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Akıllı Şehirlerde Doğal Gaz Sayaçlarının Dönüşümünün Ekonomik Analizi

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Öne Çıkanlar

- Akıllı ultrasonik sayaçlar, ömür boyu 132,19 dolar tasarruf ve mekanik sayaçlara kıyasla 18,44'lük yüksek bir fayda-maliyet oranı sağlar.
- Bu sayaçların Türkiye genelinde kullanımı, yılda yaklaşık 720 milyon m³ doğal gaz tasarrufu sağlayabilir.
- Akıllı takip sistemiyle gaz kullanımı %9 azalır; bu da ulusal çapta 720 milyon dolar tasarruf demektir.
- Sistem, sağladığı doğrudan tasarrufla yatırım maliyetini 1,94 yılda amorti eder.

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Amaç
Bu çalışma, Türkiye'deki konutlarda kullanılan geleneksel mekanik ve yeni nesil akıllı ultrasonik doğalgaz sayaçlarının ekonomik ve çevresel performanslarını karşılaştırmaktadır. Çalışma, yüksek ilk yatırım maliyetlerine rağmen, akıllı sayaçların ölçüm hassasiyeti ve veri yetenekleriyle sağladığı uzun vadeli ekonomik uygulanabilirliği ve enerji verimliliğine katkısını ortaya koymayı hedeflemektedir.

Metot
Ekonomik değerlendirme sürecinde Bugünkü Değer (BD), Gelecekteki Değer (GD) ve Fayda-Maliyet (F/M) analizi yöntemleri kullanılmıştır. Enerji Piyasası Düzenleme Kurumu (EPDK) verilerine uygun olarak 14 yıllık bir ekonomik ömür ve yıllık ortalama 1000 m³ tüketim değeri baz alınmıştır. Hesaplamalarda %4 Minimum Cazip Faiz Oranı (MCFO) kullanılarak, Amerikan Doları ($) cinsinden bir yaşam döngüsü maliyet analizi gerçekleştirilmiştir. Ayrıca, tüketici davranışlarındaki değişimin tasarrufa etkisi literatür verileriyle değerlendirilmiştir.

Sonuçlar
Akıllı sayaçların, mekanik olanlara kıyasla ömür boyu 132,19 USD tasarruf sağladığı ve fayda-maliyet oranının 18,44 olduğu tespit edilmiştir. Türkiye genelinde bu teknolojiye geçişin, tüketici alışkanlıklarını değiştirerek yıllık %9 (720 milyon m³) doğalgaz tasarrufu sağlayacağı ve yatırımın 1,94 yılda kendini amorti edeceği hesaplanmıştır.

Anahtar Kelimeler: Akıllı şehir, Mekanik diyaframlı metre, Akıllı ultrasonik metre, ekonomik analiz.

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Research Article

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Economic Analysis of the Transformation of Natural Gas Meters in Smart Cities

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Highlights

- Smart ultrasonic meters yield 132.19 USD in lifetime savings per unit, demonstrating a superior benefit-cost ratio of 18.44 over mechanical meters.
- Implementing smart ultrasonic meters in Türkiye could save approximately 720 million cubic meters of natural gas annually.
- Enhanced consumer monitoring through smart technology leads to a 9% reduction in gas usage, totaling 720 million dollars in national savings.
- Initial investment costs for smart ultrasonic meters are recovered in just 1.94 years through direct consumption savings alone.

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Abstract: With the start of natural gas use in Türkiye, mechanical diaphragm meters were first used to measure consumption and are still widely used in Türkiye. However, mechanical failures, pressure losses and time-dependent aging occur in mechanical diaphragm meters due to friction inside the meter. This situation causes pressure losses and increased energy consumption during gas transmission and indirectly increases carbon emissions. However, since ultrasonic meters do not contain moving mechanical parts, they consume less energy and have a longer life. This feature reduces the carbon footprint that occurs during the production and operation process. In recent years, energy management, efficient use of resources and sustainability have come to the fore in smart cities around the world. A smart city is an urban area that uses different types of electronic IoT sensors to collect data and then uses the information obtained from this data to manage assets, resources and services efficiently. It is known that the initial investment costs of smart ultrasonic meters are higher than mechanical diaphragm meters. Therefore, it is necessary to analyse which of the mechanical diaphragm and smart ultrasonic meters is more economical, taking into account the initial investment costs and other factors. This study aims to compare the two meter types by examining initial investment, operational costs, and economic performance over their lifecycle. The evaluation is based on (PV), (FV), (BCR) methodologies. Findings indicate that, despite their higher upfront costs, smart ultrasonic meters are economically more viable in the long term due to lower operational expenses and longer lifespan. According to the literature research, it has been understood that there is no study on the contribution of natural gas meters to the economy if used in Turkey. With the development of smart cities, it has been determined what the economic impact of the transition to smart ultrasonic meters will be in Turkey.

Keywords: Smart city, Mechanical diaphragm meter, Smart ultrasonic meter, economic analysis.

Nomenclature

AC *Aging Costs*
B/C *Benefit–Cost*
CC *Communication Cost*
EPDK *Energy Market Regulatory Authority*
F/A, A/P, P/G *interest rate*
FV *Future Value*
MARR *Minimum Attractive Rate of Return*
OC# *Opening/Closing and Maintenance Cost*
PV *Present Value*
PLC *Personnel Costs*
PL *Pressure Loss*
RC *Reading Cost*
SV *Scrap Value*
TC *Temperature Difference*
ΔF *Difference in benefits or advantages.*
ΔD *Difference in disadvantages that may occur.*
ΔM *Difference in project costs.*
IIC *Initial Investment Cost*
PV(A) *Investment of Mechanical Diaphragm Gas Meter*
PV(B) *Investment Smart Ultrasonic Gas Meter*

1. Methods For Measuring Natural Gas Flow Rate

In both Türkiye and around the world, gas meters are manufactured using various measurement methods and technologies to accurately quantify gas consumption. In general, natural gas meters can be classified into three main categories based on their measurement capabilities: mechanical, electronic, and smart meters. Among the available energy sources, natural gas stands out as one of the most significant both domestically and globally. When combusted, natural gas primarily produces CO_2 and H_2O, making it the least harmful fossil fuel to the environment. Natural gas has been in use in Türkiye for more than three decades. For companies engaged in natural gas distribution, the most critical factor is to accurately determine and invoice the cost of residential and industrial consumption [1].

At present, gas consumption (flow rate) is measured through different methods based on physical principles. The gas flow measurement systems used for this purpose are generally classified as diaphragm, rotary, turbine, orifice, Coriolis, thermal, and ultrasonic meters [2].

In natural gas installations, the most commonly used meter types are diaphragm, rotary, and turbine meters. Rotary and turbine meters are typically employed in industrial facilities and large-scale central heating systems, while diaphragm meters are predominantly used in residential and small commercial installations. According to the Customer Services Regulation of the Energy Market Regulatory Authority (EMRA), gas meters for residential and commercial installations are provided to customers by the gas distribution companies [3].

2. Mechanical Diaphragm Gas Meters and Advanced Smart Ultrasonic Gas Meters

This section presents a comparative evaluation of mechanical diaphragm meters and smart ultrasonic meters commonly used in Türkiye. The comparison encompasses various technical and economic aspects, including mechanical and electrical/electronic components, maintenance and calibration intervals, cost structures, measurement principles, accuracy levels, operational advantages, usage areas, and overall economic performance. The detailed comparison is outlined in the following section.

Structural (Mechanical) Characteristics of Mechanical Diaphragm Meters: The diaphragm chamber–based measurement system represents the most widely adopted method for natural gas metering. Meters employing this principle are known as diaphragm meters, which constitute the most common type of gas meter used in residential and small commercial applications. The first dry-type diaphragm meter, incorporating two moving diaphragms, two sliding valves (drawer-type mechanism), and a counter, was invented and patented by Thomas Glover in England in 1844.

Modern diaphragm meters utilized in Türkiye are designed with four measuring chambers and are available in various sizes, each with defined maximum and minimum flow rate capacities. Diaphragm meters operate effectively over a wide dynamic measurement range. Similar to other positive displacement meters, diaphragm meters contain a series of chambers that alternately fill and discharge a known gas volume. The primary components of these meters include:

Figure 1. Front view of natural gas meter outer body and counter

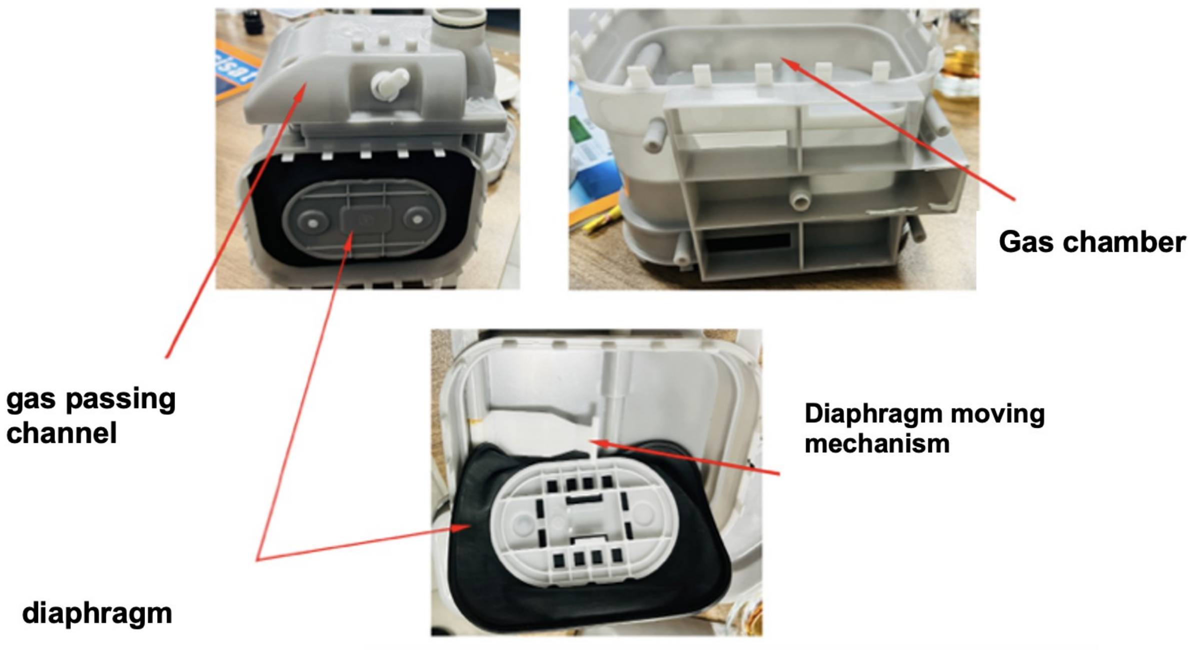

Figure 2. Front view of the natural gas meter's outer casing and register.

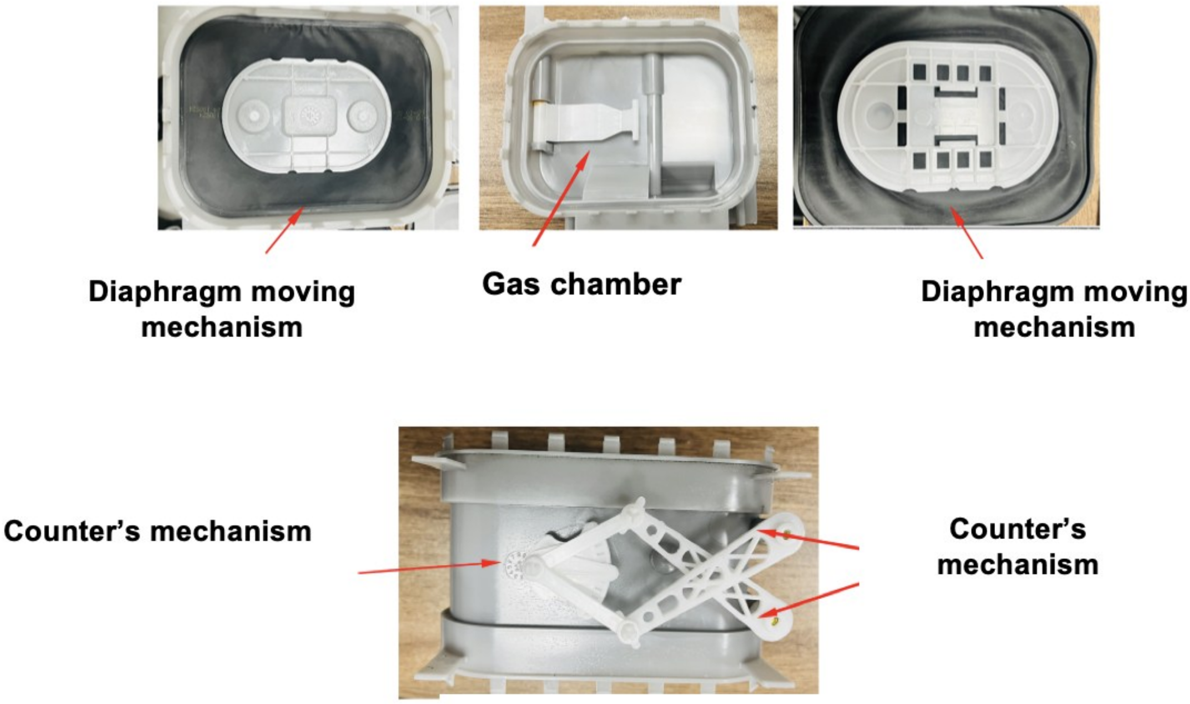

Figure 3. Main body and moving chambers and diaphragm

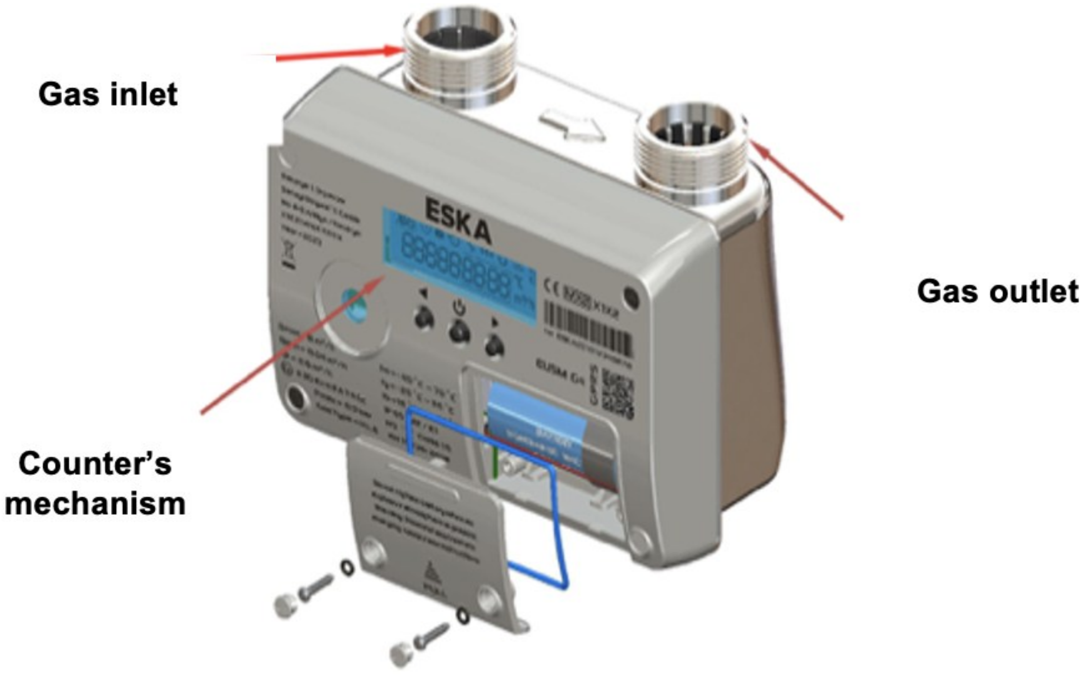

Figure 4. Smart meter

1. A valve mechanism controlling gas inlet and outlet, (Figure 1.) and
2. Measuring chambers, (Figure 2. and 3.)
3. A counter (register) mechanism for volume indication (counter) (Figure 1.) [4,5]

Structural (Mechanical) Design of Smart Ultrasonic Gas Meters: Ultrasonic gas meters perform flow measurement through an ultrasonic sensing system that determines gas velocity using high-frequency sound waves. In these meters, ultrasonic transmitters positioned along the internal measurement channel emit sound pulses that propagate through the flowing gas. The receivers detect these signals after they traverse the gas stream, and the resulting time difference or frequency shift between the transmitted and received waves is used to calculate the gas flow rate.

The variation in the propagation velocity of the sound waves directly correlates with the gas velocity, which in turn enables the precise determination of the volume of gas passing through the meter (Figure 4).

All structural and functional components of the ultrasonic gas meter are illustrated in detailed. The subsequent figure 5 and 6. present photographs of the key components, along with explanations of their measurement roles and operating principles within the system [6].

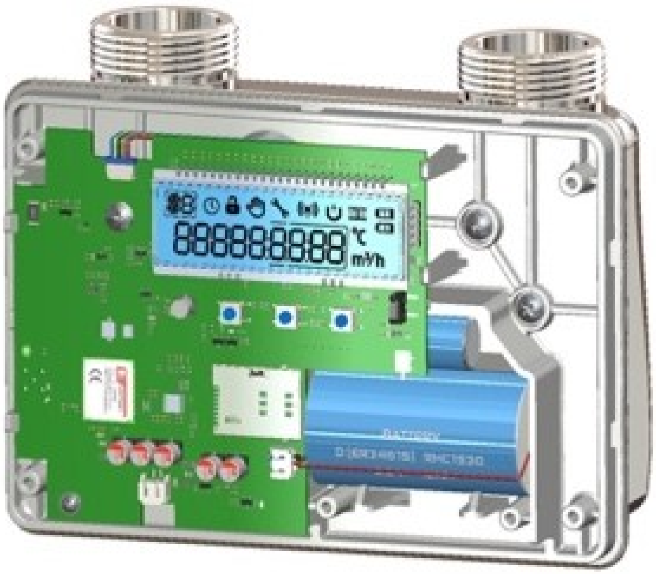

Figure 5. Smart meter upper body and electronic card

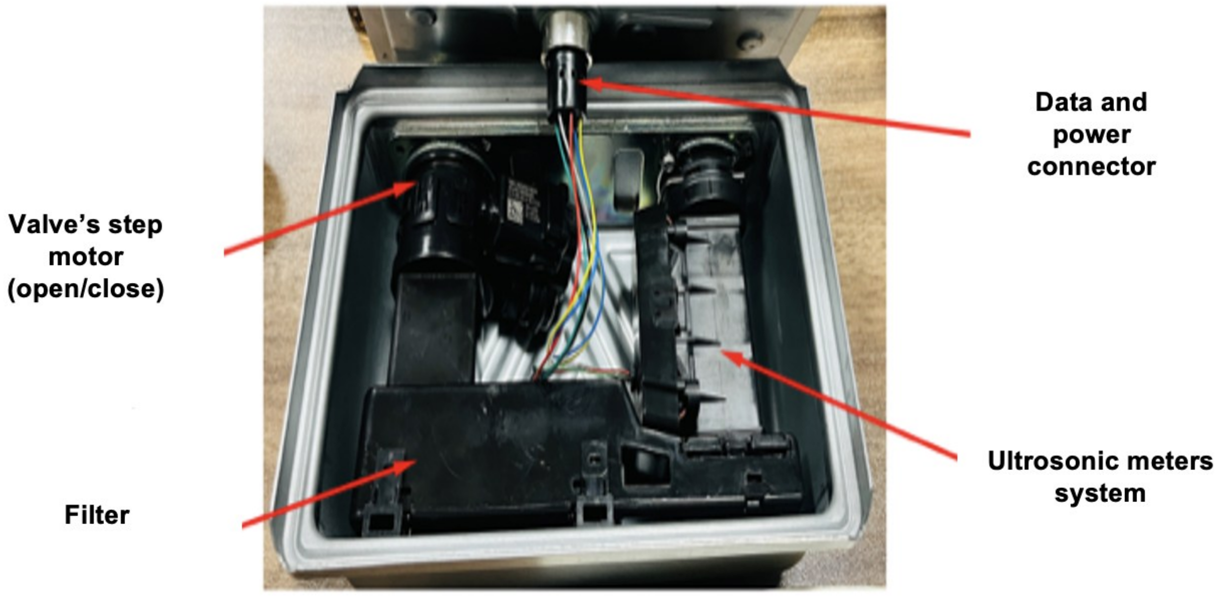

Figure 6. Main body and elements

3.1.Economic Analysis of Gas Meters

The economic evaluation of the gas meters was conducted using three fundamental financial assessment techniques: Present Value Analysis, Future Value Analysis, and Benefit Cost Analysis [7]. Although these methods differ in terminology and calculation focus, they share a common analytical framework, aiming to assess the economic feasibility and long-term financial performance of metering systems under comparable operational conditions.

3.2.Economic Analysis of Gas Meters Based on The Present Value Method

According to the EMRA, the average service life of a gas meter is 14 years. Based on statistical data, the annual average gas consumption per subscriber is assumed to be 1000 m³. Using these parameters, an economic analysis of mechanical diaphragm meters and smart ultrasonic meters was performed, considering their initial investment costs and annual operating expenses.

Initial Investment Cost: The purchase cost of mechanical diaphragm meters typically ranges between 25–50 USD, with an average value of 37.5 USD taken for calculations [8, 9, 10].

Smart ultrasonic meters, on the other hand, cost between 80–120 USD, with an average of 100 USD assumed

Annual Operating Costs: Operating expenses refer to costs incurred during production or operation, which vary depending on the type and characteristics of the system. For both mechanical diaphragm and smart ultrasonic meters, the main cost components include calibration, personnel, pressure losses, temperature deviations, disconnection/ reconnection, billing dispute handling, and communication/software expenses. The estimated annual cost per meter based on these components is discussed.

Calibration and Maintenance Costs: Mechanical diaphragm meters require calibration after 10 years of use. After recalibration, they can be operated for another 10 years, after which they must be replaced. Thus, their maximum economic life is 20 years. Within the 14-year EMRA-defined period, at least one calibration is required, costing 14 € (≈15.66 USD) per meter.

Smart ultrasonic meters, however, require no recalibration or mechanical maintenance throughout their life, except for a battery replacement (5 €) after 15 years. Therefore, maintenance costs are considered negligible.

Personnel Costs: Personnel costs for mechanical diaphragm meters arise from manual reading, field visits for disconnection/reconnection, and sealing operations in cases of non-payment, malfunction, or billing objections.

Meter Reading: In a city with 350,000 subscribers where meters are located close to each other, one person can manually read about 500–600 meters per day. Approximately 60 personnel are required to complete all readings, with an average of 8.000 connection/disconnection operations monthly. Considering a personnel cost of 50,000 TL/month (March 2025) and additional vehicle rental and fuel expenses, the average annual reading cost per mechanical meter is 4 € (≈4.35 USD).

For smart ultrasonic meters, readings are performed remotely. Only five staff members are required for monitoring and support, while a SIM card communication cost is incurred. Thus, the annual reading cost per smart ultrasonic meter is 2 € (≈2.18 USD).

Connection/Disconnection Costs: Each subscriber with a mechanical meter requires an average of three field visits over 14 years for disconnection/reconnection due to new subscriptions, unpaid bills, or maintenance. Each operation costs 5 € (≈5.45 USD).

For smart ultrasonic meters, such operations are executed remotely, thus eliminating most costs. However, occasional field visits for installation or repair are still necessary, estimated at 2 € (≈2.18 USD) annually.

Communication and Software Costs: Mechanical diaphragm meters do not incur any communication or software expenses. Smart ultrasonic meters, however, require costs for SIM card data transmission, server infrastructure, software maintenance, and staffing. These total 1 € (≈1.14 USD) per meter annually.

Operating Costs Arising from Pressure Losses: Mechanical diaphragm meters inherently cause an average pressure loss of 2 mbar, while ultrasonic meters have a pressure loss of 0.5 mbar [8, 11]. To compensate for the higher loss, gas booster stations must consume additional energy. Over 14 years, the excess energy consumption of mechanical meters corresponds to 14 m³ of natural gas, equivalent to 4 € (≈4.35 USD) per year [12, 13, 14].

In ultrasonic natural gas meters, it is observed that the device consists of only three major components. Consequently, there are no mechanical transmission elements or parts that may cause friction within the system. According to the EN 14236 standard [12], Class 1.5 ultrasonic meters must exhibit a pressure loss of 0.5 mbar or less during gas flow, which may occur only across the inlet filter or internal flow channels [15, 13, 16].

As previously calculated, mechanical diaphragm meters demonstrate significantly higher pressure losses due to their internal moving components. Since the pressure loss of smart ultrasonic meters is negligible and does not meaningfully affect gas consumption or operational performance, it should not be included in the cost and energy-loss computations.

Costs Associated with Age-Related Under-Registration: Age-related measurement errors in mechanical diaphragm gas meters lead to revenue losses due to systematic under-registration [1,4,9]. The mechanical components of these meters including gears, levers, and diaphragms—undergo material degradation over time, resulting in deviations between the initial calibration performance and the measurement accuracy observed after ten years of operation. Experimental field measurements conducted on meters with an annual consumption of approximately 1000 m³ indicate that age-related under-registration increases between 4% and 15%, depending on environmental conditions and usage frequency [13,14,17].

Based on these evaluations, it is estimated that a mechanical diaphragm meter produces a cumulative under-registration of approximately 425 m³ over ten years. Considering this information, the annual incremental under-registration caused by aging during the first decade was calculated as 1.67 € per year, which corresponds to 1.90 USD per year.

In cases where the meter is recalibrated and reused for an additional cycle, aging-induced measurement errors are expected to accelerate due to deformation in the diaphragm and gear mechanisms accumulated during the first ten-year period. For simplicity, the remaining four years of the meter's lifetime were assumed to follow similar age-related error characteristics, and the same rate was applied in the cost analysis.

In contrast, studies conducted on smart ultrasonic meters show that the maximum measurement deviation over twenty years of operation without requiring recalibration is no more than 1.5% [18, 19, 20]. This value falls well within the acceptable limits defined by the standards, meaning that the meter effectively maintains an operational error rate of 0% relative to calibration requirements. Consequently, ultrasonic meters do not generate any cost associated with under-registration.

Costs Arising from Temperature-Related Measurement Deviations: The density of natural gas varies with temperature; therefore, billing calculations must apply a correction factor to determine the actual consumption. Meteorological temperature data are typically used to derive this factor by determining a gas-density based correction coefficient for each month. However, temperature can fluctuate not only throughout the month but even within a single day. Additionally, regional temperature variations such as differences between the northern and southern or eastern and western districts of a city contribute to deviations in the applied correction factor. Considering a metropolitan area such as Istanbul, these spatial and temporal variations can lead to significant discrepancies. As a result, billing calculations inherently contain a degree of uncertainty.

Based on meteorological data and temperature measurements obtained from 525 smart ultrasonic meters deployed in a field study, it was determined that the discrepancy between the correction factor derived from meteorological averages and that derived from actual meter-level temperature readings resulted in an annual under-billing of 2.5 €, equivalent to 2.72 USD [4,9].

In smart ultrasonic meters, the presence of an integrated temperature sensor enables real-time temperature measurement, which is collected through the data acquisition system. Consequently, temperature-dependent correction factors can be calculated with higher accuracy. This allows billing to be based on actual consumption values, ensuring precise invoicing. Under these conditions, neither the gas distribution company nor the subscriber faces uncertainty regarding billing accuracy.

Scrap Value: Since the internal components of mechanical diaphragm gas meters are primarily made of plastic, their salvage value is negligible; only the external metallic housing contributes to residual value. Based on scrap metal prices for the year 2025, the unit price of scrap iron is approximately 10 TL per kilogram. Considering that a standard mechanical diaphragm meter weighs roughly 2 kg, its salvage value corresponds to 20 TL, which is equivalent to 0.54 USD.

Due to their smaller physical dimensions, smart ultrasonic gas meters have a lower metal content. Accordingly, their salvage value can be assumed to be approximately 10 TL, corresponding to 0.27 USD.

Minimum Attractive Rate of Return (MARR): The official annual interest rate applied to the Turkish Lira was set at 24% as of June 2024. However, since the economic evaluation in this study is conducted in USD, interest rates applicable to USD-denominated deposits were examined using data obtained from commercial banks' publicly available resources. The review indicates that the average annual interest rate for USD time deposits is approximately 4%. Therefore, a MARR of 4% was adopted in the economic analysis.

According to the Measurement and Calibration Law published in the Official Gazette dated 21 January 1989 (No. 20056) [20] and the EPDK. Decision No. 6807 [3], the service life of natural gas meters is defined as 14 years. Accordingly, the operational lifetime of both mechanical diaphragm meters and smart ultrasonic meters has been taken as 14 years for the purposes of this study.

Table 1. Meters have a lifetime of initial investment costs and expenses.

DESCRIPTION	MECHANICAL DIAPHRAGM	SMART ULTRASONIC
Initial Investment Cost (IIC), $	**$37.50**	**$100.00**
Personnel Costs		
Reading Cost ($/year)	$4.35	$2.18
Communication Cost ($/year)	—	$2.18
Activation/Deactivation – Failure Costs		
($/5th year)	$5.45	$2.18
($/10th year)	$5.45	$2.18
($/14th year)	$5.45	$2.18
Pressure Loss ($/year)	**$4.35**	—
Temperature Difference ($/year)	**$2,72**	—
Ageing Costs ($/year)		
Years 1–10	$1.90	—
Years 10–14	$1.90	—
Calibration and Maintenance ($/10 years)	**$15.66**	—
Scrap Value ($/14th year)	**$0.54**	**$0.27**
Service Life (years)	**14**	**14**

The economic evaluation was conducted by considering this service life together with market-based interest rates, incorporating all relevant expenditures occurring throughout the life cycle of both meter technologies.

According to the values determined in Table 1, the cost and expenditure parameters of mechanical diaphragm meters and smart ultrasonic meters are presented in tabular form.

The cash flow table for the lifetime of a mechanical diaphragm meter is given in Figure 7.

Cash Flow Diagram of the Mechanical Diaphragm Gas Meter (1 Calibration – 10 Years)

The cash flow table for the lifetime of the smart ultrasonic meter is presented in Figure 8.

The interest factor table values used in the calculations such as F/A, A/P, and P/G for an interest rate of 4% and periods of 5, 10, and 14 years are presented in the table 2. The subsequent calculations are performed using these values.

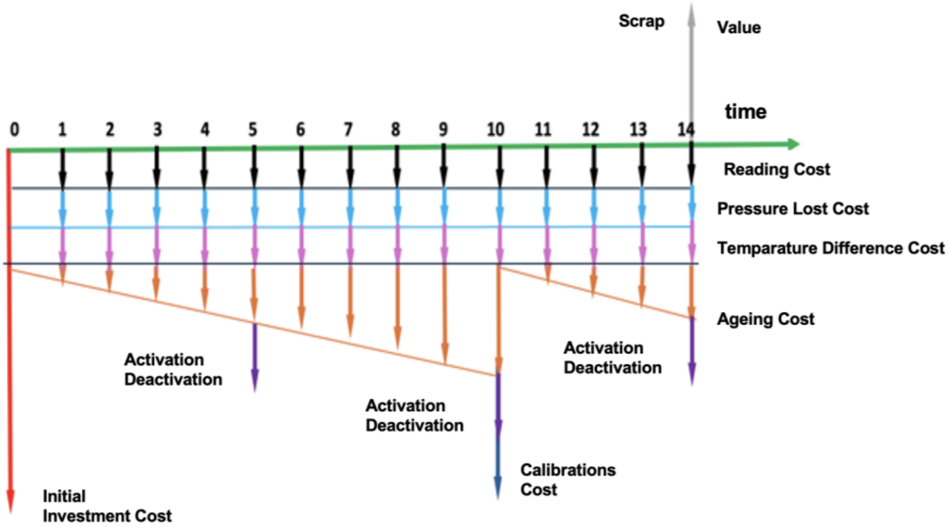

Figure 7. Mechanical diaphragm meter cash flow chart

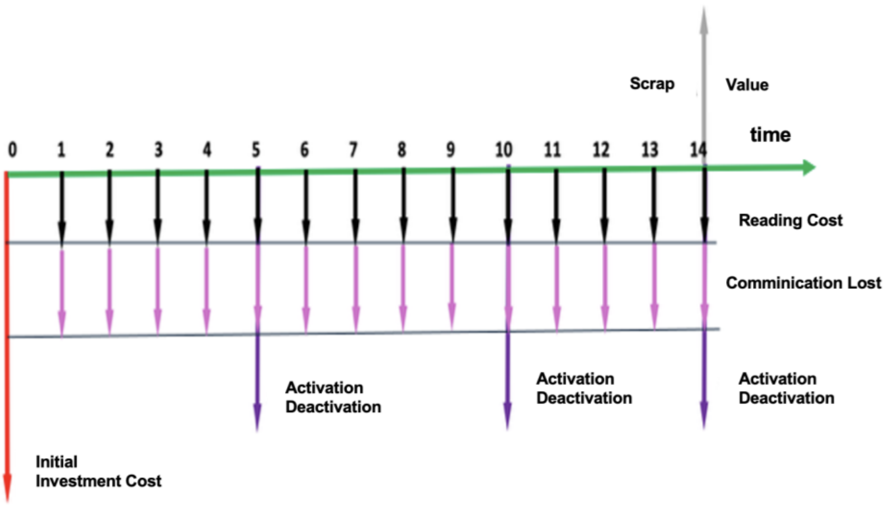

Figure 8. Smart Ultrasonic Natural Gas meter cash flow chart

Table 2: Present value calculation table

DESCRIPTIONS	MECHANICAL DIAPHRAGM METERS	PV Factor	Amount ($) (PV)	SMART ULTRASONIC METERS	PV Factor	Amount ($) (PV)
Initial Investment Cost (IIC), $	$37.50	1	-$37.50	$100.00	1	-$100.00
Personnel Costs						
Reading Costs ($/year)	$4.35	10.563	-$45.95	$2.18	10.563	-$5.49
Communication Costs ($/year)	—	—	----	$1.14	10.563	-$12.04
Activation/Deactivation Failure Costs (5th year)	$5.45	0.822	-$4.48	$2.18	0.822	-$1.79
Activation/Deactivation Failure Costs (10th year)	$5.45	0.376	-$2.05	$2.18	0.376	-$0.82
Activation/Deactivation Failure Costs (14th year)	$5.45	0.263	-$1.43	$2.18	0.263	-$0.57
Pressure Loss Costs ($/year)	$4.35	10.563	-$45.95	—	—	—
Temperature Difference Costs ($/year)	$2.72	10.563	-$28.75	—	—	—
Ageing Costs ($/year) (Years 1–10)	$1.90	33.881	-$64.37	—	—	—
Ageing Costs ($/year) (Years 10–14)	$1.90	5.267	-$10.01	—	—	—
Calibration & Maintenance Costs (10th year)	$15.66	0.376	-$5.88	—	—	—
Scrap Value (14th year)	$0.54	0.263	$0.14	$0.27	0.263	$0.16
PRESENT VALUE (PV)			**-$254.09**			**-$121.90**
FUTURE VALUE (FV)			**-$440.01**			**-$211.10**

$$PV(A) = -(IC) - RG * (P/A;\%10;14) - OC5 * (P/A;\%10;5) - OC10 * (P/A;\%10;10) - OC14 * (P/A;\%10;14) - PL * (P/F;\%10;14) - TC * (P/F;\%10;14) - AC * (P/G;\%10;10) - AC * (P/G;\%10;4) - CC * (P/F;\%10;14) + SD * (P/F;\%10;14) \quad (1)$$

$$PV(A) = -(37.5) - 4.35 * (10.563) - 5.45 * (0.822) - 5.45 * (0.676) - 5.45 * (0.578) - 4.35 * (10.563) - 2.72 * (10.563) - 1.90 * (33.881)) - 1.90 * (5.267) - 15.66 * (0.676) + 0.54 * (0.578)$$

$$PV(A) = -254.09\ USD$$

Present Value of the Smart Ultrasonic Meter: In the calculations, the following notation is used: PV, IC, RC, CC, SC 5,10,14: Service Costs for Switching/Failure at Years 5, 10, and 14, CC, and SV.

$$PV(B) = -(IC) - RC * (P/A;\%10;14) - CC * (P/A;\%10;14) - SC5 * (P/A;\%10;5) - SC10 * (P/A;\%10;10) - SC14 * (P/A;\%10;14) + SV * (P/A;\%10;14) \quad (2)$$

PV(B) = -(100.0) – 0.52(10.563) – 1.14*(1*.563) – 2.18*(0.822) – 2.18*(0.676)- 2.18*(0.578) + 0.27*(0.578)*

$$PV(B) = -121.90\ USD$$

Comparison of Present Value Analysis: The investment alternative with the smaller PV value is considered more economical under present conditions.

PV(A)= 254,09 USD

PV(B)=-121,90 USD

According to the PV analysis, replacing mechanical diaphragm meters with smart ultrasonic meters results in an average cost saving of 132.19 USD per gas meter. Since $PV(A) > PV(B)$or $254.09 > 121.90$, Option B (Smart Ultrasonic Meter) should be selected as the more economical investment.

3.2.Economic Analysis Based on The Future Value Method

According to the calculations presented above, the Present Values of Investments A and B are as follows:

- For the Mechanical Diaphragm Meter: PV(A) = –254.01 USD
- For the Smart Ultrasonic Meter: PV(B) = –121.90 USD

For investments with known present values, the future value after 14 years can be calculated by applying an appropriate interest rate. Assuming an annual interest rate of 4%, the results are:

- For the Mechanical Diaphragm Meter: FV(A) = –440.01 USD
- For the Smart Ultrasonic Meter: FV(B) = –211.10 USD

Based on these results, a similar evaluation can be made: the investment with the lower future value is preferred. The calculated values indicate that FV(A) > FV(B). Therefore, the investment B, corresponding to the Smart Ultrasonic Meter, is deemed more economically advantageous.

Table 3: Initial investment cost and other expenses.

DESCRIPTION	MECHANICAL DİIAPHRAGM	SMART ULTRASONIC
Initial Investment Cost (IIC), $	$37.50	$100.00
Personnel Costs		
Reading Cost ($/year)	$4.35	$0.52
Communication Cost ($/year)	—	$1.14
Activation/Deactivation – Failure Costs		
($/5th year)	$5.45	$2.18
($/10th year)	$5.45	$2.18
($/14th year)	$5.45	$2.18
Pressure Loss ($/year)	$4.35	—
Temperature Difference ($/year)	—	—
Ageing Costs ($/year)		
Years 1–10	$1.90	—
Years 10–14	$1.90	—
Calibration and Maintenance ($/10 years)	$15.66	—
Scrap Value ($/14th year)	$0.54	$0.27
Service Life (years)	14	14

3.3. Benefit/Cost (B/C) Ratio Analysis

The Benefit/Cost (B/C) ratio method is generally applied to large-scale projects. By comparing the total benefits and costs, one can determine whether a project should be undertaken. For this analysis, a sample city with 350,000 subscribers is considered, and the calculations are based on the present value results obtained earlier.

For each alternative, the equivalent total cost is determined in Table3.

Costs are defined as the sum of initial investment costs and annual operating costs. Since the operating costs are expressed annually, the total cost must also be expressed on an annual basis.

For the mechanical diaphragm meter, the initial investment cost, reading expenses, and connection/disconnection expenses are converted to annual values as follows:

$$AV(A) = (IC) * (A/P;\%10;14) + (RC + SC) = 37.50 * (0.095) + (4.35 + 1.22 + 0.67 + 0.52) \quad (3)$$

$AV(A) = 10.31\ \$$

Smart Ultrasonic Meter: Similarly, for the smart ultrasonic meter, the initial investment cost, reading expenses, and connection/disconnection costs are calculated annually as:

$$AV(B) = (IC) * (A/P;\%10;14) + (RC+SC) = 100 * (0.095) + (0.52+0.49+0.27+0.09) \quad (4)$$

$AV(B) = 10.84\ \$$

Alternatives are ranked by increasing cost:

$AV(A) < AV(B)$.

Benefits (Advantages): For the mechanical diaphragm meter, the scrap value is considered an advantage:

$B(A) = SV = 0.051\ \$$

$B(A) = 0.051\ \$$

For the smart ultrasonic meter, the scrap value is also considered a benefit:

$B(B) = SV = 0.026\ \$$

$B(B) = 0.026\ \$$

Disadvantages: For mechanical diaphragm meters, the main disadvantages include high pressure losses, calibration and maintenance costs, and measurement errors due to aging and temperature changes:

$$D(A): PL + TD + YG + CC(AV) = 4.35 + 2.72 + 1.92 + 1.93 \quad (5)$$

$D(A) = 10.92\ \$$

For smart ultrasonic meters, the only notable disadvantage is communication cost:

$$D(B) = CC = 1.14\ \$$$

Incremental Costs and Benefits

a) The difference of costs is calculated

$$\Delta M = M(B) - M(A) = 10.84 - 10.31 \quad (6)$$

$\Delta M = 0.53\ \$$

b) The difference of benefits is calculated

$$\Delta F = F(B) - F(A) = 0{,}026 - 0.051 \quad (7)$$

$\Delta F = -0.026\ \$$

c) The difference of disadvantages is calculated

$$\Delta D = D(B) - D(A) = 1{,}14 - 10{,}92 \quad (8)$$

$\Delta D = -9.78\ \$$

The benefit–cost ratio is then computed as in the values of Table 4:

ΔFΔ/M >1.0 high cost alternative is used

$$\frac{F}{M} = \frac{\Delta F - \Delta D}{\Delta M} \quad (9)$$

$$\frac{F}{M} = \frac{0{,}026 - (-9{,}78)}{0{,}53} = 18.44$$

$$\frac{F}{M} = 18{,}44 > 1$$

Since this ratio is greater than 1, the higher-cost alternative (B, the Smart Ultrasonic Meter) should be preferred.

Table 4: Benefit/Cost calculation table

DESCRIPTIONS	MECHANICAL DIAPHRAGM METERS		SMART ULTRASONIC METERS		DIFFERENCES
	Income/Expense	**AV**	**Income/Expense**	**AV**	**(Δ)**
Initial Investment Cost (IIC), $	$37.50	$3.55	$100.00	$9.47	
Personnel Costs					
Reading Costs ($/year)	$4.35	$4.35	$0.52	$0.52	
Activation/Deactivation – Failures (5th year)	$5.45	$0.82	$2.18	$0.33	
Activation/Deactivation – Failures (10th year)	$5.45	$0.67	$2.18	$0.27	
Activation/Deactivation – Failures (14th year)	$5.45	$0.53	$2.18	$0.21	
Total Costs		**$10.31**		**$10.84**	**$0.53**
		DISADVANTAGES			
Pressure Loss ($/year)	$4.35	$4.35	—	—	—
Temperature Difference ($/year)	$2.72	$2.72	—	—	—
Ageing Costs ($/year) – Years 1–14	$1.92	$1.92	—	—	—
Calibration and Maintenance ($/10 years)	$15.66	$1.93	—	—	—
Communication Costs ($/year)	—	—	$1.14	$1.14	—
Total Costs		**$10.92**		**$1.14**	**$9.78**
		ADVANTAGES			
Scrap Value ($/14th year)	$0.54	$0.051	$0.27	$0.026	$0.026
Total Costs		**$0.051**		**$0.026**	**-$0.026**
BENEFIT/COST (B/C) RATIO ANALYSIS	$\frac{B}{C} = \Delta A - \frac{\Delta D}{\Delta C} = \$18.44$				

4. Economic Contributions, Evaluation, and Recommendations

According to the British Gas Distribution Company [21], the use of smart gas meters is strongly recommended for consumers. The company states on its website: "Smart meters, with their in-home display screens, allow you to see how much energy you are using at a glance and therefore help you save." "A smart meter and its accompanying in-home display can help you track your daily, weekly, or monthly energy usage, enabling better household budgeting." [22,23]. Similarly, France's Gas Distribution Company (GRDF) reports that through its Smart Gas Meter Project covering 6 million installed meters an energy saving of 1.5% was achieved. With daily data collection, optimization in gas distribution is expected to yield 150 million euros in savings [24]. These examples demonstrate that developed countries are actively encouraging the widespread use of smart meters.

According to the literature research on consumer habits, it was determined that pilot consumers using smart meters in different countries saved an average of 6% energy after checking or reporting instant consumption values using channels such as home screen, web, mobile application, SMS, etc.

Potential Energy Savings in Türkiye: According to official data, residential natural gas consumption in Türkiye between 2020–2023 ranged between 17–21 billion m³, accounting for 35% of total gas consumption. Based on global studies showing an average 9% energy saving achieved through smart meter adoption, a national saving of 1.8 billion m³ of natural gas could be realized annually. Assuming a gas cost of 0.4 USD/m³, this corresponds to a saving of approximately 720 million USD. The cost difference between a smart ultrasonic meter and a mechanical diaphragm meter is about 70 USD per unit. Given approximately 20 million residential subscribers, the total investment for full deployment would be 1.4 billion USD.

Thus, the benefit–cost ratio can be estimated as:

$$\frac{\text{1.4 billion USD investment}}{\text{720 million USD annual saving}} = 1.94$$

This means that the investment in smart ultrasonic meters would pay for itself in 1.94 years.

For this reason, it is understood that expanding/widespreading the use of smart meters will contribute to users changing their consumption habits, increasing their tendency to save energy, reducing pressure losses, making more accurate and clear consumption forecasts, contributing to the country's economy, reducing imports and subscribers' consumption, foreign exchange substitution and also reducing the carbon footprint.

In addition, the use of smart meters enables the recording of when and how much natural gas consumers use, thereby making it possible to implement special and/or tiered tariff structures. Studies conducted on subscribers subject to such special and/or tiered tariffs indicate that electricity consumption decreases by 13.8% overall**,** 11% during peak demand periods**,** and 8.9% according to analyses based on time-of-use consumption patterns

Broader Economic and Environmental Benefits: The widespread adoption of smart meters contributes to:

- Changing consumer energy habits,
- Enhancing energy-saving behaviour,
- Reducing pressure losses in the distribution network,
- Enabling more accurate consumption forecasts,
- Reducing natural gas imports and carbon emissions.

Moreover, since smart meters record time-based consumption data, time-of-use and tiered pricing models can be implemented. Studies show that such pricing reduces electricity consumption by 13.8%, peak demand by 11%, and time-shifted usage by 8.9%.

From a safety and technical perspective, mechanical diaphragm meters are susceptible to tampering, leading to unbilled losses. Smart ultrasonic meters minimize such non-technical losses. Field studies in Türkiye show that losses amount to 0.94 m³ per meter annually. Considering national consumption of 20 billion m³, this corresponds to a potential saving of 1.88 million m³ annually.

Due to their structural design, mechanical diaphragm meters can be easily tampered with from the outside. The effects of such interference typically manifest as non-technical losses. The use of smart ultrasonic meters, however, directly contributes to reducing both unbilled gas consumption and losses arising from various operational factors. Field studies conducted in Türkiye have shown that mechanical diaphragm meters exhibit an average loss of 0.94 m³ per meter**.** Considering Türkiye’s annual natural gas consumption of approximately 20 billion cubic meters**,** the potential savings achieved through the deployment of smart ultrasonic meters based solely on this 0.94% loss ratio would amount to roughly 1.88 million cubic meters**.** Therefore, expanding the use of smart meters would not only provide significant economic benefits for the country but also contribute to reducing the national carbon footprint.

5. Evaluations, Conclusions and Recommendations

Based on benefit–cost (BD and GD) analyses, replacing mechanical diaphragm meters with smart ultrasonic meters can yield 132.19 USD savings per meter over their lifetime. Despite higher initial investment, long-term analyses show that smart ultrasonic meters are more economical and functionally superior.

Furthermore, annual pressure loss per residential meter is estimated at 14 m^3. Reducing these losses will also decrease electricity and gas consumption at BOTAŞ compressor stations, providing indirect benefits to the national economy. Therefore, within the scope of smart city initiatives, accelerating the transition to smart ultrasonic meter technology in households is strongly recommended.

Although the initial investment cost of smart meters is roughly four times higher than that of mechanical meters, the analysis demonstrates that the lifetime benefit cost ratio (18.44) strongly favours the smart ultrasonic option.

Real-time data provided by smart meters allows both consumers and utilities to monitor and optimize consumption patterns. Integration with smart grids and renewable systems enhances sustainability and efficiency, contributing to carbon footprint reduction and foreign exchange savings.

Consequently, promoting the widespread use of smart ultrasonic meters will not only strengthen national energy efficiency and economic resilience, but also play a crucial role in advancing smart urban infrastructure and environmental sustainability.

Mechanical diaphragm meters are not capable of providing instantaneous gas consumption data for end-users. In contrast, smart ultrasonic meters enable the acquisition of real-time consumption information. The real-time data collection and analytical capabilities offered by these meters provide substantial benefits to both consumers and energy suppliers. Consumers can also receive timely notifications that promote informed and energy-efficient behavioural adjustments.

Moreover, real-time consumption data allow smart city administrations and gas distribution companies to perform more accurate demand forecasting by analysing usage patterns. This facilitates more efficient planning of gas supply and infrastructure investments. Smart ultrasonic meters can also be seamlessly integrated into renewable energy systems and smart city infrastructures, thereby supporting broader energy-management and sustainability objectives.

The integration of gas consumption data into smart energy grids contributes to the optimization of renewable energy utilization. Consequently, these technologies promote city-wide energy savings and play a significant role in reducing carbon footprints.

In addition, the deployment of smart ultrasonic meters particularly in residential applications offers a wide range of direct and indirect benefits. These include advantages related to smart-city integration, equitable and accurate measurement, enhanced data availability, improved meter security, and broader societal safety. For these reasons, the adoption of smart ultrasonic meters in both replacement programs and new installations should be prioritized, as they provide significant economic advantages for distribution companies and the EPDK, while also generating multiple indirect societal benefits.

Furthermore, the widespread utilization of domestically manufactured smart ultrasonic meters in residential settings would contribute to foreign currency substitution and promote the selection of a more economically favourable technology for long-term national investments. This transition would therefore support both the financial sustainability of the natural gas sector and the overall economic stability of the country.

Table 5: Comparison table of results

Analysis Category	Parameter	Mechanical Diaphragm Meter	Smart Ultrasonic Meter	Difference / Advantage
TECHNICAL & OPERATIONAL	Measurement Principle	Moving Diaphragm / Gears	Ultrasonic Sound Waves	Eliminates mechanical wear and tear.
	Pressure Loss	2.0 mbar	0.5 mbar	75% less energy loss.
	Measurement Accuracy	4% - 15% Deviation (Age-related)	0% - 1.5% Deviation (Stable)	Prevents systematic revenue loss.
	Temperature Correction	Estimated (Meteorological)	Real-Time (Integrated Sensor)	Precise and fair billing.
	Data Acquisition	Manual (Field visits)	Remote / Instant (SIM-based)	Operational speed and security.
ECONOMIC (Per Unit)	Initial Investment Cost	$37.50	$100.00	Ultrasonic is ~2.6x more expensive.
	Annual Operating Cost	~$10.92	~$1.14	Ultrasonic is ~10x cheaper to operate.
	Present Value (PV)	-$254.09	-$121.90	$132.19 Lifecycle Saving.
	Payback Period	-	1.94 Years	Short Pay-Back Period
NATIONAL IMPACT (Türkiye)	Potential Energy Saving	-	1.8 Billion m^3 / Yr	Enhanced national energy security.
	Economic Contribution	-	~720 Million $ / Yr	Reduction in current account deficit.
	Strategic Benefit	Low Security / Limited Data	High Security / Smart City Integration	Prevention of non-technical losses.

Studies conducted on consumers using smart meters indicate that the data communication systems integrated into these devices—along with smartphone applications and in-home display interfaces—enable users to monitor notifications and consequently regulate their energy consumption behaviour. These capabilities have been shown to encourage consumers to modify their usage patterns and increase their propensity for energy conservation.

In the case of Türkiye, it is estimated that the adoption of smart ultrasonic gas meters could yield an annual savings of approximately 700 million cubic meters of natural gas. Based solely on this direct savings figure and excluding other economic benefits analyses show that the initial investment cost of smart ultrasonic meters could be recovered within 2.85 years. Such a payback period demonstrates a clear contribution to foreign currency substitution and enhances the economic sustainability of the natural gas sector.

Moreover, enabling consumers to monitor and manage their own gas consumption provides indirect benefits to the national economy and contributes to a reduction in the country's overall carbon footprint.

From the perspective of user behaviour, the deployment of smart ultrasonic meters is expected to enable the use of special or tiered tariff structures, similar to those applied in electricity metering. This, in turn, will enhance consumers' responsiveness to price signals, encourage adjustments in consumption habits, and is therefore expected to facilitate additional natural gas savings.

According to data obtained from field studies conducted in Türkiye, a loss of 0.94 m³ per meter has been observed, corresponding to approximately 1.88 million cubic meters in total. Due to the insufficient safety performance of mechanical diaphragm meters, these losses occur at a notable scale. The deployment of smart ultrasonic meters is expected to significantly reduce such losses, owing to their enhanced safety features and advanced measurement technology.

Research conducted on consumers using smart meters shows that the data communication systems integrated into these meters, along with interface displays on smartphones or in homes, encourage users to monitor and control their energy consumption based on the notifications they receive. Consequently, consumers tend to change their energy-use behaviours and exhibit an increased inclination toward energy savings.

In Türkiye, assuming an average annual savings rate of 9% with the deployment of smart ultrasonic meters, it is estimated that approximately 720 million cubic meters of natural gas could be saved each year.

Although, according to present value and future value analysis, it has been calculated that smart ultrasonic meters will save $132.19 per natural gas meter by using natural gas. The use of ultrasonic smart meters will change the usage habits of subscribers and therefore, according to research, it will save approximately 9%, a total of 720 million dollars, 36.00 dollars per meter and 168.19 dollars in total.

According to the calculations, even without considering the additional economic benefits of smart ultrasonic meters, the initial investment costs can be recovered within 1.94 years solely through their implementation. From this perspective, their use will contribute directly to foreign currency substitution. Moreover, allowing users to monitor and control their gas consumption will indirectly benefit the national economy and support the reduction of the overall carbon footprint.

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