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Co-funded by
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3.7-MED25-40GA-3.7

AN UPDATE ON TECHNICAL AND NON-TECHNICAL LOSSES

Consumers Working
Group
(CUS WG)

Empowering Mediterranean regulators
for a common energy future

ABOUT MEDREG

MEDREG is the Association of Mediterranean Energy Regulators, uniting 28 regulators from 23 countries across the European Union, the Balkans, and the MENA region. Established in 2007 and co-funded by the European Union, MEDREG serves as a platform for cooperation, knowledge sharing, and capacity building in energy regulation. It fosters coherent regulatory approaches and practices at the regional level, aiming at progressive market integration in the Euro-Mediterranean basin. To support its members, MEDREG organises training sessions, workshops, and tailored, hands-on initiatives that enhance the capacity of energy regulators.

MEDREG's goal is to establish an integrated Euro-Mediterranean energy market that strengthens energy security and drives the clean energy transition. This includes integrating renewable energy sources, reinforcing cross-border infrastructure, promoting innovation, enhancing energy efficiency, and advancing renewable gases such as hydrogen. Additionally, MEDREG advocates for transparent and non-discriminatory regulation to attract infrastructure investments, modernise electricity and gas markets, and improve consumer protection.

The MEDREG Secretariat is located in Milan, Italy.
For more information, visit www.medreg-regulators.org

ACKNOWLEDGEMENTS

This report is the result of a project carried out by the MEDREG Consumers Working Group (CUS WG), which provided the data and comments. MEDREG thanks the CUS Working Group for their contributions and efforts.

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DISCLAIMER

Executive Summary

This report is an update of a 2022 report on the same subject that studied the quantitative effects of COVID-19 and the price surge on technical and non-technical losses. This version of the report tackles the issue from an alternate perspective, providing a comprehensive analysis of the strategies deployed to mitigate both Technical Losses (TLs) and Non-Technical Losses (NTLs) across the Mediterranean electricity and gas networks. The primary conclusion is that while the fundamental challenge of reducing losses is universally acknowledged, the actual effectiveness of loss management is hindered by data gaps and the absence of fully modernised regulatory frameworks.

Pervasive Data Gaps and Regulatory Limitations

A critical finding is that most regulators struggle to implement truly targeted remedies because they cannot accurately distinguish between the two types of losses. The common reliance on a residual approach, where NTL is calculated as the total system loss minus the estimated TL, is a pragmatic workaround but a significant regulatory obstacle. This ambiguity implies that if a utility reports only a high total loss figure, the regulator cannot fully identify whether the problem lies with an ageing, inefficient grid or with widespread fraud. This lack of clarity prevents efficient capital allocation and the application of accurate measures. An exception, which employs a crucial regulatory innovation, is applying regionally differentiated standard NTL factors. This practice establishes performance benchmarks that explicitly acknowledge and account for the varying socio-economic realities and theft prevalence across different geographical areas, resulting in a more accurate and equitable regulatory model. On the natural gas side, definitions of losses are less uniform, often distinguishing between specific, measurable events, such as fugitive emissions, and the broader, more opaque accounting term, Unaccounted-for Gas (UfG).

Drivers, Incentives, and Enforcement Challenges

Losses are fundamentally driven by both physical constraints and human behaviour. TL is primarily caused by the inherent physical properties and age of the grid, including resistive I^2R losses in older conductors, inefficient transformers, poor power quality, and operational inefficiencies, such as network imbalance. Conversely, NTL is overwhelmingly caused by theft and fraud, a fact confirmed by every responding country. These illicit activities are enabled by poor record-keeping, faulty or ageing metering infrastructure, and socio-economic factors such as poverty and perceived high tariffs.

To combat these issues, the regulatory trend is shifting from prescriptive, top-down control to performance-based incentive models. Sophisticated systems, such as the symmetrical reward and penalty frameworks in Spain and France, effectively transfer the financial risk of excess losses from the consumer to the utility. By allowing companies to retain a portion of the financial gains from outperforming the loss benchmark, regulators create a strong, perpetual incentive for continuous investment in efficiency and anti-theft measures. However, the operational effectiveness of these incentives is frequently undermined by institutional challenges. Specifically, slow and cumbersome legal processes for prosecuting energy theft, coupled with a lack of clear jurisdictional authority between energy regulators and law enforcement, inhibit swift and decisive action against perpetrators, limiting the deterrent effect of legal sanctions.

The Decisive Role of Technology and Grid Modernisation

The future direction of loss management is centred on the synergistic deployment of Advanced Metering Infrastructure (AMI) and data analytics. The widespread commitment to rolling out smart meters across the region (e.g. France, Jordan, Egypt) is transforming loss management from a manual, reactive process into a data-driven science. AMI provides the granular, real-time data necessary for applying advanced algorithms and AI to detect irregular consumption patterns and predict fraudulent activities with far greater accuracy than periodical physical inspections.

Further, grid modernisation is essential to maintain efficiency in a sustainable energy system. While the integration of Distributed Renewable Energy Sources (RES) offers the benefit of reduced technical losses by minimising the distance power must travel, it also introduces new, non-traditional technical challenges. Uncoordinated, high-penetration RES can induce reverse power flows and significant voltage fluctuations in low-voltage networks. This can stress components and create new forms of energy dissipation, potentially offsetting the very loss reduction benefits sought to be achieved. This challenge, highlighted by countries like Italy and North Macedonia, underscores that the transition to sustainable energy must be coupled with mandated supported through appropriate assessments in grid development and smart grid investments to safely and efficiently manage these complex, bidirectional energy flows.

Recommendations

- **Mandate Clear Loss Separation**: Regulators must move beyond the residual approach by requiring utilities to develop and report methodologies that clearly and separately quantify both TLs and NTLs, enabling truly targeted and effective interventions.
- **Accelerate AMI and Smart Grid Deployment**: The full rollout of AMI must be prioritised, especially in high-loss areas, alongside mandatory investments in smart grid technologies to manage bidirectional power flows and reduce TL from intermittent RES integration.
- **Implement Regional NTL Benchmarking**: Adopt the Italian model to apply regionally differentiated standard NTL factors, creating regulatory baselines that accurately reflect and account for the varying socio-economic drivers of energy theft.
- **Strengthen Enforcement and Legal Frameworks**: Regulators must collaborate with legal institutions to streamline the prosecution process for energy theft, ensuring that anti-theft operations are backed by escalating financial penalties and the requisite legal authority to act decisively.

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1 Introduction

1.1 PURPOSE AND STRUCTURE OF THE REPORT

In a modern energy system, the efficient and reliable delivery of power is paramount. However, a significant portion of the energy produced is lost before it reaches the end consumer. These "power losses" represent not only a major financial drain on utilities and a hidden cost to consumers but also a source of inefficiency that impacts energy security and sustainability. Losses can be broadly categorised into technical losses, which are an inherent consequence of the physical laws governing electricity and gas transmission, and non-technical losses resulting from external factors such as theft and administrative errors. Effectively managing both types of losses is a fundamental objective for energy regulators and operators worldwide, requiring a balanced approach that combines technological innovation, sound regulatory policy, and robust enforcement. This report, an update to the 2022 MEDREG study on the same topic, examines in detail how Mediterranean energy regulators are tackling this complex challenge.

This document synthesises the questionnaire replies from MEDREG's member regulators to provide a comprehensive overview of how power losses are defined, calculated, and regulated across the region. It serves as a vital resource for understanding the diverse legal and technical approaches countries are adopting to address this persistent challenge. The analysis reveals a shared understanding of what constitutes power losses and highlights a wide range of regulatory maturity and operational strategies shaped by each country's unique energy landscape. The report's findings are based on a detailed survey of MEDREG's members, ensuring that the insights reflect the on-the-ground reality and diverse experiences of countries in the region.

The report provides a detailed and logical examination of the multifaceted nature of energy losses, moving from fundamental definitions to the innovative solutions being implemented. The core of the document focuses on three key areas:

Defining and Differentiating Losses: The first part of the report provides a detailed overview of how MEDREG members legally and technically define both TL and NTL for electricity and gas. It explores the shared principles, such as the energy balance method, and highlights unique national legislative approaches, as well as the challenges in separating the two types of losses in practice.

Regulatory Frameworks and Enforcement: The second section analyses the diverse regulatory models and financial mechanisms used to combat losses. It examines both prescriptive, target-based approaches and more flexible, performance-based incentive models. This part also details the operational tools, such as physical audits, data-driven analytics, and legal sanctions, used to enforce accountability and promote efficiency.

Challenges, Gaps, and Innovative Solutions: The concluding section offers a critical perspective of the persistent challenges—including data gaps, outdated technology, and institutional weaknesses—that hinder effective loss management. It then presents a forward-looking viewpoint of the successful initiatives and innovative technologies, such as smart grids and advanced metering infrastructure, which are helping regulators and utilities overcome these obstacles.

This report aims to serve as a benchmark for best practices and a catalyst for collaboration among regulators, encouraging the adoption of effective strategies to reduce energy losses and build a more efficient and secure energy future for the Mediterranean region.

1.2 METHODOLOGY

To address the report's objectives, the MEDREG Secretariat collected the data and information from its members and collaboratively drafted the report with the CUS WG chairs. The questionnaire was circulated to them, and their replies would later be used as building blocks for the report's different chapters and sub-chapters. The questionnaire template circulated encompassed the three sections mentioned above.

Moreover, the report integrates case studies from countries that have effectively and successfully addressed similar challenges in the past, for knowledge sharing among the members.

The replies of **Albania, Algeria, Bosnia and Herzegovina, Egypt, France, Greece, Italy, Jordan, Lebanon, Morocco, North Macedonia, Portugal, Spain,** and **Türkiye** are considered in this study.

2 Overview of Power Losses

The management and regulation of power losses are cornerstones of a well-functioning energy market. This chapter synthesises the replies from MEDREG's member regulators to provide a comprehensive overview of how power losses are defined, calculated, and measured across the Mediterranean region. The responses reveal a shared understanding of the problem but a diverse range of legal and technical approaches to addressing it, shaped by each country's unique energy landscape and regulatory maturity.

2.1 DEFINITION OF LOSSES

A fundamental step in tackling power losses is a clear legal definition that provides a basis for regulation and enforcement. The survey responses reveal that most countries in the region have established a legislative framework for power loss management, with a few notable exceptions.

Figure 1 - Countries that Define Power Losses

2.1.1 Electricity Losses

Most countries assessed in this report confirm the existence of a definition of power losses in their primary or secondary legislation. This not only underscores the importance of a formal framework for regulatory oversight but also stresses how significant losses are.

A straightforward definition of electricity losses in a power system refers to the Total System Losses, which is the difference between the electrical energy injected into the network by all generating sources and the energy metered and billed to consumers.

Countries like **Bosnia and Herzegovina, Egypt**, **Portugal**, **Spain**, and adhere strictly to this definition, viewing losses as the inevitable discrepancy between the total energy flowing into the system and the total energy measured and delivered to end consumers. Italy also bases its 'Actual Losses' on this injection-withdrawal difference, but this figure accounts for both actual technical and non-technical (commercial) losses, since there is no separate measurement for each. The calculation's complexity is recognized in countries like France, which differentiates the accounting flows based on the voltage level. At the Transport (TSO) Level, the flow considers electricity injected by generation and imports versus consumption, withdrawals by distribution grids, and exports. Conversely, at the Distribution (DSO) Level, the flow accounts for injections from the TSO, neighbouring distribution networks, and decentralized generation versus local consumption and energy flowing up to the transmission network. Whether measured across a single network element (as noted in **Albania's** TSO and DSO Code) or the entire system, the definition relies on balancing energy input against measured energy output.

Breaking down the electricity losses, TLs are the expected and unavoidable consequence of the physical properties and operation of the transmission and distribution network. They represent the active energy consumed or dissipated within the network itself through inherent physical processes. Operationally, **Algeria** defines TLs as the "active energy consumption induced by the operation and use of the electrical network". **Morocco** defines them similarly as active power dissipation within the network caused by electricity transmission. For accounting and measurement purposes, TL factors are often calculated based on system design, load flow analysis, and historical data, and can then be applied to the energy quantities allocated during market settlement, as is the case in Italy. TLs will be discussed more elaborately later in the report.

The other branch of losses, NTLs, also known as commercial losses, are the portion of the energy imbalance not attributable to the physical dissipation of energy within the grid. These losses result from external, administrative, or non-operational factors related to metering, billing, and system integrity. **Türkiye's** definition specifically mentions losses arising from reasons, such as "illegal use and not based on a technical reason". These losses directly affect the financial performance of utility operators. A key challenge is the measurement of these losses, as Italy highlights; there is often "no separated measurement for actual technical/non-technical losses". Consequently, the total imbalance figure includes both, necessitating the use of estimated "standard loss factors" framed by regulatory authorities to account for NTL separately from TL for settlement purposes. NTLs, too, will be discussed more elaborately later in the report.

The formal definition and management of electricity losses are deeply embedded in national energy legislation, grid codes, and regulatory mandates. Concerning the statutory basis, the **Türkiye** definition is enshrined in the Electricity Market Law, while Jordan addresses the energy lost through its General Electricity Law and regulatory codes covering transmission performance and distribution standards. Oversight is often provided by a regulatory commission; for instance, while **North Macedonia** lacks an explicit definition in primary law, the Energy Regulatory Commission (ERC) is granted legal competence to approve and manage loss reduction plans submitted by network operators, confirming the critical regulatory focus on the issue. Finally, for many countries, the working definitions and procedures are housed in the operational documents of the grid operators or TSO/DSO Codes. Both **Albania** and **Morocco** cite their respective TSO/DSO Grid Codes as the source of their specific definitions. In **Morocco**, the National Electricity Regulatory Authority (ANRE) is legally authorised to approve quality indicators for the electricity transmission network, including the efficiency of the electricity transmission network. In this context, ANRE has approved these indicators by decision and has adopted the active power losses rate as an indicator for measuring network efficiency through network performance. The target value of these losses is also approved by ANRE.

Conversely, **Greece**, **Lebanon**, and **North Macedonia** report the absence of a legal definition of power losses in their legislation. These countries understand and manage the concept through operational codes and regulatory commissions. For example, **Greece** relies on a regulatory decision (RAAEY's Decision No 236/2017) to define electricity theft—a key component of NTLs—rather than providing a definition for the total loss figure itself. This indicates a focus on addressing the causes of losses through specific regulatory actions rather than a broad legislative definition.

2.1.2 Gas Losses

The legal and regulatory definitions for gas losses are less standardised, reflecting the varied maturity and scale of gas networks in the region.

Natural gas losses, like electricity losses, are fundamentally defined by the imbalance between the energy (or volume) introduced into the network and the volume ultimately withdrawn, measured, and billed to consumers. This principle is generally understood in **Greece** and formally applied in **France**, using the basic mass balance approach: the volume of gas injected into the network versus the volume withdrawn. In the French distribution context, this is specified as the sum of gas delivered by the TSOs and biomethane injected by producers, minus the quantities billed to consumers.

In the gas sector, regulatory definitions often draw a sharp distinction between specific, measurable physical losses and the broader, residual accounting term known as Unaccounted-for Gas (UFG). The definition in **Jordan** clearly positions UFG as the ultimate volume difference between what enters the system (inlet custody-transfer meters) and what is billed, calculated after deducting documented TL. This means UFG represents the remaining volume difference caused by factors such as administrative errors or theft.

Conversely, the **Italian** transmission network defines "Network losses" very narrowly as the amount of unmeasured gas attributable solely to physical occurrences like fugitive emissions, pneumatic emissions, and venting. Significantly, this Italian definition explicitly excludes both UFG and Fuel Gas (gas consumed by compressor stations), demonstrating a regulatory approach that distinguishes physical loss types from the broader accounting discrepancy.

Gas loss definitions across regions categorise the imbalance based on the nature of the event: whether the loss is unintentional, intentional (operational), or due to accounting adjustments. **Albania**, through its TSO and TAP Network Codes, defines "Local loss" or "In-Country Losses" as the unintentional loss of natural gas from the transmission system, explicitly excluding losses resulting from force majeure events or from planned or unplanned maintenance activities.

This contrasts with the definition used in **Portugal**, where "power losses" are associated with the discharge or flaring of gas for process purposes, representing a controlled and voluntary burning or dispersal of gas necessary for system operation. Algeria adopts a technical definition, classifying TL as the consumption of gas induced by the operation and use of the network. The regulatory approach in **Spain** is highly granular, introducing detailed regulatory accounting terms: Real losses are calculated from the physical gas balance of the infrastructure, retained losses are the quantity of gas deducted from the user’s balance for measurement differences, and the Loss balance is the difference between these two. **Spain** also defines Operational gas as that needed for the operation of equipment and installations.

The formal classification and governance of gas losses are defined in specialised sector codes and national laws. The detailed classification in **Spain** is mandated by Circular 7/2021 and supported by the national Hydrocarbons Law. In **Albania**, the definitions are codified in the Natural Gas TSO Code and the TAP Network Code. Conversely, in **North Macedonia**, there is no explicit definition of losses in the national energy legislation; however, the Energy Law acknowledges the existence of TLs and regulates their treatment in the tariff-setting process. Similarly, **Türkiye** does not define technical gas loss but clearly defines illegal use (an NTL) as consuming natural gas in violation of legislation, such as by interfering with the system or meter. This confirms that even where the physical loss is not formally defined, its financial and legal treatment is strictly regulated.

2.2 TECHNICAL LOSSES

TLs are an inherent part of the physical process of transmitting and distributing electricity and gas. They are universally understood as energy dissipated due to the physical properties of the grid's components and minimising them through efficient network management is a primary concern for regulators and operators.

2.2.1 Primary Causes

Replies to the questionnaire consistently identify the physical infrastructure of the grid as the main driver of TLs. This encompasses a range of factors fundamental to grid operation. Some main causes identified are as follows:

Grid Infrastructure: The fundamental design and materials of the power network are a primary cause. The most significant loss is the I^2R loss, where electrical resistance (R) in conductors causes energy to be lost as heat when current (I) flows. This is exacerbated in older lines, lines with small conductor sizes, or those that cover very long distances. Similarly, transformer design is crucial. All transformers have fixed losses, known as core losses, simply because they are energised, while their variable losses (or copper losses) increase with the load they carry. Finally, the chosen voltage level dictates current: a lower voltage requires higher current to transmit the same power, which exponentially increases I^2R losses.

Technology: This category focuses on the quality and intelligence of the equipment in use. Using outdated or inefficient equipment can lead to higher loss rates. Beyond the hardware, two power quality issues driven by technology greatly increase losses. A poor power factor means a sizeable portion of the current flowing, though not doing useful work, still contributes to I^2R losses. Further, harmonic distortion, caused by modern non-linear loads (like inverters or electronics), injects unwanted high-frequency currents that dramatically increase resistive and core losses in system components.

Environmental Factors: External conditions act as accelerators of technical losses. Elevated ambient temperatures increase the resistance (R) of conductors and transformer windings, directly augmenting the I^2R losses—a frustrating, self-reinforcing issue. Moreover, weather and pollution can introduce new loss pathways. Corona losses, for example, are the energy dissipated as air ionises around high-voltage lines, an effect worsened by humidity or rain. Contamination from salt or industrial dust on insulators can also increase current leakages, adding to the overall energy waste. Over a longer horizon, the ageing and degradation of equipment and insulation due to environmental exposure naturally lead to higher resistance and increased fixed losses. **Spain** and **Morocco** add "temperature and terrain variations" to the list of causes, underscoring how environmental conditions can affect the physical properties and performance of network components.

Operational Factors: How the system is managed day-to-day plays a significant role. An operationally inefficient system is a loss-prone one. Network imbalance, where the three phases are unequally loaded, forces some phases to carry disproportionately high current, thereby increasing overall I^2R losses compared to a balanced system. The lack of real-time monitoring prevents quick identification of issues like overloaded lines or low-voltage spots, leading to sustained inefficiency. Lastly, suboptimal switching or a poor network topology choice—meaning the system is not running in its lowest-loss configuration—results in current being routed along excessively long or resistive paths, needlessly burning energy. **Egypt** cites "Operational Factors" as a cause, which can include inefficient load management, poor voltage control, and system imbalances.

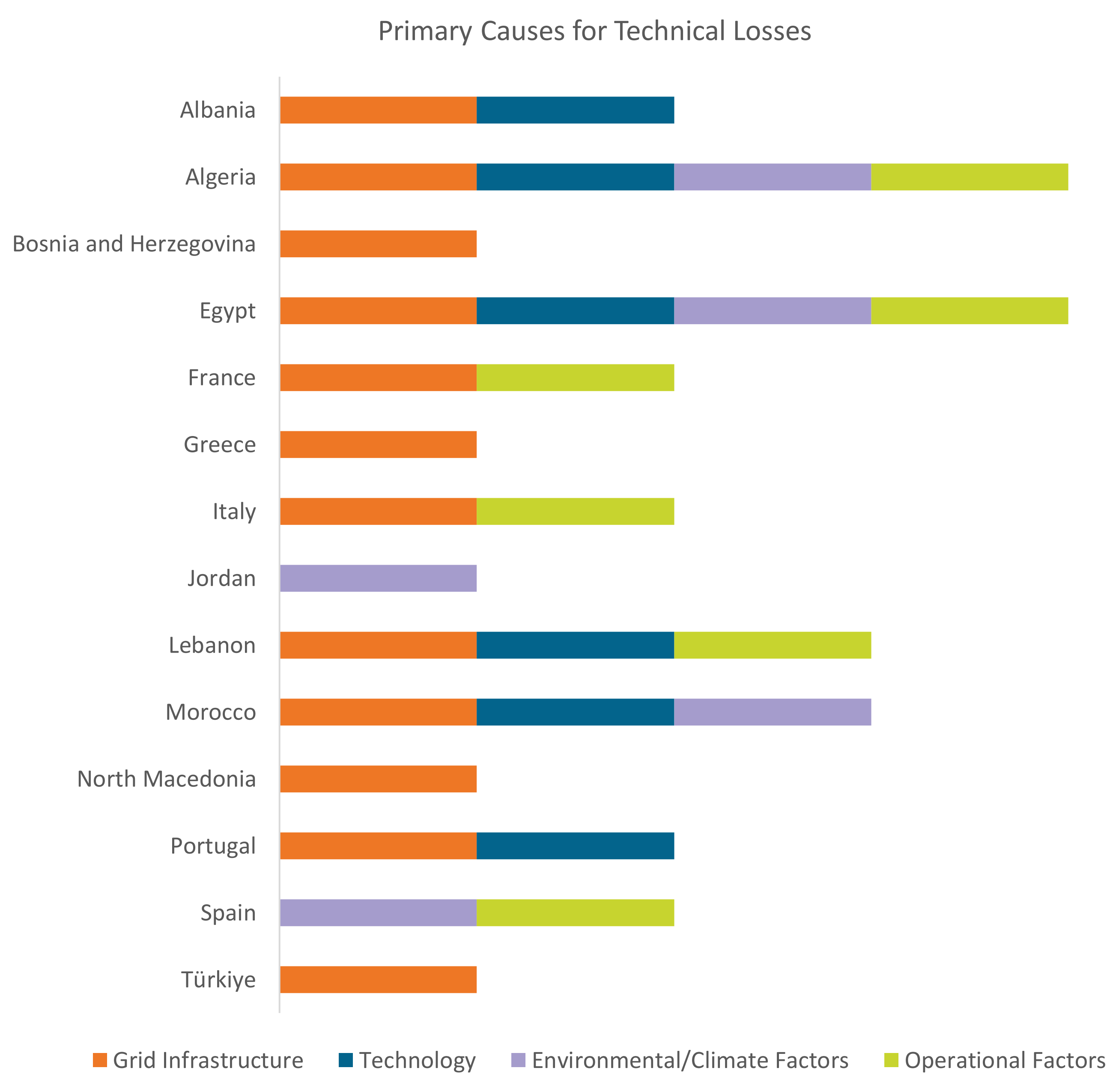

Figure 2 - Primary Causes of Technical Losses

2.2.2 Calculation Methods

Using an energy balance model is the most common and direct approach. Countries like **Albania**, **Algeria**, and **Bosnia and Herzegovina** calculate TLs as the difference between energy input and output at a network element or system-wide level. This method is practical for high-level reporting and is used by both Transmission System Operators (TSOs) and Distribution System Operators (DSOs). For instance, **Albania's** TSO and DSO Code specifies that TLs are the difference between energy injected into and measured energy exiting from a single network element.

More advanced methods go beyond a simple balance to estimate and model TLs. **France** employs a quadratic formula, which is a sophisticated approach that models losses based on load and seasonal coefficients. This method is more precise as it accounts for varying conditions that impact losses throughout the year. **Egypt**'s Distribution Companies (DISCOs) use a sampling approach, applying a losses calculation programme to specific network clusters and then extrapolating those results to the entire network to determine losses for different voltage levels. This methodology enables loss estimation without the need for comprehensive real-time metering across the entire grid.

Italy has a unique approach, which sets "standard technical losses" as fixed, predetermined values per voltage level (e.g., 1.8% for HV lines, 3.5% for MV lines, and 7.8% for LV lines), based on estimates and used for settlement purposes. This method provides a clear and stable benchmark for regulatory compliance, moving away from complex, real-time calculations. By setting a fixed loss factor, the regulator simplifies the incentive structure for utilities, encouraging them to operate below this benchmark.

For gas networks, the calculation methods are more varied due to the nature of the losses. In **Italy**, for instance, TLs are calculated by the TSO based on component-specific emission factors and utilisation rates, reflecting a highly detailed, engineering-based approach. In **Spain**, a broader balance is used, where the difference between inputs and outputs (after considering self-consumption) is used to determine total losses, which includes both technical and non-technical components. **North Macedonia** simplifies this by recognising allowed TLs up to a fixed percentage of the total gas entering the system (0.5% for transmission, 0.7% for distribution). In **Egypt**, TLs are included in the broader category of UfG, calculated as part of the daily network balance. The Network Code provides the following formula for the commercial balance of the entire network:

$$I+S=O+C+UfG$$

where I is the quantities injected/delivered by the shipper at entry points, S is the quantities from storage (if storage exists), O is the offtakes by the shippers at exit points, C is the TSO consumption (e.g. gas used for compressor stations, pre-heating), and UfG the accounted gas (TLs and line-pack changes, representing about 0.8% of any gas quantity injected into the network).

Spanish Case

In **Spain**, Circular 6/2019, issued by the CNMC, establishes the methodology for determining the remuneration of companies engaged in electricity distribution. This aims to ensure the adequate provision of electricity services, promote improvements in supply quality, and reduce losses in distribution networks. It applies objective and uniform criteria throughout the Spanish territory while seeking to minimise costs to the system.

The following formula includes the energy losses in each network and is used to financially compensate each company. The result of the formula is not energy, but within the formula, the lost energy is introduced for this economic retribution.

This formula includes TLs and NTLs.

$$
\begin{aligned}
{E_{perd}}^{i}_{p,n-2} = \sum_{pf,j} E^{p,i}_{pfGD,n-2,j} \cdot \left(1 + C^{p}_{j+1,n-2}\right) + \sum_{pf,j} E^{p,i}_{pTD,n-2,j} \cdot \left(1 + C^{p}_{j,n-2}\right) \\
- \sum_{cons,j} E^{p,i}_{cons,n-2,j} \cdot \left(1 + C^{p}_{j,n-2} + CZ^{i}_{j}\right)
\end{aligned}
$$

$E^{p,i}_{pfGD,n-2,j}$ energy, expressed in kWh, measured during the tariff period p of year n-2 at each of the pf generation-distribution and distribution-distribution border points, considering the generation of all technologies, at each voltage level j for the distribution company i.

$E^{p,i}_{pTD,n-2,j}$energy, expressed in kWh, measured during the tariff period p of year n-2 at each of the transmission-distribution frontier points pf, at each voltage level j for the distribution company i.

For these purposes, the energy that enters the networks of the distribution company and at each of its border points with networks of other distribution companies, generation points, and transmission networks is considered with a positive sign, and the energy outgoing through these points with a negative sign.

$E^{p,i}_{cons,n-2,j}$energy, expressed in kWh, measured in the consumer's meter during the tariff period p of year n-2 of each of the consumers connected to the voltage level j of the distribution company's networks i.

$C^{p}_{j,n-2}$ is the standard coefficient of losses of the tariff period p in force in year n-2 for the elevation to central bars of the energy of each type of consumer according to the voltage level j or for the elevation to power plant bars from the generation-distribution, transport-distribution, and distribution-distribution border points of company i. These standard loss coefficients will be those set out in the circular of the CNMC establishing the methodology of tolls for the transmission and distribution of electricity.

CZ_j^i is the zonal correction coefficient applicable to each distribution company i, calculated according to the percentage of supplies connected to its networks in each distribution area, as per the following formulation:

$$CZ^i = \sum_z K_z \left(\frac{CUPS_z^i}{CUPS_T^i} \right)$$

Where:
i is the distribution company to which the incentive applies.
z is the distribution area considered, according to the classification established in article 99 of Royal Decree 1955/2000, of 1 December:

- U: Urban area.
- SU: Semi-urban area.
- RC: Concentrated rural area.
- RD: Dispersed rural area.

$CUPS_z^i$ is the number of supplies of company i in zone z.

$CUPS_T^i$ is the number of total supplies connected to the company's networks.

K_z is a coefficient of correction in zone z.

2.3 NON-TECHNICAL LOSSES

NTLs are a significant challenge for utility companies and regulators, as they represent lost revenue and can strain grid stability. Unlike TLs, NTLs are a result of human actions and administrative failures.

2.3.1 Primary Causes

Replies to the questionnaire reveal a strong consensus that the primary cause of NTL is the human element, specifically **theft and fraud**. Every country that responded to this question cited this as a primary cause. This includes a range of illicit activities such as illegal connections, meter tampering, and bypassing of meters. The main causes were identified and defined as follows:

Theft and Fraud: This is the most overt cause of NTLs. Theft occurs when power is taken illegally from the network, usually by bypassing the official meter entirely through unauthorised connections (often called "hooking" or "illegal tapping"). The consumer receives completely free power. Fraud, by contrast, is typically committed by registered customers who deliberately manipulate their electricity meters—perhaps with magnets, tampering with internal components, or interfering with meter programming—to slow down the meter's rotation or stop it altogether. In essence, they trick the utility into recording a usage far lower than their actual consumption. Both of these are criminal acts that directly rob the power company of rightful revenue.

Billing and Metering Issues: This category includes losses that stem from inaccuracies in measuring and recording consumption. Metering issues arise when the device meant to track energy use is faulty. This could be an ageing meter that has lost its calibration, an error in setting up the transformer ratios connected to the meter, or simply human error during the actual meter reading process (recording the wrong number). Further, billing issues cause losses when the utility's system generates an incorrect bill due to software glitches or administrative mistakes. The resulting loss also includes a simpler but costly problem: billed energy that is never paid for by the customer, which becomes a commercial write-off for the utility. Countries like **Egypt, Morocco** and **Portugal** explicitly highlight these issues. **Spain** notes that NTLs in gas networks primarily arise from "data handling issues."

Administrative and Management Issues: These factors are internal weaknesses in the utility company that enable NTLs to flourish. A primary problem is poor record-keeping, where inaccurate or outdated customer and grid data make it impossible to conduct an accurate energy balance and pinpoint where the losses are occurring. Coupled with this is a failure of audits and enforcement, meaning meters are rarely checked, and when theft or fraud is detected, the utility lacks the legal resources or political will to follow through with prosecution. The most corrosive administrative issue is employee corruption, where utility staff deliberately collude with customers to manipulate meter readings or issue fraudulently low bills in exchange for bribes, directly subverting the system from the inside. **Egypt** points to this as a significant contributor.

Socio-Economic Factors: These are the broader societal pressures that drive non-compliant behaviour. High levels of poverty and unemployment are critical factors, as many citizens simply cannot afford to pay the legally mandated tariffs. When the price of electricity is perceived as too high or unjust, a section of the population may feel morally justified in engaging in theft or fraud. This is often exacerbated by poor utility-customer relations, where the utility’s unreliable service or a perceived lack of fairness leads to a lack of public cooperation. Finally, in areas with informal housing or rapid, unauthorised development, the utility often cannot install legal, metered connections, which forces unauthorised tapping of the grid and contributes to systemic losses.

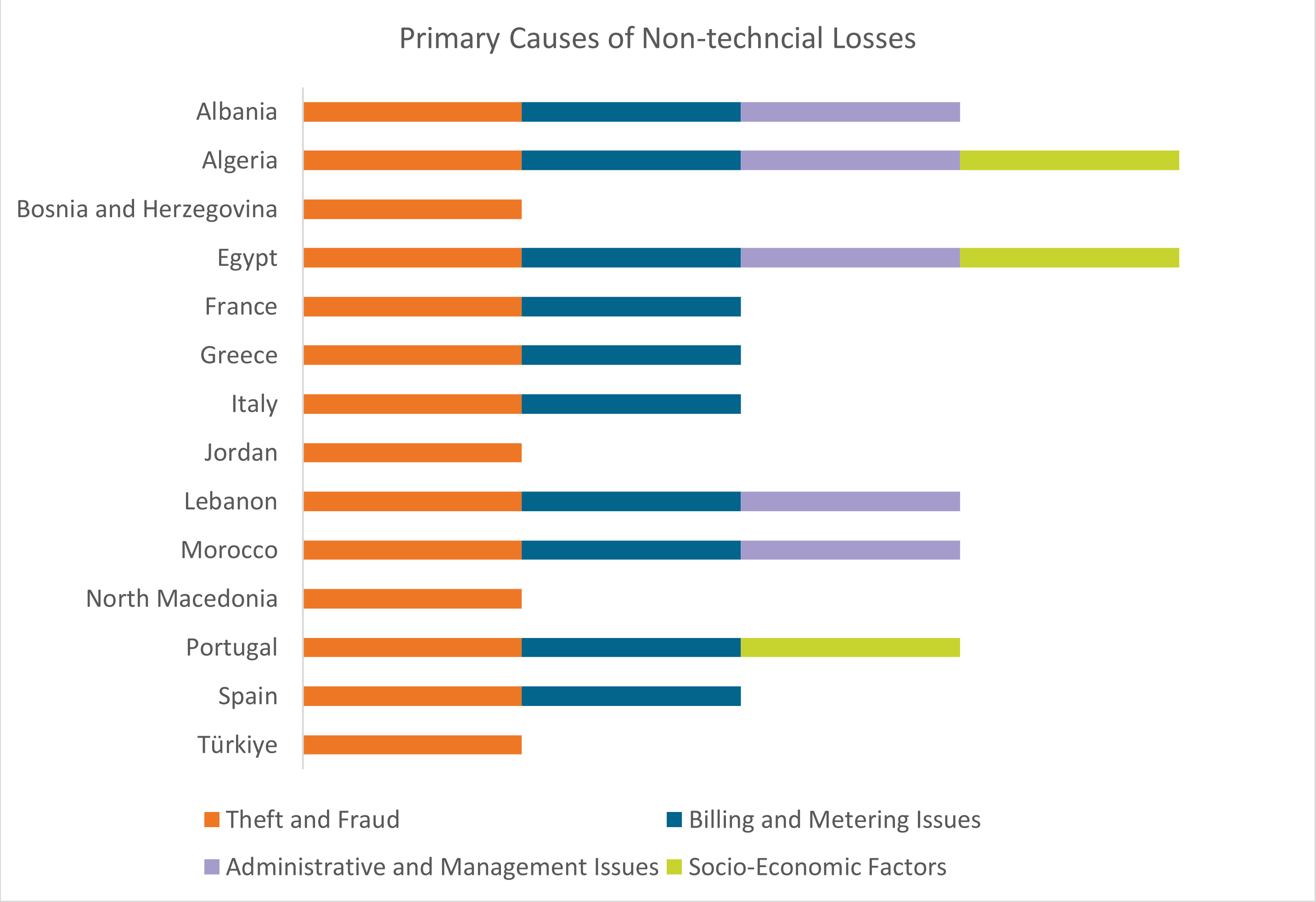

Figure 3 - Primary Causes for Non-Technical Losses

2.3.2 Calculation Methods

The most common method of calculating NTL is through a "residual approach," where NTL is the difference between total losses and calculated technical losses. **Albania**, **Egypt**, **France, Morocco** and **Portugal** use this method, which is also implicitly used by others.

$$\text{NTL} = \text{Total Losses} - \text{TL}$$

Italy adopts a more sophisticated approach by assigning regionally differentiated standard NTL values. This acknowledges that factors such as socio-economic conditions and the prevalence of illicit activities vary significantly from one area to another. For example, the standard NTL in northern Italy for LV consumers is 0.90%, whereas in the south, it is 4.87%, reflecting a clear disparity built into the regulatory framework.

For some countries, the focus is on legal prosecution rather than a purely quantitative calculation. **Greece**'s focus on defining electricity theft in a regulatory manual rather than a loss calculation formula highlights that the priority is to provide a legal basis to combat illegal acts. Similarly, **Türkiye** does not separate the two loss types but implements a performance-based punishment system for high losses and calculates specific penalty fees for illegal consumption, such as multiplying the estimated illegal consumption by a coefficient of 2 for the first offence and 2.5 for subsequent offences. This shows a strong emphasis on deterrence.

The case of Italy: Regional Approach to Non-Technical Losses

ARERA, the Italian Regulator, has developed a system that not only defines losses but also applies a nuanced, regional approach to their calculation and management, providing a unique insight into a potential best practice for other countries in the Mediterranean region.

Italy defines NTLs as related to "power theft, errors in metering, and billing and data management." This definition aligns with the consensus, but Italy's approach to calculation is what is unique. The country calculates "Standard non-technical losses" as the difference between "actual losses" (measured annually by subtracting withdrawals from injections) and a set of predetermined "standard technical losses." This pragmatic approach acknowledges the difficulty of precisely measuring each type of loss in isolation, using instead a residual method to quantify the overall impact of NTL.

The most distinguishing feature of Italy's approach is its recognition of the varying socio-economic conditions that drive energy theft. Instead of applying a single national value for NTL, Italy differentiates its loss factors by region. For example, the standard NTL factor for low voltage (LV) lines is significantly higher in southern Italy (4.87%) compared to the north (0.90%). This method explicitly links the prevalence of NTL to regional economic and social factors, providing a more accurate picture of the issue and enabling more targeted regulatory and enforcement strategies.

Italy's use of "standard loss factors" is also a key component of its regulatory toolkit. These factors, which include both TL and NTL, are set by ARERA as predetermined values per voltage level. These values serve a dual purpose: they are used for settling imbalances and for defining incentives that encourage distributors to actively reduce network losses. By creating a clear benchmark, the regulator provides network operators with a powerful financial incentive to invest in technologies and measures that can align their actual losses with or below the set standard, thereby improving overall network efficiency.

2.4 IMPACT OF RES AND ENERGY STORAGE

The integration of Distributed Renewable Energy Sources (RES) and Energy Storage Systems (ESS) has an unusual impact on technical losses. MEDREG member regulators reveal a nuanced understanding of this relationship, recognising both the significant potential for loss reduction and the new challenges that a decentralised grid can present.

2.4.1 Benefits of Proximity and Effect of Loss Reduction

There is a strong consensus among Mediterranean countries that have begun integrating RES technologies regarding their positive impact on TL. The core principle behind this benefit is the proximity of generation to consumption. Electricity produced from sources like rooftop solar panels or small-scale wind turbines reduces the need for power to be transported over long distances from large, centralised power plants. This directly minimises the amount of energy dissipated as heat in transmission and distribution lines, which is the primary cause of resistive losses. However, it needs to be mentioned that the positive proximity effect works only with small scale RES.

Countries such as **Albania**, **Bosnia and Herzegovina**, and **Egypt** confirm this benefit. **Jordan** echoes the same, stating that RES and ESS help to reduce losses by "decreasing dependency on the national grid and minimising energy dissipation in transmission lines." Residential photovoltaic (PV) systems can alleviate the load on local distribution networks during periods of high solar generation, preventing the overloading of transformers and feeders. This contributes to improving grid stability and enhancing energy distribution efficiency.

2.4.2 Bidirectional Flow Problems and Effect of Loss Increase

While the potential for loss reduction is clear, a crucial counterargument is presented by countries with high RES penetration. **Italy** highlights that high-penetration RES can lead to a significant challenge: **reverse power flows** on low-voltage networks.

In a traditional grid, power flows in one direction, from the high-voltage transmission network down to the low-voltage distribution network and finally to consumers. However, the widespread adoption of distributed generation means that power can flow in the opposite direction, from residential buildings back up to the grid, particularly during times of low local consumption and high solar output. This bidirectional flow can stress network elements that were not designed to handle it. The non-optimal loading of network components, such as transformers and lines, can lead to new losses that are not present in the traditional one-way system. The integration of distributed generation introduces a critical challenge through reverse power flows. As various responses from MEDREG's member National Regulatory Authorities (NRAs) note, this bidirectional flow can increase TL if the existing grid infrastructure is not adequately designed or managed to accommodate it. Beyond these physical losses, reverse power flows also induce significant voltage fluctuations, a factor that further complicates grid management, reduces power quality, and diminishes overall system efficiency. These responses underscore a critical lesson for other countries in the region: while RES and ESS offer a pathway to a more sustainable energy future, their integration must be carefully managed with infrastructure upgrades and smart grid technologies to ensure that the benefits of loss reduction are realised without introducing new forms of inefficiency and instability.

North Macedonia, which has been rapidly deploying new PV capacity, acknowledges that the widespread and often uncoordinated integration of residential RES and storage systems introduces reverse power flows and voltage fluctuations. These conditions can create non-optimal loading of network elements, potentially increasing TL if the grid is not adequately designed or managed. Similarly, **Portugal** recognises that the impact of self-consumption in residential buildings is the reduction of losses resulting from the fact that this energy no longer needs to circulate through the grid, but observes that the phenomenon is still under study.

2.5 FREQUENCY OF MEASUREMENT

The regularity of loss measurement is a critical indicator of the commitment of the regulator and the utility to grid efficiency. The replies to the MEDREG questionnaire reveal a range of practices, from routine annual reporting to more granular, real-time monitoring, with a clear trend towards more frequent data collection enabled by innovative technologies.

The most widespread practice across the region is annual measurement. This is adopted by **Egypt**, **Greece**, **Italy** (for electricity, losses are reported annually for the incentive mechanism, while energy injections and withdrawals are mostly measured on a quarter-hour or one-hour basis), **Jordan**, **Lebanon**, and **Portugal**. The primary advantage of this approach is its **simplicity and consistency**. It provides a stable, yearly benchmark for reporting and regulatory purposes, allowing utilities and regulators to track long-term trends in losses and providing a straightforward basis for performance-based regulations and tariff setting. For instance, the annual documentation of losses is essential for **Egypt** to monitor the performance of its DISCOs, and in **Portugal**, it provides the foundation for its regulatory framework. This frequency is less resource-intensive, making it a viable option for countries with less advanced metering infrastructure. However, the key disadvantage is the **lack of timeliness**. Annual data cannot capture rapid changes or pinpoint the precise timing of an anomaly, making it challenging to respond quickly to a surge in non-technical losses, for example.

In contrast, several countries are moving towards more frequent snapshots of grid performance. **Bosnia and Herzegovina**, **Morocco**, and **Türkiye** measure losses on a monthly or quarterly basis. The clear advantage here is **improved responsiveness and operational insight**. This more frequent data provides a dynamic view of the grid's health, allowing for quicker identification of anomalies or emerging issues. For example, quarterly data in **Morocco** can help identify seasonal trends or the impact of specific events on losses. This enables a more proactive approach to both technical and non-technical issues. However, the disadvantage is the **increased cost and complexity** of data collection, processing, and analysis.

France adopts a compromise: losses are measured monthly but reported on and analysed annually.

Some countries are moving towards even more granular, real-time measurement, particularly for gas networks. **Italy**, for instance, calculates gas losses daily. The primary advantage of this is **maximum operational control and immediate response**. It enables utilities to identify and respond to losses almost as they happen, which is critical for safety and efficiency in gas networks where leaks can be dangerous. The balance for gas in **Spain** is also calculated monthly and annually, highlighting a hybrid approach that combines frequent operational checks with periodic official reporting. The major disadvantage, however, is the **significant investment in advanced metering and data management systems** required to support this level of granularity.

The varying frequencies of measurement reflect the various stages of digital grid transformation and the specific regulatory priorities of each country. A shift towards monthly or even daily measurement is a clear signal of a move towards a more proactive and data-driven approach to loss management, allowing regulators to intervene more quickly to address both technical and non-technical issues.

Chapter Analysis

Findings highlight a shared understanding of the problem of power losses, but significant diversity in regulatory and technical approaches, mostly driven by national energy market maturity and specific infrastructural challenges.

Definitional Framework and Statutory Basis

- Consensus on Total System Losses: The fundamental definition of electricity losses across most countries (e.g. Bosnia and Herzegovina, Egypt, Portugal, Spain) is the Total System Loss, which is the difference between energy injected and energy measured and billed. This simple mass-balance approach forms the bedrock of regulatory oversight.
- The Technical/Non-Technical Split: A crucial distinction is made between TLs, which are the unavoidable physical dissipation of energy (e.g. I^2R losses, core losses in transformers), and NTLs (or Commercial Losses), which stem from external factors like theft, fraud, and administrative errors.
- Gas vs. Electricity Diversity: Gas loss definitions are less standardised. While the basic balance (injection vs. withdrawal) applies, gas regulations often segment losses into specific physical events (e.g. fugitive emissions in Italy) and the broader accounting term, UfG, which explicitly includes both administrative discrepancies and technical factors.
- Statutory Gaps: While most countries embed definitions in primary or secondary legislation (e.g. Türkiye's Electricity Market Law), a few (Greece, Lebanon, North Macedonia) lack a formal legal definition, instead managing the issue through regulatory commissions and operational codes.

Causes of Power Losses

1. Technical Losses TLs are consistently attributed to four main groups, emphasising the physical constraints of the grid:

- Grid Infrastructure: The most fundamental cause is I^2R resistive losses in conductors, which are exacerbated by older lines, small conductor sizes, and low voltage levels.
- Technology: Inefficient equipment, poor power factor, and harmonic distortion from non-linear loads increase dissipation beyond normal levels.
- Environmental Factors: External conditions like high ambient temperatures increase conductor resistance, and weather/pollution can lead to corona losses or leakage currents.
- Operational Factors: Poor system management, such as network imbalance and suboptimal network topology, leads to current flow along inefficient and loss-prone paths.

2. Non-Technical Losses

NTLs are a direct result of human and systemic failures.

- Theft and Fraud: Cited by every respondent as the primary cause, this includes illegal connections and intentional meter tampering.
- Billing and Metering Issues: This includes faulty or uncalibrated meters, incorrect meter readings, and administrative billing errors.
- Administrative and Management Issues: Internal utility weaknesses, such as poor record-keeping, lack of enforcement/audits, and employee corruption, allow NTLs to persist.
- Socio-Economic Factors: High poverty/unemployment and perceived high tariffs can drive citizens to engage in illegal consumption.

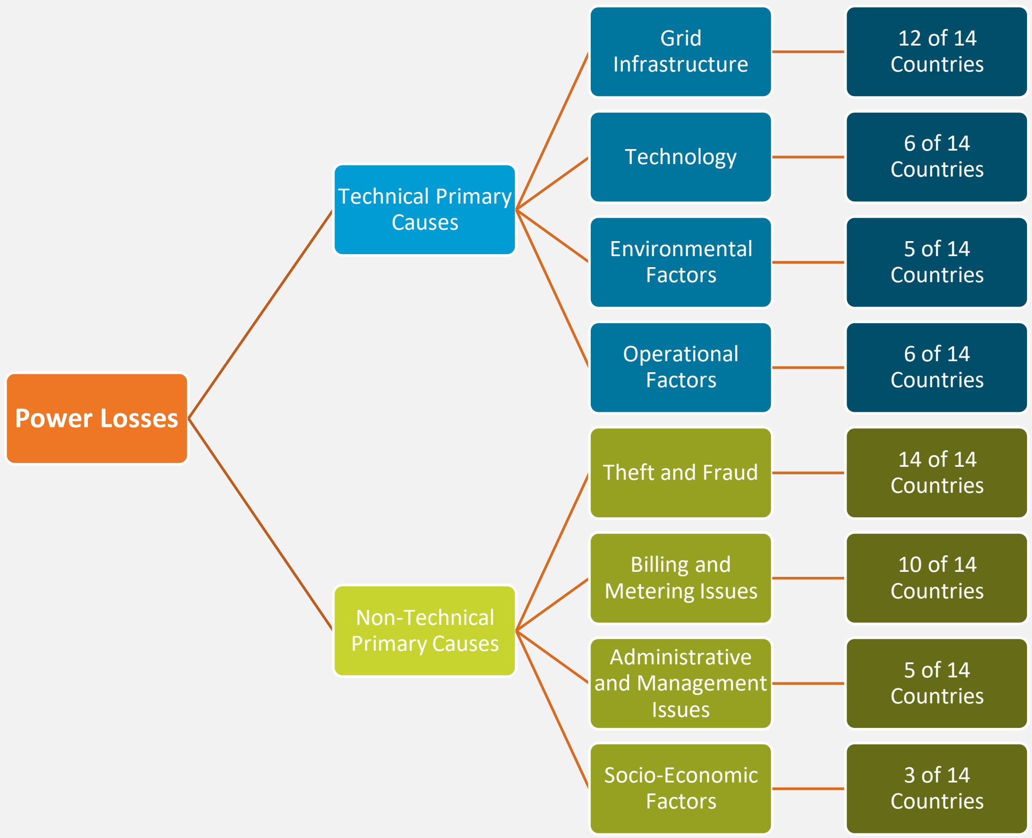

Figure 4 - Summary of Losses

Calculation Methods and Regulatory Innovation

The calculation methods for total losses range from simple to complex, with a clear regulatory divergence on how to handle the NTL component:

- Residual Approach (NTL): The most common method determines NTL as the difference between Total Losses and calculated TLs:

$$NTL = \text{Total Losses} - TL$$

- Modelling and Extrapolation (TL): More advanced methods include quadratic formulas (France) to model load/seasonal impacts and sampling approaches (Egypt) to extrapolate losses from specific network clusters.
- Fixed/Standard Loss Factors (Italy): Italy adopts a significant regulatory innovation by setting predetermined "standard technical losses" (e.g. 7.8% for LV lines) for settlement purposes. This creates a clear financial benchmark and a direct incentive for utilities to operate below this value.
- Regional Differentiation (Italy): Crucially, Italy further refines this by applying regionally differentiated standard NTL values (e.g. 4.87% in the South vs. 0.90% in the North),

explicitly linking regulatory benchmarks to varying socio-economic realities and theft prevalence.

Impact of RES/ESS

- Benefits of Proximity: Distributed RES and ESS can reduce TLs by placing generation closer to consumption, minimising the distance power must travel, and lowering line losses (confirmed by Albania, Jordan, Egypt).
- The Bidirectional Challenge: However, uncoordinated, high-penetration RES can increase technical losses and create instability. This is due to reverse power flows on low-voltage networks, which stress components and cause voltage fluctuations (highlighted by Italy and North Macedonia). This underscores the need for grid upgrades and smart management.

Measurement Frequency

The frequency of measurement practices ranges from the standard annual measurement (e.g. Egypt, Portugal) for simplicity and regulatory reporting to more frequent monthly/quarterly checks (e.g. Morocco, Türkiye) for improved responsiveness. By supervising and monitoring regularly the losses as a grid quality metric, Moroccan Regulator ANRE ensures the efficiency of the national electric network. Gas networks, driven by safety concerns, often use daily calculation (Italy) for maximum operational control.

3 REGULATORY LANDSCAPE FOR ENERGY LOSS REDUCTION

This chapter examines the range of regulatory frameworks and interventions designed to combat energy losses and fraudulent behaviour. It moves beyond the simple definition of losses to analyse the strategies, tools, and incentive mechanisms that govern utility and consumer behaviour. From direct, target-based approaches to sophisticated, performance-driven models, the analysis reveals a dynamic landscape of regulatory action. Ultimately, this chapter aims to provide a comprehensive overview of the current state of regulation, highlighting both the innovative solutions being implemented and the persistent challenges that regulators face in their ongoing efforts to create a more efficient and secure energy system.

3.1. MODELS OF REGULATION

This section provides an in-depth examination of the diverse regulatory frameworks and financial incentives employed by MEDREG member NRAs to combat TL and NTL. The analysis, drawing on the responses to the questionnaire from various regulators, reveals a spectrum of approaches, ranging from prescriptive, direct controls to more flexible, indirect market-based mechanisms. This strategic mix underscores a regional consensus that effective loss reduction requires a blend of regulatory oversight and economic motivation.

3.1.1. Varied Approaches

Regulatory frameworks can be broadly classified into **direct mechanisms**, which are prescriptive and target-oriented, and **indirect mechanisms**, which are more incentive-driven and flexible. The MEDREG region showcases a dynamic interplay between these two models.

Direct Mechanisms: The Target-Based Approach: In several countries, regulators favour a direct, top-down approach by setting explicit, fixed targets for loss reduction. This model is prominent in countries like **North Macedonia** and **Albania**, where a predefined "allowed" level of T&NTL is integrated into the utility's tariff. Any losses exceeding this threshold are not recognised as eligible costs, forcing the utility to absorb the difference. This system is straightforward and provides a clear, non-negotiable directive for utilities to improve their performance. It is particularly effective in regions with a history of high losses, as it establishes a baseline for required improvement.

Indirect Mechanisms: The Performance-Based Incentive Model: In a shift towards market-based regulation, several MEDREG members are adopting or exploring indirect, performance-based incentive models. **Spain** and **France** offer some of the most sophisticated examples of this approach. Their frameworks use a symmetrical or near-symmetrical incentive mechanism. In **Spain**, if a company's performance is better than the standard, it is rewarded with a financial bonus; if it is worse, it is penalised. In that regard, **Spain** compares a utility's actual losses to a sector-wide "standard" or "reference" value, while in **France**, the regulator freely sets the target. The bonus is a set share of the collective gain stemming from the system operator's overperformance, and the penalty a set share of the collective loss caused by the system operator's underperformance. This system encourages overperformance and continuous improvement, fostering a competitive environment among utilities. A key advantage of this model is that it benefits consumers in every case and incentivises the system operators to overperform and create more value for consumers.

Mixed Models: A Hybrid Approach: Many countries, including **Egypt**, **Jordan**, and **Bosnia and Herzegovina**, have adopted a hybrid approach, blending elements of both direct and indirect regulation. For instance, Egypt's framework combines direct mandates—such as setting performance targets and enforcing penalties for illegal connections—with indirect incentives, including encouraging the adoption of smart grids and promoting energy efficiency. Jordan's system is similar, setting an annual combined TL and NTL target of 12% while simultaneously using a smart meter rollout as a powerful indirect incentive to reduce losses. This pragmatic blend allows regulators to maintain control while also leveraging market forces and technology to drive efficiency.

3.1.2. Economic Incentives and Penalties

The financial incentives and disincentives in place are the primary drivers for utility action. They are designed to align the utility's business interests with the regulatory objective of minimising TL and NTL.

Rewarding Efficiency: Many regulators provide tangible financial rewards for utilities that excel in loss reduction, thereby rewarding efficiency. In **Albania**, for example, the Energy Regulatory Entity (ERE) applies an "efficiency improvement coefficient" to the DSO tariff when it successfully reduces losses to or below the approved target level. This acts as a direct revenue stream linked to performance. Similarly, in **Greece**, a sophisticated regulatory mechanism embeds the cost of energy losses into the DSO's revenue calculation, ensuring that effective loss management is a financially beneficial strategy, not just a regulatory obligation. In **Italy**, DSOs are allowed to retain a portion of the financial gains from reducing their actual losses below the standard levels, motivating improvement in grid management.

Meanwhile, in a "carrot and stick" terminology, the "stick" is used to **penalise poor performance**. For instance, in **Türkiye**, a performance-based reward/punishment system is in place, where underperforming utilities are financially sanctioned. The most striking example of a punitive mechanism is in **Türkiye's** gas sector, where a penalty for illegal consumption multiplies exponentially with each repeated offence, acting as a severe deterrent against recidivism. This approach highlights a clear distinction in how regulators view TL (often addressed through investment incentives) versus NTL (which are frequently treated with strict penalties).

Some regulators, however, are pioneering innovative state-of-the-art incentive schemes. **Portugal**'s framework, for instance, has evolved to include three components: a symmetrical mechanism based on the annual energy balance, a direct sharing of results from anti-theft actions, and a separate bonus/penalty for the success of these actions. This sophisticated design provides targeted incentives for both infrastructure efficiency and the active combat of illicit consumption. In **France**, the regulator has a layered approach, tackling both the volume of losses and the price of the electricity used to compensate for them. The French system is a graded system that incentivises efficiency while also protecting consumers from price volatility in wholesale energy markets.

3.2. OPERATIONAL TOOLS AND ENFORCEMENT MECHANISMS

This section moves from the policy level to the operational reality of combating TL and NTL, detailing the practical tools and enforcement mechanisms used by MEDREG members. It appears that across the Mediterranean region, there is a blend of traditional, on-the-ground interventions mixed with modern, data-driven strategies, reflecting the difficulties. This section showcases how regulators and utilities in the region are actively working to reduce losses, covering both the electricity and gas sectors.

3.2.1. Audits and Inspections

Physical audits and inspections remain a cornerstone of regulatory oversight and a primary tool for verifying compliance. Although sometimes not conducted directly by regulators, they serve as a crucial check on the overall health of the energy system and the integrity of a utility's operations. The practice is widespread, though the specifics vary by country. For instance, for both electricity and gas, regulators in countries like **Albania**, **Algeria**, and **Bosnia and Herzegovina** use systematic audits to scrutinise a utility's reported loss figures. This is not a mere formality but a critical part of the tariff-setting process, as utilities are required to justify their actual losses against an allowed level. This mechanism ensures utilities are held accountable for network efficiency and cannot simply pass on the costs of an inefficient network to consumers. In **Portugal**, the regulator ERSE monitors power losses through a meticulous energy balance, which is subject to regular audits and inspections in both the electricity and gas sectors. This level of scrutiny compels utilities to be transparent and accountable for their technical performance. For non-technical losses, on-site inspections are a vital, proactive tool. **Jordan** observes that field inspections are stipulated to detect illegal connections and tampered meters for both electricity and gas, an approach that is proactive and hands-on. Similarly, in **Morocco**, monitoring of TSO and DSO performance implicitly involves such operational checks for the electricity network. The sheer scale and complexity of NTL, which can involve everything from "cable hooking" to meter bypasses and tampering, make physical verification indispensable. As seen in **Türkiye**, a legal obligation for gas distribution companies to conduct annual meter checks is a systematic and national-level commitment to preventing fraud at the point of consumption, ensuring billing accuracy.

3.2.2. Enforcing Accountability

Beyond physical checks, penalties and sanctions serve as the enforcement mechanism of the regulatory framework. These are powerful deterrents for both utilities and perpetrators of theft. For utilities that fail to meet loss reduction targets, a common financial penalty is the non-recognition of costs for losses that exceed approved levels. As detailed in the previous section, countries like **Albania**, **North Macedonia**, and **Italy** apply penalties by not allowing the utility to recover the costs of excess losses through tariffs. **French** consumers only cover part of it. This creates a direct financial incentive to invest in network upgrades and anti-theft measures for both electricity and gas. In **Bosnia and Herzegovina**, a utility's inability to justify its losses can impact its ability to recover costs through tariffs, a key component of its regulatory model. For individuals or businesses engaged in energy theft, the regulatory toolkit includes strict legal and financial penalties. The replies from **Jordan** and **Türkiye** confirm that theft of either electricity or gas can lead to fines and even criminal prosecution. The Turkish penalty system for gas is particularly severe, with a coefficient that multiplies exponentially for repeat offences, escalating the financial burden and serving as a strong disincentive for recidivism. In **Greece**, the framework allows for "overcompensation" from customers who have committed systematic energy theft, ensuring that the utility not only recovers the cost of the stolen energy but also recoups additional damages, a tool applied to both sectors. This legal and punitive framework is essential for transforming energy theft from a simple operational issue into a serious criminal offence with grave consequences.

3.2.3. Data-Driven Tools

The most significant evolution in loss management is the increasing reliance on data-driven tools, which represent a strategic shift from reactive, manual processes to proactive, predictive models. Regulators are using data to enhance their oversight and enforcement. For instance, **Egypt's** framework includes a formal complaints system to monitor customer reports, which can reveal patterns of suspected losses, and conducts regulatory reviews of billing and metering data to identify anomalies in both the electricity and gas sectors. The proliferation of smart meters, mentioned by **Egypt, France, Jordan**, and **Spain**, is a game-changer for both industries. These devices provide real-time consumption data, enabling utilities to detect sudden drops or irregular usage patterns that may indicate tampering or theft. The true power of this technology lies in its synergy with traditional enforcement. By analysing energy input at a distribution station against the total consumption recorded by downstream meters, utilities can identify an "energy imbalance" that points to non-technical losses. This enables them to target their physical inspections more effectively, moving from random checks to data-informed investigations. This strategic use of data is transforming the entire process of loss management and is becoming a cornerstone of modern regulatory frameworks in the Mediterranean region (see Chapter 4).

3.3. CHALLENGES AND GAPS IN REGULATORY FRAMEWORKS

This section critically analyses the main challenges and gaps identified by MEDREG members in their regulatory frameworks for TL and NTL. The responses reveal a consensus on several key obstacles, including technical limitations in measurement, systemic failures in legal enforcement, and broader institutional and social issues. This section highlights that while many regulators have implemented sophisticated frameworks, significant challenges remain in their effective implementation and enforcement.

3.3.1. Measurement, Monitoring, and Data Gaps

A primary challenge identified by most regulators is the fundamental difficulty in accurately measuring and monitoring losses. The inability to clearly differentiate between technical and non-technical losses represents a significant gap across both the electricity and gas sectors. As mentioned in earlier definitions, losses are sometimes measured as the total sum of energy that is unaccounted for. Regarding the Balkan countries, **Bosnia and Herzegovina** and **North Macedonia**, most utilities report only total losses, making it very difficult for regulators to design targeted and effective interventions, given that the source of the losses is hard to identify. In **Spain**, a similar challenge exists, as the regulatory framework does not discriminate between the two types of losses. Likewise, in **Türkiye**, it is considered difficult to distinguish them. This lack of clear distinction is a major barrier to strategic planning and the application of appropriate remedies. For the gas market in **Italy**, a scheme to enhance the quality of gas metering has been introduced; this aims to better understand the drivers behind UfG, which, as mentioned, is a key metric for NTL. This highlights a targeted effort to close this specific measurement gap in the gas sector.

Worsening the challenge, outdated technology and data collection systems can sometimes be problematic. Many countries, including **Albania** and **Algeria**, still rely on manual meter reading, a process that is labour-intensive, prone to errors, and hinders the real-time detection of anomalies (among the causes assessed for NTL). **Egypt**, **Jordan**, and **Lebanon** pointed to a limited or slow rollout of smart meters and other real-time monitoring tools. For example, in Lebanon, the lack of modern metering and data systems limits the country's ability to detect and address unauthorised consumption, while **Jordan** avers that its inaccurate loss calculations are due to outdated methods and insufficient historical data. **Portugal,** however, has used smart meters to measure the entry and exit points and at the borders between voltage levels. This demonstrates that while the problem is widespread, technological solutions are being implemented to overcome these data gaps in both the electricity and gas sectors. Notably, **Türkiye**'s response regarding gas highlights a unique issue: technical losses in gas are considered negligible and therefore not even defined in legislation, which could represent a gap in data collection and oversight.

3.3.2. Legal and Institutional Challenges

Beyond the technical hurdles, regulators face significant legal, institutional, and political challenges that undermine their efforts to reduce losses. The **inadequacy of legal and regulatory** frameworks constitutes a major gap. For instance, in **North Macedonia**, the national legislation does not explicitly distinguish between TL and NTL, which complicates strategic planning. **Algeria** identifies the absence of automated data collection systems as a gap, which increases reliance on manual processes and makes it harder to impose financial consequences on utilities. In **Morocco**, a key challenge is the introducing incentive-based regulation that includes quality indicators and tariffication, suggesting that the legal and institutional foundation for such a model is not yet fully in place. Similarly, **Italy**'s response highlights that its standard loss recognition, while a step forward, does not fully capture a company's actual performance, indicating a gap between the regulatory design and its real-world application. For gas, **France** points to a major development, the EU's adoption of Regulation 2024/1787, which aims to reduce methane emissions and is expected to improve the monitoring of gas leakages. This underscores the importance of a top-down legal approach to address a key technical loss challenge.

Further, the weak enforcement capacity and slow legal processes are recurring issues. In **Bosnia and Herzegovina**, while anti-theft provisions exist, enforcement is inconsistent, and many cases go unpunished due to slow administrative and legal processes. This is a widespread problem across many jurisdictions, as prosecuting utility theft can be a lengthy and resource-intensive process, often falling outside the direct purview of energy regulators. **Spain** and **Portugal** also allude to this, with **Portugal** observing that while unauthorised consumption (fraud) requires quicker intervention, the authority to act does not belong to the energy regulatory body. This highlights a fundamental jurisdictional gap that can hinder swift action against theft.

Finally, the lack of consumer engagement and public awareness is a notable and often overlooked challenge. As stated by **Bosnia and Herzegovina**, public understanding of the impact of NTL is low, and there is no systematic programme for involving consumers in detecting theft. This is a significant gap, as widespread public knowledge and cooperation could be a powerful tool for reducing losses. The replies collectively suggest that without reforms that promote standardised loss definitions, better measurement systems, and more robust collaboration with legal institutions, a significant gap will remain in the effective regulation of energy losses across the Mediterranean region.

Chapter Analysis

The main finding in this chapter is that effective loss reduction requires a strategic mix of prescriptive mandates, performance-based incentives, and data-driven enforcement, all facing significant institutional and technical hurdles.

Diverse Regulatory Models & Financial Drivers

The region employs a spectrum of regulatory models:

- Direct (Target-Based): Prescriptive, fixed targets in the tariff (Albania, North Macedonia). Focuses on mandatory improvement.
- Indirect (Incentive-Based): Symmetrical reward/penalty systems tied to performance versus a standard (Spain, France). Encourages continuous efficiency and benefits consumers.
- Hybrid Models: Blending direct mandates with indirect incentives (Egypt, Jordan).

These models are enforced by strong financial drivers ("carrot and stick"):

- Rewards: Efficiency improvement coefficients or retention of gains for overperformance (Albania, Italy).
- Penalties: Financial sanctions for underperformance, often through non-recognition of excess loss costs in tariffs (Türkiye, North Macedonia).

Enforcement Tools: Bridging the Gap from Policy to Practice

Operational measures rely on a mix of the old and new:

- Traditional Checks: Physical audits and on-site inspections remain critical for verifying reported figures and detecting NTL (Jordan, Portugal).
- Accountability: Strict sanctions and escalating penalties for utilities and perpetrators of theft (Türkiye's exponential gas penalty; Greece's "overcompensation").
- Data-Driven Shift: The rise of smart meters and energy imbalance analysis (Egypt, Spain, France) enables utilities to move from random checks to targeted, proactive investigations.

Persistent Challenges and Gaps

The effectiveness of these schemes is severely limited by:

- Measurement Gap: The fundamental inability to accurately differentiate between TL and NTL (Bosnia and Herzegovina, Spain, Türkiye), which prevents targeted remedies.
- Technological Gap: Reliance on manual meter reading and slow smart meter rollout (Albania, Lebanon).
- Institutional Gap: Weak enforcement capacity, slow legal prosecution of theft, and a lack of clear jurisdictional authority between regulators and law enforcement (Bosnia and Herzegovina, Portugal).

Some of the observed trends include the following:

	Description	Implications
Shift to Hybrid Regulation	Most countries are adopting a mixed model, combining direct tariff control with indirect, performance-based incentives.	This acknowledges the necessity of both *control* and *market motivation* for sustainable loss reduction.
Symmetrical Incentives	There is a growing use of symmetrical mechanisms (bonuses for overperformance, penalties for underperformance).	The focus is shifting from merely meeting a threshold to encouraging continuous improvement and sharing the financial benefits with consumers.
Data-Driven Enforcement	There is increasing reliance on smart meters and data analytics to detect NTL.	This represents a strategic move from reactive, manual enforcement to proactive, predictive oversight in both electricity and gas.
Measurement Paralysis	The widespread difficulty in separating TL from NTL remains the top technical barrier (e.g. in Balkan countries and Spain).	The lack of data resolution prevents regulators from designing truly effective, source-specific interventions (e.g. should the utility invest in grid upgrades or anti-theft operations?).
Severity of NTL Penalties	Penalties for energy theft are increasingly severe and exponential (Türkiye's gas sector) compared to fines for high TL.	This highlights that regulators view NTL (fraud) as a criminal/deterrent issue, distinct from TL (an investment/efficiency issue).

4 Best Practices

The challenge of technical and non-technical losses is a shared concern across the Mediterranean region, with regulators and utilities implementing a diverse and increasingly sophisticated range of initiatives to enhance the efficiency, safety, and financial sustainability of their energy networks. The replies from MEDREG's member regulators reveal a strategic, multi-faceted approach that combines traditional infrastructure modernisation with cutting-edge technologies, proactive regulatory innovation, and targeted social campaigns. Specifically, these replies highlight a clear trend towards the adoption of sophisticated, data-driven technologies to combat power losses. Beyond the foundational infrastructure upgrades, regulators and utilities are increasingly leveraging smart grid components, Advanced Metering Infrastructure (AMI), and data analytics to gain granular control and insight into their networks. This section details these successful interventions, categorising them into four key areas, with a deliberate focus on both electricity and gas where replies provided information, and explores these innovative technologies, identifying common strategies and unique approaches adopted by countries in the region.

4.1. TECHNOLOGICAL UPGRADES AND SMART INFRASTRUCTURE

A central theme among the replies, particularly for electricity networks, is the strategic investment in technology to both reduce technical losses and combat theft. Several countries, including **Albania**, **Algeria**, and **Egypt**, have prioritised large-scale infrastructure modernisation. This includes the rehabilitation and upgrading of distribution networks, the replacement of overloaded transformers, and the reinforcement of electrical cables. These actions are fundamental to reducing TL by improving the physical integrity of the grid and minimising energy dissipation. Algeria's distribution company, for example, has invested in targeted transformer upgrades and line replacements to optimise voltage, a classic method for ensuring that energy is transmitted with minimal loss. Similarly, Egypt has introduced smart grid pilot projects to enhance real-time monitoring and management, a foundational step towards a more efficient and responsive network.

The implementation of smart metering is a particularly prominent and successful initiative for addressing non-technical losses. **France**, with its widespread Linky smart meter rollout, provides a compelling case study of the economic benefits. The project has already reduced NTL by 2.2 TWh per year, generating significant annual savings. This success demonstrates the power of advanced metering to not only provide accurate billing but also to automatically detect anomalies indicative of fraud or tampering. Similarly, **Jordan** is leveraging a nationwide smart meter rollout, complemented by SCADA (Supervisory Control and Data Acquisition) systems, to gain real-time insights into consumption patterns and identify irregularities.

In **Lebanon**, despite the profound challenges facing its power sector, Électricité du Liban (EDL) has successfully piloted smart metering and established a digital control centre. These initiatives, supported by external donors, have enabled real-time consumption monitoring and fault detection, proving effective in pinpointing illegal connections and meter tampering. The initial success of outsourcing meter reading, billing, and collection to private companies also showcased how improved data accuracy and accountability can lead to a significant, if not always sustained, reduction in NTL.

4.2. REGULATORY AND FINANCIAL REFORMS: INCENTIVISING EFFICIENCY

Beyond technological upgrades, regulatory bodies across the region are implementing proactive and financially driven incentive mechanisms. These reforms encourage utilities to invest in loss reduction by directly linking their performance to financial outcomes. **Greece** and **Portugal** both highlight the use of **incentive regulation** to reduce power losses. This approach rewards DSOs for exceeding loss reduction targets, creating a powerful financial motivation to invest in efficiency and loss-reducing measures.

Italy's regulator, ARERA, it is completing a reform to introduce starting from 2027 a forward-thinking approach that better aligns recognized losses with actual operational conditions. Under this model, end customers purchase electricity with a standard technical loss factor, while the DSO is responsible for the difference between actual and standard technical losses. This cost is then subject to a price cap, incentivizing the DSO to improve operational efficiency and minimize losses beyond the standard allowance. This model is a sophisticated way to manage losses in a liberalized market, ensuring that utilities are not simply passing on the costs of inefficiency to consumers.

In **Morocco**, losses are compensated in kind by renewable energy producers (liberalised market). Then, in its tariff decisions relating to tariffs for the use of the electricity transmission and distribution networks, the regulator ANRE sets a limit for these losses that must not be exceeded This approach encourages TSO/DSOs to reduce their losses and monitor them on an ongoing basis to improve their efficiency and benefit the consumer.

Türkiye has implemented a performance-based reward/punishment system that has led to a significant decrease in the country's average loss rate for electricity. This system creates clear accountability and a strong financial incentive for utilities to proactively manage and reduce losses. The gas sector in Türkiye also benefits from these measures, as distribution companies conduct frequent inspections in areas with high illegal consumption and check on customers with abnormal usage patterns, demonstrating a proactive stance on NTL for both energy carriers.

A particularly innovative regulatory reform was highlighted by **North Macedonia**. Faced with the increasing complexity of energy flows from prosumers and decentralised generation, the regulator transitioned from a percentage-based loss approval model to one based on **absolute values of energy losses**. This shift provides greater accuracy, transparency, and regulatory control, as it accounts for the fact that losses do not decrease proportionally with a reduction in imported energy.

This approach is a critical evolution for a modernising grid with bi-directional power flows and highlights a regulatory understanding of the changing dynamics of energy networks.

4.3. TARGETED ANTI-THEFT AND AWARENESS CAMPAIGNS

Non-technical losses are often linked to social and economic factors; consequently, several countries have launched direct campaigns to combat them. **Albania**, as part of its broader sector recovery efforts, has initiated targeted **anti-theft and anti-corruption campaigns** alongside infrastructure upgrades. These campaigns are crucial for addressing the root causes of electricity theft and fostering a culture of compliance.

In the gas sector, both **Portugal** and **Spain** report that network operators have developed specific campaigns against fraud, which include in-depth metering inspections and the distribution of informational leaflets to consumers. These efforts underscore the importance of direct consumer engagement and education in preventing fraud.

Egypt has gone a step further with robust **judicial seizure campaigns** to penalise electricity theft, demonstrating a strong legal commitment to enforcement. This is complemented by consumer awareness campaigns by EgyptERA to inform the public about the financial and legal consequences of illegal consumption. **Jordan** has combined legal and physical reforms to address theft, upgrading its connection system in high-theft areas to make illegal tapping of low-voltage lines more difficult and dangerous. This multi-pronged strategy—combining legal, social, and technical deterrents—has proven highly effective. Similarly, in **Morocco**, utilities have implemented targeted anti-fraud campaigns to curb theft and rehabilitated meters to reduce NTL, supported by the deployment of high-performance information systems to identify and manage fraudulent activity.

4.4. COLLABORATIVE AND DATA-DRIVEN APPROACHES

The most successful initiatives often combine multiple strategies, relying on data analytics and cross-stakeholder collaboration. In **Algeria**, the energy regulator (CREG) conducts performance audits to hold utilities accountable. The development of a centralised platform to unify customer records and track consumption has been a key initiative, providing the data necessary to monitor and manage losses effectively.

In **France** and **Portugal**, the main distribution network operator employs a sophisticated data analytics approach. They intensify on-the-ground actions based on identifying critical, high-loss areas and apply an algorithm that combines consumption variation with smart meter events to generate fraud alerts. This highly effective, data-driven approach allows utilities to focus their resources on the most problematic areas.

4.5. ADVANCED METERING INFRASTRUCTURE (AMI) AND SMART GRIDS

AMI is at the forefront of the technological push to reduce both technical and non-technical losses. The deployment of **smart meters** is a shared strategy across numerous countries, including **Bosnia and Herzegovina**, **Egypt**, **France**, **Greece**, **Italy**, and **Morocco**. These meters enable two-way communication between the utility and the consumer, providing real-time data crucial for effective loss management.

For **Albania**, a multi-pronged metering strategy is in place. It combines the installation of smart meters in high-loss regions with Automated Meter Reading (AMR) devices at substations and for high-voltage customers. This comprehensive approach ensures complete control over energy flows, from the high-voltage transmission level down to the end consumer, making it easier to pinpoint exactly where losses are occurring.

Egypt and **Jordan** are actively rolling out smart meters as a key component of their broader **smart grid** development. These smart grids, equipped with SCADA systems and automated distribution controls, enable real-time monitoring and management of electricity flows. This real-time visibility is essential for quickly identifying and isolating faults that cause TL and for detecting the irregular consumption patterns associated with NTL. Similarly, **Portugal** is using smart meters to generate alerts based on consumption variations, which helps to identify potential theft.

In the gas sector, both **Portugal** and **Spain** are using or considering smart metering. While gas losses differ from electrical losses—primarily stemming from leaks and unmetered consumption—smart meters for gas can provide accurate, real-time consumption data, enabling utilities to identify discrepancies that may indicate theft or unreported usage.

4.6. DATA ANALYTICS, AI, AND SPECIALISED TOOLS

The true power of smart meters lies in the data they generate. Utilities are increasingly turning to advanced **data analytics** and **artificial intelligence (AI)** to process this vast amount of information. This is a crucial step beyond simply collecting data; it is about making sense of it to identify previously undetectable patterns.

France, for example, has established dedicated teams and algorithms to monitor meter data and detect suspicious behaviour, such as a sharp decrease in consumption after a meter has been physically opened. Such sophisticated analysis goes beyond simple alerts to proactively identify and flag fraudulent activity. Similarly, **Egypt** is using data analytics to identify anomalies and theft patterns, while **Jordan** is integrating AI to enhance its theft detection capabilities.

Morocco and **Portugal** are also leveraging data analytics. Moroccan utilities are using high-performance information systems to manage and conduct anti-fraud campaigns. Portugal's approach is highly targeted, using algorithms that combine consumption data with events from the measurement equipment to generate precise alerts for on-the-ground action.

Besides data analytics, some countries are employing other innovative tools. **Egypt** is using **Geographic Information Systems (GIS)** to map its network and identify loss-prone areas, a visual and spatial approach that complements data-driven analysis. **Türkiye** is even using **drones** to detect illegal consumption, showcasing a creative and practical application of technology to patrol difficult-to-reach or high-risk areas. The use of drones provides a visual and physical means of verification, which can be invaluable in complex theft cases.

4.7. BEYOND TRADITIONAL TECHNOLOGIES

Some countries are exploring innovative approaches that extend beyond the standard smart grid and AMI framework. **Türkiye**, for instance, is using **Automatic Meter Reading Systems (OSOS)** and actively comparing incoming and outgoing energy flows in the distribution network as a foundational step to identify imbalances. This practical, network-wide approach serves as a high-level indicator of where losses are most significant.

In **Lebanon**, while a full AMI programme is being considered, the focus is also on broader, systemic improvements. The country's plans include rebuilding the National Control Centre (NCC) to ensure the proper functioning of the transmission system and a national campaign in collaboration with government ministries and the army to physically remove illegal grid connections. These efforts highlight that technology is only one part of the solution; it must be coupled with robust legal and operational frameworks to be truly effective. The Lebanese plan to deploy an AMI system would enable remote disconnect/reconnect actions, which would be a powerful tool for enforcing payment and combating theft.

Chapter Analysis

This chapter detailed a wide range of initiatives adopted by the NRAs and utilities of the Mediterranean region, equipping themselves with various strategies to address both technical and non-technical energy losses. These interventions appear innovative and embrace the rapid modernisation of energy markets.

Three major pillars define the regional strategy for loss management:

1. Technological and Data-Driven Proactivity

The most significant trend is the fundamental shift towards data-centric and proactive loss management.

- Widespread AMI Adoption: There is near-universal commitment to deploying AMI. Countries like France, Jordan, and Italy are leading rollouts to move from manual, reactive checks to real-time, continuous monitoring. This is seen as the foundational technology for reducing NTL by automatically detecting anomalies and improving billing accuracy.

- Leveraging Advanced Analytics: The focus has moved beyond simply collecting data to sophisticated algorithms and AI. Utilities (e.g. in France and Portugal) are using complex algorithms to combine consumption data with meter events to proactively predict and flag fraud, enabling highly targeted on-the-ground action and efficient resource deployment.
- Integration of Smart Grid Components: The deployment of smart meters is often coupled with broader smart grid initiatives, including SCADA systems and automated controls (Egypt, Jordan), to enhance network visibility and reduce TL by quickly identifying and isolating faults.

2 Regulatory and Financial Accountability

Regulators are moving from passive oversight to creating powerful financial incentives and enforcing cost accountability to drive utility investment in efficiency.

- Performance-Based Incentives: A common mechanism is the use of reward/punishment systems and incentive regulation (Türkiye, Greece, Portugal). This directly links a utility's financial performance to its success in reducing losses, creating a sustained financial motivation for continuous investment.
- Sophisticated Cost Allocation: Regulators are adopting models that prevent utilities from simply passing the cost of inefficiency on to consumers. Italy's ARERA model exemplifies this by holding DSOs financially responsible for the difference between actual and standard technical losses, making operational efficiency a mandatory financial concern.
- Sophisticated Cost Allocation: Regulators are adopting models that prevent utilities from simply passing the cost of inefficiency on to consumers. Italy's ARERA model exemplifies this by holding DSOs financially responsible for the difference between actual and standard technical losses, making operational efficiency a mandatory financial concern. For the Moroccan model, setting a loss ceiling by ANRE and injecting losses in kind by producers into the liberalised market makes TSOs/DSOs accountable for continuously reducing the level of losses in their networks.Modernising for New Energy Flows: The regulatory shift (e.g. North Macedonia's move to absolute value loss approval) reflects a necessary evolution to accurately manage losses in modern grids with complex, bi-directional power flows from decentralised generation and prosumers.

3. Multi-Dimensional Strategies

The most successful strategies are holistic, recognising that losses are not purely a technical issue but involve legal, social, and financial dimensions.

- Blending Enforcement and Awareness: Solutions combine strong legal action (e.g. judicial seizure campaigns in Egypt and targeted anti-theft campaigns in Albania) with consumer awareness and education efforts (Spain, EgyptERA). This addresses both the consequences and the root causes of NTL.

- Physical and Systemic Deterrents: Utilities are using physical reforms, such as upgrading connection systems in high-theft areas (Jordan), alongside systemic reforms like establishing centralised data platforms (Algeria) and improving metering accountability (Lebanon's outsourcing success) to make theft structurally more difficult and visible.
- Adopting Unconventional Tools: The use of specialised tools like GIS (Egypt) and drones (Türkiye) shows a willingness to step beyond traditional utility methods to gain unique insights and verification for enforcement.

The analysis demonstrates that loss management in the Mediterranean region is transforming from a reactive, manual process into a proactive and semi-automated one. The global perspective is the synergistic deployment of smart technology and sophisticated data analytics, carefully backed by regulatory frameworks that provide clear financial incentives and accountability.

5. CONCLUSION AND RECOMMENDATIONS

The analysis of power loss management in the Mediterranean region confirms that regulators and utilities operate with a sophisticated, yet often fragmented, understanding of the underlying causes and remedies for both TL and NTL. While the fundamental Total System Loss definition is standardised, the report reveals a critical divergence in effective management strategies, dictated by the complexity of separating the two loss types and the subsequent ability to apply targeted solutions.

The most significant analytical insight is the pervasive reliance on the residual approach (NTL = Total Losses – TL) for calculating non-technical losses. This method, while pragmatic given the limited metering infrastructure, poses a major regulatory obstacle. If utilities primarily report only total losses (as seen in **Bosnia and Herzegovina** and **North Macedonia**), regulators lack the essential data to discern whether high loss rates stem from an ageing grid (TL) requiring capital expenditure or systemic fraud (NTL) requiring legal enforcement and social campaigns.

This ambiguity hinders strategic capital allocation. A utility may be penalised for NTL when the problem is an inefficient, old network, or conversely, a problem of theft may be obscured by an inaccurate TL calculation, ultimately forcing consumers to absorb costs that could have been avoided through enforcement. The regionally differentiated NTL factors adopted by **Italy** represent a regulatory best practice, acknowledging that social drivers of theft necessitate non-uniform, area-specific benchmarks.

The shift from prescriptive, top-down regulation to performance-based incentive models (like the symmetrical reward/penalty systems in **Spain** and **France**) is a positive development. This change effectively transfers the risk of exceeding standard losses from the consumer to the utility. By allowing utilities to retain a portion of the gains from outperforming the loss benchmark, regulators create a strong, perpetual financial motivation for continuous improvement and investment in both grid hardening and anti-theft technologies. This contrasts sharply with models where allowed losses are simply factored into the tariff, offering little incentive for a utility to innovate or overperform.

Additionally, the widespread acknowledgment of Advanced Metering Infrastructure (AMI) as a crucial solution marks the future direction of loss management. AMI enables utilities to transition from reactive, periodic auditing to proactive, data-driven science. In that regard, real-time data collection enables the use of advanced analytics and AI to detect irregular consumption patterns far more effectively than manual inspections. The success of **France's** Linky rollout, which has shown billions of kWh in NTL reduction, validates this approach. Further, for gas losses, the focus on daily measurement and component-specific emission factors (e.g. in **Italy** and the **EU's** push to monitor methane emissions) indicates a similar trend towards granular, high-frequency monitoring for safety and efficiency.

On a different note, while RES and ESS integration offers the benefit of reduced technical losses by minimising energy transport distances, it simultaneously introduces new, non-traditional technical challenges. The risk of reverse power flows and voltage fluctuations, which is still under study in some EU countries, highlights a potential gap in our infrastructure. If the grid is not upgraded to accommodate this bidirectional flow, the perceived benefit of loss reduction can be offset or even reversed by new losses caused by system instability and the non-optimal loading of the network. This underscores that RES integration must be approached carefully and coupled with smart grid investments to ensure that sustainability goals do not compromise efficiency.

RECOMMENDATIONS

Based on the challenges and gaps identified, the following recommendations are crucial for advancing loss management in the Mediterranean region, focusing on data clarity, regulatory sophistication, system modernisation, and public action.

To facilitate targeted interventions, regulators must consider separate reporting of TLs and NTLs. This requires utilities to develop and report methodologies that clearly and separately quantify these figures, moving away from relying solely on total system losses. Concurrently, it is important to accelerate smart meter deployment. In that regard, NRAs must prioritise the full implementation of AMI in both electricity and gas networks, particularly in high-loss areas. This is the foundational technology for improving billing accuracy and enabling the real-time, data-driven detection of NTL.

To ensure regulatory precision, countries should consider adopting regional NTL benchmarking. Following **Italy's** example, regulators should develop and apply regionally differentiated standard NTL values. This move is essential for acknowledging and accounting for the varying socio-economic drivers of energy theft, resulting in a fairer and more accurate regulatory baseline. Further, it is necessary to strengthen legal and enforcement mechanisms. This involves collaborating with legal institutions to streamline the prosecution process for energy theft. Regulators should implement escalating financial penalties and ensure that anti-theft operations have the necessary legal and operational support, such as judicial seizure campaigns.

To ensure that renewable energy adoption promotes efficiency, regulators must invest in Smart Grid Upgrades. They should mandate and incentivise DSOs to invest in smart grid technologies and infrastructure upgrades necessary to manage bidirectional power flows safely and efficiently. This critical step will ensure that the integration of RES reduces, rather than increases, TL. Alongside physical upgrades, it is recommended to develop dynamic loss models. This encourages the adoption of advanced calculation methods, such as quadratic formulas or load-flow analysis, which can accurately account for the dynamic and varying conditions introduced by distributed generation and storage.

CONCLUSION AND RECOMMENDATIONS

Addressing the human element of NTL requires public action. Regulators must launch public awareness campaigns to initiate systematic efforts to educate consumers on the financial and safety impacts of NTL. This helps to foster a culture of compliance and encourages public cooperation in reporting illegal activities.

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