FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 10 No. 16, June, 2026, pp 562 – 569
DOI: https://doi.org/10.33003/fjs-2026-1016-5843

Smart Single-Phase Energy Metering With Multi-User Unit-Sharing: A Systematic Literature Review

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ABSTRACT
Key issue with multi-tenant residential systems is the inability to fairly and accurately measure electricity use with a prepaid meter in developing economies. Prepaid meters measure electricity consumption at the individual household unit level, but cannot divide up the electricity consumed by multiple independent household units fairly and accurately. Recent advances are coupled with new smart and Internet of Things (IoT) technologies, Global System for Mobile Communications (GSM) and smart metering applications. Consequently, there is a need to discuss the applicability of the new solutions to address problems of multi-user allocation, cost, connectivity and electricity equity. Many studies were searched based on PRISMA 2020 guidelines using IEEE Xplore, Scopus, Web of Science and Google Scholar. A full-text screening was completed for 1003 records and a narrative synthesis of 31 peer-reviewed studies. Quality appraisal was done using a modified MMAT 2018, and the scores were then summarised in five thematic clusters: metering evolution, smart and IoT metering, prepaid/GSM systems, multi-user metering and Blockchain (peer-to-peer energy trading). The review found that though smart and prepaid meters can provide good improvements, there is no low-cost single-phase meter with the ability to provide an independent user disconnection. Furthermore, realtime individual feedback and an equitable per-user unit allocation, which satisfies the accuracy requirements of IEC 62053-21:2020 were explored. The outcome was a huge techno-social issue that need the development of a Smart Single-Phase Energy Meter with Multi-Unit-Sharing Capability for shared residential environment in developing economies.

Received: 31 Aug. 2026
Accepted: 01 Sep. 2026
Published: 07 Sep. 2026

Keywords: Smart Metering; Multi-User Allocation; Prepaid Electricity Meter; Electricity Equity; Systematic Review

INTRODUCTION

Electricity is essential for sustainable development and has positive impacts on education, health care, productivity and welfare of households (IEA, 2022; World Bank, 2024; IEA, 2025). However, in Sub-Saharan Africa, access is still limited due to a lack of infrastructure, coverage, affordability and inefficiency of billing (Munro and Schiffer, 2019; CATF, 2025; World Economic Forum, 2025). There are an estimated 53.85%, or more than 7 million out of 13.3 million, of the total registered customers who are still unmetered, and an additional 38.91 million potential customers are not connected; Nigeria is not an exception to this challenge (NERC, 2024a; NERC, 2024b; Nairametrics, 2024). Prepaid metering is important in terms of payment discipline, revenue recovery/billing transparency. The conversion of electromechanical meters to electronic, smart meters, GSM and IoT meters has provided better meter measurement, meter monitoring, remote recharging, tamper detection and interaction with consumers (Omijeh and Ighalo, 2013; Peter and Iderus, 2021; Amhenrior *et al.*, 2022; Adebisi *et al.*, 2022). The problem, however, is that a single-user design is used by most systems, and the fact that hostels, compound houses and multi-tenant apartments are all made up of independent users, each paying for their own prepaid unit, may present a problem.

A single-phase conventional prepaid meter is a single meter which measures the total amount of energy used by a single home or account, and does not contain any way to allocate the energy used to a single energy use in a 'joint purchase' between various consumers. They are smart, GSM, IoT, and AMI technologies which all enhance monitoring, communication, remote recharge and control; but mostly continue with the single-user design (Gungor *et al.*, 2011; Uribe-Pérez *et al.*, 2016; Garcia *et al.*, 2017). This may cause disturbance, unequal cost allocation and lack of trust among shared housing users because the amount consumed by the user is not known and can be any percentage of a total pool or even a user's balance of an electricity meter. Akasoro *et al.* (2023) demonstrated multi-user operation based on RFID identification, which was combined with a current sensor and controller (Arduino microcontroller) without the introduction of an explicit equity-based allocation scheme, individual feedback per user or detailed validation following IEC 62053-21:2020 (IEC, 2020a). The problem is that lowcost and validated system for distributing the prepaid units equally and fairly to individual users connected to the same residential supply has not existed.

Although there is extensive research conducted on prepaid, smart, IoT, GSM, AMI or energy-management systems, the research is fragmented across various technological, geographical and application domains (Sawarkar and Golait, 2015; Rajaguru and Johansson (2024); Mazhar *et al.*, 2024). Only one or two studies have done systematic mapping regarding metering hardware, multi-user allocation, user-level feedback, and affordability, as AMI (with enablement of cloud and Blockchain) is constrained by infrastructure and electricity availability in a shared home space. Therefore, this study follows the PRISMA 2020 guidelines to synthesise evidence related to metering hardware, prepaid and smart systems, IoT technologies, and the allocation of multi-users and access to electricity in developing economies (Page *et al.*, 2021). It has plotted the evolution of metering; examined prepaid, GSM, and IoT/smart metering solutions for Nigeria and others; examined multi-user solutions and unit allocation; and finally plotted the unfilled gaps for the development of the low-cost Smart Single-Phase energy Meter with Multi-Unit-Sharing Capability for hostels like setups. The guiding question is: how far can the current technology on residential prepaid and smart metering go for technically correct, affordable, connectivity-independent, equitable allocation of electricity units to multiple independent consumers/users at electricity supply points and ability to disconnect anyone who's unit is exhausted.

MATERIALS AND METHODS

Systematic Review

A systematic literature review was performed, following the PRISMA 2020 guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Page *et al.*, 2021; Olugbemi *et al.* 2026). A review protocol was developed before starting the data collection process to make sure that the research question, eligibility criteria, search strategy, screening procedure, quality appraisal, and data-synthesis approach were well defined. One negative feature of the review process is that the protocol has not been publicly posted on one of the web-based databases, such as PROSPERO.

Eligibility Criteria

The inclusion criteria were studies that met the following criteria: peer-reviewed journal articles, published in English between 2011 and early 2026, which discussed electricity metering hardware, firmware, or complete systems. Potential topics were considered to be: smart or prepaid electricity metering, Internet of Things (IoT) monitoring of electricity, allocation of electricity to multiple users or metering based on microcontrollers or electricity in developing economies. Studies that were only mid-phase metering, three-phase metering for industrial applications, were not peer-reviewed, or were grey literature, unpublished theses or institutional reports were not considered. Also, studies that only discussed renewable-energy generation, without a metering-hardware component, were not considered.

Identify Information Sources and Search Strategy

A systematic search was done in IEEE Xplore, Scopus, Web of Science (WoS) and Google Scholar. A three-part conceptual approach strategy to the search was created. The technology domain included "smart meter", "prepaid meter", "energy meter" or "AMI" or "advanced metering infrastructure"; the context domain included "multi-user", "shared metering" or "unit sharing" or "multi-tenant" or "compound house" or "low income housing"; the geography (equity) domain included "Nigeria" or "Sub-Saharan Africa" or "developing economies" or "energy equity" or "electricity access". They were then hand-searched for reference lists from the IEEE Transactions on Smart Grid, Energy for Sustainable Development and Sustainable Energy Technologies and Assessments.

This selection and screening of studies was done in the following way: Two-stage screening of the articles for selection as studies was done. Records retrieved were first screened on the title/abstract according to the predefined eligibility criteria, and then full text screening of the potentially relevant records was carried out. If there were any disagreements during the screening, the reviewers were able to discuss and come up with a consensus. 1,606 records were retrieved from the four databases (i.e., 412 from IEEE Xplore, 389 from Scopus, 274 from Web of Science and 531 from Google Scholar) using the PRISMA process as shown in Figure 1. After duplicate removal (*n = 603*), 1003 remaining records were screened based on the title and abstract. Of these, 721 were excluded, and 282 full-text articles remained for assessing eligibility. Another 251 were excluded because they did not use peer review, were overly broad and were outside of the scope of the study, or the full text article was not available, leaving 31 studies that were used for the final narrative synthesis.

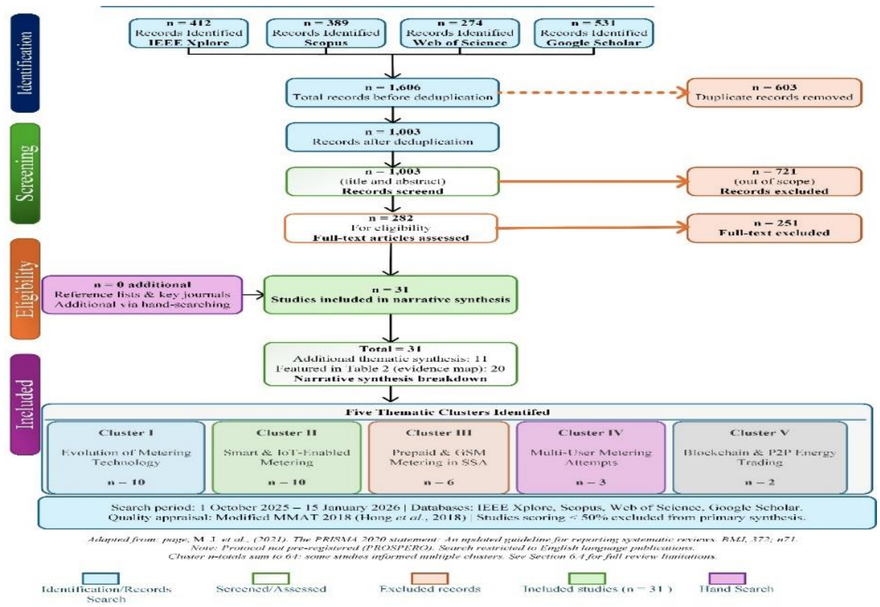

Figure 1: Presents the PRISMA 2020 flow diagram. (Original concept from (Page et al., 2021))

Data Collection and Handling

A consistent data collection strategy was used that included: author(s) and year of publication; country where the study was conducted and setting of the study; metering technology; key technical approach; study results; limitations of the study reported; and relevance to multi-user unit sharing of electricity. Special attention was given to smart and prepaid metering, communication technologies, microcontroller implementation, user identification, unit allocation, individual user feedback and connectivity requirements and applicability in the developing-economy environment. The range of studies covered in this review spanned from hardware prototypes, implementations of experimental tests, simulations and conceptual reviews to the extracted evidence map and has thus been organised in a structured evidence map before the synthesis.

Quality Appraisal and Risk of Bias

A modified Mixed Methods Appraisal Tool (MMAT) version 2018 (Hong *et al.*, 2018) was used to assess methodological quality. MMAT was chosen because the review contained a wide range of evidence - experimental hardware studies, simulation-based investigations, applied engineering studies, plus some reviews or conceptual research. The framework has been adapted for use in the context of an engineering-focused review. Five criteria were assessed: (i) clarity of objectives of studies; (ii) validity of methodology of measurements; (iii) rigour of experimental/simulated procedures; (iv.) transparency of reporting the data; and (v) relevance to multi-user electricity unit sharing. Each criterion score was awarded a total of 1 (Yes), 0.5 (Partial) or 0 (No), and was given the maximum score of 5. Studies with scores below 2.5 (50%) (where applicable) were not incorporated into the main synthesis but may be referred to for the purposes of providing context for the discussion.

Data Synthesis Methods

The lack of consistency in the studies in terms of their design, technology, setting, and performance indicators precluded any statistical meta-analysis and instead, a thematic narrative synthesis was employed. The evidence was grouped into 5 clusters: (i) evolution of energy metering; (ii) smart and IoT-based metering; (iii) previous multi-user metering; (iv.) prepaid and GSM metering in Sub-Saharan Africa; and (v) blockchain and peer-to-peer energy trading. Of the total number of 31 studies, 20 as presented in Table 1, were highly relevant and suitable for detailed mapping of the evidence in all five clusters.

Table 1: Structured Evidence Synthesis for Selected Key Studies

Author(s) & Year	Approach	Country	Key Finding	Limitation
Gungor *et al.* (2011)	AMI communication technologies and standards	USA/Global	AMI enables granular monitoring and bidirectional utility communication	Designed for single-user grid-connected households
Omijeh and Ighalo (2013)	GSM-based prepaid meter recharge model	Nigeria	Established remote recharge feasibility for Nigerian prepaid meters	No equity mechanism; single-user design
Uribe-Pérez, *et al*. (2016)	State-of-the-art smart metering review	Spain/Global	Comprehensive taxonomy of AMI communication protocols	Pre-2020; IoT and blockchain developments not covered
Rashid, *et al.* (2022)	GSM prepaid meter management	Pakistan	Automated credit exhaustion cutoff; SMS recharge interface	Single-user; no fairness allocation
Jawaduddin, *et al*. (2020)	Automatic energy monitoring system	Malaysia	Automation reduces meter-reading errors	Single-household design; equity gaps unaddressed
Kumar, *et al.* (2021)	IoT-based smart energy meter	India	Power quality analysis with IoT integration improves metering efficiency	Single-user architecture; high component cost
Mehta, *et al* (2021)	IoT smart meter for smart grid	India	Real-time cloud monitoring reduces energy waste	Requires persistent internet; unsuitable for shared living
Peter and Iderus (2021)	Enhanced meter with GSM and protective relays	Nigeria	Relay integration improves safety and billing accuracy	Multi-user fairness not addressed
Reddy, *et al.* (2021)	IoT prepaid energy transaction system	India	IoT prepaid transactions reduce billing disputes	No shared-household allocation mechanism
Amhenrior, *et al.* (2022)	GSM/Wi-Fi smart prepaid meter	Nigeria	Tamper-resistant design; remote recharge via SMS; low fabrication cost	Single-user architecture; no equity allocation
Adebisi, *et al.* (2022)	Web-based single-phase load monitoring	Nigeria	IoT enables remote auditing and reduces billing disputes	Requires internet; single-user design
Rind, *et al.* (2023)	IoT dynamic pricing system	Saudi Arabia	Real-time tariff signals reduced peak demand	Requires stable internet; not multi-tenant focused
Akasoro, *et al.* (2023)	RFID-based 4-user prepaid meter (Arduino UNO)	Nigeria	Demonstrated functional feasibility of multi-user meter; mass production potential identified.	No equity allocation logic; no per-user LCD/keypad feedback; limited load testing; no IEC benchmarking
Arshi, *et al.* (2024)	Comprehensive IoT energy review (17 domains)	Global	IoT improves demand management and enables real-time feedback	High infrastructure cost; unsuitable for off-grid contexts
Mazhar, *et al.* (2024)	Smart grid integration with Industry 5.0	Global	AI and IoT convergence enhance grid resilience	Applicability constrained in data-scarce environments
Veerasamy, *et al.* (2024)	Blockchain P2P energy trading in microgrids	Singapore	Resilient microgrid control with secure, transparent P2P trading	Infrastructure demands are prohibitive for developing-economy deployment

Author(s) & Year	Approach	Country	Key Finding	Limitation
Koukouvinos, *et al.* (2025)	Performance evaluation of five metering systems	Greece/EU	Smart meters outperform electromechanical devices in precision and optimisation	Limited relevance to developing-economy contexts
Nazir, *et al.* (2025)	Blockchain P2P energy trading model	Global	Privacy-preserving reserve-pricing model enables prosumer trading	High complexity; unsuitable for low-resource consumers
Rao, *et al.* (2025)	GSM-based prepaid energy meter	India	Reliable remote top-up and automatic disconnection demonstrated	Single-user; no unit-sharing logic
Kavitha (2026, in press)	Smart energy management with theft prevention	India	Detects energy theft and provides real-time billing estimation	No multi-user unit-sharing capability

RESULTS AND DISCUSSION

An Overview of the Studies Included is Given Here

The 31 eligible studies (2011 - early 2026) covered electricity metering, smart and prepaid systems, IoT monitoring, microcontroller-based designs, multi-user allocation and decentralised energy technologies. The sources included an African country such as Nigeria, other countries in Sub-Saharan Africa, India, Bangladesh, Malaysia, Pakistan, Spain and Greece, as well as international studies. The GSM Prepaid Metering, Remote Recharge, Load Monitoring and Multi-User features were particularly relevant to the job in Nigeria. Apart from metering and smart-grid communication, the scope has been extended to electronic (static) meters, GSM/prepaid, IoT monitoring, multi-user architectures and peer-to-peer (based on Blockchain) trading mechanisms (Gungor *et al.*, 2011; Uribe-Pérez *et al.*, 2016; Garcia *et al.*, 2017; Mazhar *et al.*, 2024). Designs involved reviews, conceptual models, prototypes, simulations, IoT systems and blockchain/P2P frameworks, and complicated a synthesis of the narratives.

Prominences of the data were that single-user household metering models persisted despite improvements in the accuracy of meter measurements, communication, monitoring, and automation, as well as the presence of prepaid and meter remote control (PMRC) (ERCOT, 2023; Sawarkar and Golait, 2015; Rajaguru and Johansson, 2024). The conventional meter and electronic meter measured only total metering in all the households. The AMI is capable of bi-directional communication; IoT provides realtime metering, and GSM prepaid allows recharge from remote and automatic disconnection. For the most part, one meter, one account and one consumer holds true for these developments. Now, no such study was found where both pre-purchased unit allocation (equitable) and realtime per-user consumption were considered. Also, information and user disconnection when units are exhausted, and accuracy validation per IEC 62053-21:2020 were achieved in a lowcost single-phase multi-user meter (IEC, 2020a).

History of Metering Technology

From the literature reviewed it is established that, electromechanical induction meters have been replaced by electronic/static meters overtime and subsequently by Advanced Metering Infrastructure (AMI) (Garcia *et al.*, 2017; Uribe-Pérez *et al.*, 2016). Electromechanical meters offered strong overall metering, but were mechanical, required manual reading and were only capable of metering one meter per consumer. Hence, was not disaggregating shared supply. The advent of electronic and static meters instead of moving parts used electronic sampling and improved accuracy; electronic processing, and allowed for the measurement of active, reactive and apparent power and tamper detection. Under normal working conditions, the error of the well-designed electronic meter can be less than 0.5% (Masnicki, 2018; Urekar *et al.*, 2017). These developments relate to IEC 62053-21:2020 and IEC 62053-22:2020 for static AC active-energy meters (IEC, 2020a; IEC, 2020b). AMI allowed for two-way communication and provided realtime exchanges of data for remote monitoring and demand-side management over cellular, ZigBee, Wi-Fi, and power-line networks (Stata and Ngimenev, 2007; Gungor *et al.*, 2011; ERCOT, 2023; Cetina *et al.*, 2017; Erkin *et al.*, 2013). They are big systems featuring massive infrastructure and sturdy networks and thus rather difficult to be deployed in resource-poor Nigeria. Numerous fixes for connectivity and accuracy have not solved the problem for distinct metered customers in separate units, on a single home meter.

Smart/IoT Based Energy Monitoring

With the introduction of IoT, meters are now able to carry out realtime monitoring, report to the cloud, analyse power quality, allow demand and provide alerts, analyse consumer behaviour and can also be controlled remotely (Arshi *et al.*, 2024; Jawaduddin *et al.*, 2020; Kavitha, 2026). Some of the IoT smart meter developed are found in: Kumar *et al.*, (2021) developed the IoT smart meter with power quality analysis, Mehta *et al.*, (2021) developed IoT meter for smart-grid application, Reddy *et al*., (2021) developed IoT prepaid transaction meter with automatic disconnection at zero credit, and Koukouvinos *et al.*, (2025) presented the evaluation of smart-meter performance for energy management, dynamic pricing and consumer behaviour. Repeatedly cited are two limitations: Most systems are based on the assumption of one household, and many require an internet connection which is not consistently available in many target communities.

The individual household solution proposed by Rind, *et al.* (2023), which supports the reduction of peak consumption through IoT dynamic pricing, and the solution by Taştan (2019), who proposed to shift the consumption to lower tariff time by embedding scheduling in an IoT home energy-management platform, are other individual household solutions. Putra (2025) proposed an IoT (Internet of Things) based Kwh measurement system using the NodeMCU ESP8266 microcontroller and the results obtained showed an accuracy of around 15.8% with the nameplate Kwh, proving the feasibility of microcontroller implementation and the need for calibration. It is thus concluded that low-cost monitoring and automatic control of elements and remote communication are set as requirements in the IoT literature but not a validated multi-user unit sharing with equitable allocation.

Prepaid Systems and GSM in Sub-saharan Africa

This cluster is targeted at prepaid and GSM metering especially in Nigeria, where prepaid metering was introduced to reduce non-payment revenue leakage among others. In Q3 2024, 46.15% (about 6.16 million) of 13.3 million registered customers were metered, while 7.18 million (53.85%) remained on estimated billing (NERC, 2024a; Nairametrics, 2024). This is underscored by the fact that DisCo expects to spend ₦275 billion from 2024 to 2027 renting meters while the World Bank has committed to US$500 million for meters (NERC, 2024b; World Bank, 2024). Omijeh and Ighalo (2013) had proposed the GSM remote recharge. Similarly, Peter and Iderus (2021) had proposed the GSM smart prepaid meter with protective relay with single user system. Amhenrior *et al.* (2022) had proposed the low cost GSM/Wi-Fi Smart Prepaid meter with tamper resistance and SMS recharge. Meanwhile, Adebisi *et al.* (2022) had demonstrated the web based single phase load monitoring using IoT. These systems provide remote recharge, disconnection from source, accurate billing and tamper resistance with revenue assurance. However, there was not option to divide collective recharge units with different users in a single recharge supplying both.

At a more general level, Sub-Saharan African data shows that some 600 million Africans still do not have access to electricity. Electricity drive is not keeping up with population growth in general. There are lots of electricity outages, losses, insufficient investment in power generation, and tarrifs are out of reach for at least some people (IEA, 2025; World Bank, 2024; World Economic Forum, 2025; CATF, 2025; Rajaguru and Johansson, 2024). Everyday epileptic supplies are recorded in urban Africa as reported by Munro and Schiffer (2019). Despite the positive findings of the study by Ayamba *et al.* (2025) on better consumption awareness with smart meters in Ghana, the key limitation in shared-residential metering identified by the study is the lack of transparency and trust, which must be incorporated into the design of metering.

Architectures for Multi-User Metering

The most directly related cluster to multi-user metering and the largest evidence gap was multi-user metering. Akasoro *et al.* in 2023 developed a four-user prepaid meter by using the RFID identification. The quasi-current sensor along with ATmega328P microcontroller is programmed by Arduino UNO. The prototype was run from recharge to display and remote transactions. However, it did not have an explicit unit sharing equity algorithm, a feedback keypad/LCD per unit and comprehensive load testing based on IEC 62053-21:2020. GSM prepaid recharge and automatic cut-off in Rao *et al.*, (2025) and Rashid *et al.*, (2022), Omijeh and Ighalo, (2013) treated all household as a billing entity. The previous work has only identified user identification, prepaid recharge, remote communication, disconnection, measurement and monitoring. But, could not integrate these features in a validated architecture which distributes the collectively purchased units evenly, provide feedback to the user's realtime and disconnect them when their units is exhausted.

Blockchain-Enabled Peer-to-Peer (P2P)

Blockchain-enabled peer-to-peer (P2P) energy trading is the most advanced parallel identified. Veerasamy *et al.* (2024) developed specific proposed resilient microgrid control using Blockchain and Nazir *et al.* (2025) proposed the privacy-preserving reserve-pricing model for smart-grid P2P trading. These systems are decentralised accounting, have secure transactions, transparent, prosumer exchange, privacy, but are costly in terms of computation, connectivity and key management. Thus, they are not well suited to low-income housing with a low degree of connectivity and reinforce the need of a simple locally maintainable architecture in Nigeria. A synthesis of the results obtained in all the thematic analysis stages is carried out in the next stage.

Cross-Thematic Synthesis of the Results

Technological development trend is obvious and applications are lacking for the five clusters as a whole. Table 2 is a summary of the main capability that has been achieved in each cluster and the limitation that still have limited or absents of solution for shared residential metering.

Table 2: Research Gap Analysis - Technology Cluster

Thematic cluster	Principal capability established	Persistent limitation
Electromechanical meters	Aggregate electricity	Manual reading and no user-level allocation
Electronic/static meters	Higher measurement accuracy and digital processing	Primarily single consumer architecture
AMI/smart metering	Bidirectional communication, monitoring and demand management	High infrastructure and connectivity requirements
IoT-based metering	Realtime monitoring, cloud reporting and automated control	Internet dependency and predominantly single-user design
GSM/Prepaid metering	Remote recharge, billing control and automatic disconnection	No equitable multi-user allocation
Multi-user metering	Demonstrates technical feasibility of serving several users	Lack of equity logic, per-user feedback and comprehensive validation
Blockchain/P2P	Decentralised and transparent energy transactions	High computational, connectivity and infrastructure requirements
Demand Response/Dynamic Pricing	Load shifting to off-peak periods; waste reduction; economic incentives	Individual-household focused; no shared-cost dispute resolution mechanism

The following are the four key findings. The first is Smart-meter accuracy and reliability are initially measured in the case of a single user application. Second, The Joey is made more transparent and remote access enabled by IoT and GSM. Third, multi-user metering is quite possible, but in the absence of equity logic is not fully validated. Fourth, Blockchain and other highly technology solutions are not a good fit in low resources multi tenancy environments. The majority of the architecture in play today still considers electricity usage a one-to-one relationship such as house, household account, household bill whether it is electromechanical meters or blockchain platforms. So, there is an unanswered issue in research to design a lowcost metering system for an equitable multi user unit allocation for providing the individual user's consumption feedback, individual user disconnection and validated consumption measurement accuracy using microcontroller.

Principal Findings

The 31 studies contain evidence of strong developments within the measurement and smart measurement, in prepaid systems, IoT monitoring and decentralised energy management, whereas the latter (energy allocation dealing equitably among independent users supplied by a shared supply) is less advanced. There is no validated multi user architecture, but there are individual functions. In the case of electricity, testing and evolution of metering has improved collectively purchased metering measurement and communication, but not distribution (Masnicki, 2018; Urekar *et al.*, 2017; Gungor *et al.*, 2011). IoT and microcontroller systems are practical with respect to the cost and are mostly single-user and connectivity dependent (Kumar *et al.*, 2021, Mehta *et al.*, 2021, Reddy *et al.*, 2021, Putra, 2025). GSM based system for Nigeria was able to implement remote recharging, billing control, tamper resistance and disconnection without taking the jointly purchased recharge unit and distributing it among the users (Omijeh and Ighalo, 2013; Peter and Iderus, 2021; Amhenrior *et al.*, 2022; Adebisi *et al.*, 2022).

While, Akasoro *et al.* (2023) shows that several users can use a single architecture with the implementation of RFID, current sensing, user feedback and microcontroller control but not with explicit equity algorithm, dedicated per user feedback, IEC 62053-21:2020 validation for different loads. Multiple users do not mean multi-user energy management. However, Blockchain and P2P studies introduce decentralised accounting and energy sharing methods, which lead to infrastructure requirements and can only be implemented at houses with connection (Veerasamy *et al.*, 2024; Nazir *et al.*, 2025). The building blocks have been mentioned in the literature but have never been combined to form a lowcost equitable unit-share architecture for a common single-phase supply and included in the architecture.

Technical/Regulatory Gap Identification

The main gap lies between the standards that measure metering accuracy and the fair allocation of resources in real time to multiple users. Electronic meters can achieve errors below ±0.5% under normal conditions, and IEC 62053-21:2020 and IEC 62053-22:2020 specify static AC active-energy meter classes (Masnicki, 2018; Urekar *et al.*, 2017; IEC, 2020a; IEC, 2020b). There is no accuracy compliance that dictates the units allocated to the independent users. The meter could not accurately calculate the sum of the energy use of every individual. The prepaid meter could be switched off when the kWh balance reached the value 0, and there would be no fair-share rule for collectively bought electricity. Four factors remain to be added: (i) a user's consumption/balance feedback mechanism; (ii) the ability of users to share/borrow units among themselves (iii) the capability to disconnect at the user level unrelated to the other elements; (iv.) accuracy validation at various loads.

Suggestions for Practice Improvement and Further Research

Some cautions need to be noted in interpreting the results. The search of four databases (IEEE Xplore, Scopus, Web of Science, and Google Scholar) might not be thorough and may not ensure that all publications that might be considered relevant are discovered, including studies published in specialised repositories. Whilst there were some instances of grey literature or non-English sources, the review focused only on journal articles in English (peer-reviewed) and conference papers published in IEEE or IET proceedings in order to minimise the effect of this, and consequently increase the consistency of the review. Although, this may have excluded practical local deployments that were not published in journal papers or IEEE/IET conference presentations. Since they are diverse in methodology, statistical meta-analysis of and direct comparison between performance indicators from reviews, prototypes, experiments, and simulations of IoT systems and blockchain frameworks was not possible. Lastly, although 31 studies were eligible for inclusion, only 20 representative studies were included for the detailed evidence mapping and the included studies did not necessarily make equal contributions to the comparative synthesis due to quality and relevance for inclusion and to thematic coverage.

Technical Implications for Further Designs

Future multi-user meters must carry out the electronic/static accuracy principles and include the level of accuracy based on it in user level accounting and request experimental verification with IEC 62053-21:2020a under various load allocation (IEC, 2020a). Architectures need the well-defined and unambiguous transfer of a balance representing a group of collectively purchased units to a balance that can be tracked independently, and it needs to give realtime individual feedback (Ayamba *et al.*, 2025). If another user has run out of units, then only the user should be auto unplugged. Designs specifically should be lowcost, easy to maintain, standalone, low dependence on internet, individual current sensing, local interfaces, and relay-controlled supplies, instead of depending on AMI, cloud or Blockchain platforms.

CONCLUSION

There were 31 peer-reviewed papers that were distilled for this review on electronic/static metering, AMI, IoT, GSM/prepaid, multi-user and Blockchain metering. While there are advances in measurement, remote metering, prepaid, communication and user identification and automated control, there are still no advances towards a shared single-phase metering, which is required for an equitable allocation of the multi-users. A one-account system is still used in most systems. No identified study simultaneously provides equitable allocation of collectively purchased units, realtime per-user feedback, independent disconnection, and IEC 62053-21:2020 validation. Akasoro *et al.* (2023) demonstrate multi-user prepaid feasibility without fully meeting these requirements. The principal challenge is the integration of accuracy, equity, transparency and independent control into an affordable architecture for resource-constrained residential environments. Further research needs to focus on developing fair unit-allocation algorithms, independent user disconnection, and accuracy validation under various load conditions based on IEC 62053-21:2020. They should be lowcost, standalone, have minimal dependency on the Internet or Cloud and provide per-user consumption and balance information in real time. Future tasks shall be long-term field testing and how to reduce to scale for both equal and simultaneous loading, recharge events, credit exhaustion/power outages, affordability of batteries, transparency of use of tariff, user trust and regulations; to develop them in a practical and equitable way in the shared residential environments.

REFERENCES

Adebisi, O. I., Adejumobi, I. A., Matthew, S., & Abdulsalam, A. A. (2022). Development of a web-based single-phase load monitoring and auditing system. International Journal of Electrical and Computer Engineering, 12(6): 6785–6795. http://doi.org/10.11591/ijece.v12i6.pp6785-6795

Akasoro, O. I., Ige-Adeyeye, A. A., Coker, J. O., Ogunji, A. B., Atilade, A. O. & Salaam, M. A. (2023). Design and construction of a multi-user prepaid meter. Nigerian Journal of Theoretical and Environmental Physics, 1(1): 51–59. https://doi.org/10.62292/njtep.v1i1.2023.10

Amhenrior, H. E., Oloma, I. & Ikharo, B. A. (2022). Design and implementation of a GSM and Wi-Fi based low cost smart prepaid energy meter. In: Proceedings of the 2022 5th Information Technology for Education and Development Conference (ITED), Abuja, Nigeria. https://doi.org/10.1109/ITED56637.2022.10051577

Arshi, O., Rai, A., Gupta, G., Pandey, J. K. & Mondal, S. (2024). IoT in energy: A comprehensive review of technologies, applications, and future directions. Peer-to-Peer Networking and Applications, 17(5): 2830–2869. https://doi.org/10.1007/s12083-024-01725-8

Ayamba, K., Ofori-Boateng, C. & Mensah, P. (2025). Exploring community acceptance of electricity smart metering in urban slums in Ghana. Advances in Engineering Research, 286: 112–124. https://doi.org/10.2991/978-94-6463-970-4_27

Cetina, Q., Roscoe, R. A. J. & Wright, P. S. (2017). Challenges for smart electricity meters due to dynamic power quality conditions of the grid: A review. In: Proceedings of the 2017 IEEE International Workshop on Applied Measurements for Power Systems (AMPS), Liverpool, UK. https://doi.org/10.1109/AMPS.2017.8078345

Clean Air Task Force (CATF) (2025). Reimagining utility reform in a post-aid Africa: Key insights from the 2025 Utility Roundtable. Clean Air Task Force. Available at: https://www.catf.us/resource/reimagining-utility-reform-post-aid-africa [Accessed 20 January 2026].

ERCOT (Electric Reliability Council of Texas) (2023). Smart metering data collection and reporting standards. ERCOT Technical Report. Available at: https://www.ercot.com/services/comm/metering [Accessed 15 January 2026].

Erkin, Z., Troncoso-Pastoriza, J. R., Lagendijk, R. L. & Pérez-González, F. (2013). Privacy-preserving data aggregation in smart metering systems: An overview. IEEE Signal Processing Magazine, 30(2): 75-86. https://doi.org/10.1109/MSP.2012.2228343

Garcia, F. D., Marafão, F. P., de Souza, W. A. & da Silva, L. C. P. (2017). Power metering: History and future trends. In: Proceedings of the 2017 Ninth Annual IEEE Green Technologies Conference (GreenTech), Denver, CO, USA. https://doi.org/10.1109/GreenTech.2017.10

Gungor, V. C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C. & Hancke, G. P. (2011). Smart grid technologies: Communication technologies and standards. IEEE Transactions on Industrial Informatics, 7(4): 529–539. https://doi.org/10.1109/TII.2011.2166794

Hong, Q. N., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., Gagnon, M. P., Griffiths, F., Nicolau, B., O'Cathain, A., Rousseau, M. C., Vedel, I. & Pluye, P. (2018). The Mixed Methods Appraisal Tool (MMAT) version 2018 for information professionals and researchers. Education for Information, 34(4): 285-291.

IEA (International Energy Agency) (2022). Access to electricity - SDG7: Data and projections. IEA, Paris. Available at: https://www.iea.org/reports/sdg7-data-and-projections [Accessed 5 October 2025].

IEA (International Energy Agency) (2025). Financing electricity access in Africa. IEA, Paris. Available at: https://www.iea.org/reports/financing-electricity-access-in-africa [Accessed 20 January 2026].

IEC (International Electrotechnical Commission) (2020a). IEC 62053-21:2020 - Electricity metering equipment: Particular requirements - Part 21: Static meters for AC active energy (classes 0.5, 1 and 2). IEC, Geneva. https://webstore.iec.ch/en/publication/28660

IEC (International Electrotechnical Commission) (2020b). IEC 62053-22:2020 - Electricity metering equipment: Particular requirements - Part 22: Static meters for AC active energy (classes 0.1 S, 0.2 S and 0.5 S). IEC, Geneva. https://cdn.standards.iteh.ai/samples/23378/14fc66c7d8fe4ee5b5a4cb124b536113/IEC-62053-22-2020.pdf

Jawaduddin, A., Airij, A. G. & Poopalan, P. (2020). Automatic energy monitoring system. In: AIP Conference Proceedings, 2203: 020023. https://doi.org/10.1063/1.5142093

Kavitha, K. (2026, in press). Smart energy management: Realtime monitoring with billing estimation and theft prevention. In: Advances in Electrical and Computer Technologies. CRC Press, Boca Raton, FL, pp. 631–637.

Koukouvinos, K. G., Koukouvinos, G. K., Chalkiadakis, P., Kaminaris, S. D., Orfanos, V. A. & Rimpas, D. (2025). Evaluating the performance of smart meters: Insights into energy management, dynamic pricing and consumer behaviour. Applied Sciences, 15(2): 960. https://doi.org/10.3390/app15020960

Kumar, L. A., Indragandhi, V., Selvamathi, R., Vijayakumar, V., Ravi, L. & Subramaniyaswamy, V. (2021). Design, power quality analysis, and implementation of smart energy meter using Internet of Things. Computers and Electrical Engineering, 93: 107203. https://doi.org/10.1016/j.compeleceng.2021.107203

Masnicki, R. (2018). Some remarks on the accuracy of energy meters. In: Proceedings of the 2018 IEEE EEEIC / I&CPS Europe Conference, Palermo, Italy. https://doi.org/10.1109/EEEIC.2018.8494454

Mazhar, T., Shahzad, T., Rehman, A. U., & Hamam, H. (2025). Integration of smart grid with industry 5.0: applications, challenges and solutions. *Measurement: Energy*, *5*, 100031. https://doi.org/10.1016/j.meaene.2024.100031

Mehta, G., Khanam, R. & Yadav, V. K. (2021). A novel IoT based smart energy meter for residential energy management in smart grid infrastructure. In: Proceedings of the 2021 8th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India. https://doi.org/10.1109/SPIN52536.2021.9566032

Munro, P. & Schiffer, A. (2019). Ethnographies of electricity scarcity: Mobile phone charging spaces and the politics of access in urban Africa. Energy and Buildings, 188–189: 106–116. https://doi.org/10.1016/j.enbuild.2019.01.038

Nairametrics (2024). Nigeria's metering gap widens as estimated billing customers rise by 10%. Nairametrics, 24 June 2024. Available at: https://nairametrics.com [Accessed 10 October 2025].

Nazir, I., Mushtaq, N., Ishfaq, H., Amin, W., Maaliw, R. R., Shi, X. & Saleem, M. A. (2025). Blockchain-enabled reserved pricing and privacy-preserving model for peer-to-peer energy trading in smart grid. IEEE Transactions on Consumer Electronics, 71(1): 450–462. https://doi.org/10.1109/TCE.2025.3596907

NERC (Nigerian Electricity Regulatory Commission) (2024a). Q3 2024 Quarterly Report. NERC, Abuja. Available at: https://nerc.gov.ng [Accessed 1 November 2025].

NERC (Nigerian Electricity Regulatory Commission) (2024b). Q1 2024 Quarterly Report. NERC, Abuja. Available at: https://nerc.gov.ng [Accessed 1 November 2025].

Olugbemi, O., Afolayan, O. A. ., Opeyemi, A. A., Taiwo, A., Adebayo, P., Lawrence, O., & David, I. (2026). A systematic literature review of lightweight iot and ml-based approaches for monitoring dietary compliance and user engagement. *FUDMA Journal of Sciences*, *10*(6), 263-273. https://doi.org/10.33003/fjs-2026-1006-4865

Omijeh, B. & Ighalo, G. (2013). Modeling of GSM-based energy recharge scheme for prepaid meter. IOSR Journal of Electrical and Electronics Engineering, 4(1): 46–53.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D. & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372: n71. https://doi.org/10.1136/bmj.n71

Peter, G. & Iderus, S. B. (2021). Design of enhanced energy meter using GSM prepaid system and protective relays. Materials Today: Proceedings, 39: 582–589. https://doi.org/10.1016/j.matpr.2020.08.471

Putra, N. P. (2025). IoT-Based kWh Monitoring Prototype Using PZEM-004T Sensor and NodeMCU ESP8266 Microcontroller: A Comprehensive Experimental Evaluation. *Journal of Emerging Innovations in Engineering*, *1*(02), 76-92. https://doi.org/10.65664/jeie.v1i02.11

Rajaguru, S., & Johansson, B. (2024). Exploring the Meaning of Smartness of Smart Meter Technology Within Smart Grids. *ICIS 2024 Proceedings*. 8. https://aisel.aisnet.org/icis2024/iot_smartcity/iot_smartcity/8

Rao, S. P. C., Ramakrishna, M., Sairam, V. & Narsimulu, B. (2025). GSM based prepaid energy meter. In: Proceedings of the 2025 7th International Conference on Inventive Material Science and Applications (ICIMA), Coimbatore, India. https://doi.org/10.1109/ICIMA64861.2025.11074146

Rashid, F., Rasheed, S., Farooq, A., Ali, M., Ruben, Y., Jehanzeb, M., & Wahab, A. (2022). Design and implementation of prepaid power billing system in smart grid environment. *International Journal of Electrical and Computer Engineering*, *12*(4), 3365-3374. http://ijece.iaescore.com/

Reddy, P. R., Kammanaboina, R., Prasad, D., Kapula, P. R. & Panigrahy, A. K. (2021). Implementation of smart energy meter through prepaid transaction using IoT. In: Proceedings of the 2021 Recent Trends in Electronics and Communication Systems (RTEICT) Conference, Bengaluru, India. https://doi.org/10.1109/RTEICT52294.2021.9574015

Rind, Y. M., Raza, M. H., Zubair, M., Mehmood, M. Q., & Massoud, Y. (2023). Smart energy meters for smart grids, an internet of things perspective. *Energies*, *16*(4), 1974. https://doi.org/10.3390/en16041974

Sawarkar, B. D. & Golait, S. S. (2015). A review paper on automatic meter reading and instant billing. International Journal of Advanced Research in Computer and Communication Engineering, 4(1): 340–344. https://doi.org/10.17148/IJARCCE.2015.4146

Taştan, M. (2019). Internet of things based smart energy management for smart home. KSII Transactions on Internet and Information Systems, 13(6): 2781–2798. http://doi.org/10.3837/tiis.2019.06.001

Urekar, M., Pejic, D., Vujicic, V. & Avramov-Zamurovic, S. (2017). Accuracy improvement of the stochastic digital electrical energy meter. Measurement, 98: 139–150. https://doi.org/10.1016/j.measurement.2016.11.038

Uribe-Pérez, N., Hernández, L., De la Vega, D. & Angulo, I. (2016). State of the art and trends review of smart metering in electricity grids. Applied Sciences, 6(3): 68. https://doi.org/10.3390/app6030068

Veerasamy, V., Hu, Z., Qiu, H., Murshid, S., Gooi, H. B. & Nguyen, H. D. (2024). Blockchain-enabled peer-to-peer energy trading and resilient control of microgrids. Applied Energy, 353: 122107. https://doi.org/10.1016/j.apenergy.2023.122107

World Bank (2024). Access to electricity in Sub-Saharan Africa: Progress and challenges. World Bank Group, Washington, DC. Available at: https://www.worldbank.org/en/topic/energy [Accessed 20 January 2026].

World Economic Forum (2025). Africa's energy trilemma: Security, equity, sustainability. World Economic Forum, Geneva. Available at: https://www.weforum.org/reports/africas-energy-trilemma [Accessed 20 January 2026].