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Energy efficiency and automation of electricity payment with the use of smart meters

Abstract:

This work focuses mainly on smart meters used today in distribution, supervision of power lines and in the management of electricity billing. His study setting is Togo where prepaid meters have been introduced by the Togo Electric Power Company (CEET) to replace traditional postpaid or mechanical meters. While the use of these prepaid meters solves the company's billing problems, it also poses challenges for users.
This study was conducted through a survey and research on the current state of smart electricity meters to propose a suitable solution that would satisfy both users and electricity distributors.
1 The solution proposed in this document after analyzing the results of the surveys is the use of smart meters in the supply of electricity to end users. This use solves the problems of controlling power lines, managing subscribers considering the needs of remote control of consumed or available energy, and future developments with the injection of current into the supplier's power grid. The results of our work contribute to meeting energy efficiency needs, which are now essential to the development of electricity consumption and management in all countries around the world. We offer a solution combining smart meters and IT applications for access to automatic online payment methods and management of purchased electricity.

Keywords: Electrical energy, smart meters, remote energy control, energy efficiency

1. Introduction

The use of electricity via the interurban power grid is a concern for all residents of cities and territories served. This use requires connection to the electricity grid of an electricity supplier, which installs an electricity meter to bill its subscribers. In Togo, the electricity supplier is the Togolese Electricity Company (CEET), which previously installed postpaid meters for its subscribers; in recent years, it has introduced prepaid meters [1], [2] to gradually replace traditional meters.
The use of these meters, while solving the CEET billing problem, poses other challenges for subscribers who complain not only of not understanding the billing costs but also of not receiving alert messages or notifications before the interruption of the electricity supply service, and of not being able to credit these meters remotely and automatically with the purchased energy consumption credits.

The work carried out in this study constitutes an approach to address the concerns of users of these types of prepaid meters and a general solution for countries facing similar realities. The solution we propose comes from the results of surveys conducted among users of these types of prepaid meters, which resulted in proposals for smart meters, whose applications will be implemented according to the approach presented in the following sessions. This is an essential solution for energy efficiency and control of activities related to the supply and management of electricity in the context of current technological developments; [3], [4].

2. Background and Objectives

This work is a case study in Togo aimed at illustrating the use of smart meters in electricity supply and subscriber management, considering their needs and requirements. Togo's electricity needs are estimated at 1,982.70 GWh in 2023 and 2,422.71 GWh in 2028, according to the ARSE (Togo Electricity Regulatory Authority) report [5]. Indeed, in Togo, the Togolese Electricity Company (CEET) is the traditional electricity supplier. This company has always used traditional mechanical meters in post-payment mode. Since October 2019, prepayment meters have been introduced on the Togolese electricity market, the first being called LAFIA. These prepayment meters were introduced by CEET for several reasons:

- prepayment of customer bills, thus facilitating the efficient recovery of electricity consumption costs,
- deployment of a reduced number of technicians on-site (meter readers) to read consumption from traditional meters, sometimes with difficulty accessing the concessions in the absence of occupants (closed doors),
- prevention of unpaid consumption bills of two (2) to three (3) regulatory months, or even more, for certain customers.

As can benoticed, the introduction of these meters solves CEET's profitability and billing problems. However, after a few years of use, complaints from subscribers regarding billing costs and service interruptions without prior information or without prior alert messages or notification are not long in coming (https://www.arse.tg/). These subscribers also cannot credit these meters remotely and automatically with the electricity consumption credits purchased.

Indeed, thanks to these prepaid meters, the CEET customer who has subscribed to an electricity consumption subscription can credit this meter according to his needs. A 20-digit code (reload token) is provided after payment by digital money (Flooz, Tmoney, Xcash) or bycash at CEET agency or in banks affiliated with CEET. The reload token must be entered on the meter to have a certain amount of electrical energy, according to the tariffs paid. The cost per kilowatt depends on the initial subscription power and the number of wires (two wires for single-phase or four wires for three-phase). Each customer is clearly identified by a specific geographical reference and has an electricity account with the CEET, which can be credited at will. When the subscribed electricity consumption reaches a given threshold, the meter emits a small signaling beep. This barely audible sound is only perceptible within 5 meters of the meter and often goes unnoticed.

Most CEET subscribers have their meters located away from living quarters, or even in another compound if it is not located on a housing estate on the edge of the street. It is therefore not surprising that CEET subscribers are often surprised by power outages due to the end of electricity credit subscribed. This can be both unpleasant and detrimental for them. Furthermore, if you are absent, even after payment, you do not have the option to credit your meter. Some even must disturb their neighbors to enter these codes when the meter is in another compound.

The cases of observation and inconvenience encountered among users of these meters are set out in the following lines:

Case 1: A barman, in the middle of a party with his customers, is surprised by a power outage. The atmosphere is disrupted, and the bartender, somewhat embarrassed by the situation, rushes to credit his meter. Unfortunately for him, at that precise moment, a network problem occurs. The kilowatt-hours are finally purchased, but the atmosphere is cut short.

Case 2: A shopkeeper, surprised by the power outage, knocks on her landlord's door to enter the purchase code for the kilowatt she just purchased to her account. She rings in vain and ends up getting irritated when she notices his absence. For added security, her meter had been installed in the landlord's house, adjoining the rented shop. The landlord's absence was very inconvenient for the tenant, who became irritated and worried about her frozen products.

Similar cases are common among prepaid meter users, and these examples could be multiplied. These two cases illustrate the inconvenience frequently encountered by CEET prepaid meter users.

Therefore, our research motivations are based on the following assumptions:

- How can we collect feedback from prepaid meter users to quantify the problems they encounter and proposesolutions to stakeholders?
- How can we enable users to view their energy consumption levels from their mobile devices and credit their metersremotely?
- Can current prepaid meters support this?

To find answers, our research involved:

- a survey of prepaid meter users and an assessment of real-life situations to define the scope of the problem.
- an overview of smart meter research and its usefulness in today's world, and to propose guidelines for better selection of metersto be used in electricity supply management and subscriber billing.
- a study on the practical uses of smart meters in selected countries.
- a synthesis of the survey results, the state of smart meter research, and current practices in selected countries, to propose our solution.

3. Literature review

The use of electricity meters addresses the need to bill electricity consumed by customers of electricity companies. This need is almost identical throughout the world for the use of electricity, essential to the development of economies. The means of billing electricity supplied by producers to subscribers have evolved over time and space. After traditional meters, most countries are now adopting prepaid meters and, even better, smart meters offering numerous features and benefits.
A smart meter is an electronic device that measures the electrical energy consumption of a home or building, while enabling two-way communication with the energy supplier. (https://en.wikipedia.org/wiki/Smart_meter), [1], [2], [6]. Unlike traditional meters that require manual data reading and recording, smart meters automatically transmit energy consumption information to the supplier in real time via communication networks. In the event of suspected tampering (attempt to open the casing), the device also sends an alert to the grid manager.

The main features of these smart meters are:

1. **Two-way communication**: The smart meter sends consumption data to the supplier and can also receive information (such as rate updates or consumption reduction requests).
2. **Automatic and remote reading**: Utility companiescan read energy consumption without having to send a technician on-site. This allows for more accurate billing, avoids manual reading errors, and avoids bills based on estimates.
3. **Real-time monitoring**: Consumers can track their energy consumption in near real-time using dedicated applications or interfaces. This allows them to identify consumption patterns and take steps to save energy or better manage their consumption and reduce their electricity costs (energy efficiency).
4. **Demand-side management**: Smart meters enable the implementation of demand-side management programs, where suppliers adjust rates or consumption based on network needs, for example, during peak periods.
5. **Dynamic tariff support**: They facilitate the application of flexible rates based on time of day or demand, allowing consumers to benefit from reduced rates during off-peak hours. They thus provide suppliers with accurate information to balance supply and demand.
6. **Outage detection and network quality monitoring**: Smart meters can report outages or anomalies, helping suppliers respond more quickly to restore service.

In summary, smart meters play a vital role in modernizing electricity grids, facilitating the transition to more flexible and sustainable energy systems. The little challenges noted in their use concern:

- privacy concerns (some users fear that the data collected by the meters will be used to monitor their consumption habits),
- the initial installation cost, even though it can generate long-term savings.

In recent years, research on smart meters has been diverse and varied, primarily focused on improving technical and technological performance. These include:

The work of Tobias and Natalia [4], which provides an in-depth analysis of smart meter technologies and their role in efficient energy management within homes and organizations.The authors examine various smart meter technologies, including their communication, measurement, and control capabilities. The study examines how these technologies can be used to optimize energy consumption, reduce energy costs, and improve environmental sustainability. Their research also addresses challenges related to smart meter adoption, such as data security, consumer acceptance, and integration with existing energy management systems. The results of the analysis show that smart meters offer significant benefits for energy management but require carefully planned implementation to maximize their effectiveness and minimize associated risks.

Yasin and al. [7], on the other hand, present a new method for controlling distributed energy resources (DERs) in distribution networks using smart meter data. The authors developed an algorithm that leverages real-time data from smart meters to optimize the management of DERs, such as solar panels, wind turbines, and energy storage systems. This method allows for the coordination of DERs in a way that improves grid stability, reduces energy losses, and maximizes the integration of renewable energy. The study shows that the use of smart meter data can facilitate more efficient and responsive management of distribution grid, especially in scenarios with high DER penetration.

Ding Han et al. [8] explore techniques for forecasting the next day's aggregate load using household smart meter data. The authors propose a model incorporating these data to predict short-term electricity demand at the aggregate level. The method considers seasonal variations, specific household behaviors, and other factors influencing energy consumption. The results show that the proposed method improves forecast accuracy compared to traditional models. In their work, they also highlight the importance of smart meters in providing detailed and real-time data, essential for efficient energy demand management and resource planning of electricity grids. This is information that can be easily collected and analyzed through the introduction of artificial intelligence [9].

Victor von Loessl [10] examines in his work the concerns related to the privacy of smart meter data in the context of dynamic electricity tariffs, through a stated choice experiment. He conducted a survey among consumers to understand how data privacy concerns influence their acceptance of dynamic tariffs, which adjust electricity prices according to real-time demand. The study reveals that consumers are concerned about the use of their personal data collected via smart meters, and that these concerns may reduce their willingness to adopt dynamic tariffs. The findings suggest that increased transparency and better data protection are essential to promote the adoption of these rates. The author recommends strategies to allay consumer concerns, including stricter privacy policies and clear communication about the benefits of dynamic rates.

Dawei Qiu et al. [11] studied the design of personalized retail tariffs for consumers using smart meters in the electricity market. The authors develop a framework to create personalized electricity tariffs based on individual consumption habits collected via smart meters. This model allows electricity providers to optimize tariffs to better meet specific consumer needs, while encouraging more efficient consumption behaviors. The study shows that personalized pricing can generate significant energy savings and improve customer satisfaction. The authors also discuss the economic implications and technical challenges of implementing these pricing strategies in a dynamic electricity market. They emphasize the importance of analyzing smart meter data to maximize the benefits of personalized tariffs for both consumers and suppliers.

Yu Qian Ang et al.,[12] proposed a new approach to modeling the energy consumption of urban buildings by considering the socio-economic characteristics of residents, based on smart meter data. The authors develop building archetypes that integrate data on residents' energy consumption habits, collected via smart meters, and link them to socio-economic factors such as income, age, and household composition. This method allows for the creation of more accurate urban energy models that are more sensitive to socioeconomic variations, a crucial element for designing equitable and efficient energy policies. The study shows that archetypes based on smart meter data are better at predicting energy consumption in different urban neighborhoods than traditional models. The results highlight the importance of integrating socioeconomic variables into energy models to improve urban planning and energy management.

It emerges from this synthetic bibliographic study that smart electricity meters constitute the solutions of the future and an essential use for the solutions they offer to electricity suppliers in the management of available electrical energy and energy efficiency, both for the control of distribution grid and for that of users. This is why the various research works of recent years are strongly oriented towards these solutions and will be doubled by the integration of artificial intelligence in the control of these smart electricity meters and the data collected from these meters, [13], [14], [15], [16].

3.1.Examples of prepaid meters in some countries

Most countries have understood the importance of these meters and have begun to use them for the management of electrical energy and users. This is the case in developed countries and some developing countries in which the traditional meters are replaced by smart meters.

- In England, customers with prepaid electricity meters are equipped with a smart card reader or key that they credit their balance in local shops or via smartphone apps (https://www.chooseenergy.com/providers/first-choice-power/). These cards are used on the home meter to add electricity credit.

- In Texas, we're talking about smart meters. These meters transmit energy consumption data directly to the electricity supplier via radio waves. There's no need to read meters. They also allow customers to easily make electricity prepayments. You can credit your account without leaving your couch thanks to the benefits of a smart meter. This system was developed in Texas so that instead of receiving a monthly bill, alerts are received on your mobile device and/or by email indicating the amount of electricity consumed and the remaining balance on the meter. First Choice Power is the name of the company that manages this system in Texas (https://www.choosetexaspower.org/electricity-providers/first-choice-power/).

- In France, EDF is the historic electricity supplier. The system implemented by EDF is based on two-way communication between its metering system and a single information system via concentrators installed in transformer stations. These meters, also called smart meters, communicate with the information systems of network managers to enable the data recorded by the meter to be uploaded (https://www.energie-info.fr/fiche_pratique/les-compteurs-communicants-linky-et-gazpar/). They also allow many remote operations, such as increasing power, commissioning or termination in the event of a move, as well as more efficient network management. This is called a LINKY meter. This meter allows users to track their consumption, understand their expenses, and minimize the risk of outages thanks to applications developed by electricity suppliers.

- In China, smart meters are equipped with a prepayment system for electricity. Customers can purchase electricity online and check their available electricity level at any time. After payment, the meter automatically recharges after one or two minutes.

- In Senegal, we call it a Woyofal meter. It's a communicating meter. It operates in prepayment mode. Electricity is purchased via the mobile network or a web application. Customers can purchase credit from Senelec agencies, Woyofal stores, or available collection partners. The meter data is encrypted and then transmitted via a secure private network to Senelec servers, and vice versa. After purchasing, customers receive a recharge code with which they credit their meter.The box connected to the meter issues alerts in the event of a power shortage and cuts off the power as soon as it runs out. Real-time consumption monitoring via the customer application is possible and allows the customer to implement their own energy efficiency policy. To find out the remaining credit, simply enter the code 801 (http://www.senelec.sn/wpcontent/uploads/2020/10/woyofal2.jpg) on the meter keypad. Other codes are available to the customer for other needs or information.

- In Kenya, we have a KPLC smart meter. The customer purchases electricity tokens and credit units for their meter by entering a code on the meter's customer interface (https://kplc.co.ke/content/item/30/Paying-your-Electricity-Bill). As the customer consumes electricity, their credit balance decreases daily until the units are used up, prompting them to credit. There is no messaging system for alerts.

This inventory demonstrates that all countries today need greater automation of energy management and user billing processes, hence the need for these smart meters, which offer numerous advantages. These meters control the entire sector, from generation to consumers, including the control of electricity transmission lines. The applied research that leads to the finished products of smart meters introduces technologies adapted to the needs of users and electricity suppliers. In the rest of this study, we will present our approach aimed at proposing the essential technologies or elements of the electricity meters of the future to meet the needs of users in countries that do not yet have suitable solutions.

4. Methodological approach

For our research, surveys were conducted among CEET prepaid meter users to gather their feelings and needs. The uncomfortable experiences of prepaid meter users were also recorded. The surveys were conducted anonymously. Analysis of the results allowed us to propose solutions to users and electricity suppliers offering electric meters.
The surveys were conducted among 3,000 low-voltage electricity users using Google Forms questionnaires. The responses collected from a sample of 2,800 users spread across Togo were analyzed and interpreted. The number of low- and medium-voltage subscribers using low-voltage electricity was 523,266 in December 2023, according to the ARSE 2023 report[5].

4.1. CEET Prepaid Meter User Survey

This survey was conducted using a questionnaire to collect quantitative and qualitative information from prepaid meter users. Observations and informal discussions were also conducted with some prepaid meter users. The questionnaires are presented in Table 1.

Table 1: Questionnaires for prepaid meter users

N°	The types of questionnaires formulated
Q1	Do you have a prepaid meter (Cash power)? a- Yes, b- No
Q2	Have you noticed that your prepaid (cash power) beeps when your electricity consumption is low? Yes, b- No, c- I don't have a cash power
Q3	Are you often surprised by a sudden power outage at inopportune times without warning? a- Yes, b- No
Q4	How do you often pay for your kilowatt hours or electricity? Or how do you reload your cash power? a-Flooz, b- Tmoney, c-Xcash, d- CEET Agency, e- Others

Q5	Do you know the exact number of household appliances you have at home? For example, household appliances (lamps, refrigerators, fans, televisions, etc.) a- Yes, b- No
Q6	Do you have any idea of the power consumption of these devices? a- Yes, b- No
Q7	Did you know that each device has its own power consumption indicated? a- Yes, b- No
Q8	Would you like to have a tool or application that allows you to track your electricity consumption? a- Yes, b- No
Q9	Would you like to receive alerts or messages on your smartphone, warning you about your electricity consumption levels so that you are no longer surprised by power cuts /outage? a-Yes, b- No
Q10	In which region of Togo are you live? a- Maritime, b- plateau, c- Central, d- Kara, e- Savane, f- Dapaong,g-Other, h- I don't know

4.2.Survey results and interpretations

The surveys carried out are presented in the following figures:

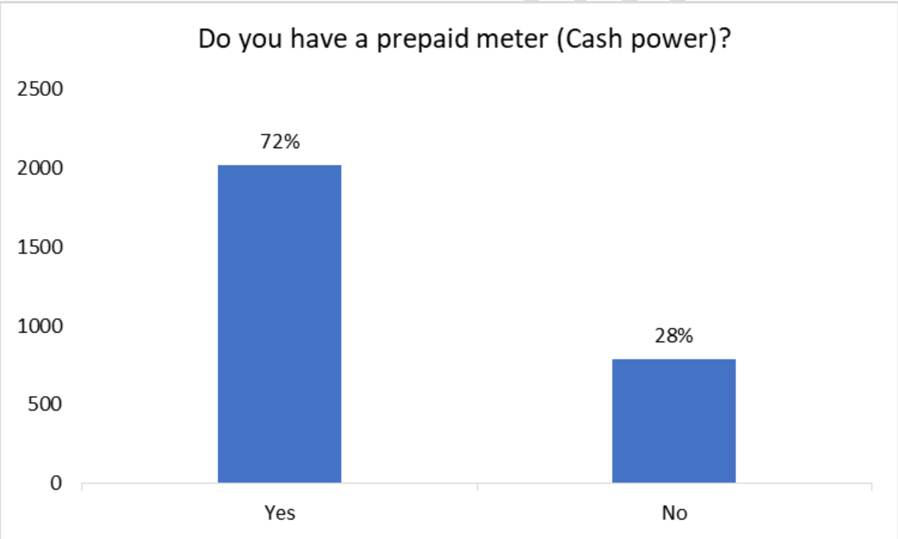

Figure 1: High number of respondents with cash power

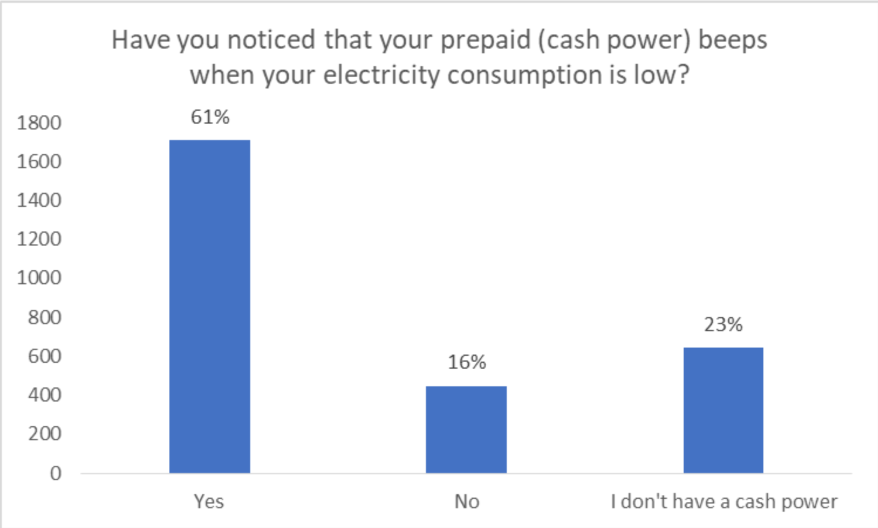

Figure 2:Responses from subscribers aware of the imminent end of Kilowatt noise

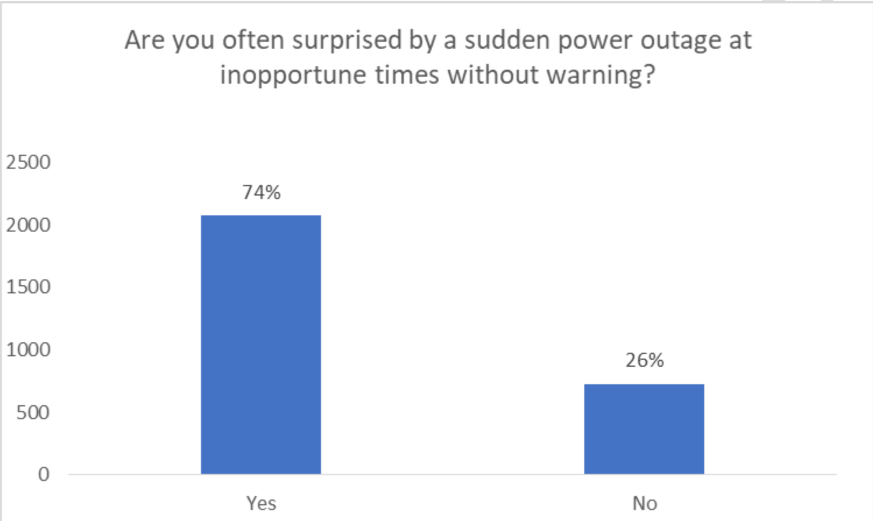

Figure 3:Many users surprised by the abrupt end of kilowatt purchases

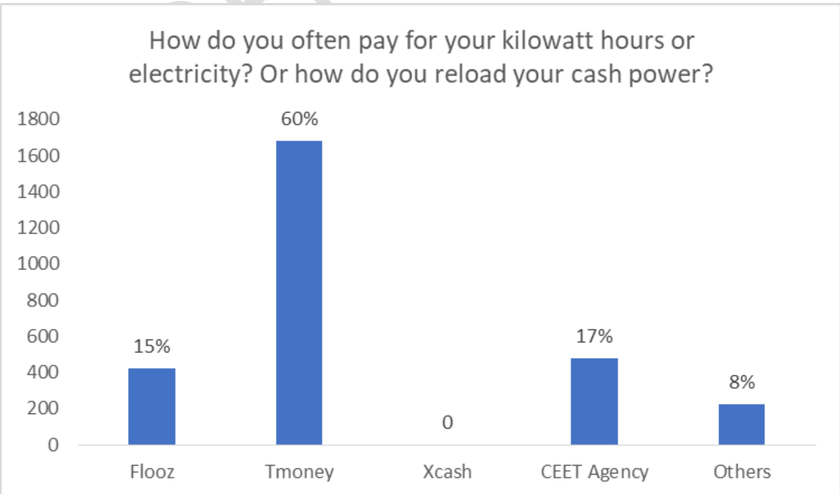

Figure 4:Payment methods for CEET cash power subscribers

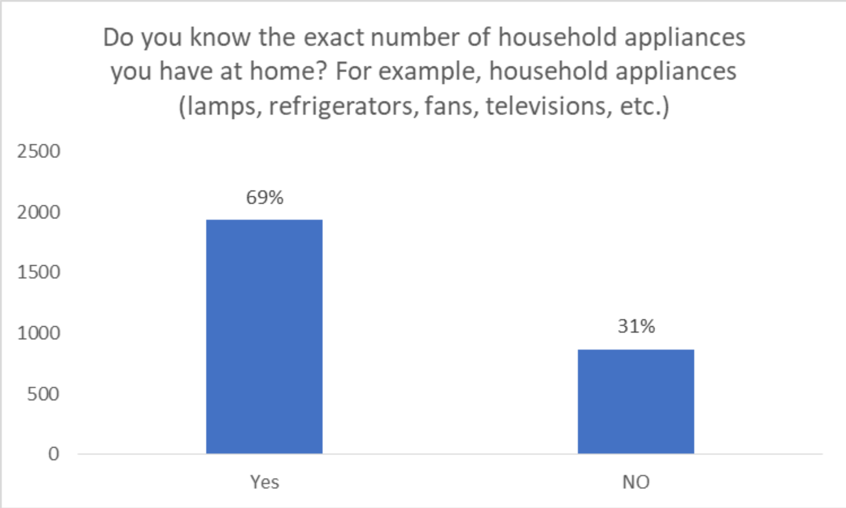

Figure5:Responses from subscribers aware of the energy-consuming equipment used

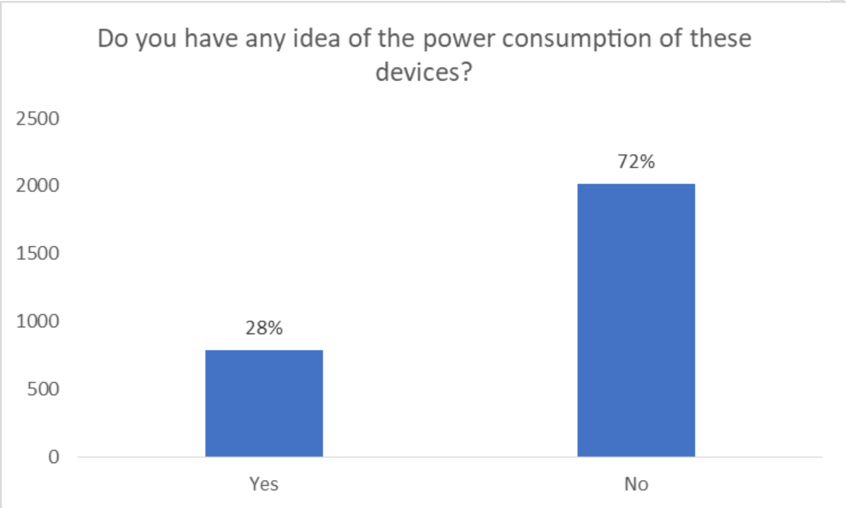

Figure 6:Responses from subscribers who are aware of the energy consumed by the equipment

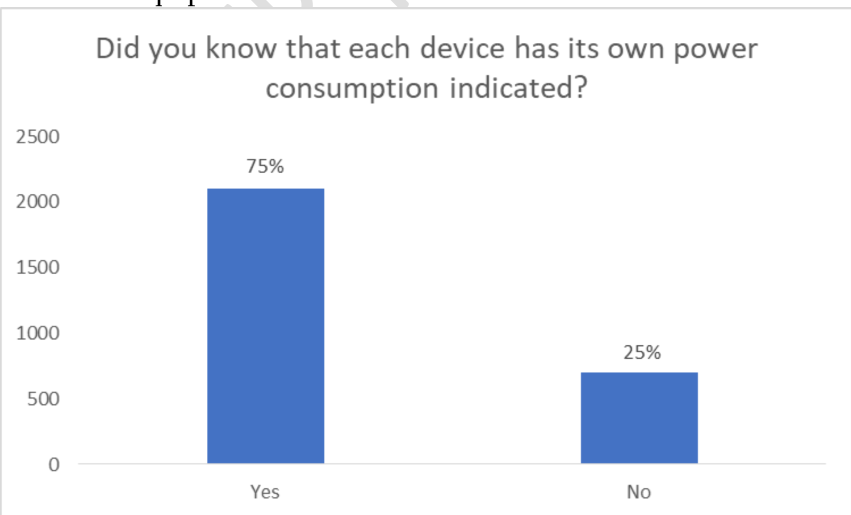

Figure 7:Responses from subscribers who can identify the power consumed by electrical equipment

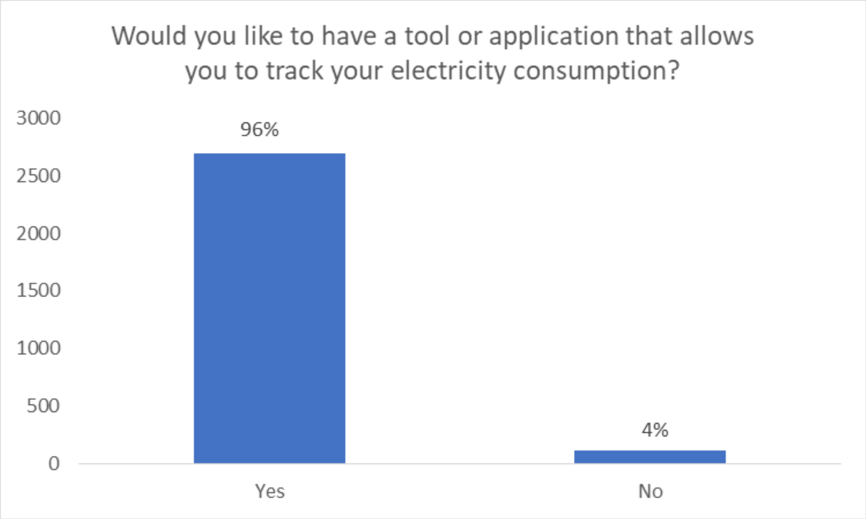

Figure8:Responses from subscribers who want to have an application for trackingelectricityconsumption

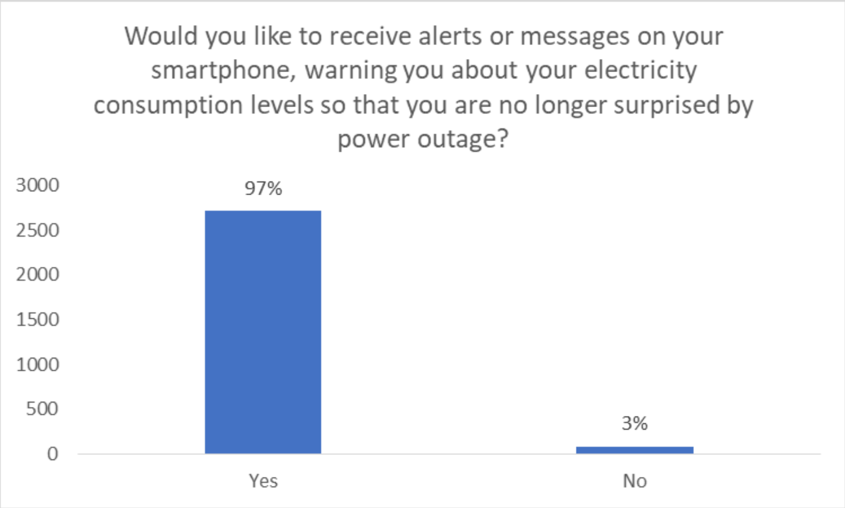

Figure9:Number of subscribers wishing to be informed of a kilowatt threshold before shutdown by message.

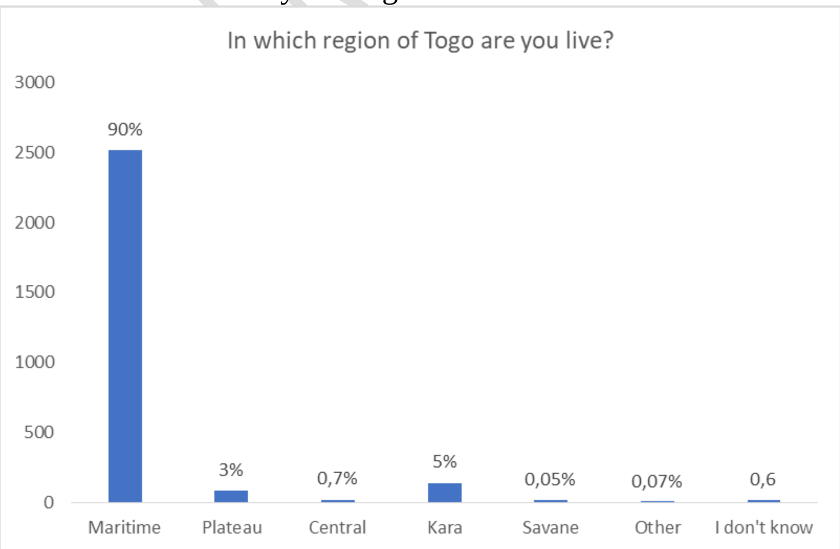

Figure10:Geographic location of respondents

5. Analysis and discussion of results

The results of the surveys carried out are gathered in Table 2 with the resulting analyses which seem to note the need to search for an automated solution based on digital technology and in particular ICT.

Table 2 : Survey results and interpretations

Questionnaires	**Answers (%)**	**Comments**
Prepaid meter users	72	Most respondents use prepaid meters
Users who heard a signal that the meter was about to stop	61	More than half of users hear the beeps of the meters without understanding that a stop is coming.
Users are often surprised by CEET power outages without warning	74	Most users are surprised by the shutdown without further warning.
Means used to purchase kilowatt credit to consume	15 (Flooz) 60 (Tmoney) 17 (Agency)	Most users 75% use digital currency payment (via smartphones)
Number of users with an idea of the energy-consuming equipment installed in their homes	69	Most respondents know that they use equipment that consumes electrical energy.
Many users have no idea how powerful household appliances available at home are.	72	Most respondents do not know how much energy their household appliances consume
Number of users who pay attention to the nominal power of their household appliances	75	Most respondents can find the rated power of household appliances
Number of subscribers wanted to have a tool or application that allows them to track their electricity consumption	96	Almost all surveys want to have an application for tracking electricity consumption
Number of subscribers wishing to be alerted to the level of energy available on their cash power	97	Almost all surveys want to be alerted to the imminent power outage with objectives of reduction and/or anticipation if possible
The region of users who participated in the survey	94,2	Respondents are located almost exclusively in the maritime region of Togo (large cities)

6. Solutions and contributions

The results of the analyses presented in Table 2 show that CEET prepaid meter users need a more automated solution that allows them to monitor their energy consumption and credit their account in kilowatt-hours according to their needs. This solution involves the use of smart electricity meters, like those already well-known, used in some countries and proposed by the researchers. These smart meters will also allow electricity suppliers to gain efficiency in the service offered to users, by allowing remote interventions on the electricity network in record time. They will also save on troubleshooting costs and personnel working at users' premises.

The results of our work apply to countries facing similar challenges to Togo, both for the electricity supplier and for users. This solution will not only improve the efficient management of power transmission lines, but also the services offered to customers today and in the future, such as the injection of current produced by other energy sources into the traditional electricity grid.

6.1.Smart meter solution

The need for automation of electricity prepayment is a reality, according to the surveys conducted. The type of meter introduced into the electricity distribution network in Togo and in certain other countries does not effectively provide total end-to-end control of the distribution chain and the electricity prepayment service offered to customers. It will be necessary to move towards a more automated solution, the proposed principle of which is described in **Figure 10**.

This solution involves using applications that interface with customer account databases and access smart electricity meters. Customers will use their smartphone and/or computer to access a web application for monitoring and managing the purchased energy, which can be easily controlled by them. The application must consider the most used electronic payment methods, identified by surveys (Tmoney and Flooz) and other similar ones, in accordance with upcoming guidelines [19], [20].

Interventions on the electrical network can also be carried out via the web application from the customer database as illustrated in **Figure 10**

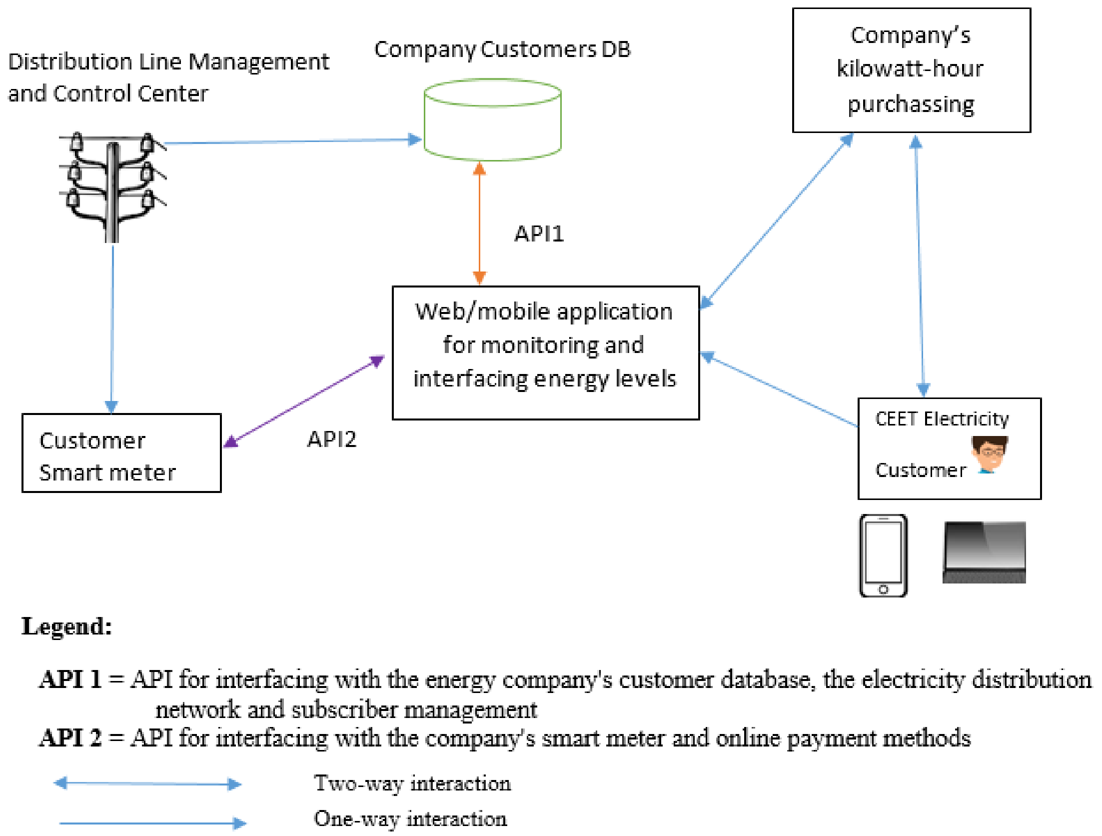

Figure 10: Modeling of control and automatic recharge communications withsmart meter and users

Adapted (communicating) meters will be able to accurately collect the data needed to alert customers and provide them with information on the energy consumption of their electrical appliances via the web and mobile application. This application also allows for the management of electrical distribution lines from its interface dedicated to technical control and customer management. The purchase of electrical energy will be automatic from the web and mobile applications, thus eliminating the need to manually enter the code on the meter.
This solution will present many advantages for customers and probably some investment disadvantages for the electricity company at the start that it will be able to make profitable in use following a well-studied investment plan.

7. Conclusion

This study, based on a survey and analysis of the problems encountered by customers of the Togolese Electricity Company (hereinafter "Togolese Electricity Company"), proposes the use of smart meters as a now essential solution for efficient electrical energy management by both electricity companies and users (their customers).
The proposed solution is an innovation combining smart meters and computer applications to facilitate managementby both the electricity suppliers and customers.

Customers willbe able to control the amount of energy subscribed to, with the option of cost-effective management and automatic energy purchasing from home, without having to leave their home, via their smartphone or any devices to access a dedicated website.

The solution is based on technological advances in electricity meters, the state of research in this field, and solutions already available in certain countries. It offers a web and mobile platform for interconnecting and integrating various existing equipment and components for energy efficiency management.

The platform will also allow the electricity supplier to anticipate power line outages and consider local energy production, which can be injected into the distribution grid as needed. It responds to a need for technological evolution in electrical energy management, essential to the development of all countries. It considers the fundamental needs of users (alerting users about their energy levels, reporting problems on the lines, monitoring the available energy level and purchasing energy as needed without having to move from their house, etc.) as well as those of the smart meters manufacturers of the future integrating IA.

Abbreviations

API	Application Programming Interface
ARSE	Togo Electricity Regulatory Authority
CEET	Togolese Electric Energy Company
DB	Data base
DER	distributed energy resources
DKIL	Distributed Knowledge and Intelligence Laboratory
FLOOZ	Mobile Money Application for Mobile phone Company 2
GWh	GigaWatt-Heure ou GigaWatt-Hours
ICT	Information and Communication Technology
DER	distributed energy resources
Senelec	Senegal Electric Energy Company
TMONEY	Mobile Money Application for Mobile phone Company 1
Xcash	Bank Transfer Money payment

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