Innovative Business Models for Scalable Smart Metering Implementation in Emerging Markets

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Introduction

Smart metering has emerged as a critical component for improving operational efficiency, billing accuracy and energy accountability in electricity distribution. However, large-scale AMI (Advanced Metering Infrastructure) implementation in emerging markets, particularly in regions like South Africa, faces challenges related to infrastructure financing, regulatory readiness and technical integration. AMI is critical and will help the utilities in revenue assurance, prepaid enablement, improved cash recovery, demand response initiatives, data driven planning and grid modernization.

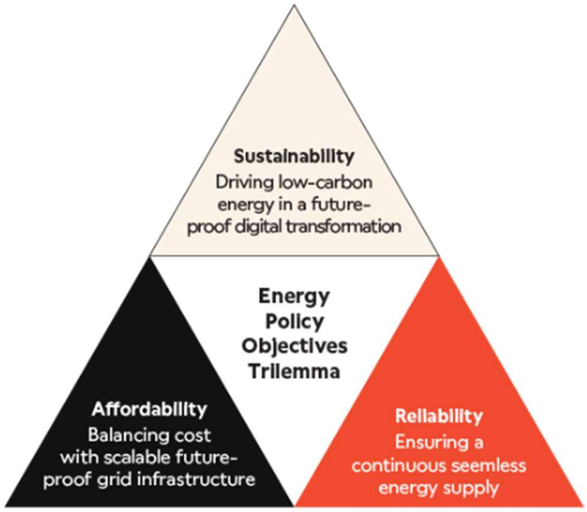
This paper presents a overview of smart metering architecture and explores viable business models for its deployment. It evaluates CAPEX, OPEX, and TOTEX business model options, analysing their applicability based on utility investment capacity, project scale, and risk tolerance. A case study on AMI implementation in India under the TOTEX (Low CAPEX & High OPEX) model, where over 39 million smart meters have already been deployed. The potential for replication of this model in South Africa is explored.

The findings aim to assist utilities and policymakers in selecting financially sustainable and technically feasible implementation frameworks for AMI rollouts.

The Energy Trilemma

Replacing bulk generation with intermittent renewables requires significant investment in transmission grid infrastructure to maintain reliability, while EV adoption increases strain on power quality for local distribution grids. Meanwhile, there is demand for energy to remain affordable, forcing a careful balance between **sustainability**, **reliability** and **affordability.** Utilities carry a growing responsibility to drive digital transformation, delivering affordable energy while modernizing systems to monitor and manage both consumption and production for seamless grid integration.

Smart meters have evolved beyond basic billing tools to become secure sensors capable of monitoring voltage, harmonics and overall supply quality. With increasing grid-edge intelligence, they are transforming into trusted digital hubs, securely linking utilities to home and business assets like storage, renewables and other distributed resources. Often grouped in decentralized clusters, these devices generate large volumes of data that must be processed either locally with edge computing and AI, or centrally. Reliable data and communications infrastructure are essential to maintain grid stability and support the growing demands of a distributed, digital energy landscape.



The world energy trilemma highlights the challenge of balancing security, affordability and sustainability in modern energy systems. AMI sits at the core of this balance, providing the data and connectivity needed to manage supply reliably, keep operations cost-efficient and support the integration of cleaner, distributed energy sources. The following sections explore how AMI use cases directly map to each dimension of the trilemma, helping utilities deliver reliable, affordable and sustainable energy for the future.

Fig.1: The Energy Trilemma

Environmental sustainability

- South Africa is heavily dependent on coal (>70% of generation), which creates a decarbonization challenge.
- Policy pressure under IRP (Integrated Resource Plan) and global climate commitments requires transition to renewables (solar, wind, battery storage).
- Decentralization is growing with embedded generation, rooftop PV, and private IPPs, reducing monopolies in the market generally but complicating grid management.

Role of AMI:

- *Enables smart grid integration of decentralized renewables by providing real-time data to grid managers.*
- *Supports demand response programs (shift loads when renewables are available).*
- *Helps utilities to manage carbon reduction strategies through consumption insights.*

Affordability (Energy Equity)

- Rising tariffs (double-digit increases in recent years) strain budgets of households and businesses.
- Legacy debt (municipal arrears, non-payment culture in some areas) affects affordability and recovery.
- Affordability is tied to balancing cost recovery (utility sustainability) vs. a consumer ability to pay.

Role of AMI:

- *Prepaid featured smart meters prevent revenue leakage by ensuring pay-before-use.*
- *Granular consumption visibility allows consumers to **budget electricity better**.*
- *Facilitates **time-of-use tariffs**, which can make electricity cheaper when demand is low.*
- *Reduces utility operational costs (manual meter reading, disconnections, fraud).*

Reliability (Energy Security)

- In South Africa, there is challenge is load shedding (even though it is in control in recent times) due to generation shortages and aging infrastructure.

- Reliability isn't just about generation. Moreover, it includes grid stability, theft, losses, and outages.
- Utilities are under pressure to maintain power quality while balancing outages.

Role of AMI:

- *Improves outage detection and faster fault localization.*
- *Helps utilities identify non-technical losses (theft, tampering) and manage demand.*
- *Enables **load limiting** during constrained supply, keeping lights and essentials on instead of total blackouts.*

South Africa's Energy Future: A Quadrilemma Perspective

South Africa is reframing its energy debate from the traditional Energy Trilemma (sustainability, security, and affordability) to a Quadrilemma, adding socio-economic development as a fourth pillar. This shift, championed by Minister Dr. Ramokgopa, recognizes that energy policy must not only deliver clean and reliable power but also drive economic growth, create jobs, and address energy poverty.

The Quadrilemma approach emphasizes:

- Linking renewable investments with job creation and inclusive growth.
- Using technology to balance coal's ongoing role with the expansion of renewables.
- Ensuring transitions are equitable, especially for vulnerable communities and underserved regions.

Policy implications:

- Invest in technologies that enable coexistence of fossil fuels and renewables.
- Create jobs in both renewable energy and adaptation of existing fossil fuel infrastructure.
- Design energy transitions that are inclusive, timely, and aligned with climate goals.

The Quadrilemma offers South Africa and Africa as a whole, a holistic and practical framework to rebuild energy systems. By embedding economic development into energy planning, the country can become a leader in shaping resilient, inclusive, and future-ready energy transitions.

AMI architecture and use cases

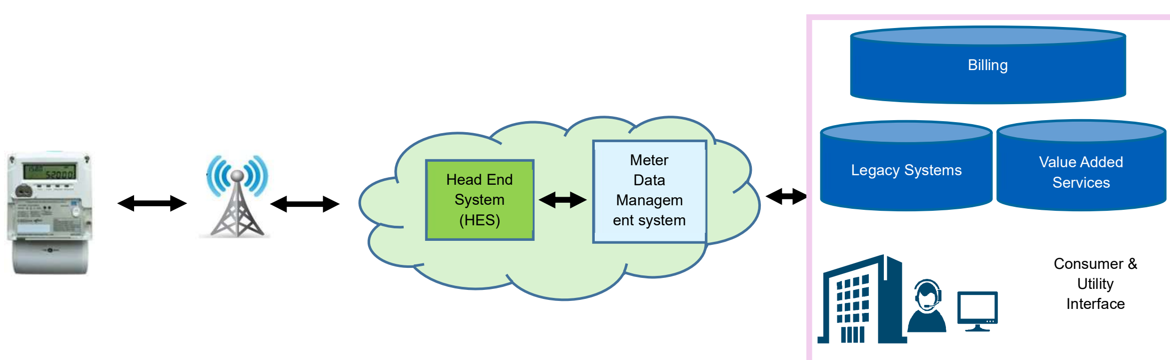


Fig1: AMI System in an distribution utility

Advanced Metering Infrastructure is an integrated system of Smart Meters, communication networks, and meter data management systems that enables two-way digital communication between utilities and consumer premises equipment. Functional blocks include HES, WAN, NAN, DCU/Gateway, and HAN.

Modules / Features	Requirement	Details / Standards
Meters	Core functionalities	Measurement of energy parameters, bidirectional communication, integrated connect/disconnect switch
	Advanced features	Tamper event detection, power event alarms, remote firmware upgrade
	Tamper resilience	Meters must continue operation under tamper conditions.
	Logging & Alerts	Must log events and send alarms to HES
Communication	Options	RF Mesh, PLCC, Cellular, or hybrid
	Requirements	Reliable two-way communication, scalable, disaster recovery enabled
HES & MDM Requirements	HES	Open platform, distributed architecture, scalable without performance degradation
	MDM	Data storage, retrieval, analysis, validation, verification; prepaid support; immediate availability of real-time and post-VEE data
Consumer Portal/App	Coverage	All consumer categories, category-specific features
	Compatibility	OS agnostic (iOS, Android), multilingual (Hindi, English, local)
	Services	Self-service (usage mgmt., billing, service requests, energy efficiency programs), integrated with payment gateways
AMI System Integrations	Integration scope	HES ↔ field devices (DCUs/routers/meters); MDM ↔ billing, CIS, GIS, SCADA, OMS, national reporting
	Standards	IEC 61968-9, IEC 61968-100, CIM-XML, CIM 2.0, MultiSpeak v3.0, Web Services

Table-1: Critical components of AMI System

AMI Digital Connectivity:

The utility sector has accumulated significant experience in deploying communication technologies for large-scale smart metering. Studies highlight the importance of making informed connectivity choices, as these decisions have long-term implications for grid operations. As utilities expand and modernize smart grids, connectivity governance has become critical, particularly with the growing role of third-party providers like Mobile Network Operators (MNOs). While MNOs bring wide coverage and proven reliability, many utilities—such as those in Europe (PLC) and North America (RF mesh)—also deploy their own technologies to maintain direct control and ownership of the network.

MNOs entered the smart metering space nearly two decades ago with 2G-enabled meters, valued for their low infrastructure costs, ease of installation, and broad coverage. However, a key challenge with cellular has been **longevity**. Grid devices are designed for 15+ years of service, yet telecom networks evolve rapidly, with 2G and 3G already phased out in many regions. To address this, utilities increasingly adopt **hybrid models**: RF mesh and PLC leverage cellular for backhaul while minimizing the number of cellular endpoints, significantly reducing costs. RF mesh, widely used in North America and India, further enhances reliability by dynamically maintaining coverage where cellular may be weak and by avoiding the electrical noise issues often faced by PLC.

Access Technology	Sustainability (Longevity)	Affordability (Cost)	Reliability (Performance)
Cellular	Vulnerable to network shutdowns and spectrum repurposing; utilities have no roadmap control.	High component and maintenance costs; subject to operator fees and licensing.	Good coverage, reliability varies by geography and operator, additional costs for high reliability.
PLC	Utility-managed private network but limited long-term viability for intelligent grid edge use cases.	Maintenance-intensive; expensive DCU installations required.	Performance depends on the distribution network infrastructure; suitable mostly for AMI.
RF Mesh (DECT NR+)	Utility-managed private network immune to third-party obsolescence.	No infrastructure or operator fees; low hardware costs; lowest total cost of ownership.	Self-healing, self-forming network with no blackspots; dedicated spectrum ensures optimal performance.

Table 2: Comparing Access Technologies

For AMI to be successful, the choice of smart metering communication technology is critical—it must ensure low operational expenditure (OPEX), high reliability, and scalability. No single technology fits all contexts; therefore, utilities need to evaluate options based on local conditions such as network topology, population density, and telecom infrastructure. In AMI, RF Mesh communication reduces OPEX majorly, since there is no subscription fee as one cellular subscription can handle around 500 meters.

In the African market, where cellular coverage may be inconsistent and power line communication (PLC) performance can be affected by the state of the distribution network, RF mesh can be considered as one of the viable options. It offers flexibility, scalability, and reliable service levels in certain deployment scenarios.

Business model options for Advanced Metering Infrastructure (AMI)

AMI projects are increasingly critical for the efficient functioning of power distribution utilities, enabling accurate metering, reliable billing, demand-side management, and improved revenue realization. However, these projects are capital-intensive and given the financial stress faced by most state-owned utilities in developing nations—including India—the ability to mobilize resources for large-scale rollouts remains a challenge. Issues such as meter tampering, billing inefficiencies, and poor collection efficiency have already weakened the financial sustainability of utilities, limiting their capacity to fund AMI projects through conventional means.
To address these challenges, different business and operational models have been explored globally and in India under the larger framework of distribution sector reforms:

- **Management Operator Model:** Only specific functions, such as metering, billing, and collection, are outsourced to private players. Payments are typically performance-linked, incentivizing improvements in revenue recovery and service quality without transferring full operational control.

- **Distribution Franchise (DF):** The entire utility operation for a defined area is handed over to a private operator for 10–20 years. The franchisee pays the utility for the bulk energy input as per the contract, and in return, manages distribution operations, reduces losses, and improves customer service. This model has been tested in several Indian states, with mixed success depending on governance and regulatory support.
- **Distribution Licensee Model:** In this case, the licensee has full operational autonomy, including power procurement, network management, and customer service. The licensee pays for the use of existing distribution assets and is responsible for improving technical and commercial performance. This requires a strong regulatory framework and significant private sector expertise.

Alongside these structural models, financing approaches are equally important for AMI rollouts:

- **CAPEX Model (ON-Balance Sheet Model):** The utility invests in the infrastructure upfront. The primary barrier here is the weak balance sheets of many DISCOMs, which limit their ability to raise funds.
- **OPEX Model (OFF- Balance Sheet Model):** The entire project is outsourced to a vendor or service provider, and the utility makes periodic payments (often monthly) linked to performance parameters such as meter functionality, billing accuracy, and collection efficiency. This reduces the financial burden on utilities but requires strict contract enforcement.
- **TOTEX/PPP Model :** A blended model where 15–20% of funding is provided upfront by the utility or government, while the remaining investment is borne by the private partner. Payments to the private party are spread over the contract period and linked to project performance, making this a more balanced and sustainable approach.

To push utilities toward efficiency, loss reduction, and smart metering, such innovative business and financing models are not only desirable but necessary. Success, however, depends on supportive policies, effective regulation, and the participation of capable private entities with the operational expertise to manage large-scale utility functions.

Comparative analysis of the different business models is given below:

Parameters	CAPEX	OPEX	TOTEX
Initial Investment	High (*Less Preferred*) Utility bears all cost upfront	Low (*Most Preferred)* Agency is paid on monthly basis - no upfront CAPEX	Medium (*Preferred*) Utility funds a portion - rest managed via OPEX
Ease of Implementation	Low (*Less Preferred*) Requires rigorous capacity building at Utility end	Medium (*Preferred*) Agency manages end–to–end operations	High (*Most Preferred*) Agency does all the heavy lifting for implementation
System Integration	Low (*Less Preferred*) Requires coordination between multiple vendors	Medium (*Preferred*) May lack flexibility for future utility needs	High (*Most Preferred*) Provides seamless system integration
Cyber Security Risk	Low (*Most Preferred*) Utilities have entire control over data	Medium (*Preferred*) Certain extent of data control by third parties	High (*Less Preferred*) Control and ownership of data lie with the agency
Private Sector Participation	Low (*Less Preferred*) Low investor confidence	Medium (*Preferred*) Order accumulation amongst few vendors	High (*Most Preferred*) Highest private sector participation

Case Study – AMI project in India under RDSS

The **Revamped Distribution Sector Scheme (RDSS)** is a flagship initiative of the Government of India, launched by the Ministry of Power in July 2021, aimed at turning around the performance of distribution utilities (DISCOMs) across the country. The scheme seeks to address long-standing challenges in the power distribution sector, such as high Aggregate Technical & Commercial (AT&C) losses, financial stress, poor reliability, and the need for modernization. Different models were in place in India for AMI and those are tested by different utilities in the pilot areas. In the below figure, details are summarised for each model.

Utility Procurement Model (CAPEX)	OPEX Model	TOTEX model
✓ Utility directly procures individual AMI components from vendors. ✓ Up to 10 % payment upon signing of the contract. ✓ 50 – 60 % of contract value paid upon completion of testing and installation. ✓ Remaining amount paid in annual instalments at the end of each year - during service period (3 – 5 years).	✓ Utility nominates a Concessionaire (AMI Solution Provider) ✓ AMISP is paid on monthly basis by utility with no upfront capex investment ✓ AMISP procures AMI components from own subsidiaries or buy from vendors. ✓ AMISP will be paid on monthly basis through concession period.	✓ Utility pays upfront up to 22.5% of smart metering meter cost (capped at certain amount) upon installation and operationalization of meters ✓ Remaining cost is paid on monthly basis as annuity payments upon meeting of SLAs for a period ranging from 7 to 8 years

Fig2: Financial implications of each model

Smart metering is the cornerstone of RDSS, implemented through the TOTEX (Capex + Opex) DBFOOT model, where Advanced Metering Infrastructure Service Providers (AMISPs) are responsible for designing, financing, operating, and transferring the solution. This ensures lifecycle accountability, transparency in billing, theft detection, consumer empowerment, and efficiency gains for Utilities.

Smart Metering Progress in India (as of Aug 2025)

- **Installations:** 39 million smart consumer meters installed
- **Sanctions:** 224 million consumer meters, 5.3 million DT meters, and 2.05 million feeder meters sanctioned.
- **Target:** Complete replacement of 250 million meters in 2 years.

RDSS Key Priorities

- Fast-track prepaid smart metering and infrastructure upgrades.
- Focus on consumer engagement, AI/ML-driven analytics, cybersecurity, and interoperability.
- Ministry to strengthen monitoring, speed up fund release, and support lagging states with workshops/field visits.

RDSS 2.0 Vision

- Modernisation of substations, transmission lines, and underground cabling.
- Integration of **AI/ML** for load forecasting and demand management.
- Promotion of **smart homes, efficient appliances, and peer-to-peer energy trading**.
- Support for **renewable integration, EV adoption, and sector automation**, ensuring long-term resilience.

Business Model for South African context

Given the weak financial condition of many municipalities and distribution utilities, a conventional CAPEX-driven AMI rollout is often not feasible. To overcome this barrier, a "**modified off-balance sheet model with an Escrow arrangement"** can provide a viable solution.

Under this model, the *entire investment* for smart metering and associated infrastructure is managed by the *AMI Implementation Agency/Service Provider***.** The utility does not bear heavy upfront costs; instead, payments are structured as monthly annuities**,** linked to clearly defined performance parameters. This reduces the immediate financial burden on utilities while ensuring risk-sharing between stakeholders. An *Escrow mechanism* further enhances risk mitigation. Revenues from consumer billing or designated utility accounts are ring-fenced, ensuring timely payments to the implementation agency and building confidence for investors and technology providers.

Note: A **sample financial structure** of this model is included in the Annexure to demonstrate the flow of funds and allocation of risks.

Key Recommendations for Successful Implementation

1. **Standard Bidding Documents (SBDs):** Develop uniform and transparent bidding frameworks for utilities to adopt.
2. **Service Level Agreements (SLAs):** Communication technology being the backbone of AMI, SLAs must emphasize network availability, reliability, and data accuracy. Payment annuities should be **linked to SLA compliance**, with penalties for underperformance.
3. **Escrow and Risk Mitigation:** Establish Escrow accounts for secure payment flows, reducing counterparty risk. Define step-in rights for lenders and government in case of non-performance by the implementation agency.
4. **Regulatory and Policy Support:** Enable recognition of the off-balance sheet model in regulatory accounting.
5. **Performance Monitoring and Reporting:** Create robust monitoring systems, including independent verification of meter installations, billing improvements, and collection efficiency. Use digital dashboards for transparency and accountability.

Conclusion

Each model has distinct advantages depending on the utility's financial health, risk appetite, and operational strategy. Selecting the right business model is critical to ensuring sustainable smart metering deployments that align with regulatory frameworks, funding mechanisms, and long-term utility goals.

For South African market a hybrid approach can be considered in the form of **Modified Off-Balance Sheet Model with Escrow Arrangement** that can bridge the financing gap for AMI projects in financially stressed municipalities. By reducing upfront capital requirements, securing payments through Escrow, and enforcing performance through SLA-linked annuities, this model strikes a balance between financial sustainability, operational reliability, and investor confidence**.**

Annexure-I: Sample financial Model for Off-Balance Sheet Model

This annexure provides a **sample financial model** that demonstrates how an **off-balance sheet structure** for AMI (Advanced Metering Infrastructure) projects could look. The model assumes **100% financing by the AMI Implementation Agency (AMI IA)** with a **5-year annuity period**.The intent is to illustrate the cost, returns, and financial viability for both the **operator (AMI IA)** and the **utility**, based on assumed parameters. Actual numbers will vary by project and utility; for a working Excel model, please contact maruthi.mallepalli@wirepas.com .

Assumptions

No of Customers	*Nos*	100000
Project Concession period	*years*	5
Total Estimated Project cost	*USD*	13.84M
Project Funding by Municipality	*%*	10%
Project Funding by Implementation Agency (Concessionaire)	*%*	100%
Finance Charges	*%*	9%
Meter mix		
Single Phase meters		75%
Three Phase meters		25%

O&M costs

	Y1	***Y2***	***Y3***	***Y4***	***Y5***
Estimated O&M Cost	3%	3%	5%	5%	5%
Cloud cost (USD)	50,000	50,000	50,000	50,000	50,000
Total O&M cost (USD)	465,219	465,219	742,031	742,031	742,031

Loan Information

Loan taken(90% of the cost)	*USD*	12,456,562
Repayment	*Years*	5
Moratorium Period	*Years*	6 Months
Loan Processing Fees	*%*	3%

The AMI IA finances the project with a loan. This financial arrangement ensures that the **utility's balance sheet remains unaffected**, while the AMI IA manages the capital recovery through annuity payments.

Return On Investment Calculations (Utility)

The financial benefits to the utility come from **loss reduction and improved collection efficiency**.

Unit price (USD / kWh) - Tariff	*0.13*
Cost reduction - Manpower	*15%*
T&D Loss	*20%*
Commercial Loss	*10%*
Total of units purchased	*320,000,000*
Total of units Sold	*256,000,000*
Per unit Purchase cost to Utility (USD / kWH)	*0.18*

Expected out comes used for Return On Investment calculations for the utility

1. **T&D Loss Reduction** – Improved metering reduces technical losses, leading to reduced import units and lower purchase costs.
2. **Collection Efficiency** – Smart meters enhance billing and collection, improving cash inflow stability.

	Y1	***Y2***	***Y3***	***Y4***	***Y5***
T&D Loss reduction (Cumulative)	***1%***	***3%***	***3%***	***4%***	***5%***
Import Units reduction	3,200,000	9,600,000	9,600,000	12,800,000	16,000,000
reduction in Purchase cost	576,000	1,728,000	1,728,000	2,304,000	2,880,000
Improvement in collection (Cumulative)	*1%*	*2%*	*3%*	*3%*	*3%*
	332,800	665,600	998,400	998,400	998,400
Total	**908,800**	**2,393,600**	**2,726,400**	**3,302,400**	**3,878,400**

Quote & Returns	***UNITS***	***Value***
Capex Cost	*USD*	*13,840,625*
Opex Cost	*USD*	*3,156,531*
Total Cost	*USD*	*16,997,156*
No of Meters	*Nos*	*100000*
Cost per meter per year	*USD*	*33.99*
Expected Returns	*%*	25%
Quote per meter per year		***42.49***

Summary

Returns	UNITS	Operator	Utility
IRR (Pre tax)	%	28%	16%
IRR (Post tax)	%	21%	12%
Loss Reduction (T&D)	%		20%
Collection Efficiency Increase	%		10%

Quote	UNITS	Operator	Utility
Annual Quote per Meter	USD	42.49	
Assets for Utility	USD		13,840,625
Annual Payment by Utility	USD		4,249,289

Key Takeaway

This model demonstrates how an off-balance sheet financing structure can enable utilities to implement AMI without upfront capex, while still achieving:

- Significant T&D loss reduction (up to 20% over 5 years)
- Improved collection efficiency (10%)
- Positive IRR for both the operator and the utility

It is a win-win structure where the utility avoids heavy debt burdens, and the implementation agency secures predictable annuity-based returns.