Battery storage in developing countries

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Transforming Energy Access

THE FARADAY INSTITUTION

This report was commissioned by the Faraday Institution and funded with UK aid from the UK government via the Transforming Energy Access (TEA) Platform. The TEA Platform supports early-stage testing and scale up of innovative technologies and business models that will accelerate access to affordable, clean energy-based services to poor households and enterprises, especially in Africa

Agenda

Total energy storage demand projections have increased, with reductions for some use-cases

↓ Lower ↑ Higher

Use-case	Segment	Change compared to 2019[1]
Mobility	Cars, 2/3 wheelers, buses/commercial	↓ Previous projections for India higher than actuals and have been scaled down. For other regions projections have increased because of higher ambition and further policy action
Stationary	Utility-scale	↑ More ambitious renewable expansion plans translating into greater need for grid balancing
	Behind the Meter (BTM)	↓ Limited progress on removing barriers and strengthening the regulatory environment
	Mini-grids	↑ Several governments have incorporated mini-grids into their National Electronification Plans the policy environment appears to be improving
	SHS/Pico	↓ Actual uptake significantly lower than previous projections; Covid-19 exacerbated impacts Barriers continue to slow uptake across most regions

1. Vivid Economics (2019): Rapid market assessment of energy storage in weak and off-grid contexts of developing countries

Energy storage demand is projected to increase by ~1,700 GW between 2023-35 in South Asia, SSA and ASEAN

Broadly even split between mobility and stationary

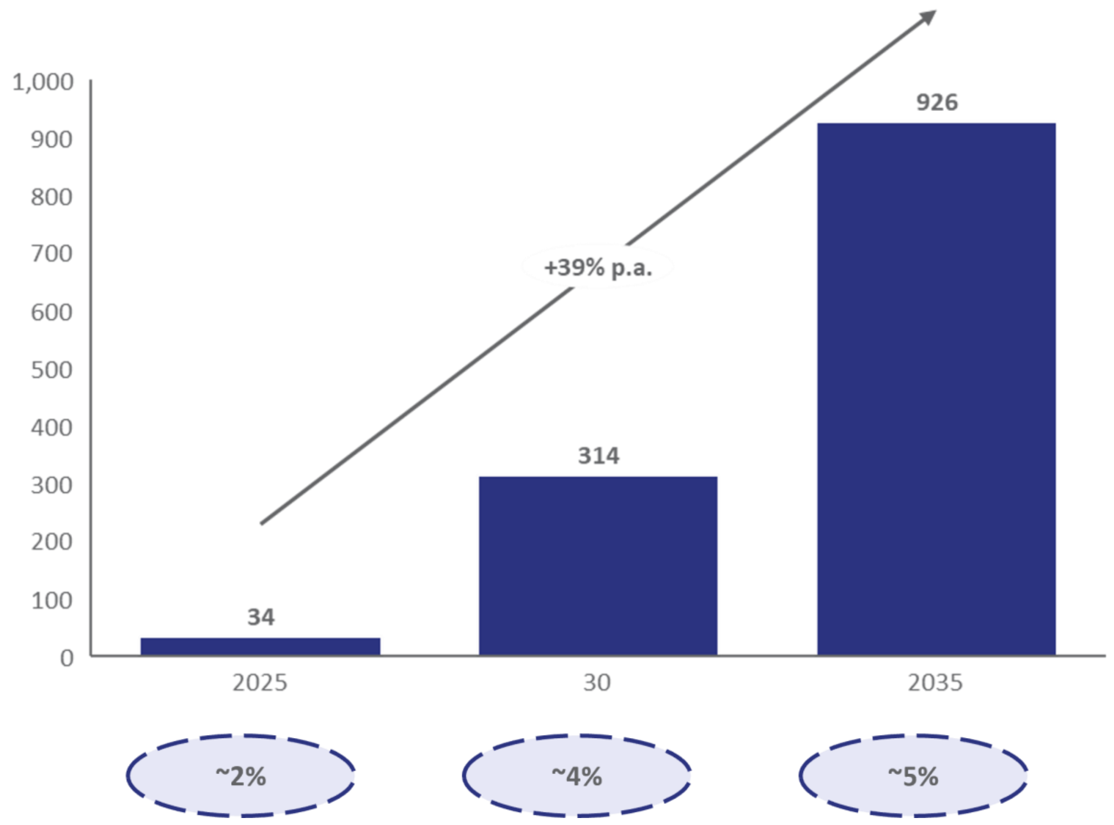
Energy storage demand (2023-2035), GW

Agenda

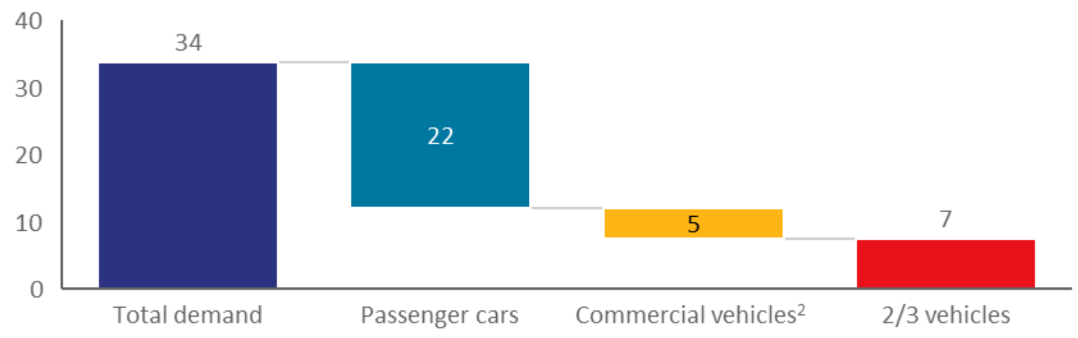
Battery demand from mobility is projected to increase by ~930 GW between 2023-35, primarily driven by passenger cars

~XX% % share in Global EV battery demand

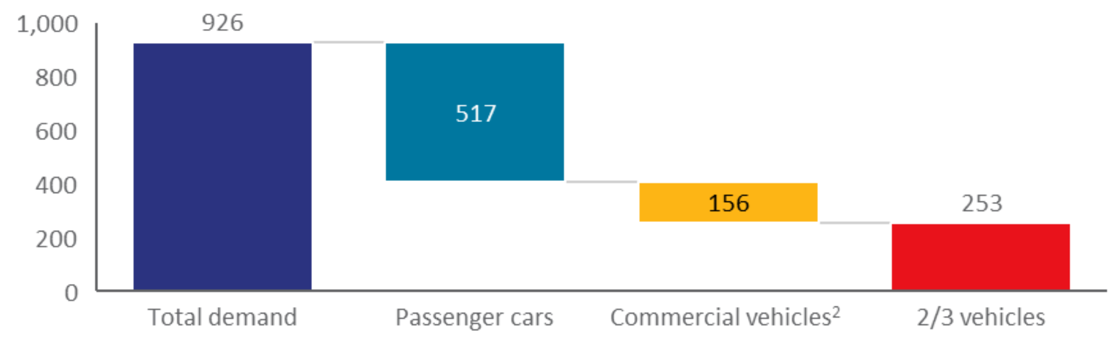
Battery demand in developing nations[1], GW



Battery demand by segment (2025), GW



Battery demand by segment (2035), GW

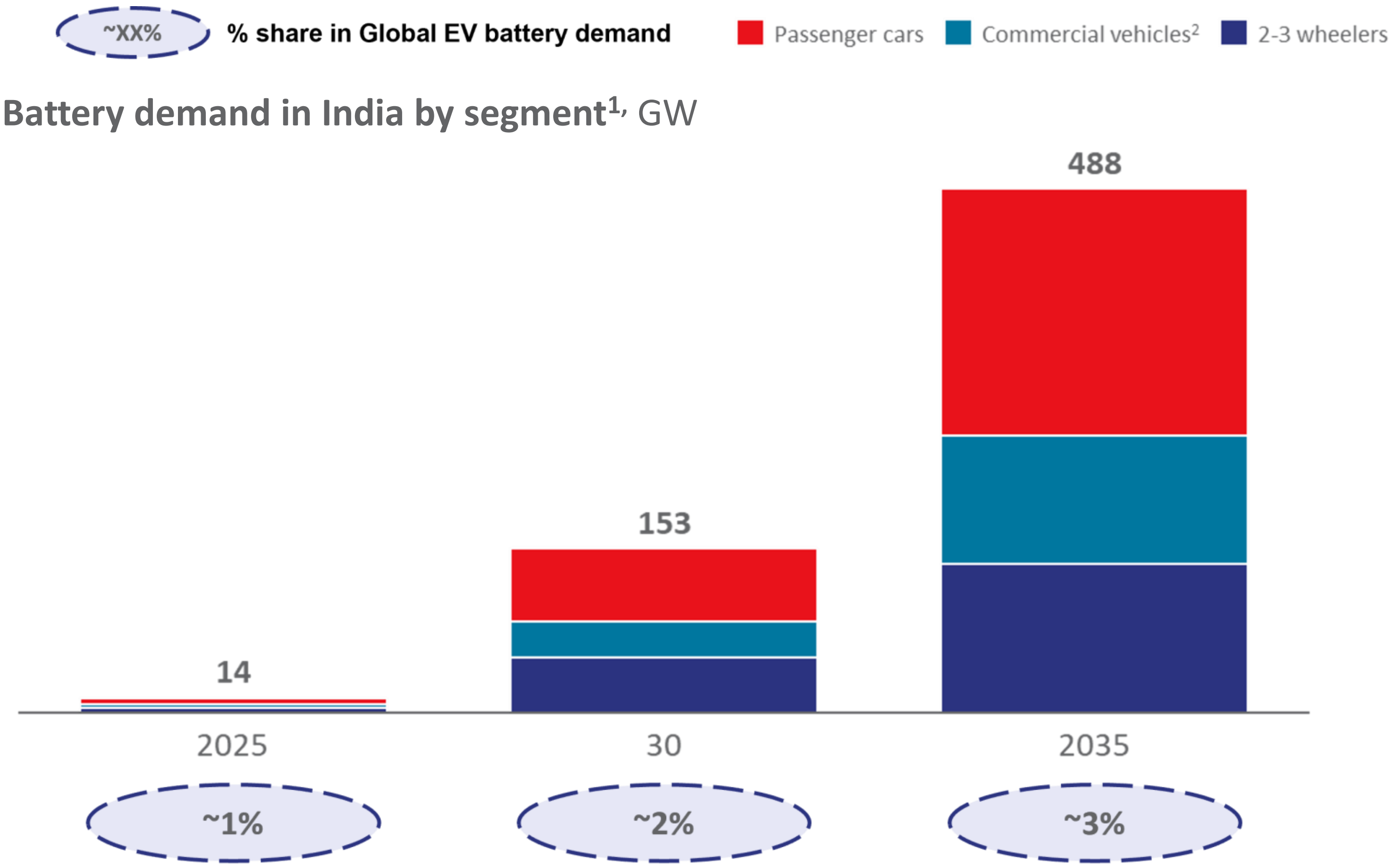


1. The estimates are based on a 1.9-degree pathway.. The regions included are: India, ASEAN and Sub-Saharan Africa
2. Commercial vehicles include buses, trucks and light commercial vehicles

Source: Shell Foundation (2022): Financing the transition to electric vehicles in Sub Saharan Africa, McKinsey (2022): Power to move: Accelerating the electric transport transition in sub-Saharan Africa, analysis by a leading management consultancy

India is projected to account for half of total mobility battery demand

This is driven by targets and a positive regulatory environment



1. The estimates are based on a 1.9-degree pathway.
2. Commercial vehicles include buses, trucks, light commercial vehicles
3. The Faster Adoption and Manufacturing of Electric Vehicles (FAME) – II aims at supporting the electrification of public and shared transportation: around 7,000 electric and hybrid buses, 500,000 lakh electric three wheelers, 55,000 electric four-wheeler passenger cars, and 1 million electric two wheelers

Source: IEA (2022): Global Electric Vehicle Outlook, analysis by a leading management consultancy

Key Drivers

Targets

EVs to account for 30% of annual passenger LDV sales by 2030.

Regulation

Fiscal incentives E.g. Under FAME II[3] scheme, 2-wheelers and 3-4 wheelers receive ~180 USD/kWh and ~120 USD/kWh of battery capacity

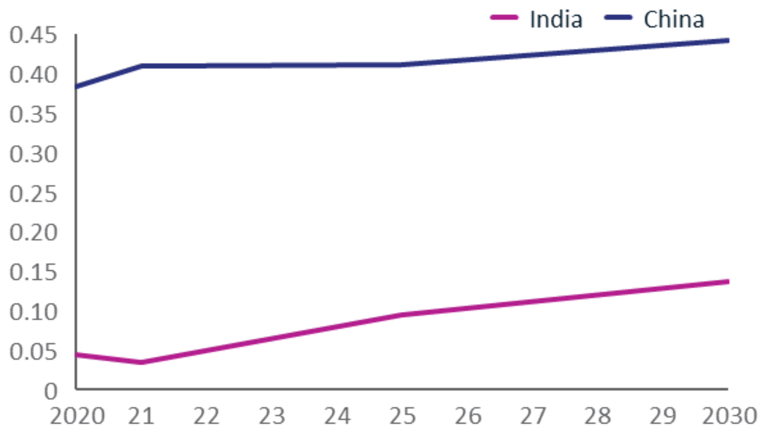
Infrastructure

EV charging infrastructure is growing. Between 2017 and 2021, total EV charging points have increased 4X from ~250 to ~1000.

Infrastructure gaps, negative consumer sentiments and uncertainty on future incentives could slow uptake in India

Charging infrastructure in India lags other developing economies

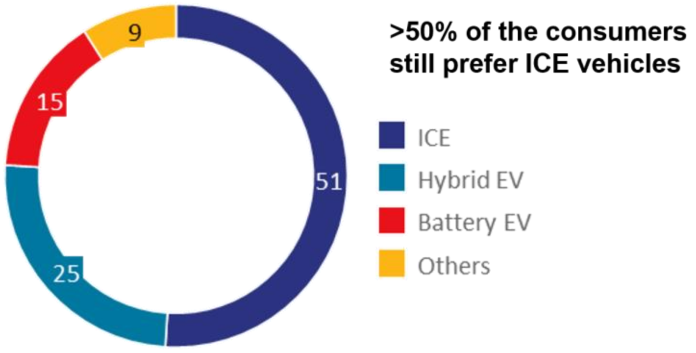
Share of publicly available fast chargers in total charging points (2020-2030), %



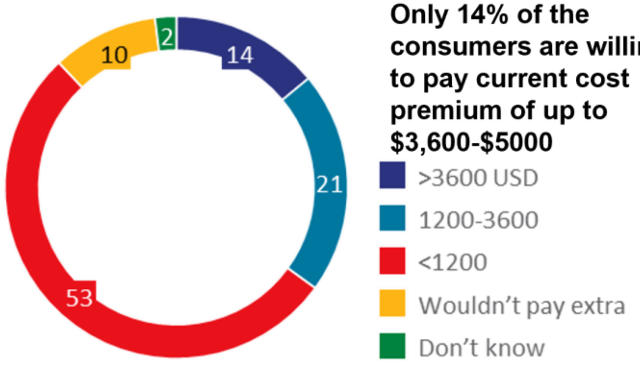
Limited availability of fast chargers could contribute to range anxiety and slow adoption, especially for larger vehicles

Limited consumer enthusiasm for EVs

Consumer preference for their next vehicle purchase, %



Consumer's willingness to pay extra for an EV, %



Policy uncertainty post 2024

Incentives per vehicle type under FAME II

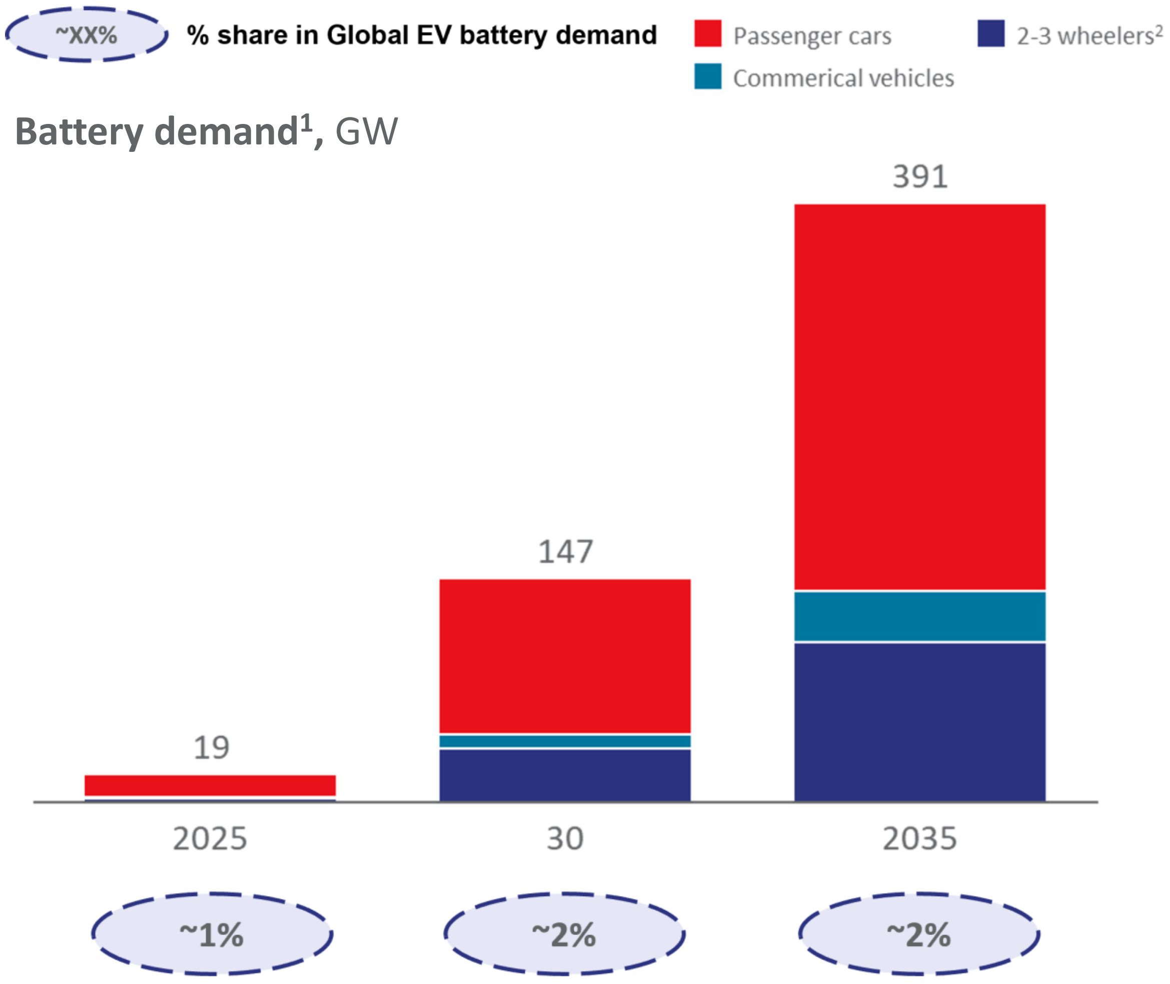
Vehicle type	Incentives/ kWh (USD)	Battery size (kWh)
2 wheelers	180	1-2
3 wheelers	120	3-5
4 wheelers	120	10-40
E-buses	240	200-350

Uncertainty on future incentive structures could slow EV uptake

Current incentives are crucial to reduce high upfront costs and improve the economics of EV ownership

Source: IEA (2022) Global EV Data Explorer, GOI - NITI Aayog, Expert interviews, The Climate Group

Battery demand is expected to increase by ~400 GW between 2023-35 in ASEAN…



1. The estimates are based on a 1.9-degree pathway.
2. ASEAN includes all developing countries in Asia except for India and China

Source: IEA (2022): Global Electric Vehicle Outlook, McKinsey (2022): Capturing growth in Asia's emerging EV ecosystem, analysis by a leading management consultancy

…driven by a favourable policy environment

Key drivers of growth of EVs in ASEAN

Targets

Ambitious targets in place in major markets. Thailand plans to have 100% share of ZEVs in new car sales by 2035; Malaysia plans 100% ZEV stock for all private transport and 40% in public transport by 2030

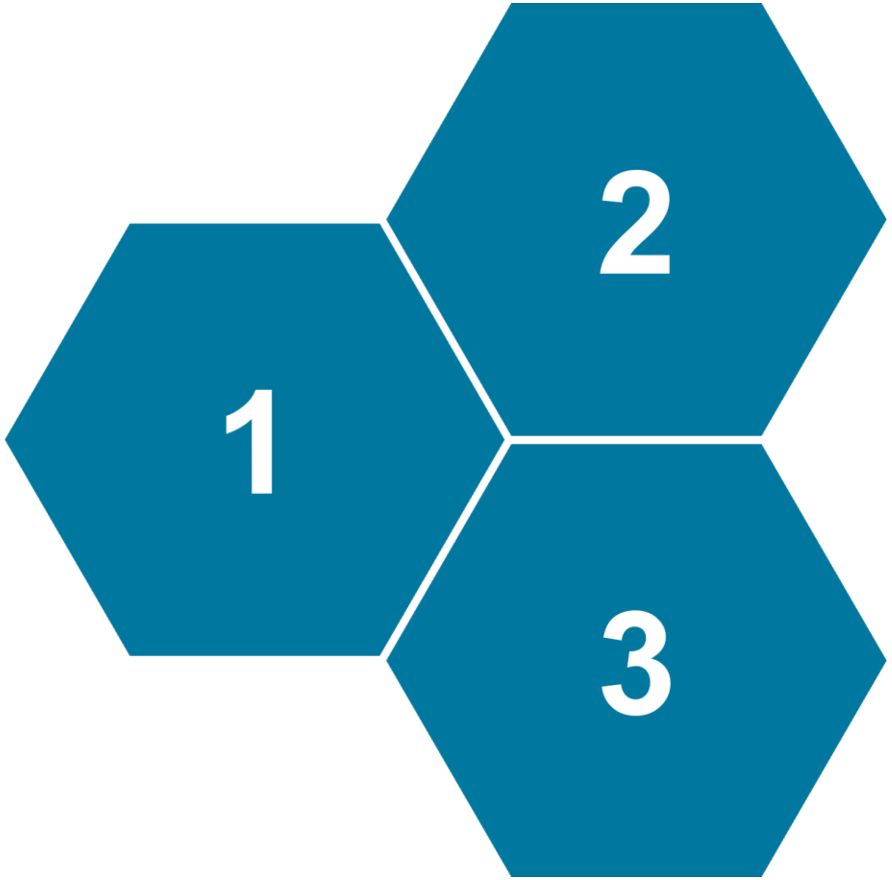
Regulation

Four major SE Asian countries (Indonesia, Malaysia, Thailand and Vietnam) introduced fiscal exemptions E.g., Thailand cut excise duties from 8% to 2% in 2022.

Infrastructure

Countries introducing EV infrastructure targets. E.g. Thailand has added >2,000 charging points between 2018 and 2021; Malaysia plans to set up 10,000 charging stations by 2025 under its Low Carbon Mobility Blueprint

Achieving the region's ambition is likely to require further action on removing barriers



1 **Insufficient infrastrucure:** Many ASEAN markets lack sufficient charging stations to support the projected growth of EVs.

2 **Higher upfront costs:** Despite subsidies, EVs are still more expensive than ICEs.

3 **Limited availability of low-cost models:** There are <20 new low-cost EV models planned for local distribution compared to >200 low-cost EV models in production or available commercially in mature Asian markets.

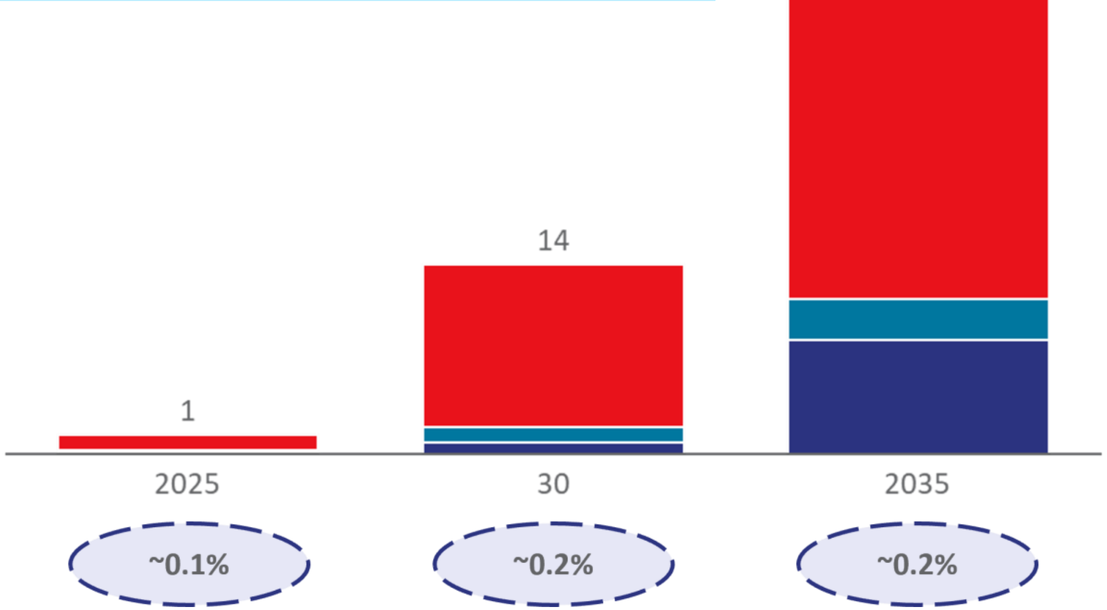
Source: IEA (2022): Global Electric Vehicle Outlook , McKinsey (2022): Capturing growth in Asia's emerging EV ecosystem, analysis by a leading management consultancy

Battery demand in Sub-Saharan Africa is expected to increase by ~50 GW between 2023-35, with passenger cars accounting for the largest share

Passenger cars | Commercial vehicles | 2-3 wheelers[2] | ~XX% **% share in Global EV battery demand**

Battery demand[1], GW

6 countries drive the automobile market in **SSA: South Africa, Kenya, Nigeria, Uganda, Ethiopia and Rwanda** account for **~70%** of the market



Key drivers

Targets

Targets are emerging in some large markets. E.g., Kenya set a target of 5% share of EVs in total vehicle imports by 2025; South Africa plans to convert 5% of the public and private vehicle fleet to cleaner alternative fuels by 2025

Regulations

Countries are reducing or eliminating import duties on EVs to encourage uptake e.g., Ghana, Rwanda, the Seychelles, Mauritius

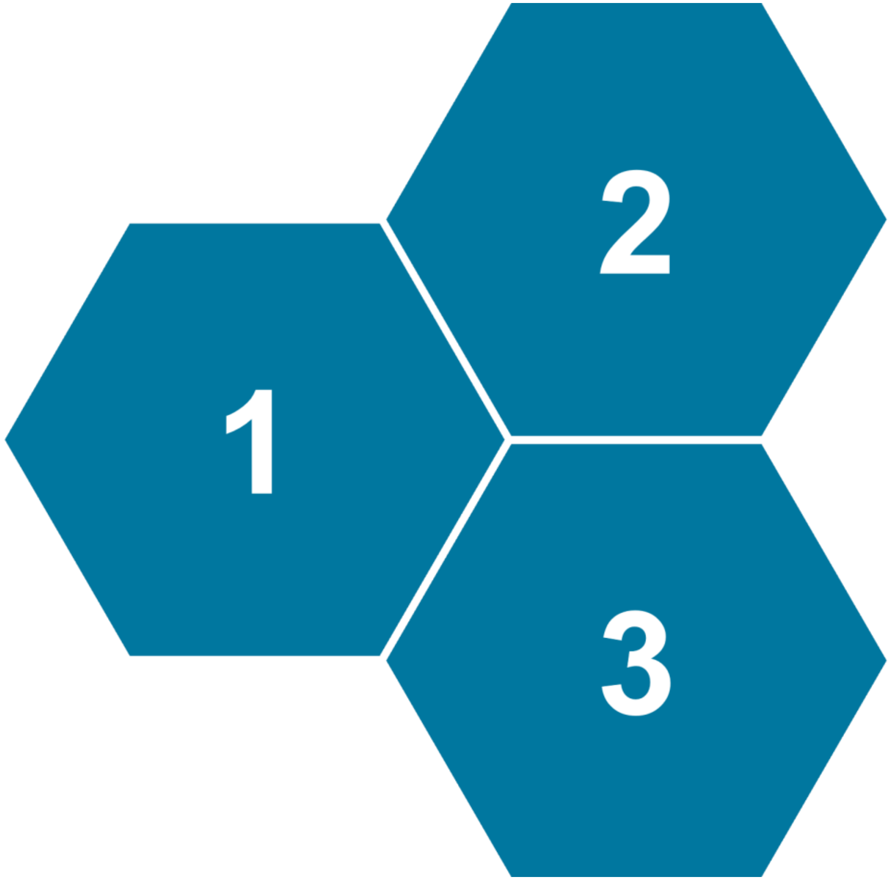
Emerging use case for electric two-wheeler adoption in SSA

The higher average distance travelled make them cost-effective over their lifetime compared to ICE equivalent vehicles

1. The estimates are based on a 1.9-degree pathway.
2. Commercial vehicle demand is based on Shell Foundation (2022). This is done for 5 key countries in SSA – Kenya, Nigeria, Uganda, Rwanda and Ethiopia. South Africa's share was adjusted based on market share of these countries in automobile sales in 2021.
3. IHS Markit consumer survey of ~1000 vehicle owners in Nigeria and Kenya

Source: IEA (2022): Global Electric Vehicle Outlook, Shell Foundation (2022): Financing the transition to electric vehicles in Sub Saharan Africa, McKinsey (2022) : Accelerating the electric transport transition in sub-Saharan Africa , Mordor Intelligence, analysis by a leading management consultancy

Further action is needed to remove barriers to EV growth in SSA



1 **Unreliable electricity supply:** electricity reliability remains a challenge across the region. In 2020, the System Average Interruption Disruption Index (SAIDI) for Sub-Saharan Africa was 39.30 versus 0.87 for OECD countries, and higher in some key markets (e.g., 60 in Kenya)

2 **Affordability:** higher upfront capital costs compared to ICEs, combined with limited asset finance at affordable rates exacerbates affordability challenges

3 **Dominance of second-hand vehicles:** Around 85% of 4-wheel vehicles sales are second-hand, which could limit the market for new EVs.

Source: Shell Foundation(2022): Financing the transition to electric vehicles in Sub Saharan Africa, McKinsey (2022):Accelerating the electric transport transition in sub-Saharan Africa , analysis by a leading management consultancy, World Bank

The private sector is developing innovative business models to overcome challenges in developing countries

Battery-specific models	1 **Battery leasing:** Customers have the option to lease the battery by making annual payments, which lowers upfront costs. 2 **Battery swapping:** Exchange a discharged battery for a fully charged one at swapping stations. 3 **Recycling/Refurbishing:** The recycle or reuse of batteries for the automotive sector or 2nd life use in stationary applications.
Vehicle-specific models	4 **B2C EV sharing:** Consumers can pick up a car at a designated site and are charged based on distance travelled and time. 5 **EV leasing:** Consumers pay an annual (or monthly) fee for exclusive access to an EV for an agreed period. 6 **Electric retrofit:** Convert internal combustion engine vehicles into an electric vehicle.
Vehicle-grid integration	7 **Vehicle-to-grid (V2G):** EVs can export electricity to the grid (or mini-grid) to support grid balancing and other services; provide advanced demand side response.

Features of mobility business models (1/2)

Business model	Revenue model	Benefits to consumers	Examples
1 **Battery leasing**	Battery leasing charges	• Lower upfront costs • Flexibility to combine with battery swap models	Ampersand, Bounce Infinity, Gogoro
2 **Battery swapping**	Fees for replacing the newly charged battery	• Avoid the cost of charging infrastructure (e.g., for home charging) • Potentially longer battery life because of professional battery management	Sun Mobility, Ampersand, Grab, Amara Raja
3 **Recycling/ Refurbishing**	Sale of refurbished/ recycled batteries	• Lower cost batteries compared to new ones	Attero, Gravita, TES
4 **B2C EV sharing**	Charges based on time and distance travelled	• Flexibility to use the car only when needed • No maintenance cost • No fixed investment	Scoo EV Rentals, Orix, UFO Drive, Sparkcars

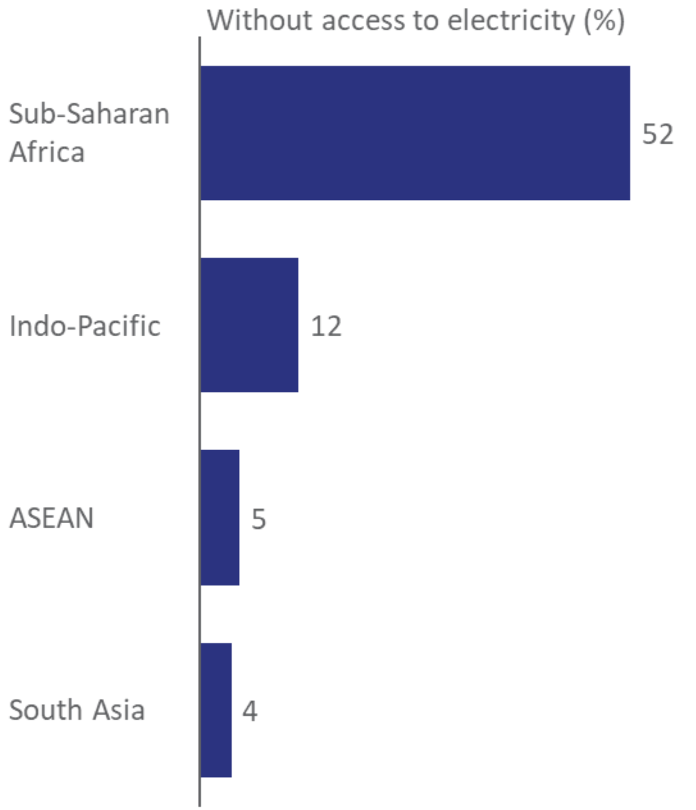
Features of mobility business models (2/2)

Business model	Revenue model	Benefits to consumers	Examples
1 **EV leasing**	Leasing charges for the car	• Flexibility of using a car only for a fixed period • No fixed investments • Lower maintenance cost	ALD Automotive, ecotrify, TATA MOTORS, ORIX
2 **Electric retrofit**	Service charges for conversion	• Cost-effective compared to new EVs (although likely to have a lower operating life)	SOLTECH WORLD, GoGoA1.com (Ride into the future), E-MOTION Zero Emission
3 **Vehicle to grid**	Difference between rates of charging EVs and selling electricity to the grid	• Additional revenue streams • More efficient charging patterns (e.g., when prices are low) could save costs • Potentially large benefits for businesses (e.g., EV fleet managers) • Additional social value through demand side response and providing other grid services	exicom

Agenda

In order to achieve universal access, a broad mix of energy solutions are needed in developing countries

A significant share of population lack access to electricity



A significant share of population lack access to electricity

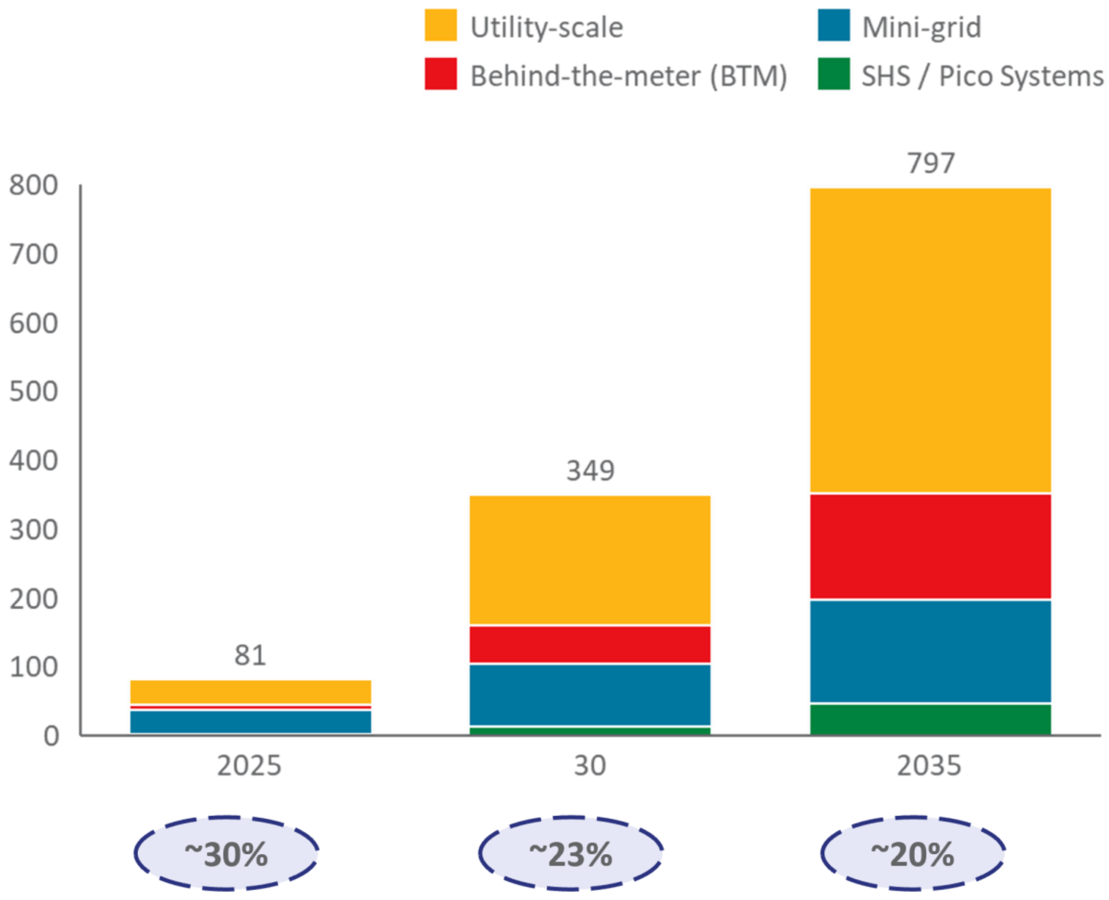
Technology	Application/Use	Drawbacks	Power ranges
Utility-grid	Suited for high power applications in densely populated areas	High capital costs and requires highly skilled operators	>10 MW
Mini-grid	Provides power to a small number of households or community in remote areas	Business case rests on large anchor customers (residential or commercial)	10 kW to 1 MW
Behind-the-meter (BTM)	Provides backup power in weak grid contexts	Solar + storage is a nascent market with high upfront costs	3 kW to 5 MW
Solar Home System (SHS)	Cost effective method to serve low-energy users in sparsely populated areas	Underdeveloped payment models and limited lifespan if not properly managed	0.5Wp to 360Wp

Source: World Bank Database, ESMAP (2022): Mini-grid Handbook, IRENA (2019), GOGLA (2022)

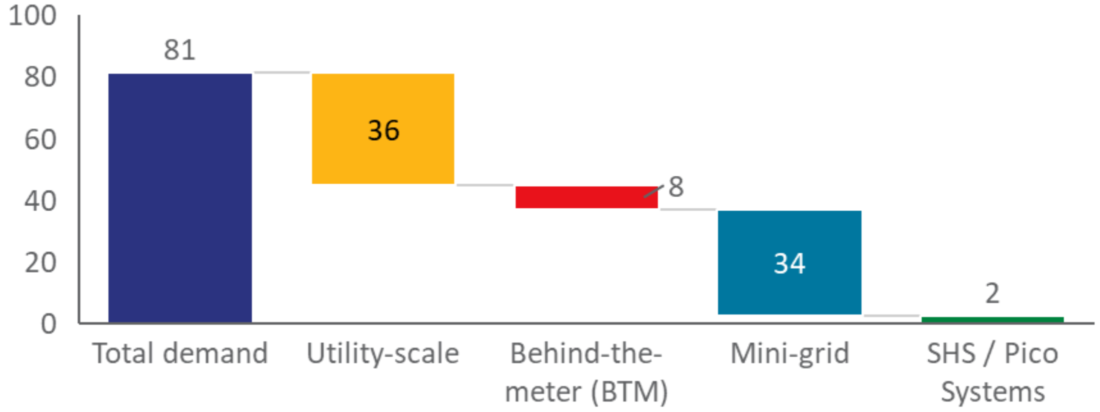
Demand for stationary storage is expected to increase by ~800 GW between 2023-35, driven by utility-scale storage

~XX% % share in global stationary storage demand[2]

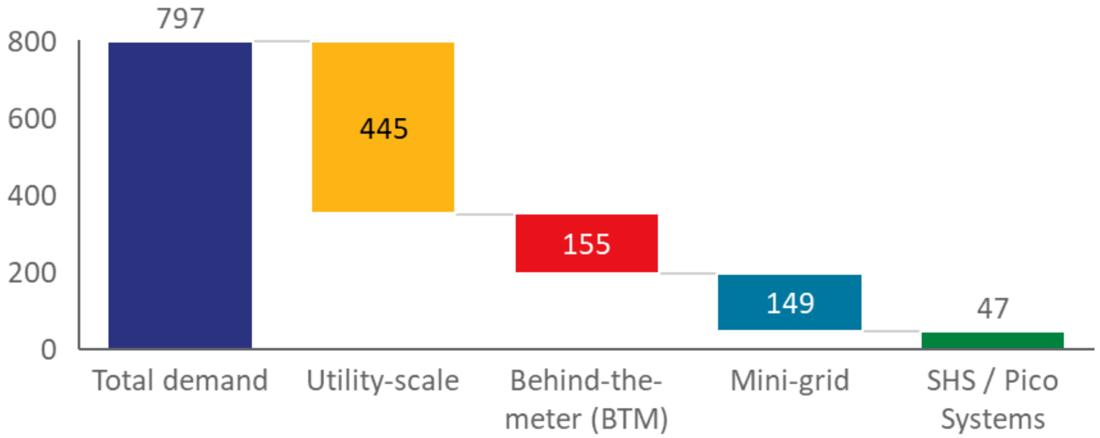
Energy storage by segment, GW



Energy storage by segment (2025), GW



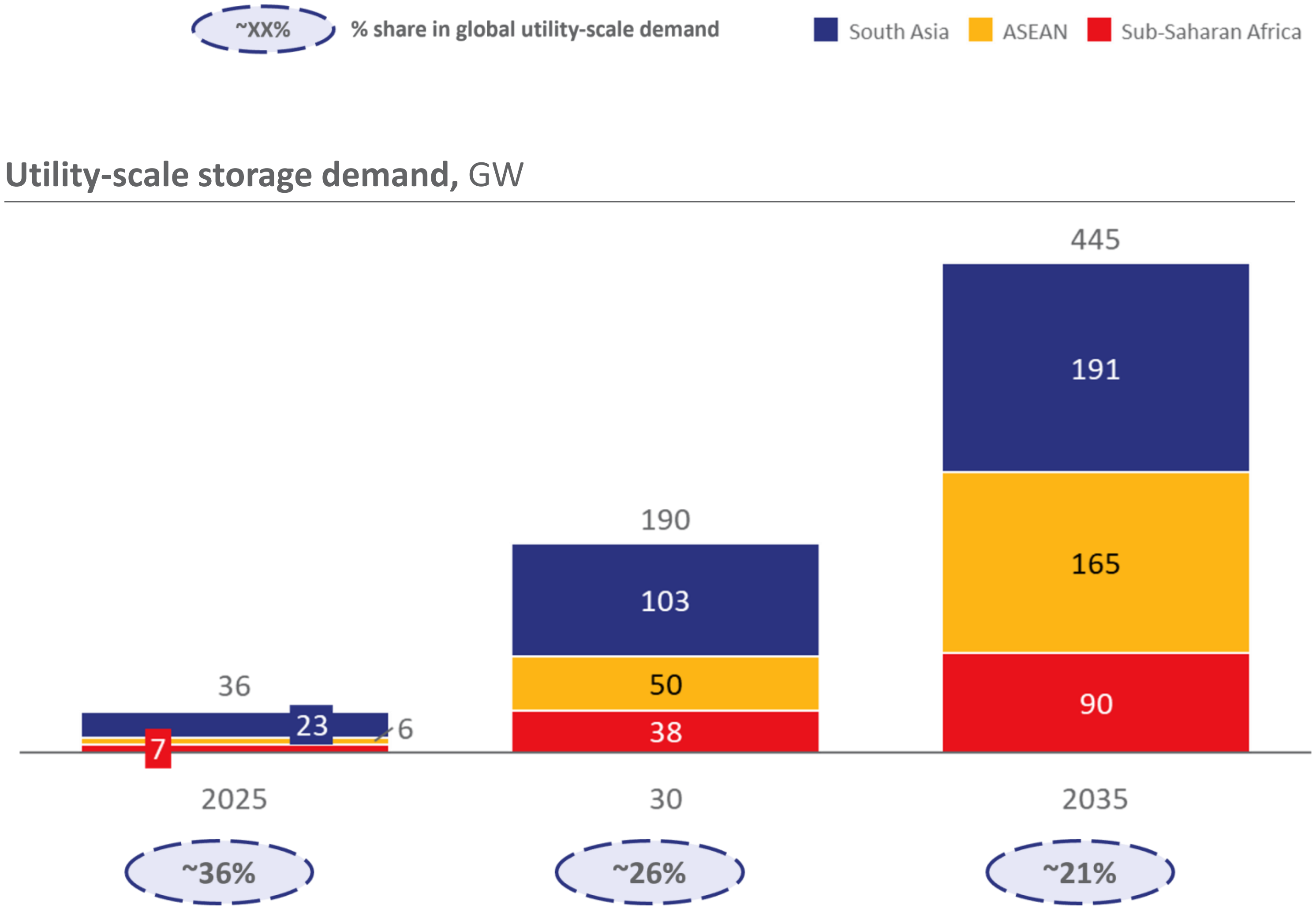
Energy storage by segment in (2035), GW



1. Only covers utility-scale and BTM. Does not include SHS/Pico and mini-grids because SSA, South Asia and ASEAN account for a large share of demand.

Source: ESMAP (2022), analysis by a leading management consultancy

Demand for utility-scale storage is expected to increase by 445 GW between 2023-35



Key drivers

Electricity demand is expected to increase by 33% by 2030 in target regions, which will largely be met by renewables[1, 2]

Renewables are expected to account for ~50%[3] of total grid capacity in these regions based on current ambition, increasing the demand for storage

1. IEA (2022): Africa Energy Outlook. IEA Report "Africa Energy Outlook 2022"
2. IEA (2022): Southeast Asia Energy Outlook. IEA Report "Southeast Asia Energy Outlook 2022"
3. Team analysis of 5 countries in the three regions: India, Malaysia, Indonesia, Kenya, and South Africa

Source: IEA (2018): WEO, IEA (2022): WEO, analysis by a leading management consultancy

Incomplete regulatory frameworks and limited technical expertise could slow the uptake of utility-scale storage

1

Incomplete regulatory frameworks

Regulatory frameworks that do not properly value the additional benefits provided by batteries (e.g., ancillary services, capacity market, voltage control) could deter investment.

2

Limited technical experience

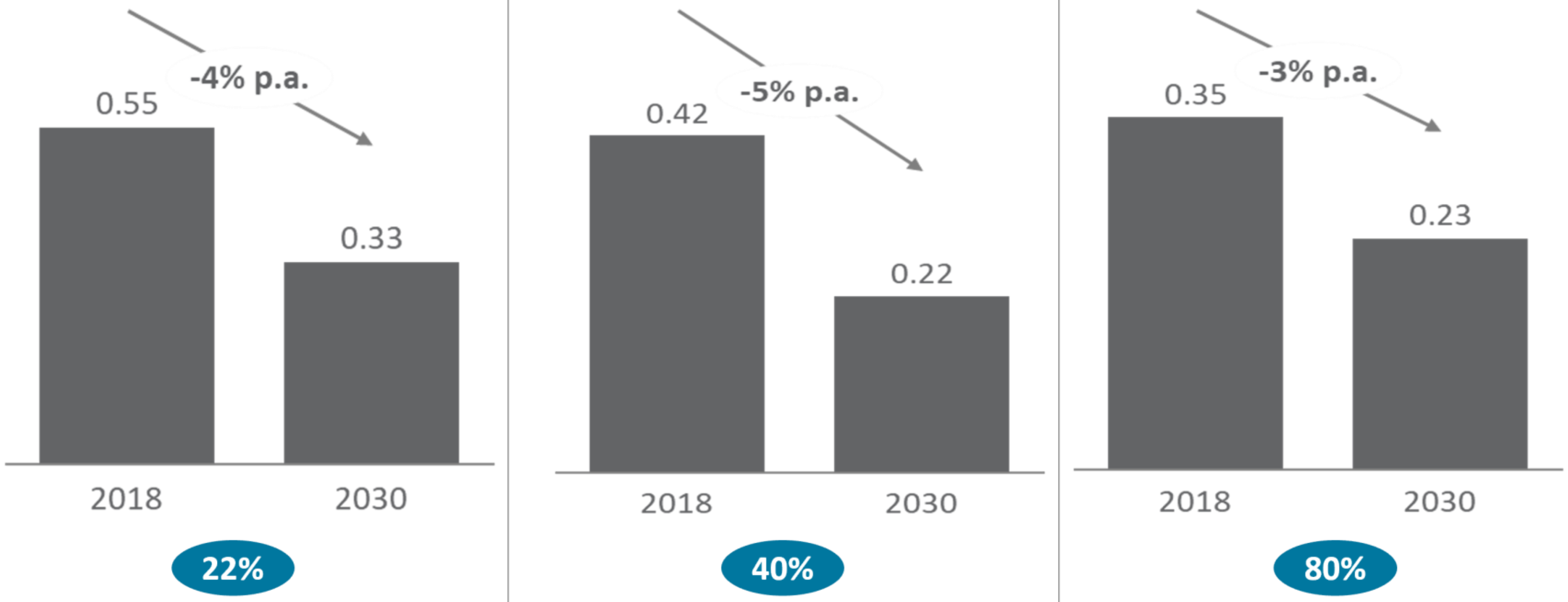
Inadequate experience by utilities and grid operators to integrate storage into long-term planning and investment operations.

Source: World Bank (2021): Stationary energy storage to transform power systems in developing countries, IRENA (2020): Electricity storage valuation framework

Mini grid LCOE is expected to decline by 30%-50% by 2030

% Mini-grid load factor

Estimated and potential levelised cost of energy[1] of mini-grids, 2018 and 2030
USD $/kWh



Low levels of income-generating / productive use activities

Significant daytime consumption by commercial clients and local businesses (e.g., agricultural milling)

Inclusion of a water pump with storage tank and an anchor load, such as a telecom tower

Significant cost reductions expected in mini-grids driven by:

- Reduction in component costs
- More efficient / effective design to optimise the size of the mini-grids
- Improved utilisation of productive use across all mini-grid infrastructure

Note: LCOE (Levelised Cost of Energy) data are for a well-designed 294kWfirm solar-hybrid mini grid in Bangladesh serving more than 1,000 customers (more than 5,000 people).

Source: ESMAP analysis

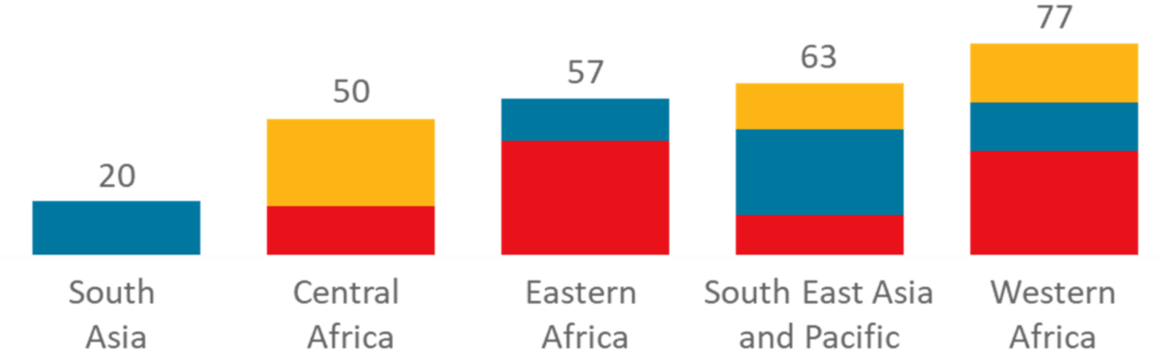
The regulatory environment appears to be improving

Governments are starting to include mini-grids in their electrification plans

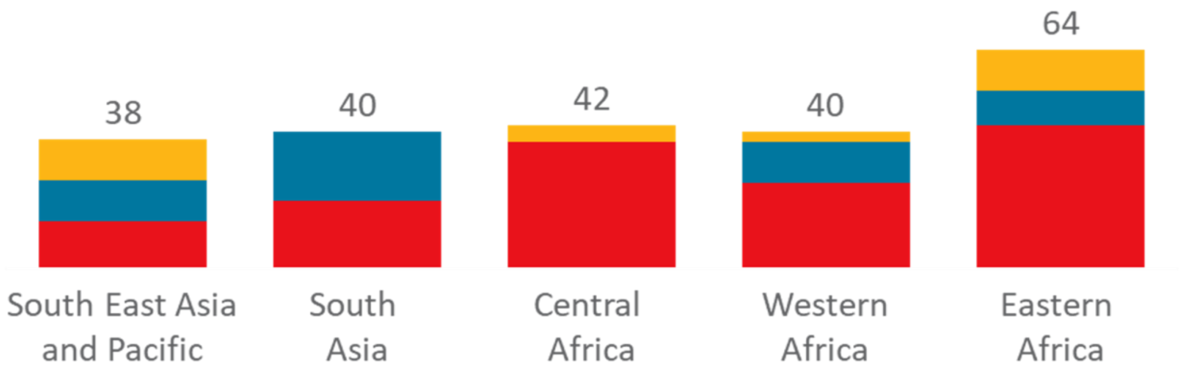
2017 improvement 2015 Improvement 2013 level

Evolution of RISE indicators since 2013[1]

Does the electrification plan include off-grid solutions?



Inclusion of community and productive services



1. World Bank's Regulatory Indicators for Sustainable Energy

Source: OGS Market Trends Report, March 2020; Vivid Economics and Open Capital Advisors from World Bank data underlying its 2018 RISE index.

NOT EXHAUSTIVE

Uganda

Uganda's Electricity Regulatory Authority (ERA) are engaging with stakeholders to update Uganda's Isolated Grid System Regulation, which could increase rural electrification through small scale generation systems

Nigeria

Plans to achieve 90% electricity access in 2030 by a mix of on-grid (70%), and off-grid (18%) and a small share of diesel generators

Kenya

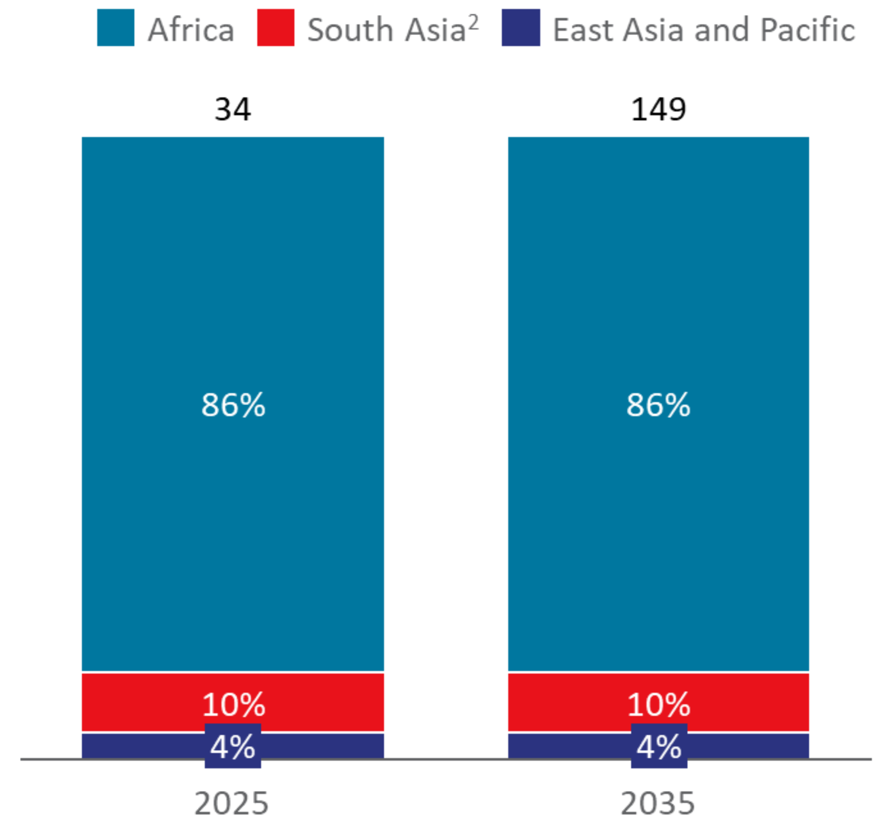
The Rural Electrification Master Plan has mandates and targets to incorporate off-grid electrification (mini-grid and SHS).

Rwanda

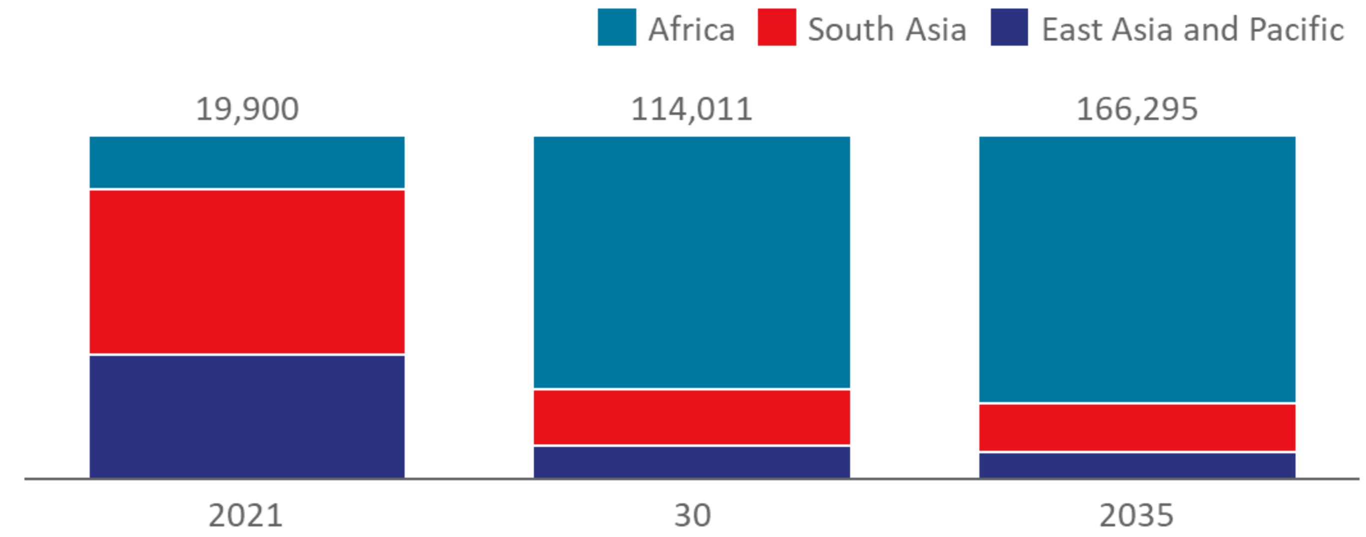
Target to achieve 100% households' access to electricity by 2024 by expanding both grid and off-grid solutions

Sub Saharan Africa accounts for ~90% of demand from mini-grids

Mini-grid storage demand (2025 & 2035), GW[1]



Mini-grid installations (2021-2035), Number[2]



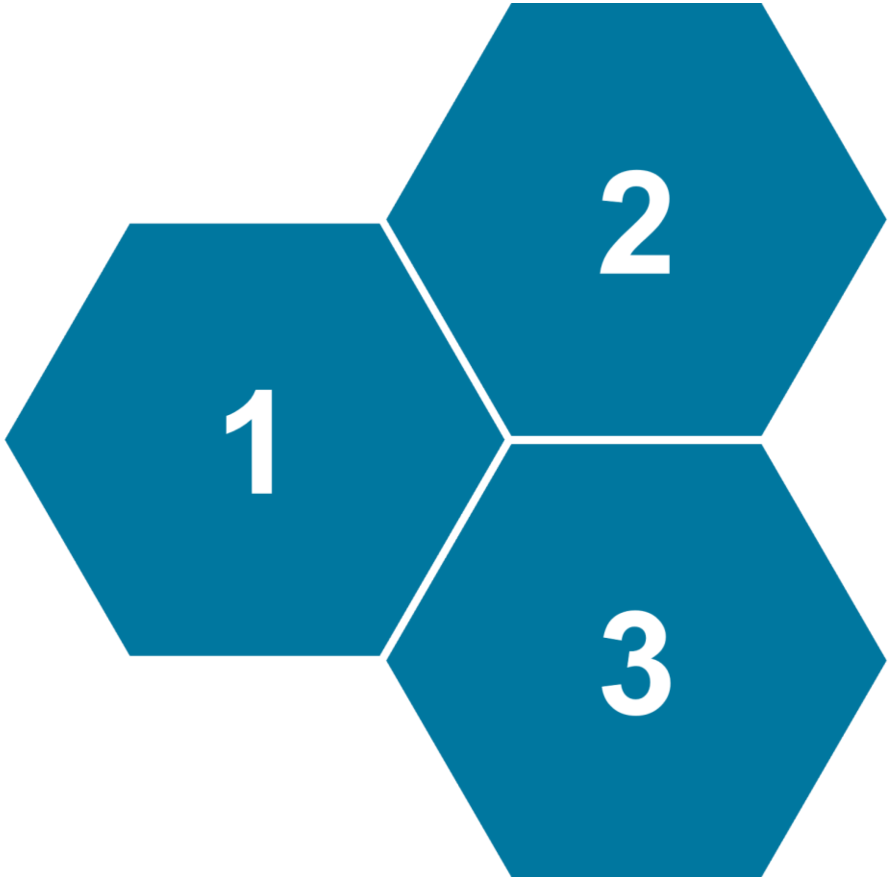
Key Takeaway

Achieving announced targets for reliable electricity by 2030 will require more than ~110,000 mini grids serving ~165 million people, translating into an increase in storage demand of ~115 GW.

1. The basis for this estimate is the Announced policy scenario of IEA, derived from ESMAP's scenarios. This scenario assumes that around 530 million people gain access to electricity by 2030 and 31% of them get-access through mini-grids
2. Analysis by a leading management consultancy

Source: ESMAP (2022): Mini Grids for Half a Billion People, IEA

However, a further strengthening of the regulatory framework is needed to expand energy access via mini-grids



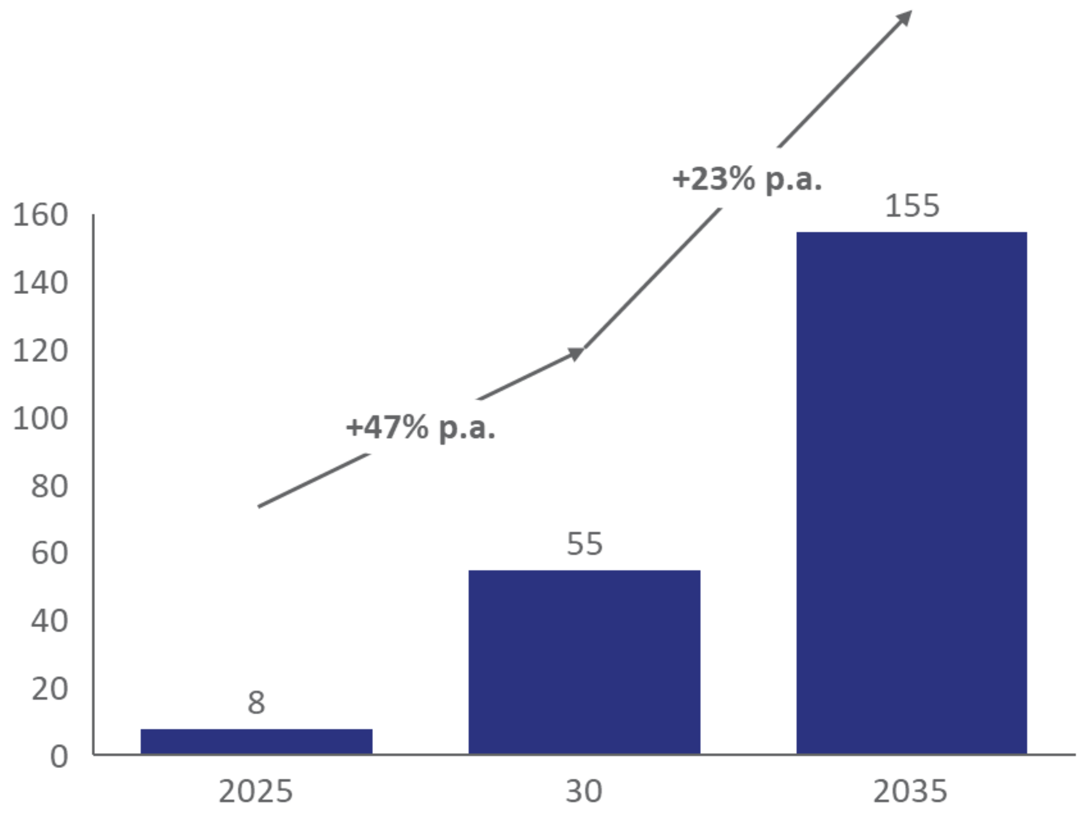
1 **Unclear regulations:** In spite of progress in integrating off-grid solutions as part of electrification strategies, there is a lack of clear regulations to stimulate private investment in mini-grids.

2 **Lack of clear strategies:** Apart from setting SDG goals, most countries do not have clear plans in place to meet those goals.

3 **Lack of subsidies:** There are no major off-grid incentives in SSA to support developers with high upfront costs.

Future growth in BTM is underpinned by three underlying drivers

BTM storage demand, GW



Drivers

1. **Energy cost management**

   Flexible and affordable electricity supply, particularly for C&I customers in regions where they pay higher prices to cross-subsidise residential customers

2. **Improve resilience**

   Improve resilience for critical infrastructure, industry and households in weak grid contexts (e.g., SSA up to 57% of the population could be affected by weak grids[1])

3. **Targets for rooftop solar**

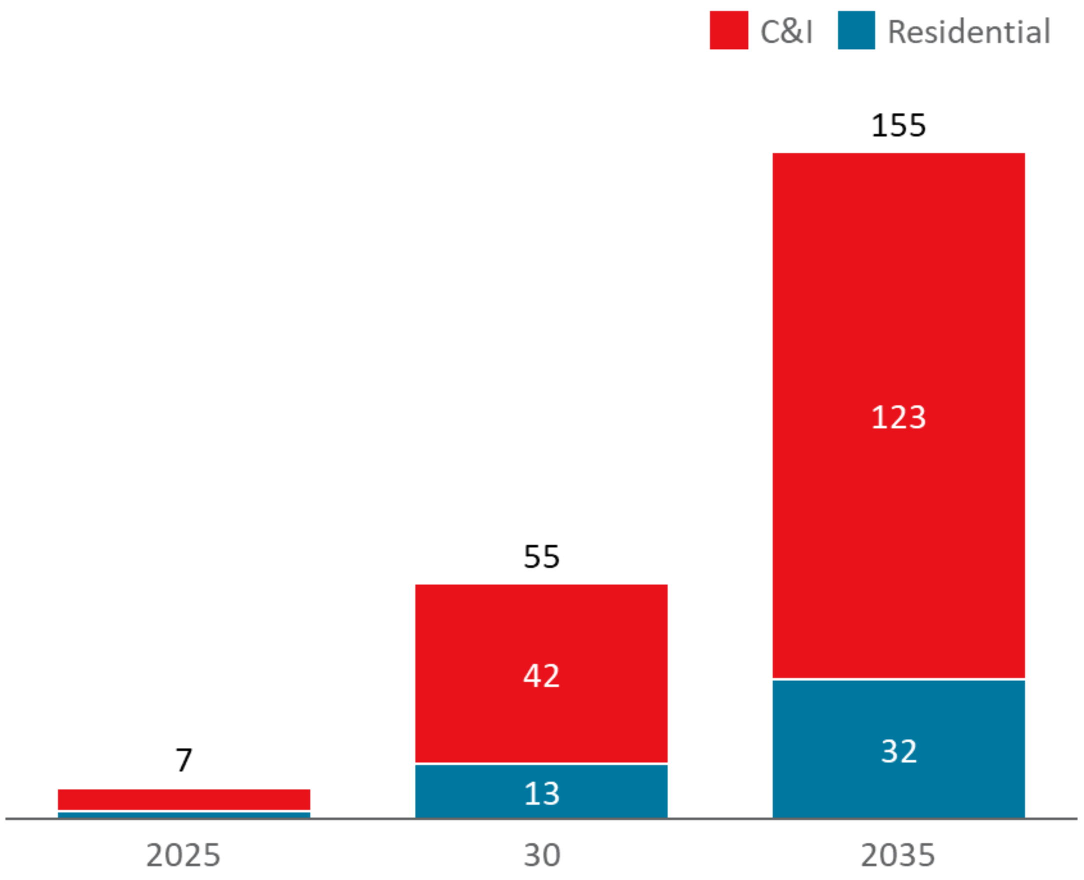
   In some cases could lead to greater battery storage. E.g., India aims to install 40GW[3] of rooftop solar by 2030

1. OPM (2020): South Africa's Crippling Electricity Problem. OPM Report "South Africa's Crippling Electricity Problem"
2. Down to Earth (2022):Rooftop laggard again; India to miss solar power target. Down to Earth Report "Rooftop laggard again; India to miss solar power target"
3. PV Tech (2022):Solar PV leading capacity installs in Africa with 125GW by 2030. IEA Report "Solar PV leading capacity installs in Africa with 125GW by 2030"

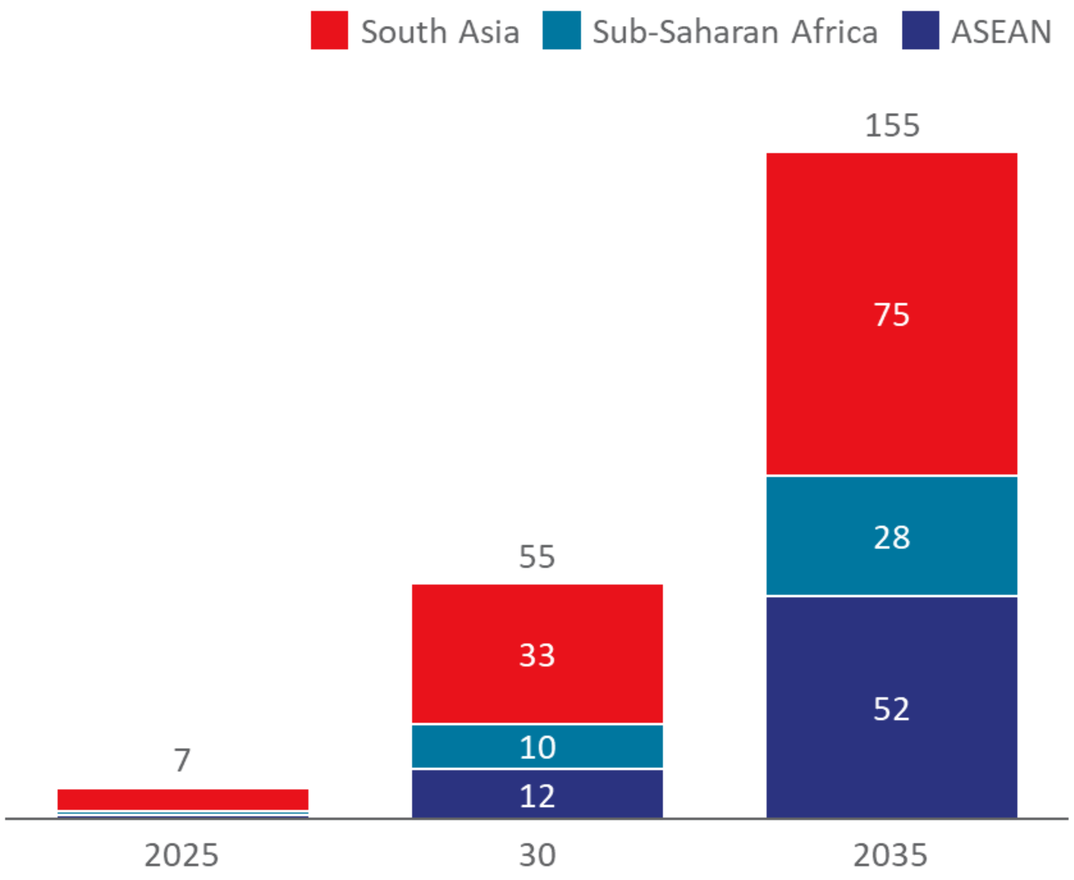
Source: Analysis by a leading management consultancy

Demand for BTM storage is driven mainly by C&I with South Asia accounting for 50% of the market by 2035

BTM storage demand by segment, GW

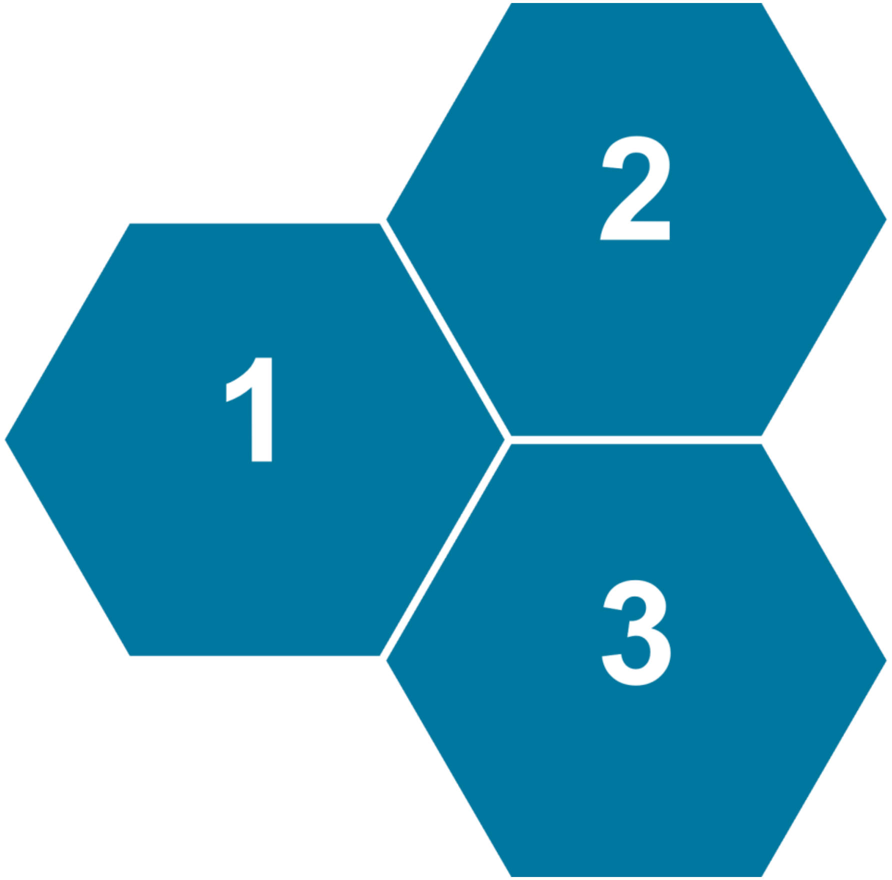


BTM storage demand by region, GW



Source: Analysis by a leading management consultancy

Further effort is needed to overcome obstacles and drive investment



1 **Information barriers:** limited understanding about the cost-effectiveness of solar + storage systems compared to alternatives[1]

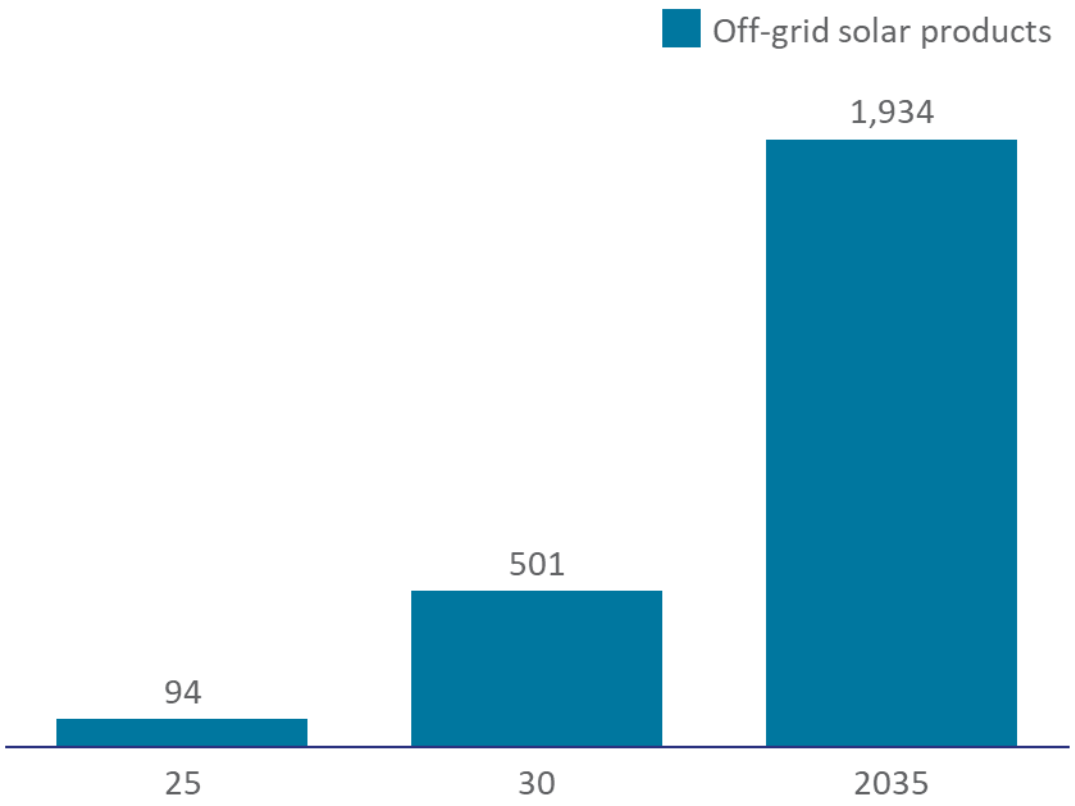
2 **High upfront costs and long payback period:** Higher upfront costs for solar + storage compared to alternatives (e.g., diesel generators) and long payback periods deters adoption.

3 **Electricity and diesel subsidies:** Electricity and diesel subsidies under-price these commodities, which could reduce incentives to adopt solar + storage systems.

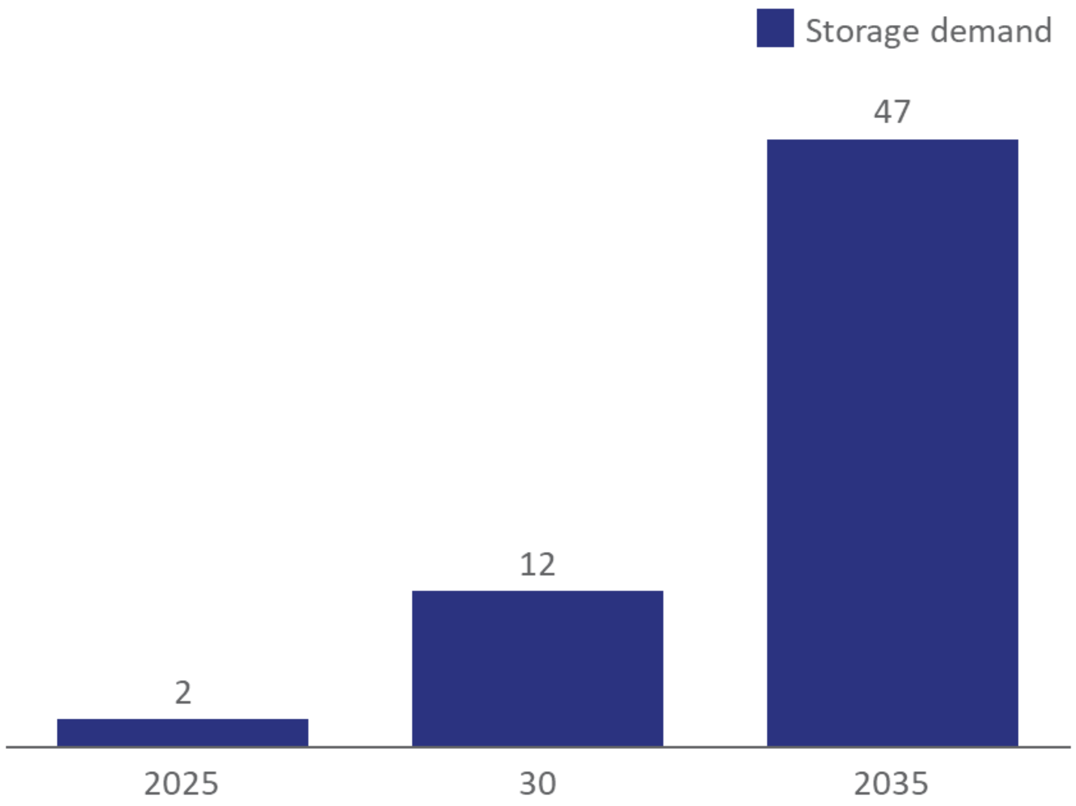
1. IFC (2020): Energy Notes, Battery Storage

OGS sales are expected to increase by ~2bn units translating into an increase of 47 GW in storage demand between 2023-35

Number of Off-grid solar (OGS) products[1,2]
Units sold, millions[3]



Storage demand, SHS and Pico Systems, GW

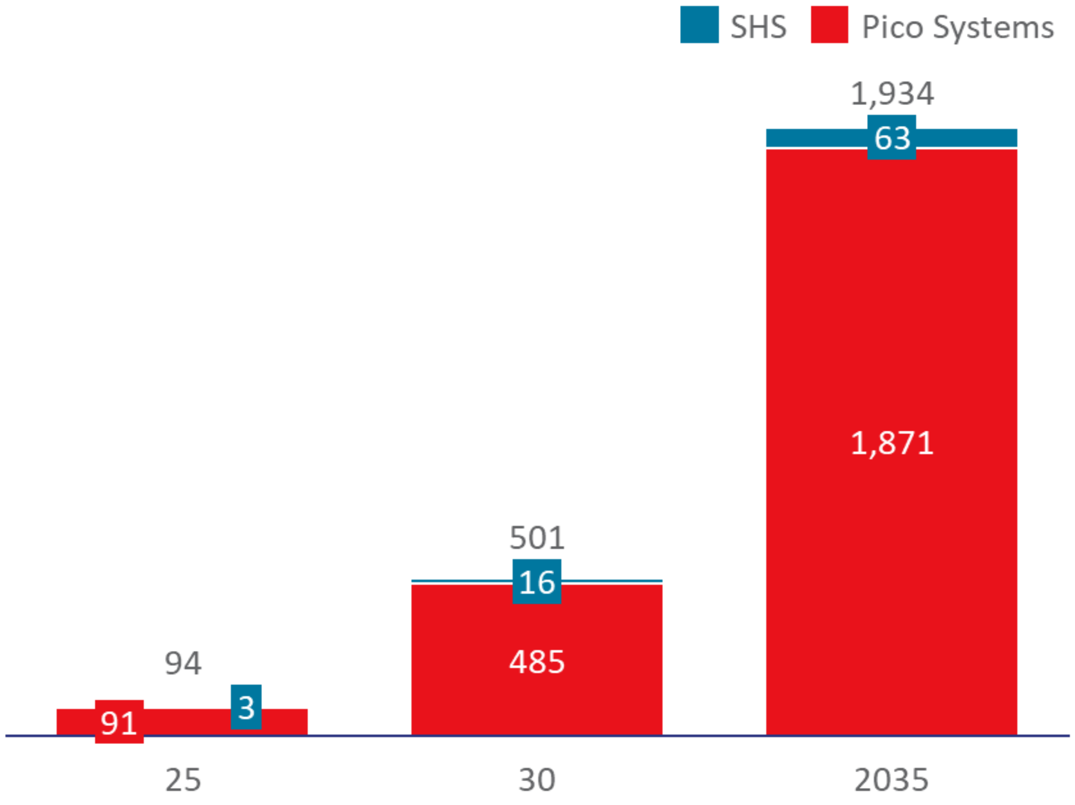


1. ASEAN market share is small for OGS products
2. OGS is off-grid solar products, covers both solar home systems (SHS) and pico systems
3. Assumption of wattage used: SHS (146 W) and Pico (20 W)

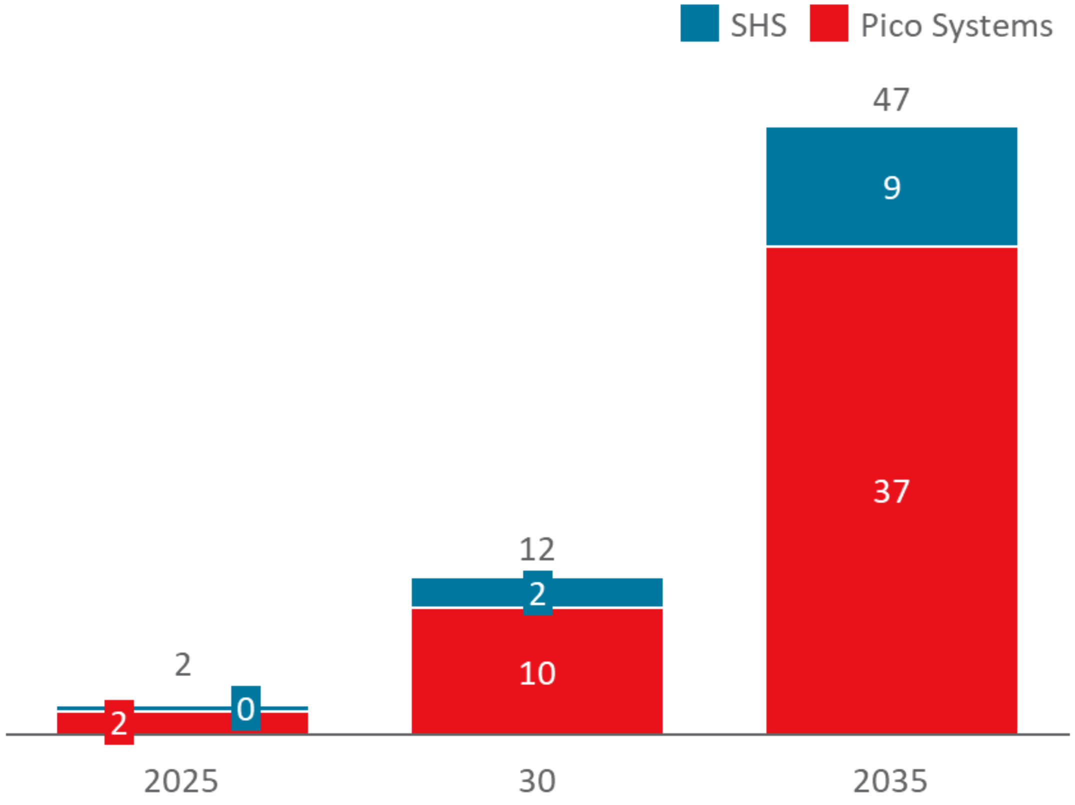
Source: GOGLA, IRENA, analysis by a leading management consultancy

Pico systems account for majority of the global OGS units sold and storage demand between 2023-35

SHS and Pico sales, 2023-2035[1,2]
Units sold, million



Storage demand for SHS and Pico, 2023-2035
Power capacity, GW



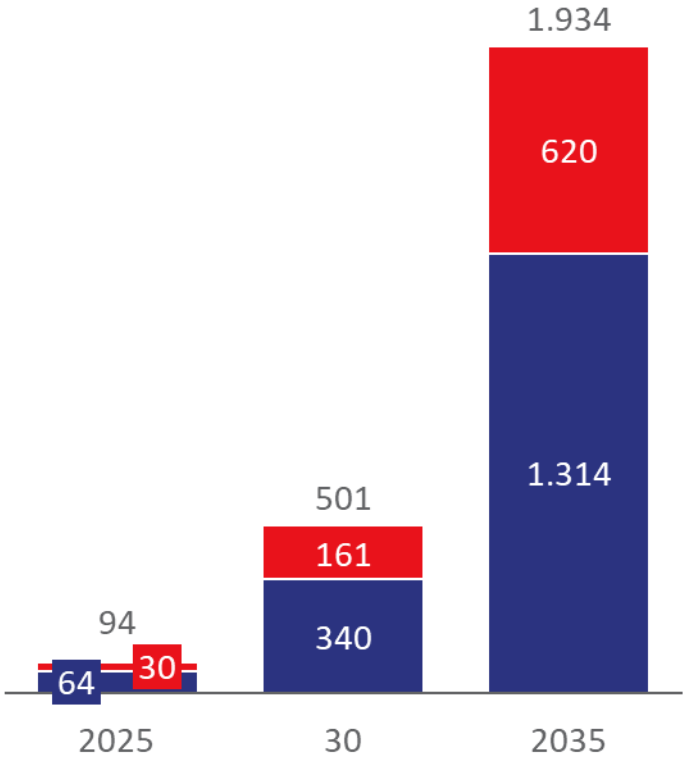
1. ASEAN market share is insignificant for OGS products
2. Assumption of wattage used: SHS (146 W) and Pico (20 W)

Source: GOGLA, IRENA, analysis by a leading management consultancy

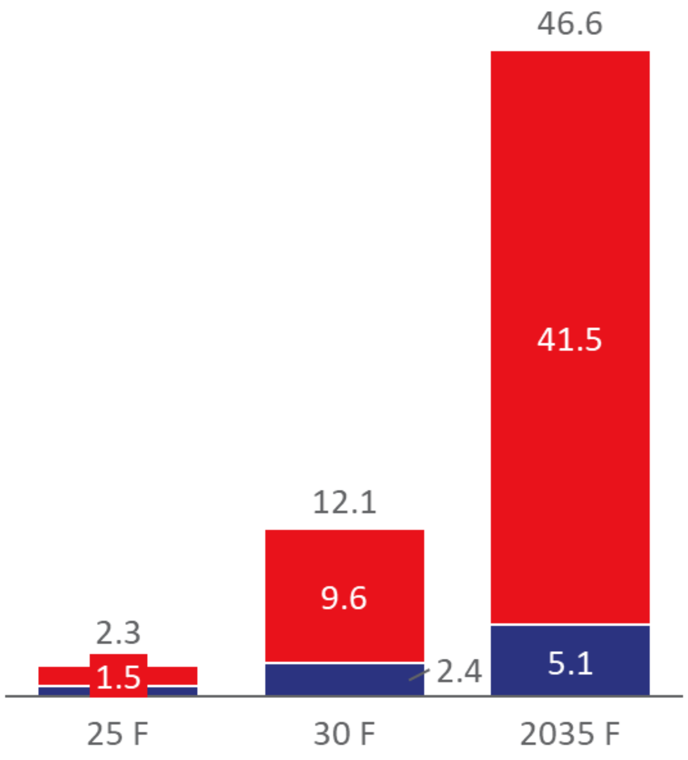
SSA accounts for 32% of sales but 90% of storage demand because of the dominance of larger units

Sub-Saharan Africa | South Asia

SHS and Pico sales, Units sold, million



Storage demand, GW



The underlying drivers for growth are different for SSA and South Asia

SSA: low electrification rates drive the purchase of larger units that serve multiple purposes

South Asia: high electrification rates (>90%) has driven the market for pico systems that are used to complement the grid

Source: GOGLA, IRENA, analysis by a leading management consultancy

Kenya's success has been underpinned by a strong regulatory environment

1

Payment models

Well-established **mobile payment infrastructure, with PAYGo[1] being the main driver for the** uptake for energy devices

- 70% of 2021 sales for solar energy kits were through PAYGo[1]

2

Enabling regulatory environment

Tax exemptions for off-grid solar products

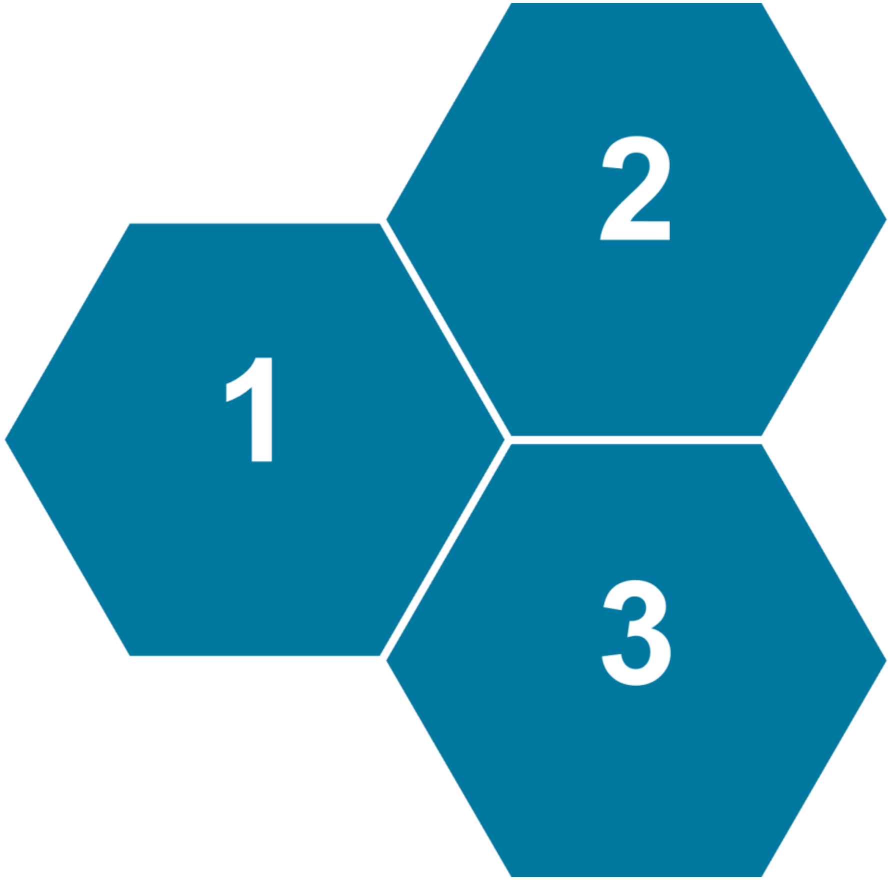
3

Competition landscape

Strong market competition has led to a diversity of products and lower costs compared to the rest of the region

1. GOGLA (2021)
2. ESI Africa (2022)
3. GOGLA (2022) estimates 140m OGS connections as market size in Nigeria

Key barriers for adopting SHS are access to credit and affordability



1 **High upfront costs:** the average price of SHS is around $350 making wide-scale adoption challenging in regions without robust financial infrastructure

2 **Limited availability of affordable credit:** when credit is available, high interest rates can discourage uptake

3 **Poor policy environment:** uncertain regulations, sudden policy changes, and insufficient initiatives to encourage market entry and scale-up have held back investment particularly in less mature markets

Source: GOGLA (2021 & 2022)

Innovative SHS business models with affordable payment options are expanding access to clean energy in some developing countries

Business model	Revenue model	Benefits to consumers	Examples
1. Battery leasing	• Battery leasing charges	• Improves affordability for larger products e.g., batteries for fridges and freezers	M-KOPA; mobile power
2. Sale of Pico Systems	• Partnering with Mobile Network Operators to link the availability of airtime to repayment terms • Service agents collect cash payments for those that cannot pay digitally	• Faster processing time • Greater access of products for unbanked customers • Increased convenience for those without digital payment methods	azuri LIFE CHANGING TECHNOLOGY; simpaenergy

The Virtual Power Plant market is currently small, but its importance is likely to grow as the share of renewables expands

Business model	Revenue model	Services offered	Benefits to consumers	Examples
1 Virtual Power Plant (VPP)	• Subscription-based • Ancillary services to the operator • Power purchase agreements (PPAs) • Pay-as-you-save (PAYS) structure	• Distributed asset monitoring • Asset analytics • Distributed asset control • Renewable energy management • Energy storage management • EV charging asset management • Demand response management	• Reduced energy costs • Lower carbon footprint • Greater control to monitor energy use	SustainSolar, solarise, sunexchange, powerhive, M+ Solar, Fourth Partner Energy, zenatix (A Hero Electronix Venture), Smart Joules, SunSource Energy (An SHV Energy Company), Solarvest (Turning Sunlight Into Investment)

Agenda

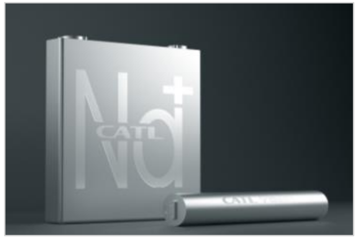
- Market assessment
- **Technology assessment**
  - Mobility
  - Stationary

A range of technologies have been evaluated for mobility and stationary storage applications

Mobility

Li-ion
(LFP/NMC)

Na-ion



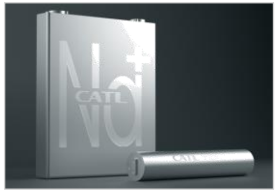
Pb-acid

Stationary storage

Battery Storage

Li-ion

Na-ion



Flow batteries

Pb-acid

Mechanical Storage

Fly-wheels

Compressed air
(CAES)[3]

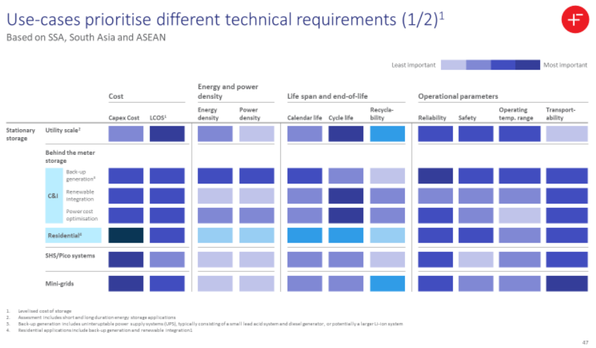
Gravity based
storage

Thermal Storage

Molten salt

Water

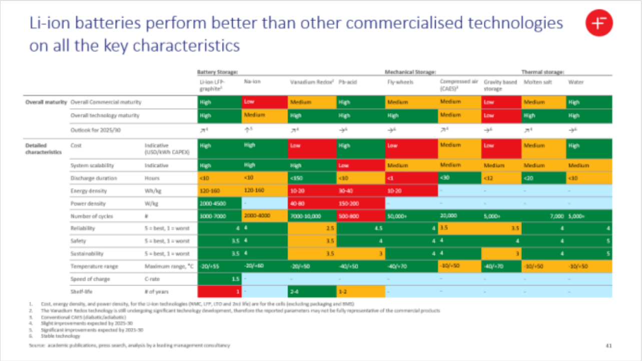
Use-case requirements, technology characteristics, and commercial maturity were evaluated to assess viable technologies in SSA, South Asia and ASEAN



Use case requirements

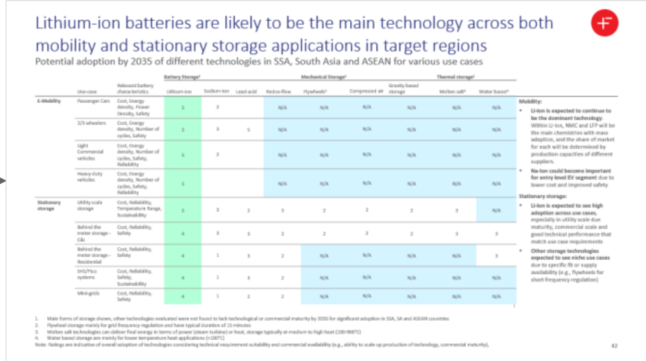
Specific requirements for SSA, SA and ASEAN regions per use case including:

- Cost
- Energy and power density
- Life span and end-of-life
- Operational parameters



Technology characteristics and commercial maturity

Comparison of technology characteristics (e.g., cycle life, energy and power density) and commercial maturity across technologies



Outlook on technology adoption by 2035

Use-cases prioritise different technical requirements (1/2)[1]

Based on SSA, South Asia and ASEAN

Least important | 1 | 2 | 3 | 4 | Most important

Stationary storage			Cost: Capex Cost	Cost: LCOS[1]	Energy and power density: Energy density	Energy and power density: Power density	Life span and end-of-life: Calendar life	Life span and end-of-life: Cycle life	Life span and end-of-life: Recyclability	Operational parameters: Reliability	Operational parameters: Safety	Operational parameters: Operating temp. range	Operational parameters: Transportability
Utility scale[2]			2	4	2	1	2	4	2	3	3	3	1
Behind the meter storage	C&I	Back-up generation[3]	3	3	3	3	3	3	1	4	3	3	3
	C&I	Renewable integration	3	3	1	1	2	4	2	2	2	2	3
	C&I	Power cost optimisation	3	3	2	2	2	4	2	3	2	1	3
	Residential[4]		4	3	1	1	2	2	1	3	3	2	3
SHS/Pico systems			4	2	1	1	2	2	1	3	1	2	3
Mini-grids			4	3	1	1	2	2	2	3	2	2	4

1. Levelised cost of storage
2. Assessment includes short and long duration energy storage applications
3. Back-up generation includes uninterruptable power supply systems (UPS), typically consisting of a small lead acid system and diesel generator, or potentially a larger Li-ion system
4. Residential applications include back-up generation and renewable integration

Use-cases prioritise different technical requirements (2/2)

Based on SSA, South Asia and ASEAN

Least important | 1 | 2 | 3 | 4 | Most important

		Cost	Energy and power density		Life span and end-of-life			Operational parameters			
		Cost	Energy density	Power density	Calendar life	Cycle life	Recyclability	Reliability	Safety	Operating temp. range	Speed of charge
Mobility storage	Passenger cars	4	3	1	1	3	1	1	4	3	4
	Commercial vehicles										
	a. Light-commercial vehicles	2	3	2	1	4	1	3	3	3	4
	b. Medium-Heavy duty trucks and buses	2	3	3	1	4	1	3	3	3	4
	2-3 wheelers[1]	4	4	1	1	2.5	1	1	4	3	3

1. Cycle-life for 2-3 wheelers may not be as important if battery-swapping models emerge

Li-ion batteries perform better than other commercialised technologies on all the key characteristics

			Battery Storage:				Mechanical Storage:			Thermal storage:	
			Li-ion LFP-graphite[1]	Na-ion	Vanadium Redox[2]	Pb-acid	Fly-wheels	Compressed air (CAES)[3]	Gravity based storage	Molten salt	Water
Overall maturity	Overall Commercial maturity		High	Low	Medium	High	Medium	Medium	Low	Medium	High
	Overall technology maturity		High	Medium	High	High	High	Medium	Low	High	High
	Outlook for 2025/30		↗[4]	↑[5]	↗[4]	→[6]	→[6]	↗[4]	→[6]	↗[4]	→[6]
Detailed characteristics	Cost	Indicative (USD/kWh CAPEX)	High	High	Low	High	Low	Medium	Low	Medium	High
	System scalability	Indicative	High	High	High	Low	Medium	Medium	Medium	Medium	Medium
	Discharge duration	Hours	<10	<10	<150	<10	<1	<30	<12	<20	<10
	Energy density	Wh/kg	120-160	120-160	10-20	30-40	10-20	-	-	-	-
	Power density	W/kg	2000-4500	-	40-80	150-200	-	-	-	-	-
	Number of cycles	#	3000-7000	2000-4000	7000-10,000	500-800	50,000+	20,000	5,000+	7,000	5,000+
	Reliability	5 = best, 1 = worst	4	4	2.5	4.5	4	3.5	3.5	4	4
	Safety	5 = best, 1 = worst	3.5	4	3.5	4	4	4	4	4	5
	Sustainability	5 = best, 1 = worst	3.5	4	3.5	3	4	4	3	4	5
	Temperature range	Maximum range, °C	-20/+55	-20/+60	-20/+50	-40/+50	-40/+70	-10/+50	-40/+70	-10/+50	-10/+50
	Speed of charge	C-rate	1.5	-	-	-	-	-	-	-	-
	Shelf-life	# of years	1	-	2-4	1-2	-	-	-	-	-

1. Cost, energy density, and power density, for the Li-ion technologies (NMC, LFP, LTO and 2nd life) are for the cells (excluding packaging and BMS)
2. The Vanadium Redox technology is still undergoing significant technology development, therefore the reported parameters may not be fully representative of the commercial products
3. Conventional CAES (diabatic/adiabatic)
4. Slight improvements expected by 2025-30
5. Significant improvements expected by 2025-30
6. Stable technology

Source: academic publications, press search, analysis by a leading management consultancy

Lithium-ion batteries are likely to be the main technology across both mobility and stationary storage applications in target regions

Potential adoption by 2035 of different technologies in SSA, South Asia and ASEAN for various use cases

			Battery Storage[1]			Mechanical Storage[1]				Thermal storage[1]	
	Use-case	Relevant battery characteristics	Lithium-ion	Sodium-ion	Lead-acid	Redox-flow	Flywheels[2]	Compressed air	Gravity based storage	Molten salt[3]	Water based[4]
E-Mobility	Passenger Cars	Cost, Energy density, Power Density, Safety	5	2		N/A	N/A	N/A	N/A	N/A	N/A
	2/3 wheelers	Cost, Energy density, Number of cycles, Safety	5	3	5	N/A	N/A	N/A	N/A	N/A	N/A
	Light Commercial vehicles	Cost, Energy density, Number of cycles, Safety, Reliability	5	2		N/A	N/A	N/A	N/A	N/A	N/A
	Heavy-duty vehicles	Cost, Energy density, Number of cycles, Safety, Reliability	5			N/A	N/A	N/A	N/A	N/A	N/A
Stationary storage	Utility scale storage	Cost, Reliability, Temperature Range, Sustainability	5	3	2	3	2	2	2	3	N/A
	Behind the meter storage - C&I	Cost, Reliability, Safety	4	3	3	3	2	2	2	3	3
	Behind the meter storage - Residential	Cost, Reliability, Safety	4	1	3	2	N/A	N/A	N/A	N/A	3
	SHS/Pico systems	Cost, Reliability, Safety, Sustainability	4	1	3	2	N/A	N/A	N/A	N/A	N/A
	Mini-grids	Cost, Reliability, Safety	4	1	2	2	N/A	N/A	N/A	N/A	N/A

Mobility:

- **Li-Ion is expected to continue to be the dominant technology**. Within Li-Ion, NMC and LFP will be the main chemistries with mass adoption, and the share of market for each will be determined by production capacities of different suppliers.
- **Na-Ion could become important for entry level EV segment** due to lower cost and improved safety

Stationary storage:

- **Li-Ion is expected to see high adoption across use cases**, especially in utility scale due maturity, commercial scale and good technical performance that match use case requirements
- **Other storage technologies expected to see niche use cases** due to specific fit or supply availability (e.g., flywheels for short frequency regulation)

1. Main forms of storage shown, other technologies evaluated were not found to lack technological or commercial maturity by 2035 for significant adoption in SSA, SA and ASEAN countries
2. Flywheel storage mainly for grid frequency regulation and have typical duration of 15 minutes
3. Molten salt technologies can deliver final energy in terms of power (steam turbine) or heat, storage typically at medium to high heat (100-900°C)
4. Water based storage are mainly for lower temperature heat applications (<100°C)

Note: Ratings are indicative of overall adoption of technologies considering technical requirement suitability and commercial availability (e.g., ability to scale up production of technology, commercial maturity),

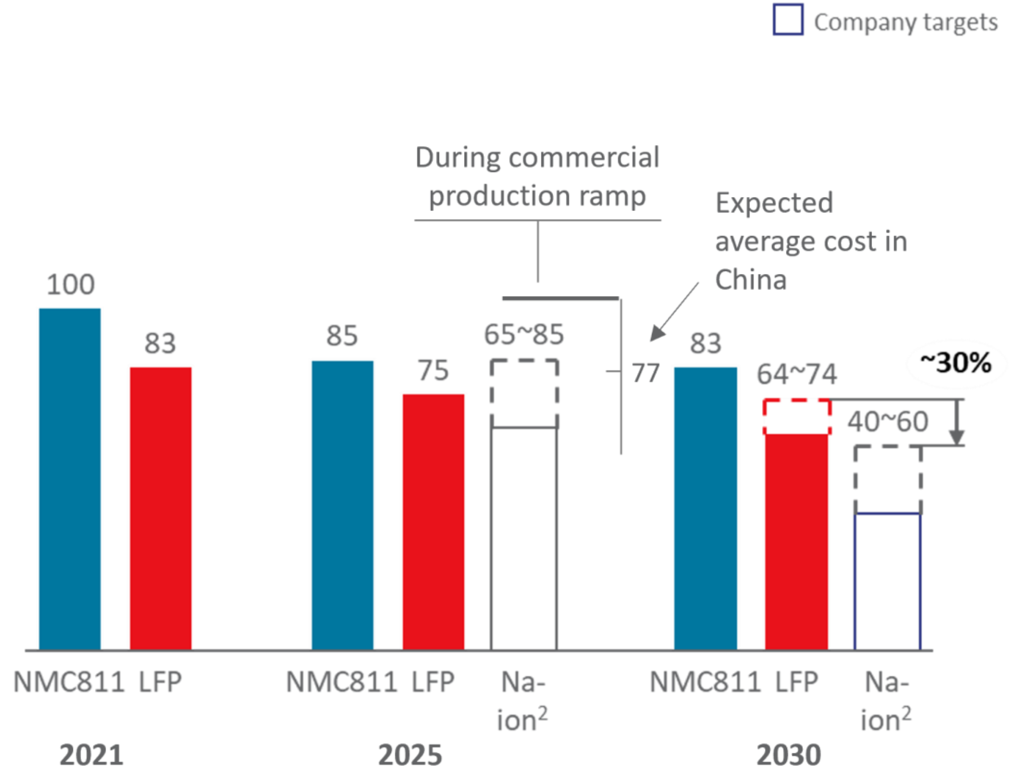
However, Na-ion batteries could emerge as a competitor to LFP in developing countries given its better performance on cost and safety

KPI assessment (relative to LFP)

Superior / Inferior

KPI	Description
Energy density	Sodium-ion energy density is inherently limited by the lower cell voltage and the lower capacity of the anode.
Power density	High power density enabled by high-rate cathodes (PBAs1 & polyanion) and hard carbon anodes with high(er) working potential than graphite with reduced risk of metal plating
Cycle/ calendar lifetime	Sodium-ion batteries have a shorter cycle/calendar life due to the instability of SEI (dissolving)
Safety	Improved safety with lower risk of thermal runaway compared to conventional NMC-based batteries and even LFP, allowing slimmer pack design due to less heat generation. Possibility of fluorine-free and non-flammable solvents. Zero-volt shipping of Na-ion batteries
Cost	Lower cost compared to conventional batteries as expensive metals (nickel, cobalt, lithium) are replaced by more abundant and inexpensive iron, manganese and sodium. The copper current collector could be replaced with cheaper aluminum.
Production	Production process similar to conventional Li-ion cells, however Na-ion cathodes are more prone towards moisture (comparable to Hi-Ni NMCs5) and thus require more controlled processing (e.g., optimised dry room conditions)

Battery cell cost estimates[1], global average, USD/kWh

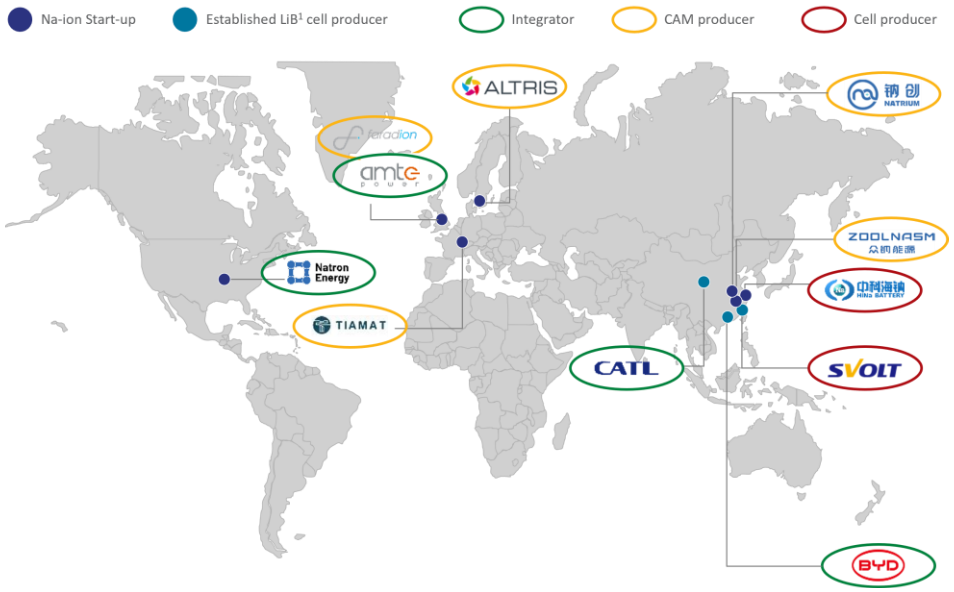


1. Considering most common Na-ion chemistry (PBA/HC) for mobility applications
2. Based on expert calls and various Chinese media sources on CATL's announcement of a Na-ion battery cell production in 2023 citing a cost of 77 USD/kWh initially and dropping to 40 USD/kWh with mass production by 2030.

Source: academic literature, analysis by a leading management consultancy

The mass production of sodium-ion battery cells for commercial applications is expected to start in 2023

2022 Q4 NOT EXHAUSTIVE



Year for SOP		Na-ion related announcements	Country	Start-up/established player	Battery component
2022	中科海钠 HiNa BATTERY	HiNa Battery opens the first GWh-class Na-ion battery cell production line of its **5 GWh** plant in 12/2022	China	Na-ion Start-up	Cell producer
2022	Natron Energy	Natron Energy and Arxada start world's first large-scale production of battery grade PBAs for **600 MWh** annual capacity of Na-ion batteries	USA	Na-ion Start-up	Integrator
2022/23	ZOOLNASM 众钠能源	Zoolnasm planning to start a production line for 10,000 ton CAM annually to supply **2 GWh** Na-ion batteries by **2023**	China	Na-ion Start-up	CAM producer
2022/23	钠创 NATRIUM	Natrium Energy commissioning a 10,000 ton CAM production line in 2022 planning to ramp to **40,000 ton** annually by **2023**	China	Na-ion Start-up	CAM producer
2023	ALTRIS	Altris wants to start production of 2,000 tons PW cathode materials annually in 2023 to supply **1 GWh** of Na-ion batteries	Sweden	Na-ion Start-up	CAM producer
2023	BYD	BYD announced Na-ion battery mass production to start in Q2 2023 aiming for **1 GWh** initially	China	Established LiB cell producer	Integrator
2023/24	CATL	CATL announced its first generation of 160 Wh/kg Na-ion batteries for 2023, with **24 GWh** in 2024	China	Established LiB cell producer	Integrator
2024	TIAMAT	Tiamat plans to enter mass production by end of 2024 ramping to **6 GWh** annually by 2030	France	Na-ion Start-up	CAM producer
2025	faradion	Faradion enters licensing agreement with amte power to produce its Na-ion cells with a plan to scale to **2 GWh** by 2025	UK	Na-ion Start-up	CAM producer (Faradion)/ Integrator (Amte)

1. Lithium-ion battery

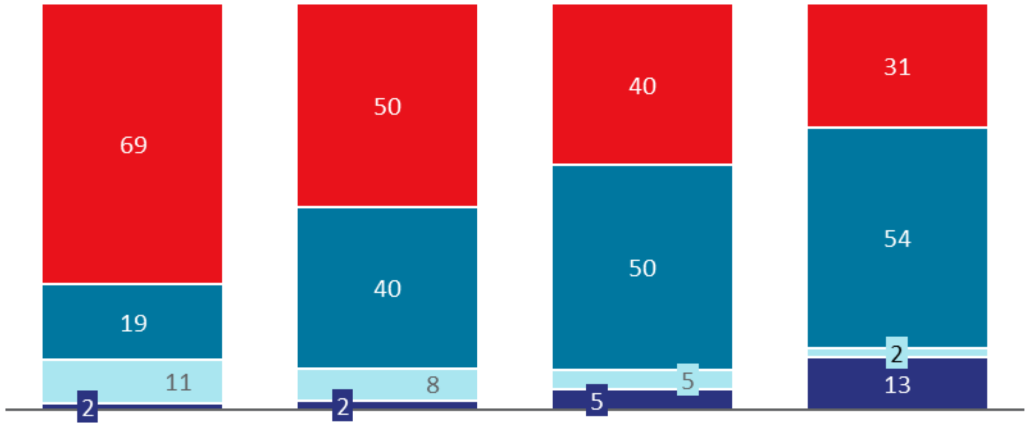
Source: Company Announcements, Web Search, analysis by a leading management consultancy

Agenda

Across regions, LFP begins to displace NMC with Na-ion gaining market share from 2030

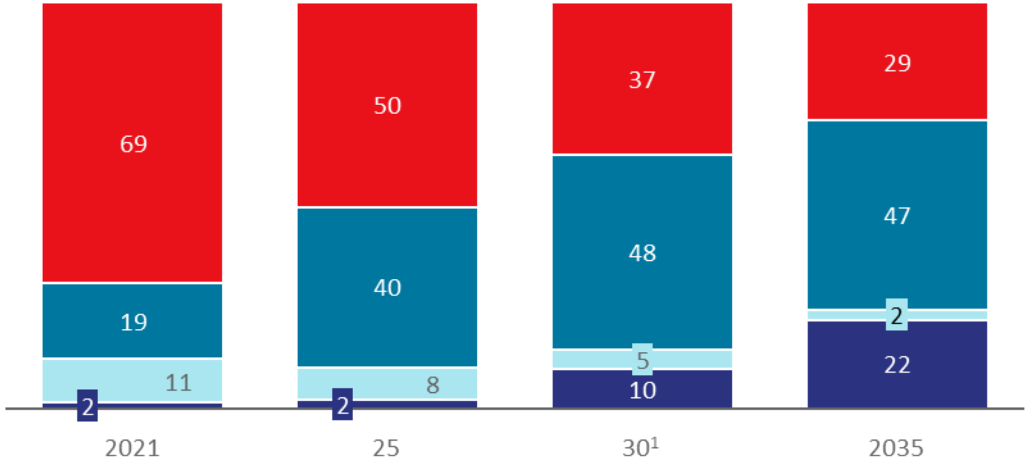
NMC | LFP | NCA | Na-ion & Others[1]

Scenario 1- Share of different chemistries in annual sales, 2021 - 2035, %



NMC 532 and 622 will be the main technology for 2-3 years, with possible shift to NMC 811 & NMC 955 driven by lower weight and cost

Scenario 2- Share of different chemistries in annual sales, 2021 - 2035, %



Na-ion could play a bigger role depending on OEM choices and capacity to scale

1. Na-ion and others

Source: Expert Interviews, Press search, analysis by a leading management consultancy

Key insights on chemistries

OEMs are actively pursuing LFP and its market share in developing countries is likely to increase for three reasons

- **Lower costs:** In 2021, LFP was 17% cheaper than NMC. The cost gap is expected to increase to 20% by 2030.
- **Higher cycle life:** LFP battery cycle life (3000-7000) is higher than NMC (2000-5000).
- **Better safety:** Lower risk of thermal runaway

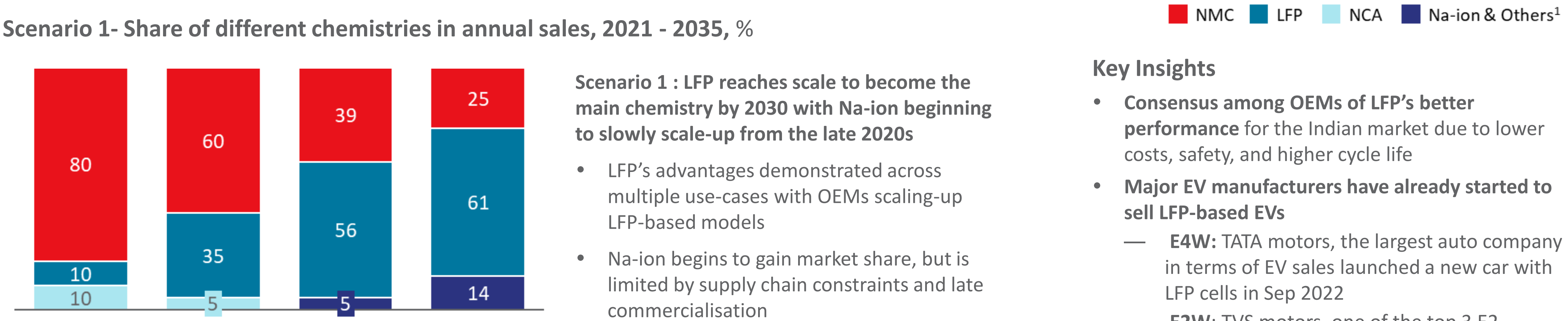
Global trends are likely to trickle down to these regions

LFP will begin to gain market share as domestic production expands and local OEMs begin to switch (e.g., in India) or through imports (e.g., ASEAN).

Sodium-ion batteries may to capture a significant share by 2035 : Improved technical performance of Na-ion in developing countries, advancements in China, and early indications of companies looking to invest in India could lead to a growing market share from the 2030s particularly for 2/3 wheelers and small buses. This would depend on commercial scale-up and a viable supply chain being in place.

India: LFP could rapidly displace NMC as the dominant chemistry, with Na-ion deployment accelerating from the late 2020s

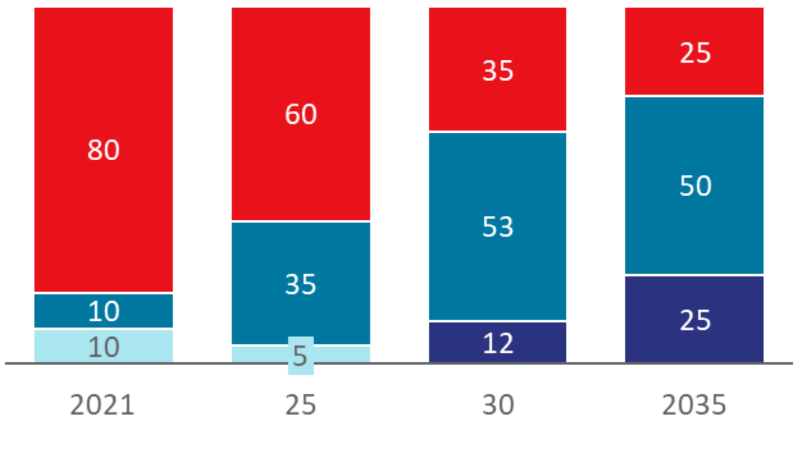
Scenario 1- Share of different chemistries in annual sales, 2021 - 2035, %



Scenario 1 : LFP reaches scale to become the main chemistry by 2030 with Na-ion beginning to slowly scale-up from the late 2020s

- LFP's advantages demonstrated across multiple use-cases with OEMs scaling-up LFP-based models
- Na-ion begins to gain market share, but is limited by supply chain constraints and late commercialisation

Scenario 2- Share of different chemistries in annual sales, 2021 - 2035, %



Scenario 2 : LFP and Na-ion both reach commercial scale

- LFP remains the dominant technology
- Na-ion is scaled commercially and companies successfully establish robust supply chains; imports of Na-ion batteries also increases

Key Insights

- **Consensus among OEMs of LFP's better performance** for the Indian market due to lower costs, safety, and higher cycle life
- **Major EV manufacturers have already started to sell LFP-based EVs**
  - **E4W:** TATA motors, the largest auto company in terms of EV sales launched a new car with LFP cells in Sep 2022
  - **E2W**: TVS motors, one of the top 3 E2 wheeler manufacturers, launched the TVS iQube with LFP cells
- **Buying-in technology to grow the market for new chemistries:** Reliance New Energy acquired Lithium Werks, (LFP) and Faraday (Na-ion)

Na-ion is likely to grow from the late 2020s but market penetration will depend on the pace of commercialisation: Companies in India are expected to begin commercial production from 2028. If manufacturers can establish a supply chain, scale production and reduce costs, Na-ion could begin to emerge as a strong competitor to LFP from the 2030s. If commercialisation and supply chain development is delayed, Na-ion's market share will be lower, met with smaller scale domestic manufacturing and imports

1. Na-ion and others

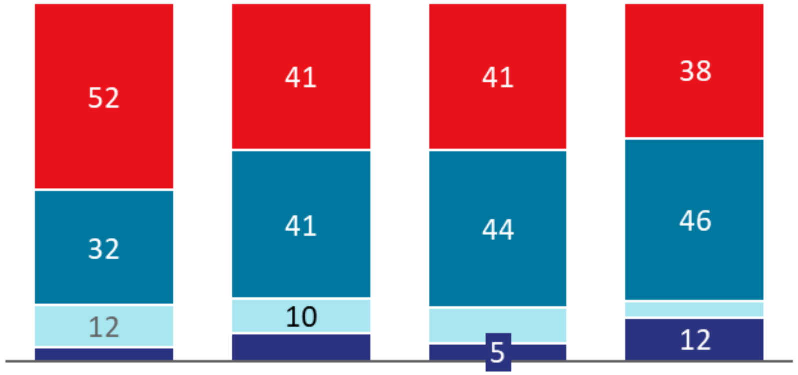
Source: Expert Interviews, Press search, analysis by a leading management consultancy

ASEAN: Market likely to be balanced between NMC and LFP

Na-ion begins to enter the market through imports

NMC | LFP | NCA | Na-ion & Others[1]

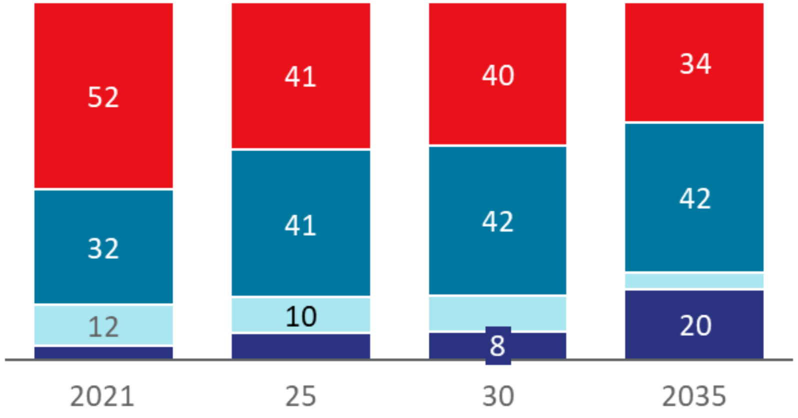
Scenario 1- Share of different chemistries in annual sales, 2021 - 2035, %



Scenario 1 : Build an end to end EV supply chain using local raw materials

- NMC plays a bigger role as ASEAN countries successfully develops an end to end EV supply chain with supportive policies
- The share of LFP grows in parallel driven by lower cost and a shift among OEMs
- Na-ion begins to play a role via imports

Scenario 2- Share of different chemistries in annual sales, 2021 - 2035, %



Scenario 2 : Low-cost chemistries displace NMC

- A preference for safer, lower cost models particularly for 2/3 wheelers translates into a larger share of LFP and Na-ion
- NMC continues to be used for larger vehicles and benefits from supportive policies

Key Insights

In the long-term, NMC is unlikely to be able to compete with LFP in developing countries: consumers place emphasis on cost and safety

- **Major EV manufacturers have already started to move towards LFP:**
  - Tesla plans to use LFP for its Model 3 and Model X
  - Volkswagen announced a move to LFP chemistries for entry-level high volume EV models.
- **Majority of the MoUs signed have not reached investment decisions :** Growing interest and announcements have not yet translated into investment

ASEAN may still see NMC demand from the MPV segment, which remains popular in the region

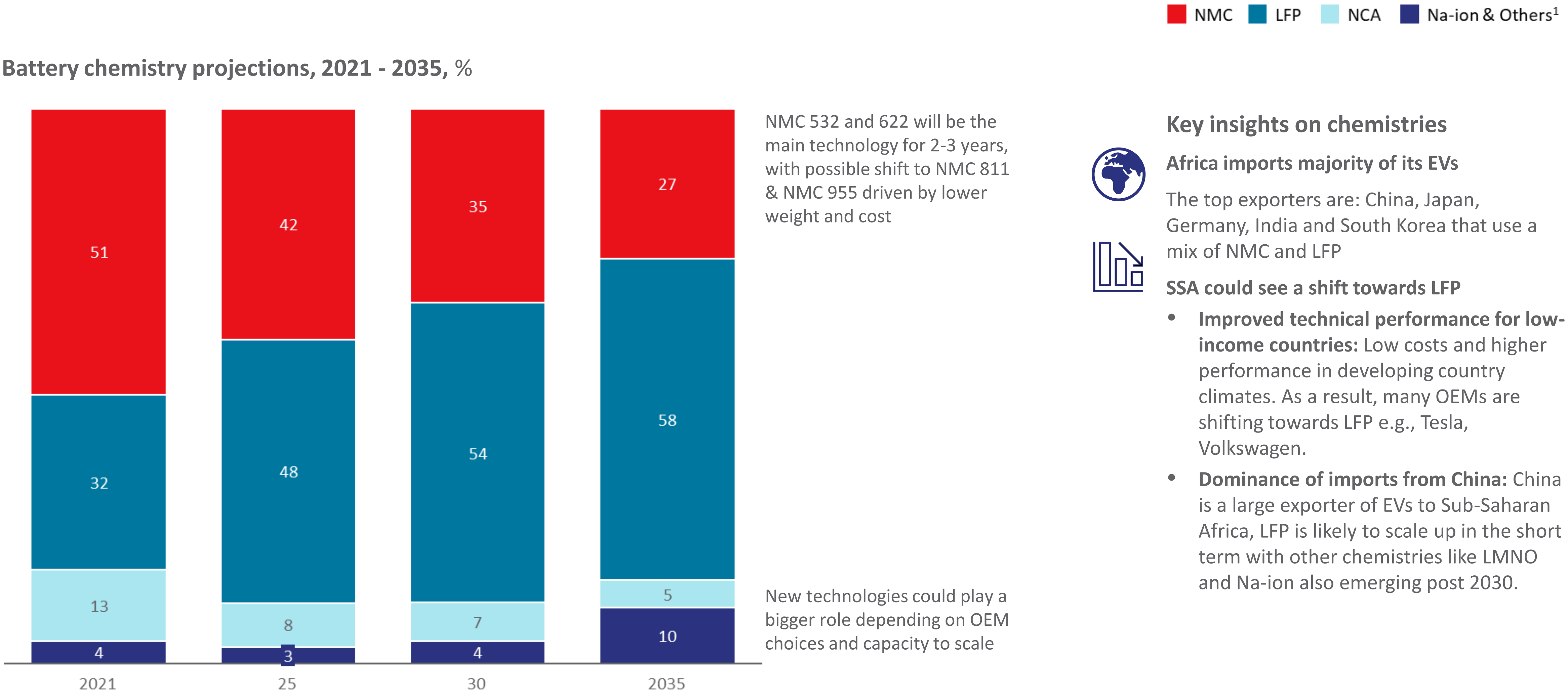
Na-ion's role grows via imports: Advances in Na-ion technology in China could see a Na-ion cars exported to the region if commercial scale is achieved and prices reduce

1. Na-ion and others

Source:, Expert Interviews, Press search, analysis by a leading management consultancy

SSA: A shift towards LFP in developing countries is likely to filter into SSA as well

Battery chemistry projections, 2021 - 2035, %



NMC 532 and 622 will be the main technology for 2-3 years, with possible shift to NMC 811 & NMC 955 driven by lower weight and cost

New technologies could play a bigger role depending on OEM choices and capacity to scale

Key insights on chemistries

Africa imports majority of its EVs

The top exporters are: China, Japan, Germany, India and South Korea that use a mix of NMC and LFP

SSA could see a shift towards LFP

- **Improved technical performance for low-income countries:** Low costs and higher performance in developing country climates. As a result, many OEMs are shifting towards LFP e.g., Tesla, Volkswagen.
- **Dominance of imports from China:** China is a large exporter of EVs to Sub-Saharan Africa, LFP is likely to scale up in the short term with other chemistries like LMNO and Na-ion also emerging post 2030.

1. Na-ion and others

Source: Expert Interviews, Press search, analysis by a leading management consultancy

Battery manufacturers in India & South-East Asia have made announcements

Decisions on exact chemistry mix is still being finalised in many cases

Manufacturer	Key technology	Country	New Announcements
Amara Raja	Lithium-ion	India	Amara Raja Batteries Ltd, will build a lithium-ion assembly plant in Andhra Pradesh to grab the major share in the EVs Battery market.
Exide	Lithium-ion	India	Invest about USD 900 mn in a state-of-the-art lithium-ion cell manufacturing unit in Karnataka.
Tata	Lithium-ion	India	The Tata Group has reportedly pledged US$600 million towards building a lithium-ion battery manufacturing plant in Gujarat for up to 10GW capacity.
Ola Electric	Lithium-ion	India	Ola Electric plans to launch its own lithium-ion cell by the end of 2023, an important component in making batteries for EVs. (around 5 GW)
Replus Electric	Lithium-ion	India	Replus, a unit of LNJ Bhilwara Group, will start operating a lithium battery assembly plant with an annual capacity of 1 GWh within the first three months of 2023.
Reliance	Lithium-ion – LFP, Sodium-ion	India	Reliance New Energy Limited, has acquired an LFP battery manufacturer Lithium Werks and a sodium-ion battery producer Faradion.
LG Energy Solution, Indonesia Battery Corporation	Lithium-ion	Indonesia	Consortium led by LG Energy Solution is set to invest $9bn as part of an agreement with PT Anteka Tambang and Indonesia Battery Corporation (IBC) for an integrated battery project
CBL, Indonesia Battery Corporation	Lithium-ion	Indonesia	PT Aneka Tambang (ANTAM) and PT Indonesia Battery Corporation (IBC), together, with CBL will jointly develop an integrated manufacturing project for EV batteries with total investment of ~6 USD bn
PTT, Foxconn	Lithium-ion	Thailand	Foxconn has laid the foundation stone for an electric car plant in Thailand as part of its joint venture with Thai energy company PTT with an initial annual capacity of 50,000 EVs.
Vingroup	Lithium-ion-LFP	Vietnam	Vingroup has officially started construction of a battery factory for its electric vehicle offshoot VinFast in the Vietnamese province of Ha Tinh. The factory is expected to have an initial capacity of 100,000 battery packs per year
Samsun SDI	Lithium-ion	Malaysia	Samsung SDI has begun constructing its second battery production facility in Malaysia. The company says the plant, will begin mass production of PRiMX 21700 cylindrical battery cells for power tools, micro-mobility applications and EVs in 2024.

Agenda

Utility scale storage deep dive: Li-Ion is better suited for utility-scale energy storage compared to other technologies

Use case description

- **Integration with renewables to provide firm power for bulk transmission** is the main use case, though other use-cases exist depending on the local power market design (e.g., capacity market, ancillary services, frequency response, voltage control)

Main use case requirements

- **High cycle life** as storage system is cycled daily
- **Safety and reliability** is a key concern (e.g., mitigating fire hazards, failsafe)
- **System scalability** to achieve utility scale storage (>5MWh)
- **Ability to scale production** to meet growing demand

Key Technology assessment

Technology	Adoption by 2035	Rationale
Li-Ion	Most important	Given its maturity, Li-Ion meets the technical requirements for utility scale storage such as cycle life and safety at utility scale, while being able to scale production to achieve mass adoption
Na-Ion	Not as important	Commercial deployment of Na-ion could begin in the late 2020s, initially in the mobility segment. As volumes increase, Na-ion could be used in utility-scale applications from the 2030s because of cost, safety, ease of transportability and storage, and lower raw materials risks.
Flow batteries	Least important	Relatively good performance characteristics, however lower technological and commercial maturity with high costs and potential raw material constraints (Vanadium) could limit mass adoption
Fly-wheels	Least important	Typically only used for short duration discharge (<15min), hence better suited for use cases such as frequency response or UPS functions

Source: Press search, analysis by a leading management consultancy

BTM C&I deep dive: Decling Li-ion costs could lead to higher adoption in BTM applications

Including as a replacement for lead acid batteries

Use case description

- BTM commercial and industrial use cases can be broadly split into 3 categories:
- **Back-up generation**: Also known as Uninterruptable Power Supply (UPS), an energy storage device (commonly Lead acid today) provides short duration power while transitioning to longer duration generation (e.g., diesel generator), though running of diesel systems can be minimised through a larger Li-Ion system
- **Renewable integration**: Integration with renewable energy generation to provide more consistent power
- **Power cost optimisation**: Optimising grid costs such as grid demand fees or energy arbitrage

Main use case requirements

- **High cycle life** to maximise asset utilisation; calendar life is more crucial for back-up generation
- **System cost** is important in developing countries
- **Safety and reliability are essential**, particularly for indoor application with proximity to workers
- **Specifically for UPS systems: calendar life** is more crucial than cycle life, **and packaging** is an important requirement

Key Technology assessment

Technology	Adoption by 2035	Rationale
Li-Ion	Important	Li-Ion meets the technical requirements of commercial applications. Adoption likely to expand as costs decline, and could begin to displace lead-acid and reduce reliance on diesel generators in back-up power use cases
Lead-Acid	Least important	Lead acid is not suitable for most BTM commercial applications as it is not able to meet the cycle life requirements. However, Lead acid is a dominant technology for back-up power applications in critical operations (e.g., data-centres) given it's relative maturity, availability and low up front cost, though could lose signfiicant market share to Li-ion and unlikley to play a role in the long-term
Na-Ion	Not as important	Commercial deployment of Na-ion could begin in the late 2020s, initially in the mobility segment. As volumes increase, Na-ion could begin to replace Li-ion batteries for small to mid-size data centres and other C&I operations.
Flow batteries	Least important	Relatively good performance characteristics, however lower technological and commercial maturity with high costs and potential raw material constraints (Vanadium) could limit mass adoption

1. Levelised cost of electricity
2. Levelised cost of storage

Source: Press search, analysis by a leading management consultancy

BTM Residential deep dive: Li-ion could displace lead acid as costs decline further

Use case description

- BTM residential energy storage systems are relatively small systems in weak grid settings. These systems are typically integrated systems with back-up generation (diesel generators), renewables (solar panels) and EV charging infrastructure

Main use case requirements

- **Low upfront cost** is the main consideration for households in developing countries
- **Reliability** is crucial as providing firm power is the main function either to bridge intermittency of renewables or provide continuous power during blackouts.
- **High calendar and cycle life** are important

Key Technology assessment

Technology	Adoption by 2035	Rationale
Li-Ion	Important	Li-Ion meets and exceeds the technical requirements for residential applications, though isn't adopted widely potentially due to high up-front costs, low availability of products in some countries, and lack of familiarity among consumers. As costs continue to decline and availability increases, adoption of Li-Ion batteries for residential energy storage is expected to rise
Lead-Acid	Least important	Lead acid is the dominant technology for residential applications today due to low up-front costs and wide availability in developing countries. However, declining costs and increased availability of Li-Ion are likely to see a declining role for Pb-acid in the long-term
Na-Ion	Least important	Commercial deployment of Na-ion could begin in the late 2020s, initially in the mobility segment. Na-ion is well suited to residential use because of cost and safety reasons. Uptake will depend on whether manufacturers can reach sufficient scale to bring down costs.

Source: Press search, analysis by a leading management consultancy

Safe end of life treatment of batteries will become crucial as battery waste grows

There are three options for safe battery treatment at end of life

Options	Description
Reuse	Remanufacturing or repairing a battery for the same application (e.g. an SHS battery reused in an SHS application)
Repurposing	Remanufacturing a battery for a different application from the one for which it was originally designed (e.g., an EV battery is repurposed for a mini-grid application)
Recycling	Implies that the raw materials within a battery are recovered and made available for future industrial use

1. The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (the Basel Convention) establishes strict controls over transboundary movements of hazardous and non-hazardous waste by applying the "prior informed consent" procedure – shipments made without consent between parties are illegal

Source: WEF (2021): Closing the Loop on Energy Access in Africa

Developing country barriers

- **High cost** of extracting lithium from old batteries compared to mined lithium
- **Low value** of recovered materials, particularly for some chemistries

  Currently depends on nickel price from mined versus recycling and the relative costs could change in the future
- **Inadequate end of life volumes**

  The Basel ban could reduce the volume of 2nd life batteries moving from developed to developing countries[1]

The commercial case for recycling depends on both the value and ability to extract materials

Cathode material[1]	Chemistry
LCO (Lithium cobalt oxide)	LiCoO2
NMC (Lithium Nickel Manganese Cobalt)	LiNixCoxMnxO2 (NMC 111)
NMC (Lithium Nickel Manganese Cobalt)	LiNixCoxMnxO2 (NMC 622)
NMC (Lithium Nickel Manganese Cobalt)	LiNixCoxMnxO2 (NMC 811)
NCA (Lithium Nickel Cobalt Aluminum Oxide)	LiNiCoALO2
LMO (Lithium Manganese Oxide)	LiMn2O4
LFP (Lithium Iron Phosphate)	LiFePO4

High raw material value

Low raw material value

The retrieval of components and materials from a battery relies on the recycling technology that is used[2]

Most recycling technologies focus on NMC and NCA due to the presence of high value materials

Traditional recycling methods i.e., hydro and pyro make it difficult to recover valuable materials as they require destruction of battery packs, mixed with electrolyte and electrodes

Direct cathode technology is complex and doesn't guarantee recovery of cobalt and nickel

- **Pyrometallurgical recycling:**
  The battery is simply burned in a high-temperature oven
- **Hydrometallurgical recycling:**
  The electrodes from batteries are dissolved in acid
- **Direct cathode recycling:**
  Involves recycling cathode materials from used batteries without initially breaking them down into their component part

1. Cobalt, with a price of $28,000-$36,000/t, is the major economic driver of li-ion battery recycling and batteries containing less or even no cobalt are less attractive and recycling often generates net costs
2. Intercalation Station (2021): LFP Batteries Reveal Recyclers' Shaky Foundations. IS Report "LFP Batteries Reveal Recyclers' Shaky Foundations"

Source: WEF Closing Loop Energy Access (2021)

Multiple factors will shape the most viable option in different regions

High-level perspective

Battery materials for recycling in developing countries is expected to grow by 444kt by 2035 (excluding China)[4]

Different Li-ion chemistries will drive recycling rate based on the value of the raw material, e.g., LCO and NMC are higher value compared with LMO and LFP

Developing countries in SSA, SA, and ASEAN are beginning to consider standards for battery waste management through policy announcements; however, there is currently no country with approved legislation

Factors driving recycling, re-use and safe disposal of lithium-ion batteries

Driver	Description
Availability of raw materials	Potential shortages of critical raw materials is driving interest in recycling globally Nickel demand may reach 4,5000kt by 2030[1], causing a theoretical supply shortage of ~833kt[2] due to EV outpacing supply
Supply chain resilience	From an ESG and geopolitical risk perspective, companies are looking at recycling and repurposing to reduce dependence on certain countries
Reduce environmental impact	Reduce environmental impact of battery and EV production process – with potential to reduce the carbon footprint of battery production by 36% by reducing the need for new materials and minimizing the amount of waste generated

1. IEA (2022): Nickel production, 2021 and projected demand in climate-driven scenarios, 2030. IEA Report "Nickel production, 2021 and projected demand in climate-driven scenarios, 2030"
2. Goldman Sachs (2022) Nickel's class divide
3. Analysis by a leading management consultancy
4. Analysis by a leading management consultancy
5. European Parliament (2022): Batteries: deal on new EU rules for design, production and waste treatment. EP Report "Batteries: deal on new EU rules for design, production and waste treatment"

Some countries are thinking of recycling, but do not currently have legislation in place for Li-ion

There have been some announcements but no legislation in place

Region	Policy status	Examples	Level of advancement
Continent of Africa 	EPR legislation[1] passed in Ethiopia, Nigeria, Rwanda, and South Africa Rwanda, is currently largest market**, with 11 MT of Li-ion batteries accumulated** from OGS In SSA, Li-ion batteries are mainly sourced from OGS and e-waste markets	German-assembled 2nd-life batteries power a mini-grid for critical infrastructure on Kibumba Island, Tanzania. Second-life batteries power a min-grid at an Eaton plant in South Africa	Very advanced
India 	The Battery Waste Management Rules (2022), covering EVs, portable and industrial batteries requires producers and importers to be accountable for collection and recycling **Includes requirements for the minimum use of recycled material in new batteries:** 15% total dry weight of a battery by 2030[3]	Attero Recycling aims to expand recycling capacity to 19,500 MT in 2023, up from 4,500 MT[2]	Advanced
Indonesia 	Current regulations on EVs cover sustainability, battery deployment, and Li-ion waste management	CATL invested $4bn in Indonesia's largest nickel smelter that includes building a used Li-ion battery recycling facility	Very advanced

2. India Times (2022): Attero to set up Li-ion battery recycling plant in Telangana investing INR 600 cr
3. Lawrbit (2022): Batteries Waste Management Rules, 2022. Lawrbit Report "Batteries Waste Management Rules, 2022"

Source: WEF (2021): Closing Loop Energy Access, Nur (2022): The Limits of Indonesia's Legal Framework for Electromobility: Regulatory and Sustainable Issues, Pandyswargo (2021): The Emerging Electric Vehicle and Battery Industry in Indonesia

Emerging insight

Compared to China and the EU, the Li-ion battery recycling market is still in its early stages, and it is anticipated that EOL and repurposing policies could begin to come into force once batteries volumes grow

Acronyms

	Regions and Use-cases	Header	Technologies
ASEAN	The Association of South East Asian Nations	CAES	Compressed Air Energy Storage
SA	South Asia	Li-ion	Lithium-ion
SSA	Sub Saharan Africa	LCO	Lithium Cobalt Oxide
BTM	Behind the Meter	LFP	Lithium Iron Phosphate
EV	Electric Vehicle	LMO	Lithium Manganese Oxide
ICE	Internal Combustion Engine	NCA	Lithium Nickel Cobalt Aluminium Oxide
LCOE	Levelised Cost of Energy	NMC	Lithium Nickel Manganese Cobalt
OGS	Off-grid solar	Na-ion	Sodium Ion
PAYgo	Pay as you Go	Pb-acid	Lead Acid
SHS	Solar Home Systems		
UPS	Uninterruptable Power Supply		

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