Experimental measurements of the new gas smart meters' current discharges to suggest improvement solutions for power supply battery life extension

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Abstract: Several reasons justified introducing the smart metering concept in the gas distribution sector and supporting its digitalization. Specifically, among their functionalities, the new smart meters would improve the ability to identify abnormal consumption or malfunctions in the gas grid or at customers' appliances as soon as possible, improving the gas distribution system's safety performance. The installation and operation of gas smart meters result in a significant amount of data to be managed. Specifically, gas consumption, the supply pressure, and information about the status of the device, such as the events that occurred, are some of the data communicated daily to the gas Distribution System Operators (DSOs). However, despite the advantages, some drawbacks were first experienced by the DSOs, requiring unplanned intervention and increasing the operative costs. Among these, the discharge of the batteries sooner than expected increases the operative costs. In fact, due to ATEX safety aspects, the smart meters are not directly connected to the electric grid but they are powered by batteries that have to be replaced only by authorized personnel. The present paper reports the preliminary results obtained during an experimental campaign to investigate the impact of data communication on the battery lifetime. Specifically, four communication protocols that differ in the number of data strings and the communication frequency were compared, and preliminary conclusions were given.

Keywords: Natural gas, Gas smart meters, Metering, Batteries, Operative life estimation, Maintenance.

1. INTRODUCTION

Natural gas (NG) smart metering was introduced by Directive CE/32/2006 in 2006 (European Parliament and European Commission, 2006). Compared to traditional devices, the gas smart meters introduced a new measurement philosophy supporting the transition towards smart energy grids and aiming to maximize the economic, safety and environmental performances of the gas grids. Several advantages were recognized for both Distribution System Operators (DSOs), i.e., the companies in charge of the correct operation of the grid, and for the end-users (AEEG, 2008; Cervigni, Castelnuovo and Sileo, 2011; Di Castelnuovo and Fumagalli, 2013; Mohassel *et al.*, 2014; Bianchini *et al.*, 2018). To achieve the goal, a large set of data is daily transmitted by the devices locally installed at the customers to the Central Acquisition System (SAC – *Sistema di Acquisizione Centrale* in Italian) managed by the DSOs. Therefore, the smart metering philosophy contributes to the digitalization of the gas energy sector. Data deriving from smart meters could be used as input to improve the accuracy of algorithms dedicated to NG consumption forecasts to minimize the potential financial losses deriving erroneous estimation during trading (Smajla *et al.*, 2021). Other benefits derived by the introduction of gas smart metering will include, for example, the possibility to recognize hazardous conditions and minimize the risk caused,

for example, by leakages or other abnormal conditions (DNV, 2021).

While the benefits are clear, the on-field performances of the devices were challenging at the beginning of the Italian roll-out phase. (FederUtility, 2018) indicated the occurrence of several technical issues such as, for example, i) metrological system anomaly, ii) discharge of the battery before than expected, iii) communication anomalies, iv) display or mechanical components failure, vi) insufficient signal coverage, and other ones that were not specified by the gas DSOs. Few works in the literature investigated the problems arising during operation and how to fix them. For example, (De Carlo, Navicelli and Tucci, 2018) statistically investigated the discharge of the batteries, finding that the cost of replacing the meters was much higher than expected. However, to the best knowledge of the Authors, no papers investigate the reasons for the early discharge of the metrological battery in gas smart meter while Saunders investigated the performances of batteries for long lifetime applications (Saunders, 1998).

The problem of battery discharge in electronic devices was known since the beginning of 2000s (Lahiri *et al.*, 2002). Guo et al., for example, investigated the effect of different parameters on battery's lifetime, including data transmission power level, distance, transmission rate, and channel (Guo,

Healy and Zhou, 2012). Similarly, Tozlu & Senel investigated the impact of different relevant parameters on Wi-Fi data communication on the battery's lifetime, including data rate, data packet size and retransmission in the case of communication failure (Tozlu and Senel, 2011). The experimental results confirmed that increasing data transmission power level and distance between nodes are responsible for a reduction of the lifetime of the alkaline battery under test. Kitahara & Nakamura investigated the possibility to adopt continuous or pulse data communication protocol to minimize the discharge of a secondary lithium-ion battery (Nakamura and Kitahara, 2008). Bag et al. proposed a tool to estimate the battery life of a wireless sensor node that can be used both by devices' manufacturers and system integrators (Bag *et al.*, 2016). However, the influence of the operative temperature, the magnitude and profile of the discharging current on the battery's capacity is not explicitly indicated while the impact of the signal coverage on the data consumption is included in the time to transmit that which estimation results challenging when the devices are distributed in a large territory.

In this context, this paper aims to show the experimental activity performed in collaboration with the local gas DSO, i.e., Inrete Distribuzione Energia S.p.A., and to describe the preliminary conclusions about the impact of data communication on the battery's lifetime. A lifespan of five years was initially assumed by gas DSOs. However, many devices experienced a lifetime lower than three years, requiring unexpected intervention by personnel on field. Data communication was preliminarily assumed as responsible for the unsatisfactory performances. Therefore, the discharged capacity was investigated for four communication protocol configurations based on the General Packet Radio Service (GPRS) standard. The four configurations differ in the amount of transmitted data and the frequency of communication. After describing the adopted methodology and exposing the main results, the considerations about the limitations and improvements suggested to extend the battery's lifetime are finally indicated.

2. METHODS AND MATERIALS

2.1 The natural gas volume converters under investigation

The gas volume converters under investigation convert the measured NG volumetric flow rate to standard or normal conditions (UNI EN 12405-1, 2022). For this purpose, NG pressure and temperature are sampled every 30 seconds by a high impedance piezoresistive absolute pressure transducer (4kΩ), and a PT1000 class A 4-wire resistance transducer, respectively. Volumetric flowmeters like turbine, rotary piston, diaphragm, or ultrasonic gas meters usually measure the actual volumetric flow-rate. Once processed, data are saved in the internal memory and transmitted daily to the Central Acquisition System (SAC), where they are used, for example, for billing purposes.

Two pictures of the external casing and the main internal components of the converters under test are shown in Figure 1 and Figure 2, respectively. The backup battery power supplies the device in case of complete discharge of the main battery

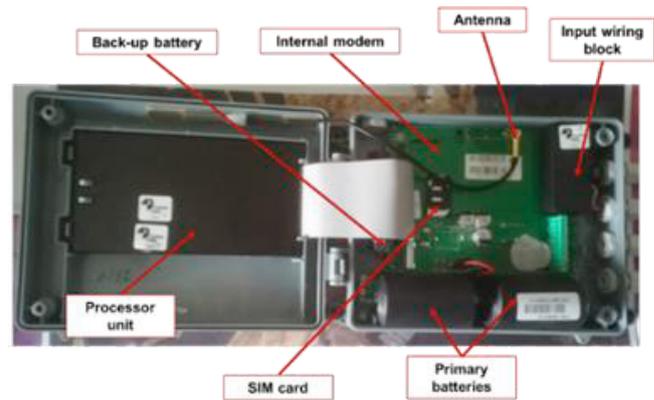pack for a limited time, allowing the substitution of the main pack without losing its functionalities.

Figure 1. Internal view of the NG volume converters under test.

Figure 2. External view of the NG volume converters under test.

2.2 The power supply battery pack under investigation

The volume converters were powered by two primary Size D Lithium-Thionyl chloride (LiSOCl₂) batteries, ensuring a high power and energy density, a high voltage response, a stable performance during the lifetime, a wide operating temperature range, and a low self-discharge rate (Evans, Nguyen and White, 1989; Saunders, 1998). In LiSOCl₂ batteries lithium (Li) oxidation occurs at the anode, resulting in the production of lithium ions (Li⁺) and electrons (e⁻) as indicated in Eq. (1):

$$4Li \rightarrow 4Li^+ + 4e^- \tag{1}$$

The electrons produced at the anode close the electric circuit reaching the cathode, reducing the thionyl chloride (SOCl₂) as reported in Eq. (2) producing chloride ions (Cl⁻), sulfur (S), and sulfur dioxide (SO2):

$$2SOCl_2 + 4e^- \rightarrow 4Cl^- + SO_2 + S \tag{2}$$
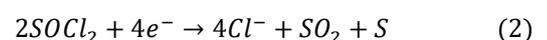
Once produced, Li$^+$ ions travel to the cathode where they immediately react with the Cl$^-$ ions, producing lithium chloride (LiCl) as indicated in Eq. (3):

$$Li^+ + Cl^- \rightleftharpoons LiCl \qquad (3)$$

By combining the reactions indicated in Eq. (2) and Eq. (3), the overall reaction reported in Eq. (4) is written:

$$4Li + 2SOCl_2 \rightarrow S + SO_2 + 4LiCl \qquad (4)$$

The solid particles of LiCl and S are deposited on the cathode's porous surface, reducing the active surface while gaseous SO_2 dissolves in the electrolyte.

During storage, a chemical reaction responsible for the formation of a LiCl passivation film on the anode occurs as indicated in Eq. (5) preventing the discharge of the battery:

$$LiO_2 + SOCl_2 \rightarrow 2LiCl + SO_2 \qquad (5)$$
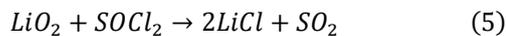
Many operative factors influence the effective capacity of the battery, for example, the amplitude of the supplied current, the operating temperature, and other mechanisms such as self-discharge and the presence of high-intensity impulse absorptions. The main characteristics of the batteries included in the gas converters under investigation are shown in Table 1.

Table 1. Main characteristics of the batteries for the power supply of the NG volume converters under test.

Parameter	Value
Nominal capacity @ 15mA & cut off voltage equal to 2.0 V, [Ah]	13.0
Open-circuit voltage, [V]	3.67
Nominal voltage, [V]	3.60
Maximum continuous recommended current, [mA]	1800
Pulse capability, [mA]	4000
Operative temperature, [°C]	[-60; 85]

2.3 The data communication protocols under investigation

Data can be transmitted through point-to-point (PP) and point-to-multipoint (PM) protocols. The PP protocol is usually preferred for communication among single devices. Specifically, Global System for Mobile Communications (GSM) or GPRS communication standards were firstly implemented because of the extended communication distances even if new standards were introduced in recent years like Narrowband Internet of Things (NB-IoT) e Long Range (LoRa). The PM profile, instead, is adopted for data communication among devices and concentrators. Radiofrequency (RF) communication is usually used in this case.

The PP profile was adopted in the devices under investigation while data are communicated in accordance with the CTR ("*Comunicazione a Trame Ridotte*" in Italian) protocol where

data strings are transmitted between the converters and the SAC in a "*Master-Slave*" configuration, where the SAC is the "*Master*" while the converters are the "*Slave*". Specifically, each data string counts 142 bytes that represent specific information depending on the position within the string. Therefore, no data transmission occurs until a specific request comes from the Master.

Figure 3 shows the protocol configured in the devices under investigations based on UNI/TS 11291-3 (UNI TS 11291-3, 2012). This protocol will be called "baseline" in the rest of the paper. As shown, the transmission process started from the wake-up command sent from the SAC and ended with the shut-down procedure performed by the device. The daily communication (i.e., "query" and "answer" consists in the transmission of six data strings totalizing 852 bytes (i.e., 6 x 142 bytes) from the converter to the SAC. Furthermore, SMS transmission is performed when the device fails to connect to the network, resulting in the inability to transmit data through other communication standards.
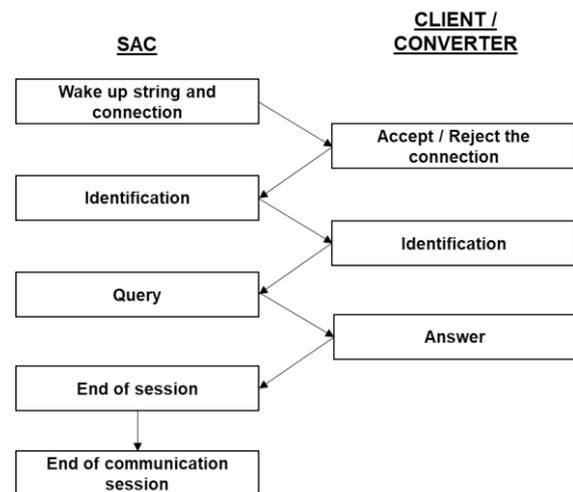

Figure 3. Flow chart of the data communication protocol.

Because of battery discharge occurred before than it was expected in some converters installed in areas characterized by a low signal coverage, it was decided to investigate changes in the data communication protocol. In accordance with the manufacturer and the gas DSO, four configurations that differ in the amount of data and the frequency of transmission were identified as alternative solution to the baseline. Therefore, the four configurations were implemented in four converters to measure and compare the energy consumption such as it would be in field conditions (Table 2):

- The second configuration under investigation was characterized by fewer bytes to be transmitted. Specifically, it was decided to remove the strings containing those data not used by the operator.
- The third configuration was configured to transmit data every two days. Therefore, each communication contains the information for two days, signifying that more strings were communicated. However, it has to be noted that the strings containing information about the converter's identification and time synchronization were not repeated.

- The fourth configuration was a combination of the second and the third.

Table 2. Configurations of the protocol under investigation.

Configuration	Amount of data	Communication frequency
First (baseline)	6 strings (i.e., 852 bytes)	Daily
Second	5 strings (i.e., 710 bytes)	Daily
Third	8 strings (i.e., 1136 bytes)	Every two days
Fourth	7 strings (i.e., 994 bytes)	Every two days

2.4 The instrumentation used in the experimental campaign

To calculate the Key Performance Indicators (KPIs), an experimental campaign was planned. The main electric operative parameters, i.e., the current and the voltage at the battery pack, were measured by the tester ISOTECH IDM 305 and by the INA 219 module implemented in an Arduino board. Specifically, Texas Instruments manufactures the components to be assembled in the INA 219 module, while Adafruit provides the algorithm to be implemented in Arduino. The main features of the INA 219 module are shown in Table 3.

Table 3. The main characteristics of the instrumentation adopted.

Main characteristics	INA 219	ISOTECH IDM 305
Full-scale (f.s.) voltage [V]	32	1000
Voltage measurement error, [%]	±0.2% (average) ±0.5% (max)	±0.06% of f.s.
Upper range limit [A]	32	10
Resolution, [A]	0.1 mA in the range [0;400] mA	10^{-6} up to 40 mA
Current measurement error [%]	±0.2% (average) ±0.5% (max)	±0.2% of f.s. in the ranges: < 40 mA; [40; 400[mA; [400, 4A]

3. RESULTS

3.1 The available database and preliminary analysis

It was initially planned to carry out one communication per hour instead of one per day to have 24 daily communications to speed up the experimental activity. However, due to the impossibility of implementing this logic at SAC, daily communication was maintained, thus extending the testing period to obtain significant statistical results. On the other hand, the obtained data were representative of the behavior of the devices such as they were in field. Table 4 shows the summary of the database available for the four configurations. The number of days available differs for the four configurations. For example, during the experimental activity, the converters implemented with configurations 3 and 4, didn't "wake up" in some days, resulting in no data transmission and affecting the number of valid days for data acquisition.

Table 4. The number of available days for testing.

Configuration	Available days for testing
First (baseline)	158
Second	141
Third	44
Fourth	86

3.2 Estimation of the electricity consumption

Three main consumption sources were identified in the devices under investigation in addition to the base load and were assumed to be responsible for the discharge of the main battery pack: i) the sensors, ii) the display, and iii) the data communication. Based on the measurement, a current ranging from 0.25 mA to 0.30 mA was continuously supplied to the device, resulting in a daily consumption of 6.0-7.2 mAh. The sensors were powered with a slightly greater current amplitude. In fact, current up to 5 mA for almost 0.5 sec were measured every 20 sec for their supply. That is, a daily consumption equal to 3 mAh was attributed to the sensors. The display was powered when switched on. In this condition, an average current equal to 0.75 mA is absorbed until the display is switched off, i.e., when no actions on the device are performed for more than 30 sec. For example, assuming the display is switched on for 2 minutes daily, a daily consumption of 0.025 mAh is calculated. Therefore, these three consumption sources annually totalize 3.3 Ah/year, i.e., 12.7% of the nominal capacity of the installed battery pack.

3.3 Characterization of data communication consumption

The electricity consumption during data communication depends on many factors including the signal coverage during the transmission and the number of data strings to be communicated to the SAC. The converters perform different tasks to complete the data communication. Three main phases were identified (Figure 4): i) the connection of the device to the network (in red), ii) the data transmission (in green), and iii) the switching-off of the device (in blue). The modem is switched on to start the communication. This phase is characterized by several peaks whose amplitude increases inversely to the coverage of the signal. Figure 5 shows the total supplied capacity for the four configurations. Those transmission that failed the communication are coloured in red.

An average capacity of 0.3 mAh was measured in case of a good signal. No significant difference was measured among the four combinations since the tasks to connect the device to the network are the same. The points circled in red represent those events resulting in a failure of the converter to connect to the network. As shown, the interruption of the connection tentative (red points) occurred in a very large range between 60 sec up to 900 sec, resulting in an increase in consumption. Therefore, no rule based on time duration seems to be present to interrupt the tentative connection. Based on the measurement, a linear trend between the discharged capacity and the time duration of the tentative was identified. Based on this information, a preliminary estimate of each tentative discharged capacity could be possible.
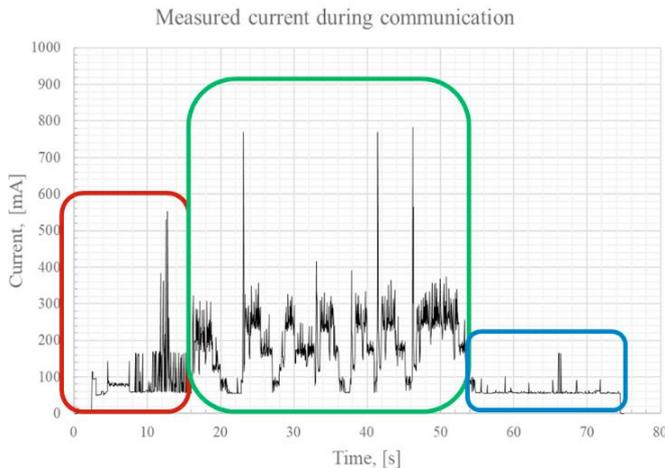

Figure 4. Current vs time during a communication. In red, the connection to the network, in green, the data transmission phase; in blue, the switching-off of the device.
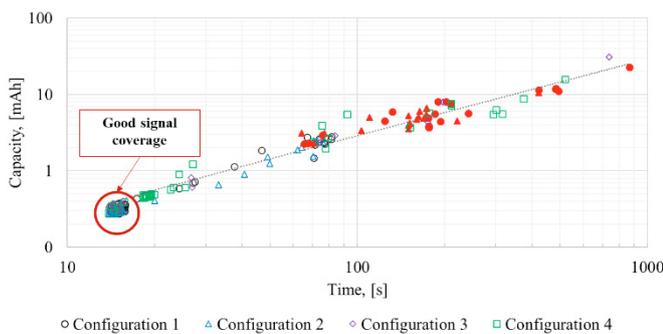

Figure 5. Measured discharged capacity vs time duration for the connection to the network that is necessary for the data transmission.

In the second phase, data are transmitted to the SAC. Figure 6 shows that consecutive peaks per the Master-Slave protocol configuration characterize the consumption profile. Specifically, six peaks corresponding to the six-string transmitted in the baseline configuration can be identified in the figure. In good signal coverage, the second configuration was responsible for the lowest mean consumption, i.e., almost 2.0 mAh. As shown in the figure, the reduction of signal coverage was responsible for both an increase in communication duration and, consequently, capacity discharge. The measured capacity discharge shown in Figure

6 was referred to as the ratio between the measured communication duration and the reference duration for good signal coverage. As shown, a good correlation appears, resulting in a possible preliminary estimate of the capacity discharge based on the time duration of the data communication.

In the last phase, the converters are powered to complete the operations before switching off the modem after finishing data transmission. This final phase was not influenced by the signal coverage and it lasts for 18-20 sec even if during the experimental activity some shorter values have been recorded but they represent very few events with poor statistical meaning. This phase was responsible for an average capacity discharge equal to 0.34 mAh.
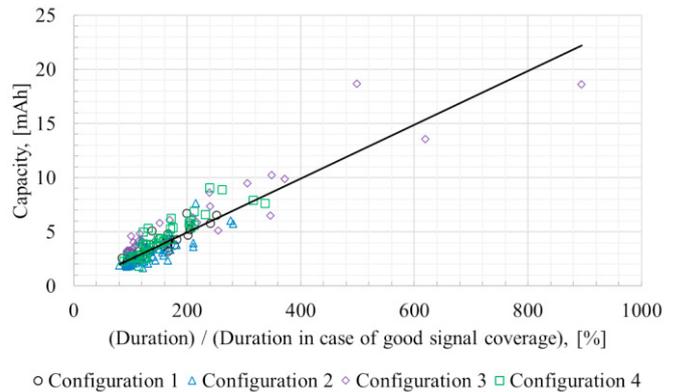

Figure 6. Measured discharged capacity for the data transmission.

4. DISCUSSION

Three main sources of consumption were identified as responsible for the discharge of the battery pack in the converters. Regarding data communication, different conclusions have to be made based on the quality of the signal coverage.

In case of good coverage, the fourth configuration minimizes the average discharged capacity (-43.9% compared to the baseline) since a single connection would be needed to send the data over two days. The effect of reducing the number of strings was evaluated from the available dataset. Specifically, an average discharged capacity of around 0.4 mAh/string was calculated. Therefore, an annual saving of roughly 4.8% of the baseline configuration can be obtained by avoiding the transmission of unused data strings. The impact of reducing the communication frequency was estimated as an annual saving of around 0.06 Ah/year. That is, on an annual basis, the baseline configuration would result in an average discharge capacity of approximately 1.0 Ah/year. On the other hand, the remaining configurations would benefit from a reduction of around 5%, 29%, and 42%, respectively.

In case of bad signal coverage, instead, it was concluded that the first phase responsible for connecting the converters to the network is the most critical in discharged capacity. Connection tentative up to 900 sec were recorded in the experimental campaign resulting in a consumption eight times higher than that expected in the case of good signal coverage. However, it

was impossible to conclude about the logic implemented to interrupt the tentative because of the spread of its duration. That is, the baseline and the second configurations were the most impacted in the case of bad signal coverage because of the daily connection to the network.

6. CONCLUSIONS

Signal coverage significantly impacts battery discharge in the converters under investigation. Specifically, the "Master-Slave" communication protocol increases energy consumption, especially in case of a bad signal. Reducing the number of data or the transmission frequency minimizes energy consumption, but it limits the potential benefits derived from the introduction of smart metering in the gas network. Gas DSOs already monitor their grids. However, the data are usually limited to relevant pipelines and equipment of the gas distribution network.

Considering the Italian scenario, more than twenty million devices smart meters will be installed for customers, i.e., where the consequence caused by a failure or accident in the gas infrastructure could be the most severe. Data communicated by the smart meters could reduce the risk of improving monitoring performances. However, the availability of big data could be limited by data transmission. Therefore, further research, including, for example, less energy-intensive communications protocols or new technical solutions to power the meters, has to be done.

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REFERENCES

AEEG. (2008). Direttive per la messa in servizio dei gruppi di misura del gas, caratterizzati da requisiti funzionali minimi e con funzioni di telelettura e telegestione, per i punti di riconsegna delle reti di distribuzione del gas naturale. *ARG/gas n°155/08*.

Bag, G., Zhibo, P., Johansson, M.E., Min, X., Shaoling, Z. (2016). Engineering friendly tool to estimate battery life of a wireless sensor node. *Journal of Industrial Information Integration*, 4, 8-14.

Bianchini, A., Guzzini, A., Pellegrini, M., Saccani, C. (2018). Gas smart metering in Italy: state of the art and analysis of potentials and technical issues. *Proceedings of the XXIII Summer School "Francesco Turco" – Industrial Systems Engineering*.

De Carlo, F., Navicelli, A. and Tucci, M. (2018). Technical analysis of the impact of smart meters' battery useful life on the management of a service company. *Proceedings of the XXIII Summer School "Francesco Turco" – Industrial Systems Engineering*.

Di Castelnuovo, M. and Fumagalli, E. (2013). An assessment of the Italian smart gas metering program. *Energy Policy*, 60, 714-721.

Cervigni, G., Castelnuovo, M. Di and Sileo, A. (2011). Costs and benefits of the Italian smart gas metering programme. Available at: www.iefe.unibocconi.it

DNV. (2021). Differentiating gas leaks from normal appliance use. Available at: www.dnv.com

European Parliament and European Commission. (2006). Directive 2006/32/CE.

Evans, T.I., Nguyen, T. V. and White, R.E. (1989). A Mathematical Model of a Lithium/Thionyl Chloride Primary Cell. *Journal of The Electrochemical Society*, 136(2), 328-339.

FederUtility. (2018). Smart metering gas: Problematiche connesse all'installazione degli smart meter e sviluppi attesi. Available at: http://www.assogas.it/uploads/files/180911 - Allegato NOTA INTERASSOCIATIVA ANOMALIE SMART METER_.pdf

Guo, W., Healy, W.M. and Zhou, M.C. (2012). Battery Discharge Characteristics of Wireless Sensors in Building Applications. *Proceedings of 9th IEEE International Conference on Networking, Sensing and Control*.

Lahiri, K., Raghunathan, A., Dey, S., Panigrahi, D. (2002). Battery-Driven System Design: A New Frontier in Low Power Design. *Proceedings of ASP-DAC/VLSI Design 2002. 7th Asia and South Pacific Design Automation Conference and 15h International Conference on VLSI Design*.

Mohassel, R.R., Fung, A., Mohammadi, F., Raahemifar, K. (2014). Application of Advanced Metering Infrastructure in Smart Grids. *22nd Mediterranean Conference of Control and Automation (MED)*.

Nakamura, T. and Kitahara, H. (2008). A Data Transmission Control to Maximize Discharge Capacity of Battery. *WCNC 2008 proceedings*.

Saunders, T.G. (1998) The performance evaluation of lithium thionyl chloride batteries for long-life meter applications. Loughborough University. Available at: https://dspace.lboro.ac.uk/2134/13855.

Smajla, I., Sedlar, D.K., Vulin, D., Jukic, L. (2021). Influence of smart meters on the accuracy of methods for forecasting natural gas consumption. *Energy Reports*, 7, 8287–8297.

Tozlu, S. and Senel, M. (2011). Battery Lifetime Performance of Wi-Fi Enabled Sensors. *IEEE Consumer Communications and Networking Conference*.

UNI EN 12405-1. (2022). Gas meters: Conversion devices-Part 1: Volume conversion.

UNI TS 11291-3. (2012). Sistemi di misurazione del gas. Dispositivi di misurazione del gas su base oraria. Parte 3: protocollo CTR.