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Analysis of Delta In-Out for Irish Natural Gas Distribution Network

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Abstract-

This article investigates the issue of Unaccounted for Gas (UAG) in the natural gas distribution network of Ireland, focusing on the *DeltaIO* (i.e. the difference between the gas entering and leaving the network). The study applies the *DeltaIO* methodology developed for Italian distribution networks to Gas Networks Ireland (GNI), the sole Distribution System Operator (DSO) in Ireland. The analysis covers the period from 2013 to 2019 and provides insights into the magnitude and trends of UAG in the Irish context. The results show that GNI's *DeltaIO* ranges from 0.93% to 1.57%, with an average of 1.15%. Comparisons with large Italian networks reveal higher *DeltaIO* values for GNI. The study demonstrates the compatibility of the *DeltaIO* methodology with the Irish distribution network and highlights the commercial implications of positive and negative *DeltaIO* values. The findings contribute to the understanding of UAG in the Irish natural gas sector and provide valuable insights for industry stakeholders and regulators.

Keywords

Natural gas, Unaccounted for gas (UAG), Delta in-out, Distribution network.

1. Introduction

Natural gas is the second-largest primary energy source used in Ireland, comprising 31.1% of the total energy in 2022 [1]. It is utilised in various sectors, including power generation, residential, small businesses, and commercial purposes. Due to its lower carbon footprint, natural gas is considered a superior energy source compared to oil and coal. However, there are plans to replace it, either partially or entirely, with renewable biomethane and/or hydrogen to achieve carbon neutrality. Nevertheless, natural gas continues to play a crucial role in the Irish energy sector, offering overall support and contributing to energy security on the island of Ireland.

Figure 1 illustrates the natural gas pipeline network in Ireland, which is categorised into transmission and distribution networks based on pipeline operating pressures. In Ireland, the transmission network operates above 16 bar, while the distribution network operates below this threshold. [2-6].

There are five different stakeholders involved in the natural gas value chain in Ireland [7] namely:

1. Gas producers
2. Network operators: These are the entities responsible for owning and operating the pipeline infrastructure. The transmission system operator (TSO) manages the high-pressure gas transmission network, while the distribution system operator (DSO) oversees the distribution networks, ensuring the delivery of gas to end-users. In Ireland, Gas Networks Ireland (GNI) exclusively carries out both of these operational roles.
3. Gas shippers and suppliers: Shippers or suppliers are the entities that own the natural gas that flows in the network. In Ireland, there are currentlyover thirty registered shippers however, only seventeen of these were active shippers in 2023.

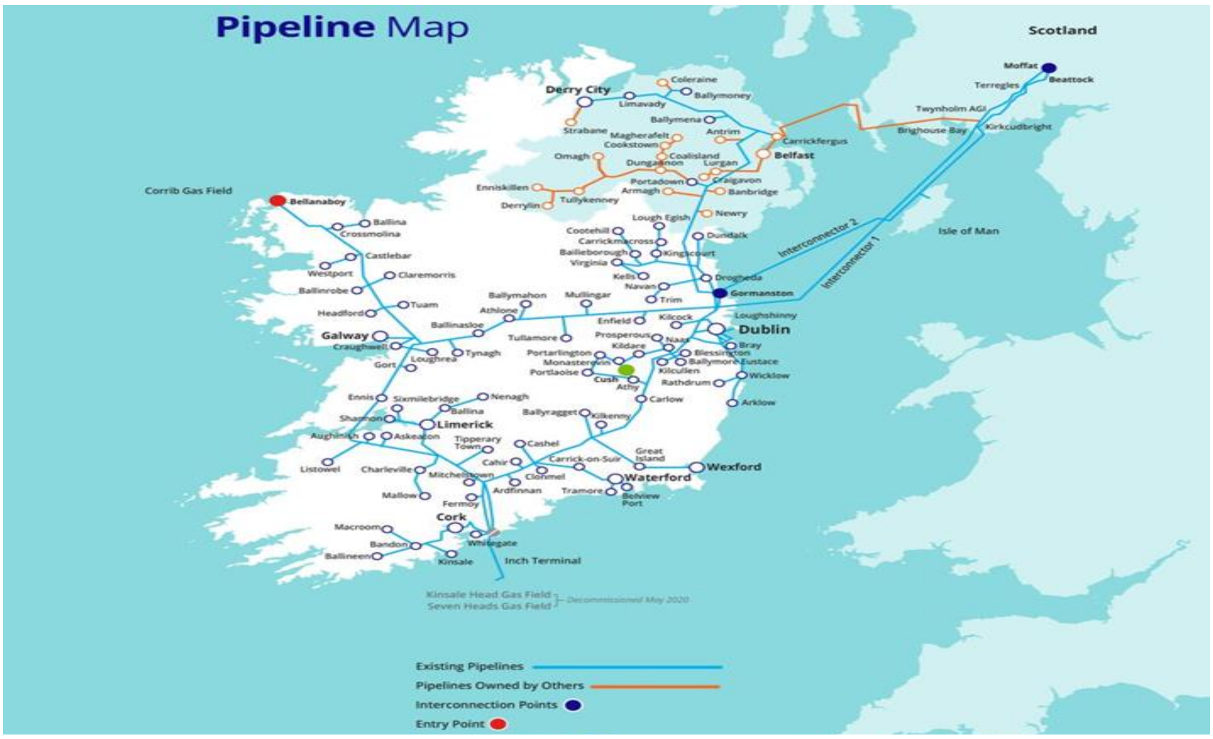

Figure 1. Irish natural gas network (source GNI).

4. Gas consumers or end-users: In Ireland, 700,000+ consumers use natural gas.
5. Regulator: Commission for Regulation of Utilities (CRU), formerly called Commission for Energy Regulation (CER).

The issue of Unaccounted for Gas (UAG) has garnered increasing attention in recent years due to its financial, environmental, and safety implications [8]. As decarbonisation efforts progress in all energy sectors, addressing UAG remains a significant concern. UAG occurs during the balancing of the natural gas network for operational and commercial purposes. A range of organisations, including the scientific community [9-13], regulatory authorities, and industry practices or consultations [14-20], have actively contributed to addressing the UAG issue. In the literature, UAG is commonly categorised into transmission UAG and distribution UAG. Henceforth in this paper, distribution UAG will be referred to as *DeltaIO*.

2. Materials and methods

2.1 UAG Calculation Equations:

UAG is calculated based on either the volumetric or energy balancing of natural gas. For the distribution network, the inputs include city gates ($I_{Citygate}$), where natural gas is transferred from the transmission network to the distribution network, and renewable gas ($I_{Renewable}$) is injected directly into the distribution network. The output of the distribution network is the natural gas consumed ($I_{Consumption}$) by connected consumers, such as domestic households. In academic literature, *DeltaIO* is calculated using the following formula [9-12]:

$$\sum I_{Citygate} + \sum I_{Renewable} = \sum I_{Consumption} + \Delta LP + \Delta Losses + DeltaIO \quad (1)$$

In Eq. 1, the two additional components are:

2.1.1 Line-pack variations (*ΔLP*): *ΔLP* is the difference between natural gas already present in the network for the beginning and end of the *DeltaIO* calculation period. For the distribution network, *ΔLP* is negligible and is considered zero [9]. The Line pack is influenced by the pressure and temperature of the gas in the pipeline, which is a time-varying parameter. In distribution networks, pressure variations are usually stable and don't fluctuate significantly on a day-to-day basis. As per Arpino [12], temperatures across a network are considered constant.

2.1.2 Losses (*ΔLosses*): *ΔLosses* are the losses associated with theft, venting, leakage and fugitive emission. In certain cases, some of these losses, such as theft and leakage, are included in *DeltaIO*. It is very difficult to quantify the exact amount of losses due to theft and leakage.

The industrial literature [13-15] introduces adjustments in the *DeltaIO* equation as follows:

$$\sum I_{Citygate} + \sum I_{Renewable} = \sum I_{Consumption} + Adjustments + DeltaIO \quad (2)$$

2.1.3 Adjustments The term '*Adjustments*' is used as an umbrella term. One example of an adjustment used in the *DeltaIO* calculation is related to the availability of consumption data in the residential sector. Not all consumption data from distribution consumers, whether provided by consumers or obtained by the DSO or suppliers, is available for the *DeltaIO* calculation period. In the absence of this data, specific algorithms unique to the DSO are employed to assign consumption data for commercial purposes, which are later corrected once the actual consumption data becomes available. Another example of an adjustment is when consumer consumption data is inaccurate and requires correction. Examples of consumer data inaccuracies include:

i. Incorrect Meter Readings: Inaccurate meter readings can lead to discrepancies in gas consumption data. Human errors or technical issues with metering equipment can result in incorrect readings, thereby affecting the accuracy of consumer data.

ii. Estimation Errors: In cases where actual meter readings are not available, gas consumption data may be estimated based on historical patterns or average usage. However, these estimations might not accurately represent the actual consumption, leading to inaccuracies in the data.

iii. Missing or Delayed Data: There may be instances where consumption data from some gas consumers is missing or delayed. This could occur for various reasons, such as data collection issues, communication problems, or administrative delays. Without complete and timely data, the accuracy of the overall consumer data is compromised.

iv. Data Entry Mistakes: When inputting consumer data into databases or systems, errors can occur. Typos, transposition of numbers, or incorrect data entry can introduce inaccuracies in the gas consumption data.

v. Metering Irregularities: Malfunctioning or tampering with gas meters can lead to incorrect readings and inaccurate consumer data. Unauthorised modifications or interference with meters, intentional or unintentional, can distort the actual gas consumption figures.

2.2 Academic vs Industry approaches:

Both equations (Eq 1 and 2) are rooted in the energy-balancing principles of the natural gas network. However, differences emerge due to their distinct applications and practical implications. Academic literature, places a stronger emphasis on finalised data and its processing. The focus tends to be on data that has undergone thorough validation and quality control procedures. This often results in the utilisation of historical data in academic studies, reflecting a window of 2 to 3 years before publication. The choice to use finalised data aims to ensure the reliability and credibility of the findings presented. In an industrial context, the processed data primarily comprises real-time and recent data. However, recent data often suffers from missing or incorrect entries, attributed to various reasons. Comparatively, concerns about data precision and accuracy are more pronounced in the distribution network due to the vast number of measurement points, with each domestic meter acting as one.

2.2.1 Meter Reading Requirements: This variability becomes evident in the diverse meter reading requirements for different consumer types. For instance, the GNI code of operations stipulates that industrial consumers, typically supplied through a transmission network, require daily measurements [21]. Conversely, smaller domestic consumers aim for a measurement target of 3 to 4 readings per meter location annually. However, it's important to note that these requirements may vary based on specific consumer profiles and regulatory frameworks. Fulfilling this obligation necessitates four location visits by personnel who need access to the meters. Meter accessibility is a notable concern, fluctuating between 83% and 86% from 2015 to 2019 according to the system performance report [2-6]. As a result, accurate output data for the distribution network is accessible annually only for these meters. Output data for the remaining meters relies on consumer input, increasing the potential for inaccuracies.

2.2.2 Calculation Period: It's crucial to acknowledge that the calculation period for the industry-utilized *DeltaIO* isn't confined to a strict annual cycle. Instead, it functions as an ongoing process tailored for real-time data. This flexibility accommodates fluctuations and adjustments. Consequently, the *DeltaIO* data employed in academic literature reflects historical data from 2 to 3 years prior to publication. The industrial domain underscores the necessity for an ongoing process. Unlike fixed time intervals, industrial operations demand a continuous adjustment mechanism capable of seamlessly accommodating changes, variations, and corrections. This aligns with the dynamic nature of industrial processes where real-time adjustments are essential to optimize energy distribution, prevent disruptions, and maintain operational efficiency. Furthermore, the industry's ongoing process involves constant monitoring, analysis, and fine-tuning of *DeltaIO* parameters. As operational conditions change, the network must adapt and recalibrate these parameters in response to demand, supply fluctuations, and infrastructure conditions. This adaptability safeguards against potential imbalances minimises energy losses and sustains the financial equilibrium of the network.

<u>2.3 Challenges in Quantifying *DeltaIO*:</u>

2.3.1 Leakage and Theft: Both academia and industry grapple with the challenge of quantifying *DeltaIO* resulting from leakage, and theft. The reasons behind leakage and theft are self-evident. Once these instances are identified and halted, it becomes exceedingly challenging to precisely determine the initial point in the calculation period at which the loss attributed to such specific leakage or theft began. Additionally, in the case of hazardous leakages, system operators are required to prioritize immediate repairs, guided by country-specific parameters that take into account safety and operational perspectives. In contrast, safe leakages can typically be addressed as part of routine maintenance procedures, which may have a vague timeline and can be postponed if necessary. Literature available from the United States [15] provides information regarding a survey conducted by Washington State University. The survey identified that out of 230 underground leakages, three specific leakages are responsible for half of the *DeltaIO*. Notably, the time frame for hazardous leakage repair can vary significantly, ranging from 1 to 15 months. It is also of interest to note that only five states in the U.S. mandate a timeline of 3 months to 5 years for repairing safe leaks. This implies that in the remaining states, safe leaks can potentially be left unrepaired indefinitely. Furthermore, it's important to acknowledge that system operators often lack the motivation to repair leakages, particularly those classified as safe leaks.

2.3.2 Emission: Quantifying *DelaIO* due to emissions can be a challenging task, primarily because of the chosen approach. The European Union (EU) employs a method known as "Marcogaz," designed to calculate methane emissions that can then be converted to *DeltaIO*. Essentially, in the Macrogaz method [22], the network is divided and audited for components such as pipes, valves, elbows, and more. It's worth noting that each type of component has a range of emission factors based on the material, such as polyethylene and steel, further complicating the quantification process. Emission from each component is calculated by using that emission factor. The complexity of this method lies in the choice of emission factor, which adds to the intricacy of the overall assessment. Additionally, it is important to note that some network operators choose to verify the emission factor through experimentation, further enhancing the accuracy of the quantification process. This verification through experimentation further improves the accuracy of *DeltaIO*. Finally, the overall emission is calculated by summing up all individual components, providing a comprehensive assessment of the emissions in the network.

3. Italian and Irish natural gas network

The development of the Irish gas network has an interesting trajectory. Before the 1970s, it comprised separate town gas networks that gradually became interconnected post-1970s. This evolution continued, culminating in the present-day network. The turning point came in the 1990s with the establishment of sub-sea pipelines connecting the UK as a gas source. Moreover, the discovery of natural gas off the northwest coast of County Mayo in 2015 further enriched Ireland's gas supply. A significant addition occurred in 2019 when biomethane was introduced to the network. The current

Irish distribution network encompasses three distinct sources, as depicted in Figure 1 [23].

There is a high degree of dynamism and complexity in the Italian natural gas network infrastructure. This network comprises a total of nine distinct sources, contributing to its remarkable versatility and reach. Among these sources, six function as pipeline entry points, namely Tarvisio, Mazara del Vallo, Gries Pass, Gela, Melendugno, and Gorizia. The remaining three entry points are represented by LNG regasification terminals. These terminals include the Adriatic (or Cavarzere) terminal located off the Veneto coast in the north-east, the Panigaglia terminal situated near Liguria in the north-west, and the Offshore LNG Toscana (OLT) terminal positioned close to Livorno on the western coast of Tuscany. Moreover, Italy boasts an impressive thirteen natural gas underground storage facilities, all of which are situated within depleted gas fields. This strategic utilization of such fields enhances the country's energy security and storage capacity, contributing to the overall efficiency and stability of the natural gas network [24].

Both the Irish and Italian natural gas networks conduct commercial balancing based on energy [21,25]. However, the information available for Ireland is reported in energy units (i.e. GWh), while in Italy, it is reported in volume units (i.e. m^3). Volume can be converted into energy by introducing one more variable of calorific value (CV), using the following formula:

$$Energy\ (MJ) = Volume\ (m^3) * Calorific\ Value\ (MJ/m^3) \tag{3}$$

The CV of natural gas in the network is determined by the entry requirements of that network. The value of CV is Higher Heating Value (HHV) (Gross Calorific Value - GCV). In Ireland, the CV range is between 36.9 to 42.3 MJ/m^3 [21]. In Italy, the range of CV is 9.71-12.58 kWh/m^3 (34.96 - 45.29 MJ/m^3) [19]. This range also represents the diversity of supplies, with a broader range indicating a more diverse supply. The CV of Hydrogen is 12.7 MJ/m^3 [26], whereas the CV of biomethane often lies near the lowest value of the CV range, as in most cases, biomethane's CV (HHV) needs improvement to meet entry requirements. It is also an industry practice, driven by financial and environmental reasons, to add as little additive as possible, generally propane, which results in the CV of entering biomethane being near the lower end of the CV range. In the future, both networks will encounter the challenge of addressing large variations in CV within *DeltaIO* balancing, stemming from hydrogen and biomethane sources.

In a study conducted by Ficco *et al*. [9], *DeltaIO* is examined in the context of 2094 distribution networks in Italy. To determine the transferability of the methodology to other gas networks, the study is replicated for GNI, which serves as the only DSO in Ireland.

4. Result and discussion

As previously stated, GNI is the sole DSO in Ireland, overseeing approximately 17,055 km of a distribution network in 2019 [2]. The availability of GNI *DeltaIO* information has been accessible to the public since 2016 [5]. Since 2016, there have been significant enhancements in the visibility, clarity, and duration of *DeltaIO* information [2-5]. These improvements suggest that both the regulator and DSO recognise the significance of *DeltaIO*. A summary of this information can be found in Table 1.

Before 2012, all *DeltaIO* costs were pass-through costs. However, in 2012, CRU implemented a performance incentive that shifted the cost burden. The mechanism for this incentive was a target volume percentage for *DeltaIO*. The incentive began at 1% for the gas year 2012/13 (October 2012 to September 2013) and gradually decreased by 0.06% each subsequent year until it was intended to reach 0.75% by the gas year 2016/2017, as referenced in [27]. In 2017, the *DeltaIO* performance incentive was revised, deviating from the previous trajectory. The revised incentive began at 0.95% for the gas year 2017/18 and subsequently decreased by 0.05% each year. The aim was for the incentive to reach 0.75% by the gas year 2021/22. This updated incentive scheme was implemented as an adjustment to the previous structure [28].

This incentive is one of the strategies employed by regulators to encourage DSOs to minimise *DeltaIO* and mitigate the associated cost passed on to consumers [13]. In addition to the aforementioned information, it is important to note that the GNI is only permitted to transfer costs up to the level of the incentive. If the *DeltaIO* exceeds the value of the incentive, any additional costs beyond the incentive threshold are borne by the GNI. This ensures that the GNI has the responsibility to cover any excess *DeltaIO* costs that surpass the incentive amount, safeguarding consumers from bearing those additional expenses. In cases where the *DeltaIO* falls below the incentive level (2014), the GNI has the ability to recover the total costs associated with *DeltaIO*. This means that if the actual *DeltaIO* is lower than the incentive amount, the GNI can recoup the entire cost incurred in managing *DeltaIO*, ensuring that their expenses are fully covered.

Table 1. GNI *DeltaIO* analysis

Year	Gas entering ($\sum ICitygate + \sum IRenewable$) (GWh)	Gas leaving ($\sum IConsumption + Adjustment$) (GWh)	*DeltaIO* (GWh)	Actual *DeltaIO* (%)	CRU Target *DeltaIO* (%)
2013	15,256	15,056	200	1.31	1.00
2014	14,285	14,152	133	0.93	0.94
2015	15,103	14,866	237	1.57	0.88
2016	15,584	15,409	175	1.12	0.82
2017	15,513	15,327	186	1.20	0.75
2018	16,742	16,588	154	0.92	0.95
2019	17,055	16,886	169	0.99	0.90
2013-2019	109,538	108,285	1,253	1.14	

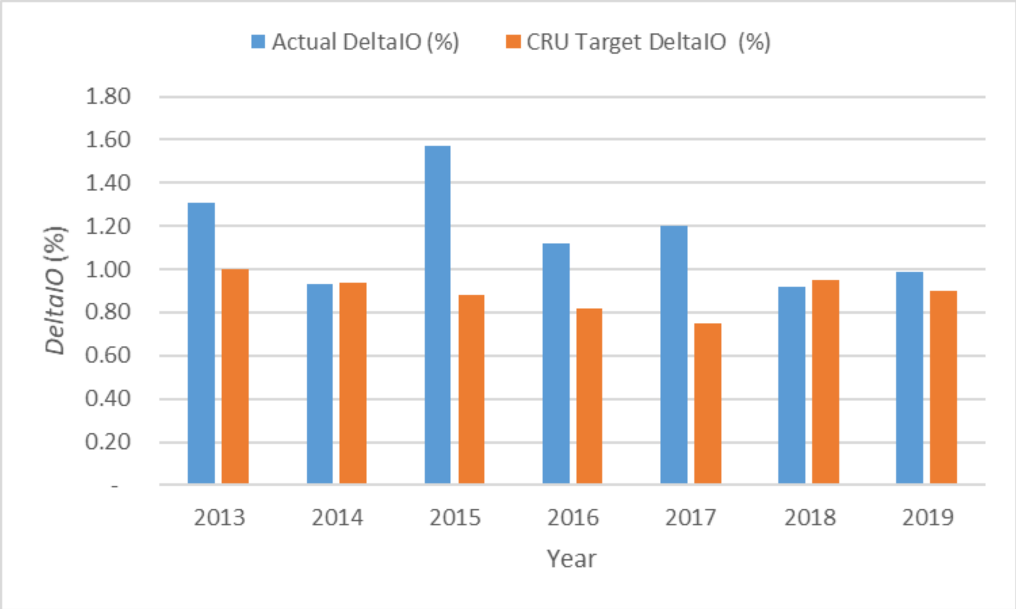

Figure 2. *DeltaIO* in Ireland

The specific values for each year are presented in Table 1. Since the gas year spans from October to the following September and mainly consists of the next calendar year, the CRU *DeltaIO* incentive for a particular year is based on the previous gas year's incentive. The actual *DeltaIO* and CRU target *DeltaIO* data is visualised in Figure 2.

In *DeltaIO* methodology [9], the distribution network is divided into three categories based on the volume handled annually: Large (>50 million m^3), Medium (5–50 million m^3), and Small (<5 million m^3). To determine the compatibility of the GNI distribution network with the *DeltaIO* methodology, it is required to convert the available energy input into volumetric measurements. This can be done using equation 3 mentioned in the previous section.

According to the GNI code of operation [21], there is an entry-level requirement dictating that the value of natural gas calorific value ranges between 36.9 to 42.3 MJ/m3. Using this range, the calculated volume ranges from 1215 to 1664 million m3. Hence, the GNI distribution network is classified as a large network.

The *DeltaIO* value for 2013-2019 represents the average value calculated using a flow-weighted average, with gas entering the network serving as the weighing basis.

5. Conclusion

The study analysed data from GNI, the sole DSO in Ireland, for the period from 2013 to 2019. The results highlighted the significance of UAG in the Irish context, with GNI's *DeltaIO* ranging from 0.93% to 1.57% and an average of 1.15%. These values indicate that a portion of the natural gas entering the distribution network is unaccounted for, posing financial, environmental, and safety concerns.

The findings of this study demonstrate the compatibility of the *DeltaIO* methodology developed by Ficco *et al.* [9] with the distribution network in Ireland, providing valuable insights for industry stakeholders and regulators. The transferability of this methodology to other distribution networks is also feasible, with attention given to the balancing entity involved. In terms of energy balancing, as demonstrated in this article, the conversion using an appropriate Calorific value range is necessary. By addressing the issue of UAG, the natural gas sector in Ireland can enhance its operational efficiency, reduce greenhouse gas emissions, and improve overall energy security. These findings highlight the importance of implementing measures to manage and minimise UAG, benefiting both the industry and the environment.

Comparisons with larger Italian distribution networks indicate that GNI's *DeltaIO* values are higher, suggesting potential variations in network characteristics and operational practices. Notably, all the analysed *DeltaIO* values of GNI are positive. The significance of positive and negative *DeltaIO* values lies in their commercial implications. Positive *DeltaIO* values, in simplified terms, indicate that consumption is lower than the inputs, while negative *DeltaIO* values suggest that consumption exceeds the inputs (which can occur in cases of metering malfunctions), potentially leading to overbilling of consumers. It is crucial to address and minimise negative *DeltaIO* values to ensure fair and accurate billing for gas consumption.

The findings of this study highlight the effectiveness of the *DeltaIO* performance incentive implemented by the Commission for Regulation of Utilities (CRU) in Ireland. The incentive has successfully led to a reduction in UAG within the GNI distribution network. The positive impact of the incentive is evident in the consistently decreasing *DeltaIO* values over the years, indicating improved operational efficiency and minimised losses. However, it is important to note that while the incentive has yielded initial positive results, further efforts are still required to achieve even greater improvements in UAG reduction. Continuous monitoring and assessment of *DeltaIO* values, along with a regular review of the incentive scheme, will be crucial to identify areas of further improvement and encourage DSOs to prioritise UAG reduction. The CRU should continue to work closely with industry stakeholders and DSOs to identify and address any remaining challenges in order to achieve optimal UAG reduction in the Irish natural gas sector. By fostering collaboration and providing guidance, the CRU can lead ongoing efforts to enhance operational efficiency, reduce greenhouse gas emissions, and ensure fair and accurate billing for consumers.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All the data used is available in the public domain.

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