditures to operate fossil fuel backup generators

All these challenges contribute to a high lifetime cost of service for the IMGs. The first wave of IMGs has an average LCOE of US$0.57/kWh (see Exhibit 30).[xxvii]

xxvii The LCOE is calculated based the total energy supplied to the IMG community from all energy sources in the IMG: PV, genset, and grid. It includes the impact of blending low-cost energy from the grid. The LCOE uses the present value of the project costs over a lifetime including all capex (initial and replacement) and all operations and maintenance costs including costs of purchasing energy from the grid/DisCo and fuel costs.

Exhibit 30

The LCOEs of pilot IMGs were high, but some still have lower LCOEs than typical isolated minigrids



Note: The LCOE from Wuse and Robinyan are projections and are expected to change as operational data for these projects becomes available over a longer period.

RMI Graphic. Source: RMI analysis of IMG pilot data, Energy Sector Management Assistance Program, **https://www.esmap.org/mini_grids_for_half_a_billion_people_the_report**

RMI has de-risked a portfolio of 40 IMG sites as part of recent scaling efforts for the sector. These IMG sites were selected from over 300 potential locations submitted by seven DisCos in Nigeria, identifying those with the greatest potential for IMGs. We conducted a rigorous feasibility study on these sites and collected detailed data on the distribution network, as well as all customers and connections in the area to estimate their demand. Using this data, we designed optimal, high-reliability IMG solutions for the selected areas and these projects are currently undergoing procurement and will be deployed in 2026.[xxviii]

xxviii REA's Distributed Access to Renewable Energy Scale-Up (DARES) Phase 1 Minimum Subsidy Tender sites are currently under a request for proposal stage.

These 40 IMG sites comprise a mix of large peri-urban settlements characterized by a significant level of productive-use load, including agricultural processing, urban residential estates, large enclosed markets with high daytime activity, and entire feeders serving numerous SME and commercial customers. These sites are significantly larger than the pilot projects, serving communities with up to 22,000 connections and peak loads of up to 5 MW, with PV capacities of up to 10 MW.

A real case study anonymized as IMG 1

IMG 1 is designed for one of the largest building material markets in a major Nigerian city with approximately 2,000 shops, SMEs, and businesses that engage in sales of tiles, plumbing, electrical, and other building materials. This enclosed market also has banks, large warehouses, and transportation companies to distribute building materials across the country. Many of the market occupants share prepaid meters with their neighbors, which contributes to the loss in efficiency in billing and collection. There are several wooden poles within the distribution network and some deficiencies within the injection substation that supply the market and affect reliability. With distribution network improvement, the DisCo can provide up to 12 hours of daily supply to the market. The table below compares the major design parameters of this real anonymized IMG case study with two of the IMG pilot projects:

	Toto IMG	Zawaciki IMG	IMG 1
PV (kWp)	352	1,000	4,900
BESS (kWh)	972	0	1,500
Electricity Demand (MWh/year)	600	3,000	10,000
No. of Connections	1,736	1,039	1,836
DisCo Supply Hours	3	16	12
LCOE (US$/kWh)	0.88	0.36	0.18

RMI Graphic. Source: RMI analysis of IMG pilot data

RMI's modeling shows that for these second-wave projects, there is an **opportunity to bring down the LCOE to an average of US$0.18/kWh, a 68% cost reduction from the pilot project IMGs** (see Exhibit 31). The main drivers for the cost reduction will be:

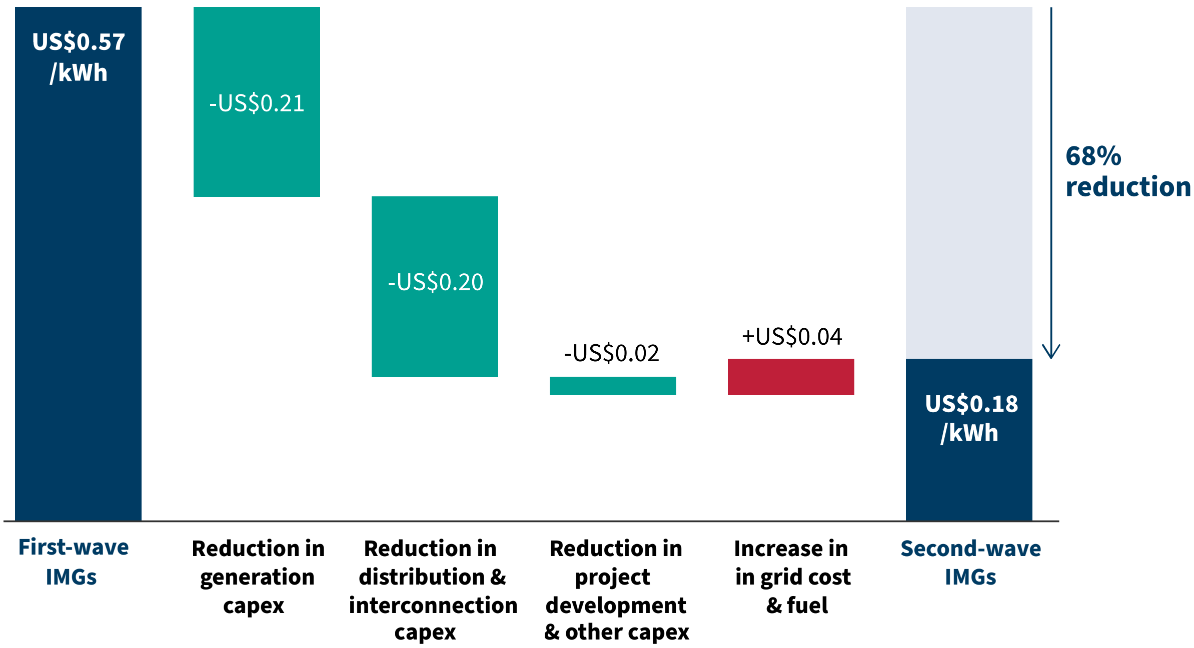
1. **Lower generation system component costs:** Solar, battery, inverter, and other component costs have come down significantly since the procurement was done for the first wave of projects. Exhibit 18 shows the benchmark costs for PV modules and BESS in 2024 are 65% and 44% less than the average costs observed in the supported projects, respectively. Experts believe these costs will keep declining rapidly, allowing the second wave of IMGs to benefit from significantly lower unit capex costs.

2. **Lower distribution and interconnection system costs:** Similarly, the costs associated with distribution and interconnection systems, particularly when DisCos select the right sites with relatively healthy distribution networks, will be lower than the first wave of projects. Standardized roles and responsibilities, improved collaboration between DisCos and developers, and innovative

distribution and interconnection architecture will also result in lower costs. *Appendix F* provides a broader set of recommendations for IMG interconnection in future projects.

3. **Lower project development costs:** In collaboration with participating DisCos, RMI has significantly mitigated risks associated with these projects through thorough project development and feasibility studies. This will lower the project development costs faced by the involved developers.

Exhibit 31 **Cost Reduction Opportunities for Second-Wave IMGs: Achieving a LCOE of US$0.18/kWh**



Note: Increase in grid cost is due to the higher DisCo tariffs expected in future projects as the Nigeria power sector moves away from consumer subsidies and toward more cost-reflective tariffs. Increase in fuel cost is because these IMGs are expected to provide a minimum of 22 hours of daily supply.

RMI Graphic. Source: RMI analysis of IMG pilot data

5. Recommendations for Sector Stakeholders

IMGs are poised to scale rapidly in Nigeria over the coming years. The REA's Distributed Access to Renewable Energy Scale-Up (DARES) program, supported by the World Bank, aims to support 125 IMGs with up to US$127 million in grant funding over the next three years.[20] At the same time, the Nigerian Electricity Regulatory Commission (NERC) has mandated DisCos procure 10% of their annual energy supply from embedded generation, with at least 50% sourced from renewable energy. IMGs will play a critical role in DisCos achieving these targets.[21]

RMI's recent analysis estimates an IMG market opportunity of up to 22 GW — 4,000 to 8,000 single projects depending on size — over the next decade,[22] almost twice the existing installed generation capacity in the country. This market opportunity could result in 25 million improved single connections, affecting 125 million people, which will be critical in achieving SDG7, Mission 300, and, more broadly, Nigeria's energy transition.[xxix]

> **"The Nigerian Electricity Regulatory Commission has mandated DisCos procure 10% of their annual energy supply from embedded generation, with at least 50% sourced from renewable energy. IMGs will play a critical role in DisCos achieving these targets."**

Despite the immense potential and progress achieved over the past three years, the IMG and utility-enabled DER market will struggle to scale without major improvements and acceleration efforts by stakeholders. RMI's analysis of the four IMG pilot projects highlights key lessons that should inform existing and future projects at the design, execution, and operational stages.

This section outlines actionable recommendations for developers, DisCos, government agencies and regulators, financiers, and donors to shift from incremental growth to exponential market expansion categorized by thematic areas.

Project preparation, design, and execution

While both DisCo- and developer-led IMG project development tracks will be required and should be pursued, to achieve scale and build the value chain specialization required for a mature market, DisCo-led procurement is likely to result in lower cost. Some key recommendations are:

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xxix SDG7 is one of the 17 Sustainable Development Goals established by the United Nations in 2015. It aims to "Ensure access to affordable, reliable, sustainable and modern energy for all" by 2030 (**https://sdgs.un.org/goals/goal7**). Mission 300 is a collaborative initiative by the World Bank Group and the African Development Bank aimed at providing electricity access to 300 million people in sub-Saharan Africa by 2030, focusing on distributed renewable energy solutions and partnerships.

- Developers and DisCos should strive for consensus on site selection criteria for a win-win outcome. They should select locations with moderate distribution network refurbishment needs that improve service to existing underserved customers while expanding to unserved ones.

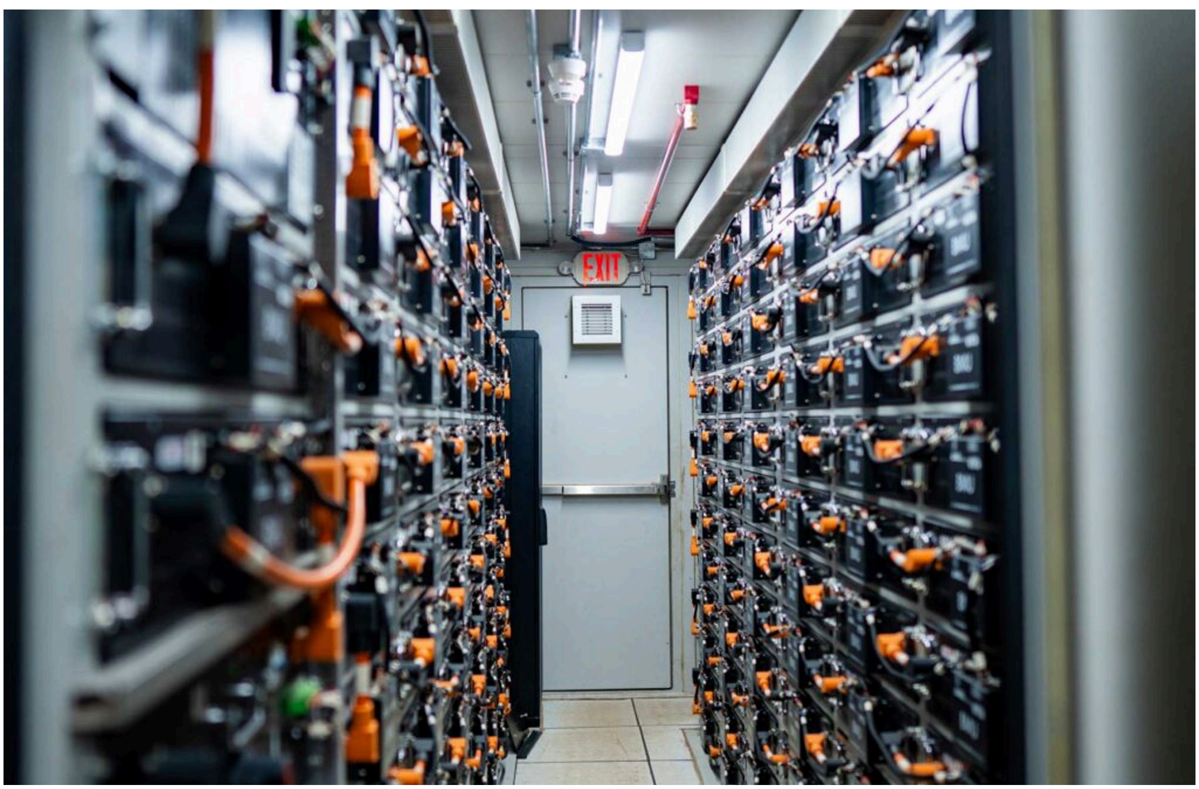
- DisCos should align their network investments (upgrades, digitization, and metering efforts) and plans with IMG/DER opportunities to maximize value and reduce developers' distribution capex. DisCos should prioritize network investments to ensure high grid availability for IMG locations to realize the expected increase in revenues and ensure project-optimized economics.

- DisCos should define clear roles and responsibilities in project agreements. Developers, on the other hand, need to build stronger collaboration with DisCos.

- DisCos should develop a substantial pipeline of IMG projects, tender them in lots, and utilize competitive procurement to achieve the least-cost development. DisCos should ensure data availability to facilitate IMG project preparation and reduce data collection lead time.

- IMG construction quality and adherence to industry standards should be enhanced. Developers should strictly follow established industry standards and best practices, ensuring the use of high-quality materials and construction techniques. Maintaining these standards is essential for securing timely project certification, minimizing rework, and enhancing the long-term reliability and performance of IMG projects.

- Developers should build scalable and modular solutions, starting conservatively and expanding as demand grows to optimize capex and returns.



Battery bank inside Wuse IMG's powerhouse.

Cost optimization and financing

A combination of larger projects and procurement aggregation, government incentives, value chain specialization, and more public and affordable financing are likely to reduce the LCOE of IMGs by at least 68% (see Exhibit 31). To achieve this:

- Developers should build larger projects and portfolios to benefit from economies of scale. Developers should leverage DisCo feeders and corridors with existing IMGs to build more IMGs and DERs that serve multiple demand hubs, reducing distribution and operations costs per project.

- Developers should outsource specialized project life-cycle components that require external expertise to avoid delays and cost overruns witnessed during the first wave of projects. As the sector grows, engineering, procurement, and construction (EPC) and operations and maintenance (O&M) are clear opportunities for outsourcing.

- Government and policymakers should allocate public financing to support network upgrades, last-mile connections, and interconnections, helping unlock an approximately US$0.20/kWh (see Exhibit 31) cost reduction opportunity.

- Financiers and donors should support initiatives that enable cost reduction, such as local currency financing.

- Public and philanthropic funds should be leveraged to de-risk investments. Allocating public and philanthropic capital to project preparation facilities can help mitigate early-stage risks and uncertainties, making IMG projects more attractive to private investors. These funds can support feasibility studies, technical assessments, and financial structuring, ultimately enhancing bankability and accelerating private sector participation.

Grid infrastructure and development

DisCos and developers should continue working together to enhance the grid infrastructure within the IMG, while also elevating collaboration for mutually increased revenue collection and ultimately better service to end-users. To achieve this:

- Developers should hire DisCo-approved contractors for distribution network upgrades, adhere to DisCo distribution network technical specifications, and coordinate implementation closely with DisCos for efficiency.

- DisCos should provide smart meters at the interconnection points of all DER customers for better visibility and reconciliation.

- Developers should prioritize data-driven asset management to reduce network losses, prevent theft, and improve revenue monitoring.

Toto IMG.

Regulatory and enabling framework

As the market heads into larger and faster project pipelines, NERC, state regulators, the Federal Government of Nigeria, and other stakeholders will have to quickly adapt to the market needs to ensure a growing supportive environment. To achieve this:

- Government and policymakers should expand the allowable installed capacity for larger IMGs.[xxx]
- Government and policymakers should adapt minigrid regulations for IMGs, addressing key challenges such as grid supply tariffs, DUOS, and legacy debt.
- Government and policymakers should monitor and report key operational improvements from existing projects, enforce performance standards, and share learnings.
- Financiers and donors should develop programs that offer a first-loss mechanism to IMG developers for DisCo energy supply shortfalls.

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xxx DARES Phase 1 is in advanced conversations with NERC for a capacity waiver from 1 to 10 MW of installed capacity for the 40 selected sites.

- Government and policymakers should expand the IDEC to include all clean energy components that meet Nigerian technical standards, expediting equipment procurement.
- Government and policymakers should promote in-country manufacturing by local and international OEMs to reduce project costs.
- Government and policymakers should clearly define IMG standards on interconnection and energy trading to reduce uncertainty and accelerate project timelines.

Institutional and workforce development

Ramping up skillsets and operational capacity of developers and DisCos will be critical to ensure market growth is sustainable. RMI's key recommendations for these are:

- Developers should improve governance and grow senior leadership teams to enhance operational effectiveness.
- DisCos should create and support dedicated DER units to drive the implementation of IMGs.
- Financiers and donors should include and prioritize workforce development to build the energy transition workforce needed for project development.

Appendices

Appendix A: Roles of DisCo and Developers in Projects

Toto IMG

Category	Developer role	DisCo role
Project Initiation	**Selected** Toto as a pilot from the shortlist of four communities.	**Originated** four communities with ~14,000 connections to implement a portfolio of IMGs.
Project Preparation	**Led** the project preparation including community engagement, IMG system design, business model design, and source for financing. **Negotiated and signed** a tripartite agreement between the Toto community leadership, AEDC, and PowerGen. **Conducted** environmental and social management plan and environmental impact assessment studies needed for NERC's approval and applied for and received NERC's permit.	**Negotiated** and signed a tripartite agreement. **Supported** PowerGen in regular community engagement.
Construction	**Procured** equipment and constructed the generation and distribution system, including interconnection equipment like transformers and voltage regulators. **Tested** the system and received NEMSA's approval.	**Validated** distribution network upgrade costs and recommended vendors to PowerGen. **Provided** oversight and quality control of the system.
Operation	**Operates** the minigrid and maintains the minigrid assets, ensures adequate service to the community, and carries out billing and collection for all energy sales in Toto.	**Invoices** PowerGen monthly for total grid electricity consumed at Toto.
Project Close	**PowerGen** has a license to own and operate the minigrid for 20 years with an option to extend.	**After 20 years,** AEDC can extend PowerGen's term or resume operations in Toto. PowerGen will receive compensation equal to the depreciated value of its assets at Toto if AEDC takes back the territory.

Zawaciki IMG

Category	Developer role	DisCo role
Project Initiation	**Selected** Gida Dubu housing estate from a list of 100 sites it identified in partnership with the DisCo.	**Identified** 100 potential DER sites in partnership with the developer, Bagaja.
Project Preparation	**Partnered** with an experienced EPC, EMONE, for the project IMG system design. **Negotiated** and signed a tripartite agreement between the Gida Dubu community leadership, KEDCO, and Bagaja renewables. **Applied** for and obtained NERC's approval and permit.	**Negotiated** and signed a tripartite agreement. **Supported** Bagaja in regular community engagement.
Construction	**Awarded** turnkey EPC projects for generation assets and distribution network upgrades to EPCs EMONE and Digibits. **Constructed** new medium-voltage line and rehabilitated the old medium-voltage network. **Tested** the system and received NEMSA's approval.	**Rehabilitated** the low-voltage networks within the community. **Provided** the bulk electricity meter. **Provided** oversight and quality control of the system.
Operation	**Operates** the minigrid and maintains the minigrid assets, ensures adequate service to the community, and carries out billing and collection for all energy sales in Zawaciki.	**Invoices** Bagaja monthly for total grid electricity consumed.
Project Close	**Bagaja** has a 20-year license to operate the IMG.	**After 20 years,** KEDCO can resume operations in Zawaciki.

Robinyan IMG

Category	Developer role	DisCo role
Project Initiation	**Selected** Robinyan and a cluster of five other neighboring villages and communities.	**Approved** developer's approach to community. Provided stakeholder engagement support to developer.
Project Preparation	**Negotiated** and signed a tripartite agreement between the Robinyan communities and Ikeja Electric. **Conducted** environmental and social management plan and environmental impact assessment studies needed for NERC's approval and applied for and received NERC's permit.	**Negotiated** and signed a tripartite agreement. **Supported** Darway Coast in regular community engagement.
Construction	**Installed** a 500 kWp solar plant and a 625 kWh BESS containerized solution. **Rehabilitated** the old medium-voltage network. Rehabilitated and extended existing low-voltage network coverage. **Tested** the system and received NEMSA's approval.	**Provided** technical standards for poles, conductors, and method of installation. **Trained** developer staff and contractors on safe work practice and technical benchmarks. **Provided** oversight and quality control of the system.
Operation	**Operates** the minigrid and maintains the minigrid assets, ensures adequate service to the community, and carries out billing and collection for all energy sales in Robinyan.	**Invoices** Darway Coast monthly for total grid electricity consumed.
Project Close	**Darway Coast** has a license to own and operate the minigrid for a 10-year period and is currently negotiating an extension to 20 years.	**After the IMG term,** Ikeja Electric can resume operations in Robinyan.

Wuse IMG

Category	Developer role	DisCo role
Project Initiation	**Ran** a pilot comprising 40 shops to test the viability of a market IMG.	**Approved** pilot and main project in the market. **Provided** stakeholder engagement support to developer.
Project Preparation	**Negotiated** and signed a tripartite agreement between the market representatives and the DisCo. **Applied** for and obtained NERC approval.	**Negotiated** and signed a tripartite agreement. **Supported** the developer in regular community engagement.
Construction	**Installed** a 1,000 kWp solar plant and a 1,200 kWh BESS containerized solution. **Tested** the system and received NEMSA's approval.	**Rehabilitated** medium-voltage lines supplying the market. **Upgraded** the bulk energy meter to be automatic meter reading/advance metering infrastructure ready. **Provided** oversight and quality control of the system.
Operation	**Operates** the minigrid and maintains the minigrid assets, ensures adequate service to the community, and carries out billing and collection for all energy sales in the market.	**Invoices** GVE monthly for total grid electricity consumed.
Project Close	**GVE** has a license to own and operate the minigrid for 20 years.	**After the 20 years,** AEDC will resume operations in Wuse.

Appendix B: IMG Cost Categories and Project Phases

Cost categories

The major capital cost categories in deploying IMGs are:

1. **Generation system costs:** All costs incurred to construct the generation system including:
    a. PV modules, commonly known as solar, PV, or panels, which convert solar energy to electricity.

    b. PV inverters, which convert the direct current output of the PV module to usable alternating current.

    c. BESS, which stores intermittent solar energy for use at night. It also includes battery or load inverters that release the energy stored in the battery to power the load.

d. Genset system, typically diesel-fired, which works together with the PV system and BESS and acts as a backup to the system. It also includes fuel tanks and related accessories.

e. Generation balance of systems, which refers to all additional components, equipment, and structures to create an operational generation system such as racks and mounting structures, electrical panels, cables, switching, and protection devices.

f. Other costs including labor costs, logistics costs, and civil works.

2. **Distribution and interconnection system costs:** This includes all costs incurred during construction of the distribution system and final delivery of the electricity from the generation system and grid to the customers including:

   a. Interconnection system, which includes transformers, voltage regulators, electrical panels, and cables that ensure the ensure proper integration between the minigrid generation system, the community distribution network, and the main distribution network.

   b. Distribution system, which includes cables, poles, meters, and other accessories that are involved in the final delivery of electricity to customers.

3. **Project development costs** including the costs of the land, design, business development, and licensing and regulatory costs.

4. **Other costs** such as contingencies, insurance, and miscellaneous.

Project phases

The major phases in deploying IMGs are:

1. **Initiation phase**, which includes the identification and engagement of underserved and willing customers with the buy-in of the partner DisCo.

2. **Preparation phase**, which involves data gathering, technical assessment, system design, tripartite agreement signing, and financial close.

3. **Execution phase**, which includes the construction of the DER infrastructure and network rehabilitation and expansion, as well as obtaining final certification of completion.

Appendix C: Common Construction Issues with IMGs

Common construction issues flagged by NEMSA during certification inspection include:

1. **Lack of visible signs, tagging, and labeling of assets:** Key subsystem components were often without visible warning signs, name tags, and labels.

2. **Undersized equipment:** Cables, protective devices, and similar equipment were sometimes undersized and deemed unsafe.

3. **Poor PV mounting structures:** Ground mounts for supporting PV arrays are expected to support the PV array throughout its useful life. Metal frames for ground mounts not made of aluminum or galvanized steel were flagged as not being fit for use.

4. **Noncompliance with functional tests:** Transformers and earth and cable insulation resistance are part of the many functional tests carried out during site inspection. Noncompliance resulted in reinspection for certification, which sometimes took several weeks to complete.

5. **Poor site sanitation and landscaping:** This is the availability of water, sanitation, firefighting equipment, and site landscaping. This is to ensure the safety of lives and properties, control weeds, and maintain the PV arrays by washing them after the accumulation of dust, which affects the overall system performance.

Appendix D: Further Analysis on IMG LCOE

LCOE formula

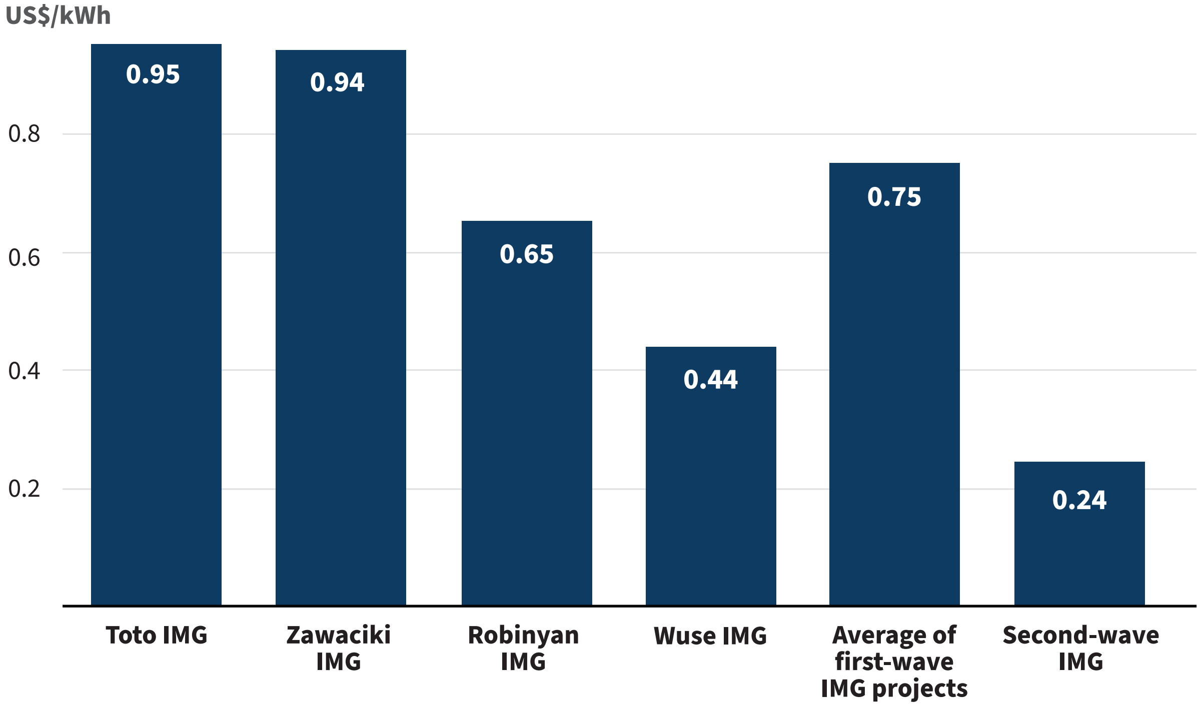
$$\text{LCOE} = \frac{\text{(Net Present Value of total costs over IMG lifetime)}}{\text{(Net Present Value of electrical energy produced over lifetime)}}$$

The LCOE analysis includes all costs, including those covered by grant financing from RMI, GEAPP, and other grant sources.

LCOE from DER only

Analyzing the LCOE from DERs only without including the impact of the low-cost grid energy gives us insight into the cost of deploying DERs in Nigeria and the opportunity for improvement. Exhibit 32 shows an opportunity to reduce the LCOE of electricity produced by DERs alone by 67% from where it is today.

Exhibit 32 **IMG LCOE from DERs alone shows a 67% cost reduction opportunity**



RMI Graphic. Source: RMI analysis of IMG pilot data

Although LCOE is a widely used metric to compare the economic competitiveness of DERs, there are several limitations to using LCOE to assess the economic competitiveness of IMGs. These include:

- **Oversimplification of costs:** Typically, LCOE primarily focuses on the cost of electricity generation. For IMGs, however, there are additional costs like distribution network improvement, metering, and customer connection costs that an IMG developer incurs that increases their LCOE and seemingly reduces their attractiveness.
- **Focus on average cost:** LCOE provides an average cost over the lifetime of a project, which obscures the variability of costs over time given macroeconomic conditions that come with high inflation in the Nigerian context. The starting tariff needed to generate a decent return to a developer is significantly lower than the LCOE if one assumes a reasonable tariff growth rate. Consequently, utilizing the LCOE as a proxy for tariffs at the start of the IMG operation can seemingly reduce their attractiveness.
- **Sensitivity to assumptions:** LCOE is highly sensitive to the assumptions used in the calculation, such as discount rates. Lowering financing costs that developers can access significantly improves the LCOE of IMGs.

Appendix E: Summary of Model Assumptions for LCOE Calculations

Parameter	Value	Units	Comments
Economic Assumptions			
Discount rate/developer's weighted average cost of capital (WACC)	16.0	%	For pilot projects, developers' actual WACC were used
Project lifetime	20	years	
Unit Costs			
Land per kW of solar PV	0.0010	acres/kWp	Unit costs were used to calculate replacement costs for pilot projects
Solar PV	306	US$/kW	
BESS — battery, battery inverter	225	US$/kWh	
Gas genset, tanks, genset accessories	1,000	US$/kW	
Diesel genset, tanks, genset accessories	258	US$/kW	
One-phase meters (including all accessories)	73	US$/meter	
Three-phase meters (including all accessories)	128	US$/meter	
Distribution transformer meters	430	US$/meter	
Land purchase	13,889	US$/acre	
Interconnection system	143	US$/kWp of solar PV	
Project development	4%	% of generation capex	
Equipment Lifetime			
Solar PV	25	years	Lifetime values were used to determine replacement timelines for pilot projects
BESS	10	years	
Diesel generator	15,000	hours	
Distribution	20	years	
Metering	8	years	
O&M			
Solar PV	10	US$/kW·year	
Battery	3	US$/kWh·year	
Diesel generator O&M	0.01	US$/kWh	
Starting diesel fuel cost	1,400	NGN/liter	
Insurance	1	% of capex	
Other operational costs	1,000	US$/year	
Annual O&M increase rate	2	%	
Diesel/gas fuel price increase rate	4.2	%	

Parameter	Value	Units	Comments
IMG 1 (Representative Second-Wave IMG) System Design			
Solar PV	4,941	kWp	
BESS	1,442	kWh	
Diesel generator	1,000	kVA	
One-phase meters	1,830	# of meters	
Three-phase meters	6	# of meters	
DT meters	7	# of meters	
ACPU	14.60	kWh/day	
Diesel consumption	543,553	liters/year	

Appendix F: Recommendations on Interconnection in IMGs: Roles, Responsibilities, and Processes

Exhibit 33 provides a set of recommendations for the roles and responsibilities between DisCos and the project developer for IMG interconnection with the main grid.

The DisCo should be responsible for feeder allocation and voltage assignment while advising on equipment specifications. It should provide technical oversight and quality control during substation and distribution network construction and rehabilitation. It must invest in the modern metering infrastructure with automatic meter reading/advance metering infrastructure (AMR/AMI) capabilities and any necessary voltage regulation.

The developer should be responsible for validating feeder reliability and selecting interconnection equipment with the DisCo's approval, adhering to relevant codes and standards. It should manage network rehabilitation beyond the point of interconnection, oversee substation construction, and may install a secondary grid meter for independent energy validation.

Exhibit 33 Summary of recommended interconnection roles and responsibilities

Process	DisCo	Developer
Feeder allocation	Assigns IMG to an existing feeder or carves out a new feeder if the existing feeder is overloaded	Validates that the assigned feeder has high availability and reliability
Voltage level assignment	Assigns interconnection voltage	No role
Network upgrade	Responsible for all network upgrades upstream from the agreed point of interconnection	Responsible for all network upgrades downstream from the agreed point of interconnection
Transformer specifications	Advises on approved vector group and earthing arrangements	Designs transformer capacity based on estimated IMG demand and future load growth projections
Substation construction	Provides oversight and quality control of the construction process	Constructs substation
Interconnection equipment selection	Provides technical guidance	Selects interconnection equipment with DisCo buy-in
Voltage correction/ regulation	Responsible for all voltage corrections and regulation at the medium-voltage level	No role
Bulk metering	Provides main grid bulk meter	Can install a secondary bulk meter to validate grid consumption
Cutover and commissioning	Signs off on interconnection and supplies power to the IMG	Notifies host DisCo and regulatory inspectors of its intent to cutover and commence commercial operations

RMI Graphic. Source: RMI analysis of IMG pilot data

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