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# QUANTIFYING IMPACT IN THE ENVIRONMENT SECTOR:
## A GREENHOUSE GAS EMISSIONS MONITORING STUDY

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# Quantifying impact in the Environment sector:
## A Greenhouse Gas Emissions Monitoring Study

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## ABSTRACT
UK's strategy to build back greener focuses on decarbonising all sectors of the economy to meet the net zero target by 2050. Hence, this study assesses the impact National Physical Laboratory (NPL) creates in generating environmental benefits through the channel of Greenhouse gas monitoring/reduction services. It is based on a simple model generalised from a knowledge case study titled 'Measuring and Reducing Fugitive Emissions' by a Senior Research Scientist of NPL. It takes in to account the environmental harm of the greenhouse gas emissions and how NPL's support creates private and social benefits through the emissions saved. The study uses objective data (invoicing data) cross referenced by the Science Area Experts. The key finding is that NPL impact can save up to 0.51 mega tonnes of CO2e over a period of 5 years (2016-2020). This reduction in environmental harm, through reducing emissions, translates into a social value of £37.4m and £30.4m respectively for the domestic and international activity. These services are estimated to contribute up to 1.30% reduction in the total UK greenhouse gas emissions (from 2016-2020). The results may be lower bound estimates as the focus was on invoices that NPL receives, and therefore only caters for direct benefits. Potential extensions for this research could be the use of the UK pollutant register for yearly emissions monitoring, exploring the connection of greenhouse gas emissions with air quality, and quantifying indirect benefits of utilising greenhouse gas monitoring services.

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## PREFACE

The government has set ambitious challenges to achieve net zero target by 2050, including aims relating to 'Clean Growth'. It seeks to curb the manufacturing and use of high carbon technologies, systems and services which is necessary to reduce the level of carbon emitted in the atmosphere. The pilot study has been prepared by the Analysis and Evaluation Team to fill the gap in the evidence, for the impact NPL creates in the realm of greenhouse gases. It aims to support NPL's contribution to the net zero target. The document will be for both internal uses and for analysists and policy makers at The Department for Business, Energy & Industrial Strategy.

The objective of the report is to provide evidence for the importance of services that NPL provides for greenhouse gas emissions monitoring and reduction. It focuses on one of the most harmful greenhouse gases, methane. The approach used in the Methane Case Study for measuring and reducing fugitive emissions is generalised to fit NPL's aggregated customer base since the case study is specific to one customer.

The report focuses on quantifying the direct outcomes and impact derived from using NPL's greenhouse gas monitoring and reduction services globally. The quantification of indirect benefits is beyond the scope of the study. Moreover, it is important to note that the analysis only focuses on paid interaction with private users. It does not include NPL's support to public organisations and academics.

## EXECUTIVE SUMMARY

The governments of 195 countries have committed to tackle climate change under the Paris agreement. The UK government has set ambitious target to achieve the net zero target by 2050. NPL being key to the measurement infrastructure in the UK, it is important to understand the impact of the unique set of greenhouse gas emissions monitoring / reduction services that it offers. The objective of the study is to evidence the impact created from utilising these services. The report focuses on one of the most harmful greenhouse gases, methane.

The study is based on a very simple model, generalised from a knowledge case study (Measuring and Reducing Fugitive Emissions). In the methane reduction case study, the quantity of savings is known which is not the case here. The quantity of savings needs to be calculated from the amount of income spent on these services. To do so, the model assumes that the value of the service offered by NPL is determined by the user's willingness to pay as opposed to the marginal cost. It also assumes that organisations have a motive to reduce their methane emissions because natural gas is resaleable in the market.

The study finds that if the products and services that NPL offers for greenhouse gas monitoring and reduction over a period of 5 years (2016-2020) stimulate action of reducing emissions, then it is equivalent to saving up to 0.51 mega tonnes of CO2 equivalent. This reduction in environmental harm, through reducing emissions, translates into a social value of £67.8m (includes both domestic and international activity). Moreover, this reduction in methane emissions equates to 1.30% of the average annual decrease in the UK's total greenhouse gas emissions that occurred during the period 2016 to 2020.

This work only analyses the direct benefit to the firms. It is simply an estimation of converting the amount spent with NPL into quantity of emissions saved (CO2e). Note that it does not differentiate carbon dioxide and other gases. It is difficult to separate invoices for each gas within the other gasses' category. This can underestimate the final value obtained as the Global Warming Potential (GWP) of nitrous oxide and sulphur hexafluoride is significantly higher than methane. On the other hand, price of gases over time can drive the impact numbers down as the study currently only considers the base year gas price.

Moreover, this study is of policy relevance because it assesses benefits of providing the users of NPL with the services and expertise they require to reduce greenhouse gas emissions, and ultimately supporting government effort at mitigating climate change and meeting the net zero target.

# 1 INTRODUCTION

The greenhouse effect refers to a phenomenon in which Earth traps heat in turn causing extremity in temperatures, commonly known as Global Warming. Scientists deem carbon dioxide and methane emissions to be the primary source for this phenomenon. Available data show that the concentration of greenhouse gases especially carbon dioxide has risen substantially over the last 200 years causing a gradual but very noticeable increase in the global average temperatures. The primary cause being industrialisation, whose main harness is burning of fossil fuels.

The preliminary focus has been on carbon dioxide as opposed to other gases because it is the main greenhouse gas in terms of its concentration in the atmosphere. However, literature suggests that the effect of trace gases: methane, nitrous oxide and chlorofluorocarbons on the environment may exceed the effects caused by increasing concentration of carbon dioxide (Lacis et al., 1981; Ramanathan et al., 1985; Hansen et al., 1988). The trace gases exist at concentrations that are two to six orders of magnitude lower than that of carbon dioxide, but are significantly important because, per molecule, their infrared radiation absorption rate is much stronger than carbon dioxide (Lashof & Ahuja, 1990; Hansen et al., 1989). Another study shows that these trace gases account for almost 43% of the increase in radiative forcing from 1980 to 1990 (Hansen et al., 1988). It is for these reasons that the study focuses on treating methane and carbon dioxide separately.

Literature also suggests that being able to monitor and record the level of carbon emissions is key to devising strategies for environment quality (Abeydeera, 2019). Tools like the statistical process monitoring (SPM) schemes help to monitor emissions data and provide the ability to spot unusual trends. It is argued that these SPM tools are applied more in manufacturing sector compared to the non-manufacturing sectors. This is due to the lack of data and the invisible work processes in the non-manufacturing sectors (Shamsuzzaman, 2021). Following on from this, the aim of this study is to use NPL's existing data and formulate a new methodology. This methodology will aid in the approximation of the quantity of emissions that are saved as a result of the services that are provided for greenhouse gas monitoring and reduction.

Due to the increasing effects of Global warming, governments of 195 countries have promised to tackle climate change by limiting greenhouse gas emissions, under the Paris Agreement. In line with the Paris Agreement, the UK government has set ambitious targets to reduce emissions in 2030 by at least 68% compared to 1990 levels. It is, therefore, important to understand the products and services that NPL provides which help the government fulfil its targets and goals. NPL offers a broad suite of emission monitoring services which are; Emission monitoring using Differential Absorption Lidar (DIAL), Continuous monitoring of fugitive emissions, Site surveys for leak detection and emission measurement, Fenceline monitoring - EPA method 325 and Stack emissions monitoring. These range of capabilities enable NPL to deliver cost-effective solutions to any emission monitoring requirement.

This report quantifies the impact NPL creates from delivering greenhouse gas monitoring / reduction services by deriving the quantity of emissions saved from the income received for the services. For the very first time, NPL will have a systematic way of quantifying impact in the greenhouse gases realm. This will pave the way for developing metrics for reduction in greenhouse gas emissions.
The rest of the study is organised as follow: section 2 of the report looks at the knowledge case study in detail followed by a further analysis section which draws out the feasibility of the project presented in the case study. Section 3 defines the conceptual framework and model for working back the quantity of emissions from income. Section 4 and 5 discuss the

data used and the impact numbers derived, respectively. The final section analyses the results obtained along with the influence of assumptions on the impact numbers. It further draws out the routes for possible further research.

# 2 MEASURING AND REDUCING FUGITIVE EMISSIONS

## 2.1 METHANE CASE STUDY

One of the major projects revolving around the greenhouse gases has been with the National Grid (Greenhouse Gas Investigation Mechanism). The case study by David Butterfield, 2018 explains that there are two parts to the project. By utilising NPL's expertise for detection and fixing leaks in pipes, it is estimated that nearly 230 tonnes of methane can be saved across the 23 sites of National grid. The second part of the project relates to first estimating the total emissions across all the sites and then setting reduced targets for emissions per compressor. The figures in the project description document suggest that potentially 265 tonnes of methane emissions can be saved.

The case study quantifies the impact based on the following assumptions:

- Natural Gas and methane are equivalent as the composition of natural gas mainly consists of methane
- Firms get a direct benefit from reducing methane as its resaleable
- By experiencing an efficiency gain due to leak detection and prevention there is no effect on the demand and supply and therefore output remains unchanged.

| **Table 2.1 Methane emission reduction Case study** | |
|---|---|
| If leaks are detected across all 23 sites you save (tonnes of methane) | 230 |
| Global Warming Potential (GWP) of methane over 100 years is | 28 |
| Equivalent saving of (tonnes of carbon) | 6440 |
| 1 tonne of natural gas has a wholesale price of (from business case) at the base year | £205 |
| **1 Private costs and benefits** | |
| Cost of project | £207,815 |
| Methane saved from reducing emissions from compressors (tonnes/year) | 265 |
| Methane saved from leak detection and prevention (tonnes/year) | 230 |
| Methane saved in total (tonnes/year) | 495 |
| Total value from saving methane (per year) | £101,336 |
| **2 Social Benefit** | |
| Saved emissions (tonnes of methane/year) | 495 |
| GWP of methane over 100 years | 28 |
| Social Cost of carbon | £73 |
| Value of saved emissions (per year) | £1,011,780 |

The table 2.1 summarises the numbers from the project with National Grid. It looks at the private and social benefits created. The cost of the project is £207,800. It is important to note that this cost does not include the transportation cost to the other sites. The project generates a flow equivalent to £100,000 every year for at least 10-20 years. As per our experts heavily involved in this project, deem this to be an acceptable timeframe to assess this project, as the climate impacts of methane are long lasting, and the improvements and knowledge gaining about the sites can be sustained over time. According to the Organisation for Economic Co-operation and Development (OECD) Library, machinery and equipment used in this industry typically have an average life of 30 years. Considering the average life and the use of natural gas being unknown (given the prime objective of Net Zero), a time frame of 10-20 years seems plausible.

## 2.2 FURTHER ANALYSIS

A simple way to estimate whether such a project for greenhouse gas monitoring / reduction is worthwhile for our customers, Net Present Value (NPV), Internal Rate of Return (IRR) and Modified Internal Rate of Return (MIRR) is calculated under different time periods. To do so, the following assumptions help build the results:

- Flow of benefits will last for at most 20 years because of Net Zero by 2050.
- Lifetime of assets in the quarrying, mining and utility sectors is approximately 30 years as per the OECD Library.
- The weighted average cost of capital (WACC) / discount rate is 10%, Reinvestment rate for the Modified Internal Rate of Return is 10%.
- Firms incur in house costs equivalent to two times the original cost, according to the National Measurement System customer survey, 2019.

The table 2.2.2 shows the results obtained for NPV, IRR and MIRR.

Scenario 1 takes the total cost and looks at a horizon of 20, 10 & 15 years. All of which conclude that the project is worthwhile. However, from the NMS Customer Survey Report (2020, Page 75), it was brought to light that firms end up incurring three times the cost which includes inhouse costs, to bring a project to life.
Scenario 2 looks at what happens if that is the case. It concludes that the project is worthwhile over a period of 15-20 years but not over a 10-year period. But note that the cost of capital taken here is high for an organisation like National Grid whose weighted average cost of capital lies between 3 to 4% which confidently implies that the project is worthwhile.
Since the cost of the project does not include the transportation cost, it will push these calculations down. But because the scenario 2 considers three times the cost, the analysis still gives a picture for whether such a project is worthwhile.

| Table 2.2.1 Key Parameter Values | |
|---|---|
| Cost of Capital / discount rate | 10% |
| Reinvestment rate | 10% |
| Cost of the project | £207,815 |
| Benefit from the project | £101,336 |

| Table 2.2.2 | 20-year period | 10-year period | 15-year period |
|---|---|---|---|
| Scenario 1 with cost £207k | | | |
| Internal Rate of return (IRR) | 49% | 48% | 49% |
| Modified Internal Rate of Return (MIRR) | 18% | 23% | 20% |
| Net Present Value (NPV) | £654,919 | £414,853 | £562,958 |
| | | | |
| Scenario 2 with cost £623k | | | |
| Internal Rate of return (IRR) | 15% | 9.97% | 14% |
| Modified Internal Rate of Return (MIRR) | 12% | 9.99% | 12% |
| Net Present Value (NPV) | £239,289 | -£777. | £147,328 |

# 3 CONCEPTUAL FRAMEWORK & MODEL

## 3.1 FRAMEWORK FOR THE MODEL

Core assumptions that will help develop the framework for the study are as follows:

- Natural Gas and methane are equivalent as the composition of natural gas mainly consists of methane.
- The dynamics of natural gas remain unchanged for 20 years (up to 2040).
- If emissions can be measured and leaks are detected, they can be avoided.

Some additional set of simplifying assumptions for this framework are as follows:

- On average customers know the expected savings that arise from the service by NPL.
- There are no fixed costs to the user for the inhouse maintenance operations or for external services.
- NPL does not take any service charge for the service provided (i.e., there is zero cost to the supplier of services to eliminate emissions.
- Customers are risk neutral.
- Customers engage in these services purely for business needs.
- All services related to greenhouse gases provided by NPL stimulate action (i.e., lead to a reduction in emissions).

Key variables include traded and non-traded value of carbon. In the greenhouse gas inventory, source emissions are categorised into traded and non-traded. Traded emissions capture those that come from installations covered by the EU Emissions Trading System (EU ETS), whereas non-traded emissions are those which do not fall within the scope of the EU ETS. The emissions from some sectors, such as the residential sector, are completely non-traded whereas emissions from other sectors, such as energy supply and business and industrial process are a combination of traded and non-traded.

UK operates a trading emissions scheme (UK-ETS) to support the climate control ambition. Emissions trading schemes work on the ‘cap and trade’ principle, where a cap is set on the total amount of certain greenhouse gases that can be emitted by sectors covered by the scheme. This limits the total amount of carbon that can be emitted and, as it decreases over time, will make a significant contribution to how we meet our Net Zero 2050 target and other legally binding carbon reduction commitments. Within this cap, participants receive free allowances and/or buy emission allowances at auction or on the secondary market which they can trade with other participants as needed. The UK ETS is applicable to energy intensive industries, the power generation sector and aviation. Auctioning is the primary means of introducing allowances into the market.

For simplification, the framework defines traded value of carbon as the value of one tonne of carbon dioxide equivalent in the market and non-traded value of carbon as the social value of carbon dioxide which takes in to account the harmful effect of carbon (see Annex D). However, the table has now been updated by BEIS where there is just one value for carbon. If the study is updated with recent data, the new values will have to be considered which implies reduction in the $CO_2$ equivalent tonnage. In addition, to create a relationship between methane and carbon dioxide, the global warming potential is used. According to available statistics, methane is almost 28-34 (over a 100-year period) times more harmful to Earth than carbon dioxide. Using this, we say that one tonne of methane is equal to 28 times of carbon in its effect on the environment.

Consider the following discussion for the framework:
Suppose there is a firm that transports and supplies natural gas across the country. The firm due to leakages in pipes is losing gas ‘$g$’. The market price of natural gas is ‘$p$’. The wholesale price per unit is ‘$c$’. The wholesale quantity purchased is ‘$q$’ and it ends up selling ‘$q-g$’. The firm can charge a markup on the whole sale price which can be written as:

$$p = (1+\mu)c \tag{1}$$

The profit function for the firm is

$$\pi = p(q-g) - cq \tag{2}$$

Substituting (1) in (2), the function can be rewritten as

$$\pi = c\mu q - (1+\mu)cg \tag{3}$$

As a result of not being able to detect leaks, firm has to bear an additional loss. By utilising Greenhouse gas monitoring/reduction services from NPL, a surplus is created which in this case is in the form of benefits from saved emissions and that is equal to the value of the emissions that will be saved as a result of using the services.

$$V = (1+\mu)cg = pg \tag{4}$$

The surplus may be shared between NPL and the user with some sort of proportion. NPL extracts the surplus in the form of the fee it charges that can be referred to as income to NPL, and the user gets the net benefit from the service.

$$V = \sum_{i=1}^{2} \gamma_i V \tag{5}$$

$V =$ Present Value of flow of benefits from saved emissions from use of a service/total surplus
$\gamma_i$ = share of parties in total surplus where $\gamma_1 + \gamma_2 = 1$
$i = 1$ for NPL's share, $i = 2$ for User's share in the total surplus

$$V = \sum_{i=1}^{2} \gamma_i V = \gamma_1 V + \gamma_2 V = v_1 + v_2 \tag{6}$$

$v_1 =$ NPL's income from the service
$v_2 =$ User's net benefit from the servrice

For simplicity, let us assume the net benefit to the user is zero and NPL extracts the entire surplus in the form of the fee it charges.

$$V = v_1 \tag{7}$$

$V$ = Present Value of flow of benefits from saved emissions
$v_1$ = NPL's income from services

Using equation (4) and (7), we can say that:

$$v_1 = (1+\mu)cg = p \times g \tag{8}$$

$v_1$ = NPL's income from services
$p$ = Market price of gas
$g$ = Quantity of emissions saved through the service

The methane reduction case study in section 3 clearly indicates the quantity of methane that can be saved by using NPL's services. However, only the amount of income from services to customers is known. Hence, quantity must be worked back from the income.

In a normal competitive setting, price is determined by the marginal cost. NPL offers unique services and therefore can be thought of committing to value based pricing. That is, the value of a service is equivalent to the customer's willingness to pay. Subsequently, willingness to pay is based on the resale value of saved methane (wholesale value) which otherwise would have been released into the atmosphere. In other words, the willingness to pay is equal to the expected savings of methane from the service utilised as show in equation (8). For more detail on how willingness to pay can be determined, please see Annex E.

Since the quantity of emissions saved are possibly a yearly benefit. The equation (8) can be rewritten as:

$$\mathrm{v}_1 = \sum_{t=1}^{n} \frac{1}{(1+r)^t} \cdot \mathrm{p}_0 (1+\rho)^t . \mathrm{g}_t \tag{9}$$

where

$\mathrm{v}_1$ = NPL's income from services

$\mathrm{p}_o$ = Price of gas at the base year

$\mathrm{g}_t$ = Quantity emissions saved overtime as a result of the service used

$r$ = discount rate

$\rho$ = growth rate of price

Note that market price of methane will increase year on year. If we assume that the rate of growth of price is the same as the rate of the discount:

$$\mathrm{v}_1 = \sum_{t=1}^{n} \mathrm{p}_0 . \mathrm{g}_t \tag{10}$$

The expression can then be rearranged to:

$$\frac{\mathrm{v}_1}{\mathrm{p}_0} = \sum_{t=1}^{n} \mathrm{g}_t \tag{11}$$

The framework laid above helps to quantify the emissions saved over time and using this the model derived in the next section will help in estimating the quantity of carbon dioxide equivalent emissions saved through the services provided.

## 3.2 MODEL DERVIATION

The theoretical framework has developed a relationship between the value of savings and the quantity of saved methane emissions. In our setting, we can value what NPL charges from the invoices and the market price of the natural gas which then allows the estimation of the quantity of emissions saved and their respective social value.

Using it, the social value of saved C02 equivalent emissions can be calculated. Equation (11) is rewritten as:

$$\text{Estimated quantity of saved emissions } (g_j) = \frac{\text{Income from invoices of the concerned Gas } (v_{1,j})}{\text{Market value of the concerned Gas } (p_j)} \qquad (12)$$

where

$j \; = \text{m (methane), c (carbon dioxide and other gases)}$

Once the quantity is estimated, the social value for the saved emissions can be calculated by the following equation;

$$\text{Social Value of } CO_2 \text{ e emissions}(s_j) = \text{Estimated quantity } (g_j) \times \text{nonTraded value of carbon}(p_{nc}) \times \text{GWP of greenhouse gas } (\varrho_j) \qquad (13)$$

where

$v_{1,j}$ = Income from invoices for the greenhouse gas gas
$p_j$ = Market value of 1 tonne of greenhouse gas gas
$p_{nc}$ = Social/nonTraded value of 1 tonne of carbon dioxide equivalent
$g_j$ = quantity of saved greenhouse gas gas
$\varrho_j$ = Global Warming Potential of the greenhouse gas gas$\varrho$
$s_j$ = Social Value of $CO_2$ equivalent emissions saved for the greenhouse gas gas

The study looks at three categories of greenhouse gases; methane, carbon dioxide and other gases. Other gases category is coupled with carbon dioxide as it's a small proportion of the total. The equations explained above are used to calculate the value of the saved emissions. F1 is used for methane invoices and F2 is used for carbon dioxide and other gases.

$$\text{F1: Value of saved } CO_2 \text{ equivalent emissions} \qquad (14)$$

$$= \frac{\text{Amount of income from invoices specifically for methane emissions}}{\text{Wholesale price of methane}} \times \text{nonTraded value of carbon} \times \text{GWP of methane}$$

$$\text{F2: Value of saved } CO_2 \text{ equivalent emissions} \qquad (15)$$

$$= \frac{\text{Amount of income from invoices for } CO_2 \text{ and other gases emissions}}{\text{Traded Value of carbon}} \times \text{nonTraded value of carbon}$$

The first part of the formula calculates the tonnes of gas saved and the second part calculates the value of those tonnes of gas saved.

# 4 DATA

## 4.1 DATA PREPARATION

The data is pulled from the Order Management System titled 'Invoiced income by project **2016-2020**' from Oracle. There are specific NPL groups whose services revolve around environment in terms of improving air quality and monitoring / reduction of greenhouse gases, namely

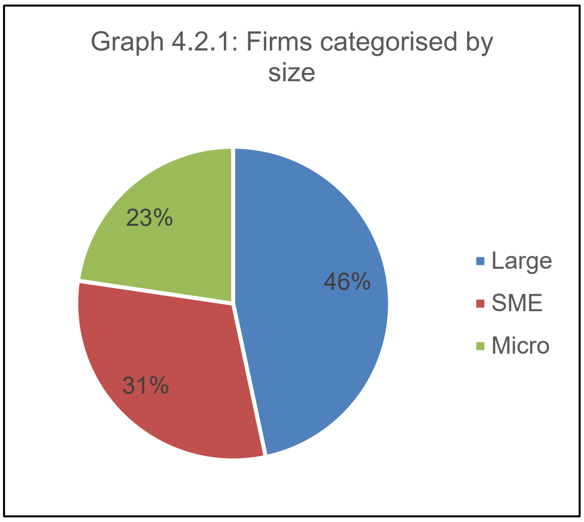
- Emissions and Atmospheric Metrology EAM
- Air Quality and Aerosol Metrology AIRQUALITY
- Gas Metrology GM
- Gas and Particle Metrology GPM

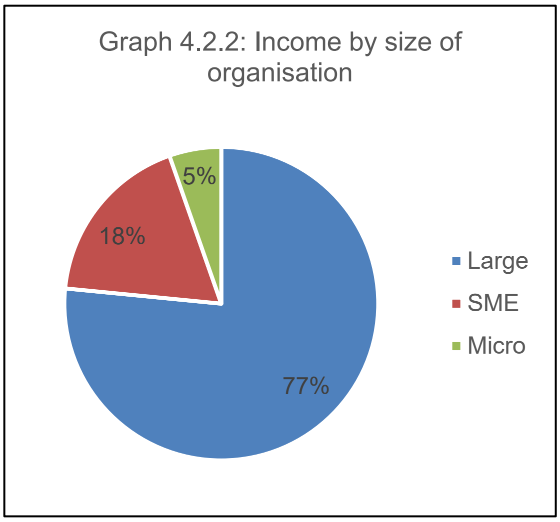
All other NPL groups are filtered out and the invoices for these four groups are kept. The next step is to take Academic institutions out as our interest lies within the Private sector UK based companies whose usage of products and services realise impact instantly. Some invoices belonging to other groups which relate to emissions and air quality were added manually to the data. The next step was to then look at the individual project descriptions for each of the invoices and tag it either greenhouse gas emissions or air quality. This was to separate the impact created by the two areas.

The next section looks at the descriptive statistics of the data.

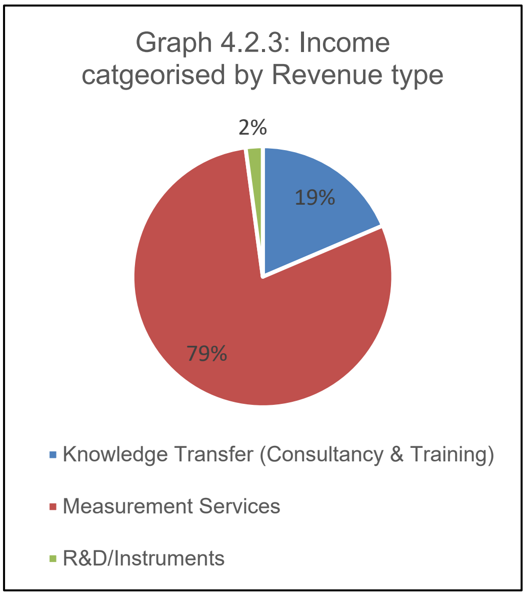
## 4.2 DESCRIPTIVE STATISTICS

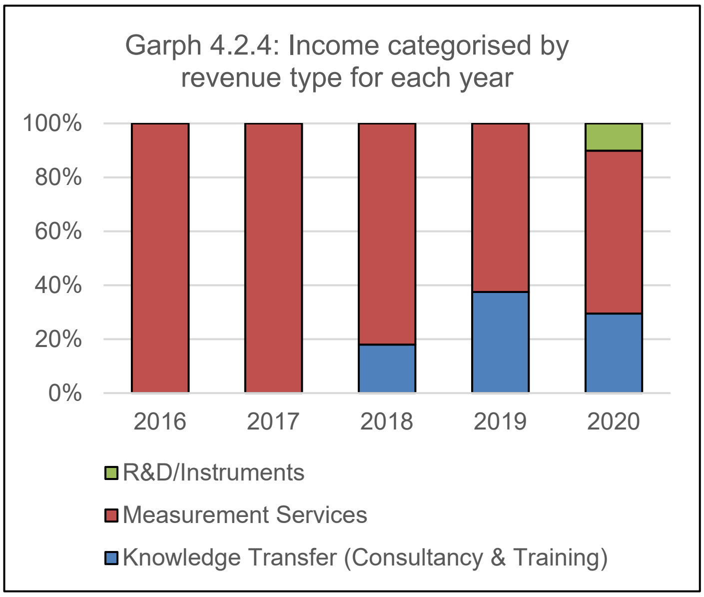
Graphs 4.2.1 and 4.2.2 suggest that approximately 50% of the firms are large and that nearly 80% of spending on monitoring / reduction of greenhouse gasses comes from large Private firms.



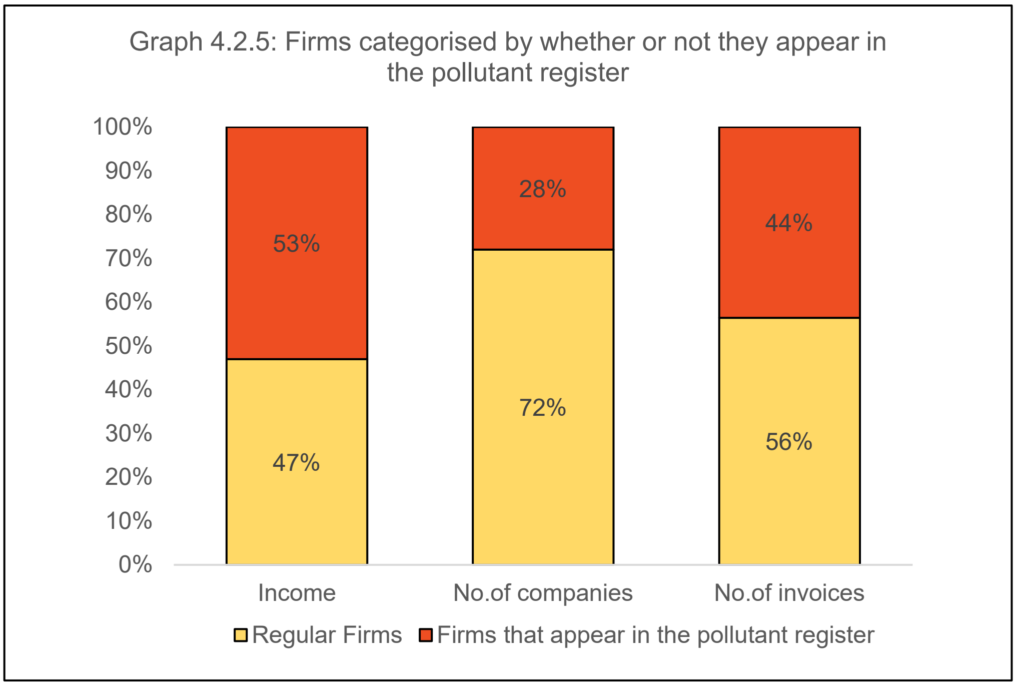



Graph 4.2.3 shows that the type of service mostly used by the firms is measurment services, nearly 80%. Graph 4.2.4 shows that most of the income is generated by the measurement services provided. Over the years, there has been an increase in Consultancy and Training and an uptake of Research & Development / Instrumentation in 2020.



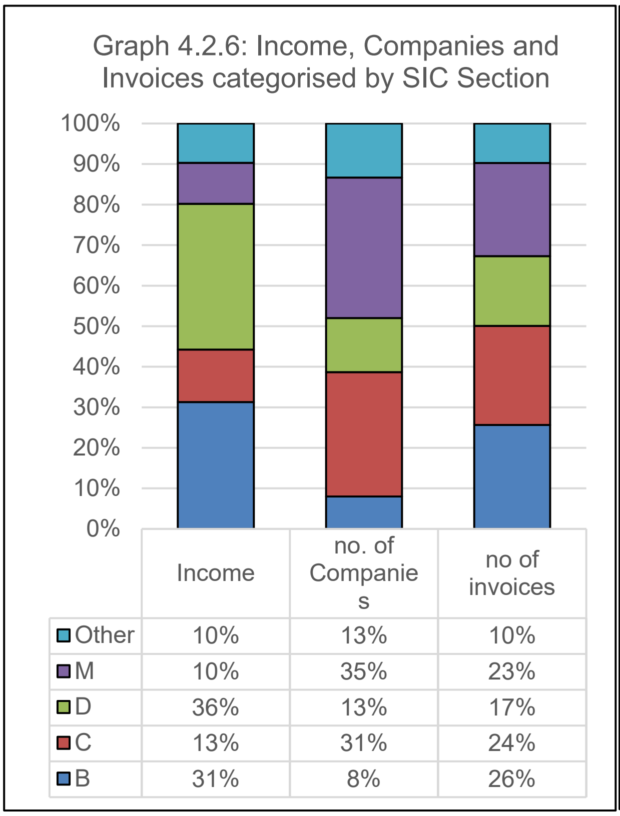



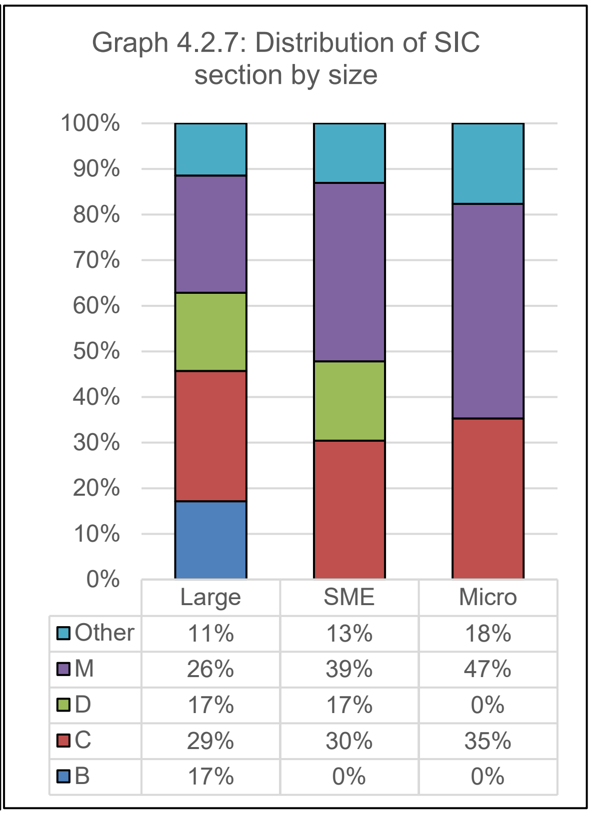

NPL's customers were matched with the firms that appear in the UK Pollutant Release and Transfer Register (PRTR). Graph 4.2.5 shows that approximately 30% of our customers are on the register with half of the spending on greenhouse gas montioring coming from them. Moving forward the pollutant register can be used to track the progress of these firms.




The next set of graphs look at the Standard Industrial Classification sections these firms belong to. The section letter and its description is shown in Table 4.2. The main sections picked out are Mining & Quarrying (B), Manufacturing (C), Utility (D), and Professional, Scientific and Technical Activities (M). The rest of them are bundled together in the 'Other' Category.

Graph 4.2.6 shows the total income, number of companies and number of invoices categorised by the key SIC sections. A significant portion of the firms belong to sections M and C but most of the spending comes from sections D and B. Graph 4.2.7 shows the distribution of SIC section in each size category. Most micro, and small medium enterprises are skewed to sections M and C. The large enterprises follow a similar pattern but also have a significant number of firms belonging to sections B and D.




| **Table 4.2** | | | |
|---|---|---|---|
| **Section** | **Description** | **Section** | **Description** |
| **A** | Agriculture, forestry and fishing | L | Real estate activities |
| **B** | Mining and quarrying | M | Professional, scientific and technical activities |
| **C** | Manufacturing | N | Administrative and support service activities |
| **D** | Electricity, gas, steam and air conditioning supply | O | Public administration and defence; compulsory social security |
| **E** | Water supply; sewerage, waste management and remediation activities | P | Education |
| **F** | Construction | Q | Human health and social work activities |
| **G** | Wholesale and retail trade; repair of motor vehicles and motorcycles | R | Arts, entertainment and recreation |
| **H** | Transportation and storage | S | Other service activities |
| **I** | Accommodation and food service activities | T | Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use |
| **J** | Information and communication | U | Activities of extraterritorial organizations and bodies |
| **K** | Financial and insurance activities | | |

## 5 IMPACT ASSESSMENT AND RESULTS

To quantify the impact NPL creates through greenhouse gas monitoring and reduction services, it is vital to have granular data on invoices. That is, what proportion of monitoring income is for methane, carbon dioxide and other gases. The reason for this lies in the scale of harm that each greenhouse gas cause. For instance, it is estimated that methane is almost 28 times more harmful in its effect on Global warming than carbon dioxide over a 100-year period (Fifth Assessment report of the Intergovernmental panel on climate change, Page 714). This is known as the Global Warming Potential for methane.

To find the total income for each greenhouse gas, two approaches were considered:

i. Each invoice to be manually scanned and given a tag depending on the project description and nature of the organisation.
ii. Emission and Atmospheric Metrology (EAM) experts to estimate the split of income between the gases

From the first approach, Methane's proportion worked out to be between 70% and 75% of the total. EAM experts estimated the following proportions for the greenhouse gases as shown in Table 5.1:

| Table 5.1 | |
|---|---|
| **Greenhouse Gases** | **Proportion** |
| Methane | 84% |
| Carbon dioxide and other gases | 16% |

The two estimates are not miles off, but the study takes the numbers given by the experts working in that area. These percentages are then used to calculate the amount received as invoices for methane, and carbon dioxide and other gases

The tables below show the working for quantifying the emissions saved through these services. The non-traded and traded value for carbon is taken from BEIS' appraisal of carbon prices and sensitivities 2010-2100, please see Annex D. The wholesale value of methane is calculated by our experts for the National Gas Grid Greenhouse Gas Investigation Mechanism. The **blue** tables contain the key parameters and breakdown of gases. The **green** table refers to the sum of all the invoices NPL receives from 2016-2020, that connect specifically to the Emissions and Atmospheric Metrology group along with other groups like Temperature & Humidity and Gas Particle Metrology. Furthermore, it shows the division of income between domestic and international activity. The split found between the two is approximately 50/50 from the data and NPL experts have confirmed this proportion. The **orange** table then takes the split and further divides it into the type of greenhouse gas, taking the estimate of proportions discussed above. The pink box calculates the **quantity and value of the $CO_2$ equivalent emissions saved.**

| Table 5.2: Breakdown of Gases | |
|---|---|
| Methane | 84% |
| Carbon dioxide and other gases | 16% |

| Table 5.3: Key Parameter Values | |
|---|---|
| Non-traded value of carbon | £73 |
| Traded value of carbon | £6 |
| Wholesale value of natural gas | £205 |

| Table 5.4: | |
|---|---|
| **Income for 2016-2020** | **Millions (m)** |
| Greenhouse gas monitoring related income from other groups | £0.59 |
| Greenhouse gas monitoring related income from EAM | £6.00 |
| Greenhouse gas monitoring related Income from EAM - Domestic | £3.05 |
| Greenhouse gas monitoring related income from EAM -International | £2.95 |

| Table 5.5: | | |
|---|---|---|
| **Breakdown of Income 2016-2020 by Greenhouse gas** | **Domestic (m)** | **International (m)** |
| Methane – Other Groups | £0.59 | |
| Methane - EAM | £2.56 | £2.48 |
| Carbon dioxide and other gases - EAM | £0.49 | £0.47 |
| Total | £3.64 | £2.95 |

| Table 5.6: | | | |
|---|---|---|---|
| **Converted Social Value of Greenhouse gas** | **Tonnes of C02e – Domestic (M tonnes)** | **Domestic (m)** | **International (m)** |
| Quantity and Value of $CO_2$ equivalent emissions saved for 5 years (m) - methane | 0.43 | £31.46 | £24.71 |
| Quantity and Value of $CO_2$ equivalent emissions saved for 5 years (m) – $CO_2$ and other gases | 0.08 | £5.94 | £5.74 |
| Total | 0.51 | £37.4 | £30.4 |

Formulae F1 and F2 (equation 14 and 15) are used to calculate the social value of the saved emissions. The results imply that the services that NPL provided between years 2016-2020 (provided they stimulate action, that is, cause a reduction in emissions), is equivalent to saving 0.51 mega tonnes of methane. This translates to a social value of £37.4m and £30.4m for the domestic and international activity respectively across the 5 years.

It is important to note that the report also looks at greenhouse gas services used internationally. This is because the area of research is deeply connected to the global challenge of climate change and the contribution of services in emissions reduction anywhere in the world is beneficial.

One thing to note is that the model specified above (with specific focus on equation 10) assumes that the rate at which the price of the gas increases is same as the rate of the discount factor. However, the price of natural gas has seen a very dramatic increase in the recent years (please refer to Annex C). The carbon values have also seen a very sharp increase (please refer to Annex D). This would drive down the impact numbers as the denominator would increase in F1 and F2.

As a way of checking the saved tonnage of emissions, the numbers obtained via the model are compared against the numbers in the knowledge case study.
The total income received from the project was £207,000 and the price of one tonne of natural gas in that period was £205. According to the model this equates to 1013 tonnes of natural gas. The methane case study however estimated a reduction of 495 tonnes of natural gas. This difference can be explained through the discussion made above about how the model does not consider the dramatic increase in the price of the gases which would push these impact numbers down. Another point to note is that at the time of the knowledge case study, such a sharp increase in gas prices could not have been forecasted.

Table 5.7 shows the UK greenhouse gas emissions estimated from 2015 to 2020. Emissions for 2020 have been approximated using the average %age reduction in the emissions over a 30-year period which gives an estimate of 1.93% reduction for 2020.

| **Table 5.7** | | |
|---|---|---|
| **Year** | **Total greenhouse gas emissions in the UK, mega tonnes of $CO_2$ equivalent** | **%age change** |
| 2015 | 510.53 | -3.24% |
| 2016 | 485.38 | -4.93% |
| 2017 | 474.23 | -2.30% |
| 2018 | 468.05 | -1.30% |
| 2019 | 454.76 | -2.84% |
| 2020 | 445.99 | -1.93% |

Table 5.8 calculates the contribution of NPL in the reduction of total greenhouse gas emissions in the UK. It can be said that if all services cause a reduction in the emissions, then NPL accounts for a share of 1.30% in the UK's total $CO_2$e emissions reduced over the 5-year period.

| **Table 5.8: NPL's contribution to reducing $CO_2$ equivalent emissions** | |
|---|---|
| Amount of greenhouse gas reduction from 2016-2020 in the UK (Mega tonnes) | 39.39 |
| Total quantity of saved $CO_2$ equivalent emissions (Mega tonnes) | 0.51 |
| NPL's share in reduction | 1.30% |

As mentioned previously, the study assumes that the net benefit to the user is zero. If one was to assume a 50/50 split between NPL and the user for the surplus created. The quantity of saved emissions considered here would double and so would NPL's share in reduction of UK's total greenhouse gas emissions.

The share of 1.30% can be compared against the proportion of total government spending on R&D which is accounted by NPL. Table 5.9 calculates an estimate of the proportion using the amount of funding NPL receives from the government for research and development. The proportion is 0.76% and NPL's share in the reduction is above the 1% mark concluding that NPL's impact is in the right direction.

| **Table 5.9** | |
|---|---|
| Government's net R&D spent in 2019 (bn) | £13.10 |
| Public funding to NPL (m) | £100.00 |
| Proportion of government spending on R&D accounted by NPL | 0.76% |
| NPL's share in reduction of UK emissions | 1.30% |

# 6 CONCLUSION AND SUGGESTIONS FOR FUTURE RESEARCH

## 6.1 CONCLUSION

The study models the contribution of greenhouse gas emissions monitoring and reduction services on the UK's top priority of reducing carbon emissions. A simple model based on a knowledge case study was used to estimate the quantity of saved emissions as a result of using the services. It was found that if these services stimulate the action of reducing emissions, a quantity of 0.51 mega tonnes of CO2e can be saved over a period of 5 years. This is equivalent to a social value of £67.8m (domestic and international, £13.5m/year). Moreover, this means that NPL can contribute a share of up to 1.30% in the total reduction of UK's greenhouse gas emissions.

There are some factors that can push the impact numbers in either direction.
If the recent rate of growth of gas price is considered, it would mean that the impact numbers derived are overestimated. This is because the model assumes that the rate of price growth and discount factor are equal. On the other hand, the list of assumptions that lead to an underestimation of the impact numbers are as follows:

- GWP of methane (28) over a 100-year period used is a lower bound value.
- Some gases in the Other Gases category coupled with carbon dioxide have a very high GWP (for example sulphur hexafluoride and nitrous oxide).
- Net benefit to the user is assumed to be zero.
- The study only considers the direct benefits and not the indirect benefits.

## 6.2 FUTURE RESEARCH

To make these impact numbers a regular annual metric, there are a few considerations and further refinements to be made. The study assumes that there are zero fixed costs to the user. If fixed costs are included in the model, the quantity of emission number goes up. Similarly, if the users are seeking specialist services to avoid any potential fines, then they have more benefit to gain then just the value of emissions. This will push the quantity number down. If both fixed costs and fine value are added to the model, then they could potentially cancel out. This can be seen in more detail in Annex A. The model specified in this study can be further developed in the future to include these new parameters.

A more systematic way of knowing which gas each invoice targets rather than estimating an aggregate, could make the process more efficient and traceable. One possible way is to use the esteem survey to capture the amount of annual income that is related to methane. Going forward, it would be fitting to include only the oil and gas related invoices and ensure livestock and other non-relevant sectors are excluded. This would ensure that projects where methane can't really be saved with the intention of reselling it, are excluded.

As mentioned in the previous section, the study only looks at the direct benefit and does not account for indirect benefits. For instance, if a dial van is purchased by an international customer and they start expanding their capabilities to measuring fugitive emissions; this would bring significant benefits to the environment. Possible extension to the study could be to explore qualitative methods for capturing the indirect benefits. Other extensions could be to look at the GWP of gases over the 20-year period as a comparison to the 100-year period. This would give us a lower and an upper bound estimate for the impact numbers calculated above. Also, the UK pollutant register and the UK emissions dashboard (which will be up and running in a few years' time) could be used for estimating the impact on emissions over a certain period. This could further strengthen the core basis for the study. Finally, the products and services for air quality can be explored to find a relationship with the impact from emissions monitoring products and services.

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## 8 ANNEX A

The study assumes that there are zero fixed costs to the user. If fixed costs are included in the model, the quantity of emission number goes up as seen.

$$\text{Total Surplus} = \text{price of gas } \times \text{quantity of emissions saved} - \text{fixed costs} \tag{16}$$

$$\frac{\text{Revenue} + \text{fixed costs}}{\text{price of gas}} = \text{quantity of emissions saved} \tag{17}$$

Similarly, if the users are seeking specialist services to avoid any potential fines, then they have more to benefit to gain then just the value of emissions. The equation below shows this:

$$\text{Total Surplus} = \text{price of gas } \times \text{quantity of emissions saved} + \text{fine value} \tag{18}$$

$$\frac{\text{Revenue} - \text{fine value}}{\text{price of gas}} = \text{quantity of emissions saved} \tag{19}$$

If both fixed costs and fine value are added to the model, then they could potentially cancel out.

$$\frac{\text{Revenue} + \text{fixed costs} - \text{fine value}}{\text{price of gas}} = \text{quantity of emissions saved} \tag{20}$$

The model specified in this study can be further developed in a future study to include these new parameters.

## 9 ANNEX B

What is the benefit of saving methane emissions i.e what is the trade-off benefit between losing methane in the atmosphere, and saving and burning it?

Consider the following discussion:
The simple equation of methane burning is

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (21)$$

1 mole of methane is equal to 16 grams. 2 moles of oxygen are equal to 64 grams. When the two react with each other they produce two moles of water which is equal to 36 grams and 1 mole of carbon dioxide which is equal to 44 grams.

So, either you emit 16g of methane which is 448 g of $CO_2e$ or you burn it and produce 44g of carbon dioxide. Clearly the latter is better as that allows you to save 90% of $CO_2e$ which would otherwise have just gone into the atmosphere.

The methane reduction case study estimates that approx. 230 tonnes of methane are lost as a result of leakage. This implies that 230 Mg of methane enters the atmosphere which is equivalent to 6440 Mg of $CO_2e$. If the same amount was not leaked and burnt, it would equate to 632.5 Mg of $CO_2e$. By burning it you are saving 5807.5 Mg of $CO_2e$

## 10 ANNEX C

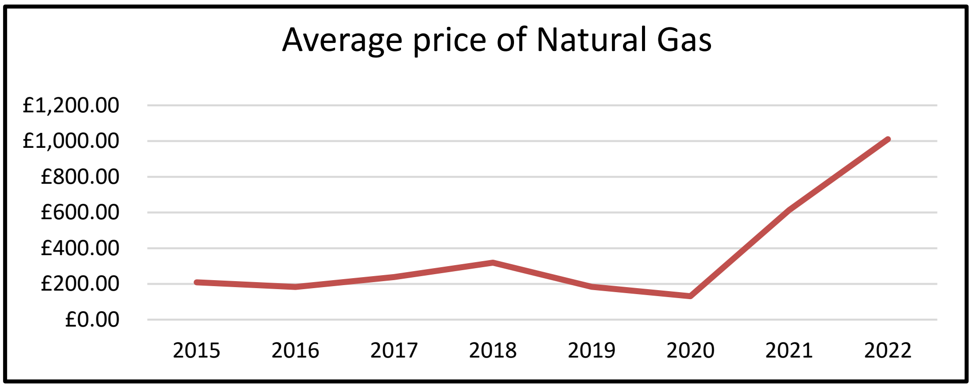
The calculations below refer to valuation of the price of 1 tonne of natural gas as per Greenhouse Gas Investigation Mechanism-Final Statement; A project NPL did with a customer.
Natural gas is primarily composed of methane. For the purposes of these calculations 1 tonne of methane is assumed to be equivalent to 1 tonne of natural gas.
Wholesale natural gas is traded in therms. Therefore, we must convert tonnes into therms to calculate the value of the gas.

- 1 tonne of natural gas is 1000kg
- 1000 kg is 1408.45 m3 (using natural gas density of 0.71 kg/m3) http://unitrove.com/engineering/tools/gas/natural-gas-density
- NGG uses a calorific value of natural gas of 39.6 MJ/m3
  Therefore 1 tonne of natural gas equates to 1408.45 x 39.6 = 55774.62 MJ
- One therm is equal to 105.5 MJ (Unit of Measurement Regulations 1995) www.legislation.gov.uk/uksi/1995/1804/contents/made
  55774.62 MJ converts to 55574.62/105.5 = 528.67 therms
- The 2016/17 System Average Price (SAP) for 1 therm was 38.7p
- 1 tonne of natural gas = 529 x 38.7 = 20472.3p

Therefore, 1 tonne of natural gas has a wholesale price of £204.72, based on the 2016/17 SAP.

The table below shows the estimated price of Natural Gas over the years.

| Year | Average p / therm | Price of natural gas in pence | Price of natural gas in pounds |
|---|---|---|---|
| 2015 | 39.58 | 20937.82 | £209.38 |
| 2016 | 34.66 | 18332.49 | £183.32 |
| 2017 | 45.06 | 23835.85 | £238.36 |
| 2018 | 60.36 | 31929.99 | £319.30 |
| 2019 | 34.71 | 18362.03 | £183.62 |
| 2020 | 24.81 | 13123.16 | £131.23 |
| 2021 | 115.89 | 61307.57 | £613.08 |
| 2022 | 191.00 | 101040.76 | £1,010.41 |



## 11 ANNEX D

| Table 3: Carbon prices and sensitivities 2010-2100 for appraisal, 2020£/tCO$_2$e | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | Traded | | | Non-traded | | | |
| | Low | Central | High | Low | Central | High | |
| **2010** | 15 | 15 | 15 | 33 | 65 | 98 | |
| **2011** | 14 | 14 | 14 | 33 | 66 | 100 | |
| **2012** | 7 | 7 | 7 | 34 | 67 | 101 | |
| **2013** | 4 | 4 | 4 | 34 | 68 | 103 | |
| **2014** | 6 | 6 | 6 | 35 | 69 | 104 | |
| **2015** | 6 | 6 | 6 | 35 | 70 | 106 | |
| **2016** | 5 | 5 | 5 | 36 | 72 | 107 | |
| **2017** | 6 | 6 | 6 | 36 | 73 | 109 | |
| **2018** | 15 | 15 | 15 | 37 | 74 | 111 | |
| **2019** | 23 | 23 | 23 | 37 | 75 | 112 | |
| **2020** | 22 | 22 | 22 | 38 | 76 | 114 | |
| **2021** | 4 | 22 | 40 | 39 | 77 | 116 | |
| **2022** | 9 | 29 | 50 | 39 | 78 | 118 | |
| **2023** | 13 | 37 | 60 | 40 | 80 | 120 | |
| **2024** | 17 | 44 | 70 | 40 | 81 | 121 | |
| **2025** | 22 | 51 | 81 | 41 | 82 | 123 | |
| **2026** | 26 | 58 | 91 | 42 | 84 | 125 | |
| **2027** | 31 | 66 | 101 | 42 | 85 | 127 | |
| **2028** | 35 | 73 | 111 | 43 | 86 | 129 | |
| **2029** | 39 | 80 | 121 | 44 | 87 | 131 | |
| **2030** | 44 | 87 | 131 | 44 | 89 | 133 | |
| **2031** | 48 | 97 | 145 | 48 | 97 | 145 | |
| **2032** | 53 | 105 | 158 | 53 | 105 | 158 | |
| **2033** | 57 | 113 | 170 | 57 | 113 | 170 | |
| **2034** | 61 | 121 | 182 | 61 | 121 | 182 | |
| **2035** | 65 | 130 | 195 | 65 | 130 | 195 | |
| **2036** | 69 | 138 | 207 | 69 | 138 | 207 | |
| **2037** | 73 | 146 | 219 | 73 | 146 | 219 | |
| **2038** | 77 | 154 | 232 | 77 | 154 | 232 | |
| **2039** | 81 | 163 | 244 | 81 | 163 | 244 | |
| **2040** | 85 | 171 | 256 | 85 | 171 | 256 | |
| **2041** | 90 | 179 | 269 | 90 | 179 | 269 | |
| **2042** | 94 | 187 | 281 | 94 | 187 | 281 | |
| **2043** | 98 | 195 | 293 | 98 | 195 | 293 | |
| **2044** | 102 | 204 | 306 | 102 | 204 | 306 | |
| **2045** | 106 | 212 | 318 | 106 | 212 | 318 | |
| **2046** | 110 | 220 | 330 | 110 | 220 | 330 | |
| **2047** | 114 | 228 | 343 | 114 | 228 | 343 | |
| **2048** | 118 | 237 | 355 | 118 | 237 | 355 | |
| **2049** | 122 | 245 | 367 | 122 | 245 | 367 | |
| **2050** | 127 | 253 | 380 | 127 | 253 | 380 | |
| **2051** | 130 | 262 | 394 | 130 | 262 | 394 | |
| **2052** | 133 | 271 | 409 | 133 | 271 | 409 | |
| **2053** | 136 | 279 | 423 | 136 | 279 | 423 | |
| **2054** | 138 | 288 | 438 | 138 | 288 | 438 | |
| **2055** | 141 | 297 | 452 | 141 | 297 | 452 | |
| **2056** | 143 | 305 | 467 | 143 | 305 | 467 | |
| **2057** | 146 | 313 | 481 | 146 | 313 | 481 | |
| **2058** | 148 | 321 | 495 | 148 | 321 | 495 | |
| **2059** | 150 | 329 | 508 | 150 | 329 | 508 | |
| **2060** | 152 | 337 | 522 | 152 | 337 | 522 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2061** | 153 | 343 | 533 | 153 | 343 | 533 | |
| **2062** | 153 | 349 | 544 | 153 | 349 | 544 | |
| **2063** | 154 | 354 | 554 | 154 | 354 | 554 | |
| **2064** | 155 | 359 | 564 | 155 | 359 | 564 | |
| **2065** | 155 | 364 | 573 | 155 | 364 | 573 | |
| **2066** | 155 | 368 | 582 | 155 | 368 | 582 | |
| **2067** | 154 | 372 | 590 | 154 | 372 | 590 | |
| **2068** | 154 | 375 | 597 | 154 | 375 | 597 | |
| **2069** | 153 | 378 | 603 | 153 | 378 | 603 | |
| **2070** | 152 | 381 | 609 | 152 | 381 | 609 | |
| **2071** | 151 | 383 | 615 | 151 | 383 | 615 | |
| **2072** | 150 | 385 | 620 | 150 | 385 | 620 | |
| **2073** | 149 | 387 | 625 | 149 | 387 | 625 | |
| **2074** | 147 | 388 | 629 | 147 | 388 | 629 | |
| **2075** | 146 | 389 | 632 | 146 | 389 | 632 | |
| **2076** | 144 | 389 | 635 | 144 | 389 | 635 | |
| **2077** | 142 | 389 | 637 | 142 | 389 | 637 | |
| **2078** | 140 | 389 | 638 | 140 | 389 | 638 | |
| **2079** | 138 | 388 | 639 | 138 | 388 | 639 | |
| **2080** | 135 | 387 | 638 | 135 | 387 | 638 | |
| **2081** | 133 | 387 | 640 | 133 | 387 | 640 | |
| **2082** | 131 | 386 | 640 | 131 | 386 | 640 | |
| **2083** | 129 | 385 | 640 | 129 | 385 | 640 | |
| **2084** | 126 | 383 | 640 | 126 | 383 | 640 | |
| **2085** | 124 | 382 | 640 | 124 | 382 | 640 | |
| **2086** | 122 | 380 | 638 | 122 | 380 | 638 | |
| **2087** | 119 | 378 | 636 | 119 | 378 | 636 | |
| **2088** | 116 | 375 | 634 | 116 | 375 | 634 | |
| **2089** | 114 | 373 | 632 | 114 | 373 | 632 | |
| **2090** | 111 | 370 | 629 | 111 | 370 | 629 | |
| **2091** | 108 | 368 | 627 | 108 | 368 | 627 | |
| **2092** | 106 | 365 | 625 | 106 | 365 | 625 | |
| **2093** | 103 | 362 | 621 | 103 | 362 | 621 | |
| **2094** | 101 | 359 | 618 | 101 | 359 | 618 | |
| **2095** | 98 | 356 | 614 | 98 | 356 | 614 | |
| **2096** | 95 | 353 | 610 | 95 | 353 | 610 | |
| **2097** | 93 | 350 | 607 | 93 | 350 | 607 | |
| **2098** | 90 | 346 | 602 | 90 | 346 | 602 | |
| **2099** | 87 | 343 | 598 | 87 | 343 | 598 | |
| **2100** | 85 | 339 | 593 | 85 | 339 | 593 | |
| **Source:** BEIS modelling | | | | | | | |
| Further guidance on the use of carbon values is available from the appraisal guidance (Chapter 3) which can be downloaded from the Green Book supplementary guidance section of GOV.UK webpage: | | | | | | | |
| https://www.gov.uk/government/collections/carbon-valuation--2 | | | | | | | |

| **Table 3: Carbon values and sensitivities 2020-2100 for appraisal, 2020£/tCO2e** | | | | |
|---|---|---|---|---|
| | **Carbon Values** | | | |
| | **Low** | **Central** | **High** | |
| **2020** | 120 | 241 | 361 | |
| **2021** | 122 | 245 | 367 | |
| **2022** | 124 | 248 | 373 | |
| **2023** | 126 | 252 | 378 | |
| **2024** | 128 | 256 | 384 | |
| **2025** | 130 | 260 | 390 | |

| | | | | |
|---|---|---|---|---|
| **2026** | 132 | 264 | 396 | |
| **2027** | 134 | 268 | 402 | |
| **2028** | 136 | 272 | 408 | |
| **2029** | 138 | 276 | 414 | |
| **2030** | 140 | 280 | 420 | |
| **2031** | 142 | 285 | 427 | |
| **2032** | 144 | 289 | 433 | |
| **2033** | 147 | 293 | 440 | |
| **2034** | 149 | 298 | 447 | |
| **2035** | 151 | 302 | 453 | |
| **2036** | 153 | 307 | 460 | |
| **2037** | 156 | 312 | 467 | |
| **2038** | 158 | 316 | 474 | |
| **2039** | 161 | 321 | 482 | |
| **2040** | 163 | 326 | 489 | |
| **2041** | 165 | 331 | 496 | |
| **2042** | 168 | 336 | 504 | |
| **2043** | 170 | 341 | 511 | |
| **2044** | 173 | 346 | 519 | |
| **2045** | 176 | 351 | 527 | |
| **2046** | 178 | 356 | 535 | |
| **2047** | 181 | 362 | 543 | |
| **2048** | 184 | 367 | 551 | |
| **2049** | 186 | 373 | 559 | |
| **2050** | 189 | 378 | 568 | |
| **Source:** BEIS modelling, based on IPCC | | | | |
| | | | | |
| Further guidance on the use of carbon values is available from the appraisal guidance (Chapter 3) which can be downloaded from the Green Book supplementary guidance section of GOV.UK webpage: | | | | |
| For further details on carbon valuation, see: | | | | |
| https://www.gov.uk/government/collections/carbon-valuation--2 | | | | |

# 12 ANNEX E

To understand how the setting of natural gas producers work. Consider the following discussion.
Let's assume there are two countries that produce natural gas and UK imports natural gas from these countries. Countries operate in a duopoly setting and operate in a Cournot game where each country chooses its quantity where the other's quantity is taken as given and maximises its profit. In a perfect setting no gas is lost, and all is sold to the end user. Let us assume three scenarios. Scenario 0 assumes both countries lose gas to leakages. Scenario 1 assumes only Country 1 uses specialist services to detect leaks for a fixed cost. Scenario 2 assumes that both use specialist services.

| | Scenario 0 | | Scenario 1 | | Scenario 2 | |
|---|---|---|---|---|---|---|
| | **Country 1** | **Country 2** | **Country 1** | **Country 2** | **Country 1** | **Country 2** |
| **Demand** | $p = \phi - \theta(q_1 + q_2)$ | | | | | |
| **TR** | $TR_1 = p.q_1$ | $TR_2 = p.q_2$ | $TR_1 = p.q_1$ | $TR_2 = p.q_2$ | $TR_1 = p.q_1$ | $TR_2 = p.q_2$ |
| **TC** | $TC_1 = c.(q_1 + h(q_1))$ | $TC_2 = c.(q_2 + h(q_2))$ | $TC_1 = c.q_1 + f$ | $TC_2 = c.(q_2 + h(q_2))$ | $TC_1 = c.q_1 + f$ | $TC_2 = c.q_2 + f$ |

where
$c =$ Wholesale price of gas
$p =$ Market price of gas $(p > c)$
$z_i =$ Quantity produced by the countries
$q_i =$ Quantity of gas sold to the user (UK)
$h =$ Some function of q lost due to leackages/effciency loss

If a country is mining $z$ and it is losing a fraction '$\delta$' of what is produced due to leakages:

$$h(q_i) = \delta z_i$$
$$q_i = (1 - \delta) z_i \quad (22)$$

Dividing the two equations, we get

$$\frac{\delta}{(1-\delta)} q_i = h(q_i) \quad (23)$$

**<u>Scenario 0</u>**

Profit maximising function for Country 1:

$$\pi_1 = \big(\phi - \theta(q_1 + q_2)\big) q_1 - c.q_1 - c\frac{\delta}{(1-\delta)} q_1 \quad (24)$$
$$q_1 = \frac{1}{2\theta}\left(\phi - \theta q_2 - c\left(1 + \frac{\delta}{1-\delta}\right)\right)$$
$$q_2 = \frac{1}{2\theta}\left(\phi - \theta q_1 - c\left(1 + \frac{\delta}{1-\delta}\right)\right)$$

Solving the two simultaneously:

$$\widetilde{q_1} = \widetilde{q_2} = \frac{1}{3\theta}\left(\phi - \frac{c}{1-\delta}\right) \quad (25)$$

$$\tilde{p} = \frac{1}{3}\left(\phi + c\left(1 + \frac{1}{(1-\delta)}\right)\right) > 0 \qquad (26)$$

## Scenario 1

Profit maximising function for country 1 & 2:

$$\begin{aligned} \pi_1 &= p.q_1 - c.q_1 - f \\ \pi_2 &= p.q_2 - c.(q_2 + h(q_2) \end{aligned} \qquad (27)$$

$$\begin{aligned} {q_1}^* &= \frac{\phi - c - \theta q_2}{2\theta} \\ {q_2}^* &= \frac{\phi - \theta q_1 - \frac{c}{1-\delta}}{2\theta} \end{aligned}$$

Solving the equation i) and ii) simultaneously:

$$\begin{aligned} \widetilde{q_1} &= \frac{\phi}{3\theta} + \frac{c}{3\theta}\left(\frac{1}{(1-\delta)} - 2\right) \\ \widetilde{q_2} &= \frac{\phi}{3\theta} + \frac{c}{3\theta}\left(1 - \frac{2}{(1-\delta)}\right) \\ \tilde{p} &= \frac{1}{3}\left(\phi + c\left(1 + \frac{1}{(1-\delta)}\right)\right) > 0 \end{aligned} \qquad (28)$$

## Scenario 2

Profit maximising function for country 1 & 2:

$$\begin{aligned} \pi_1 &= p.q_1 - c.q_1 - f \\ \pi_2 &= p.q_2 - c.q_2 - f \end{aligned} \qquad (29)$$

$$\begin{aligned} {q_1}^* &= \frac{\phi - c - \theta q_2}{2\theta} \\ {q_1}^* &= \frac{\phi - c - \theta q_2}{2\theta} \end{aligned}$$

Solving the equation i) and ii) simultaneously:

$$\begin{aligned} \widetilde{q_1} &= \widetilde{q_2} = \frac{\phi - c}{3\theta} \\ \tilde{p} &= \frac{\phi}{3} + \frac{2}{3}c \end{aligned} \qquad (30)$$

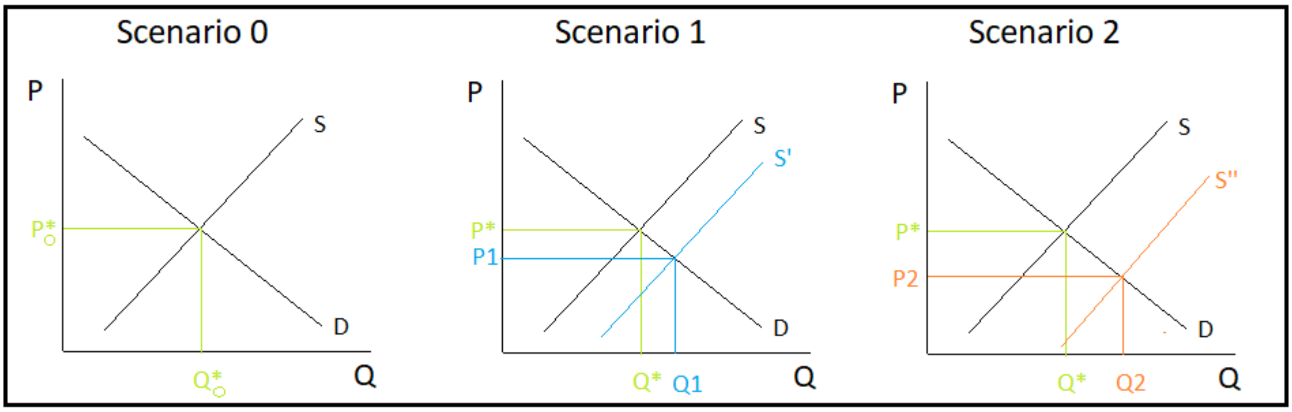
One thing to note is that because Country 1 sells more in Scenario 1, being in a Cournot setting, Country 2 automatically sells less in addition to the emissions lost. There are two effects. Direct effect on outputs as result of using specialist services. Then there is an indirect effect on the output because of the market forces (operating in a Cournot setting)

The table below summarises the discussion above and compares the price and the quantity of the gas sold in each of the three scenarios.

| | Specialist Services | | |
|---|---|---|---|
| Scenarios | | Country 1 | Country 2 |
| | 0 | ✗ | ✗ |
| | 1 | ✓ | ✗ |
| | 2 | ✓ | ✓ |

| | Scenario 0 | | Scenario 1 | | Scenario 2 | |
|---|---|---|---|---|---|---|
| | Country 1 | Country 2 | Country 1 | Country 2 | Country 1 | Country 2 |
| **Price** | $\frac{\phi}{3}+\frac{2c}{3(1-\delta)}$ | | $\frac{1}{3}\left(\phi+c\left(1+\frac{1}{(1-\delta)}\right)\right)$ | | $\frac{\phi}{3}+\frac{2}{3}c$ | |
| **Quantity** | $\frac{1}{3\theta}\left(\phi-\frac{c}{1-\delta}\right)$ | $\frac{1}{3\theta}\left(\phi-\frac{c}{1-\delta}\right)$ | $\frac{\phi}{3\theta}+\frac{c}{3\theta}\left(\frac{1}{(1-\delta)}-2\right)$ | $\frac{\phi}{3\theta}+\frac{c}{3\theta}\left(1-\frac{2}{(1-\delta)}\right)$ | $\frac{\phi-c}{3\theta}$ | $\frac{\phi-c}{3\theta}$ |

From the equations above we can deduce that for:
Country 1 quantity: $\widetilde{q_1}^1 > \widetilde{q_1}^2 > \widetilde{q_1}^0$
Country 2 quantity: $\widetilde{q_2}^2 > \widetilde{q_2}^0 > \widetilde{q_2}^1$:
Overall quantity: $\widetilde{Q^2} > \widetilde{Q^1} > \widetilde{Q^0}$
Price: $\widetilde{p^0} > \widetilde{p^1} > \widetilde{p^2}$




Country 1 loses revenue which is related to the value of emissions lost as a result of not using specialist services.
Country 1 knows the amount it is losing and therefore the revenue associated with it. Country 1 will use the specialist services if:

$$\pi_1{}^1 > \pi_1{}^0 \quad (31)$$

$$p^1.q^1 - c.q_1{}^1 - f \ge p^0.q_1{}^0 - c\left(q_1{}^0 + h(q_1{}^0)\right)$$

The maximum amount Country 1 would be willing to pay can be inferred from the expression below:

$$f \le \widetilde{p^1}.\widetilde{q_1{}^1} - \widetilde{p^0}.\widetilde{q_1{}^0} - c(\widetilde{q_1{}^1}) - c\left(\widetilde{q_1}^0 + h\left(\widetilde{q_1}^0\right)\right) \quad (32)$$

On the emissions front, let's look at what happens in each of the three scenarios.

| | Scenario 0 | | Scenario 1 | | Scenario 2 | |
|---|---|---|---|---|---|---|
| | Country 1 | Country 2 | Country 1 | Country 2 | Country 1 | Country 2 |
| **Emissions lost** | $\frac{\delta}{(1-\delta)}\widetilde{q_1}^0$ | $\frac{\delta}{(1-\delta)}\widetilde{q_2}^0$ | No emissions lost | $\frac{\delta}{(1-\delta)}\widetilde{q_2}^1$ | No emissions lost | No emissions lost |
| **Total emissions lost** | $\sum_{i=1}^{2}\frac{\delta}{(1-\delta)}\widetilde{q_i}^0$ | | $\frac{\delta}{(1-\delta)}\widetilde{q_2}^1$ | | No emissions lost | |

Change in total emissions from Scenario 1 to 0

$$\frac{\delta}{(1-\delta)}\left(\widetilde{q_2{}^1} - \widetilde{q_1{}^0} - \widetilde{q_2{}^0}\right) < 0 \qquad \text{where } q_1{}^0 = q_2{}^0 > q_2{}^1 \tag{33}$$

Change in total emissions from Scenario 2 to 0

$$-\frac{\delta}{(1-\delta)}\left(\widetilde{q_1{}^0} + \widetilde{q_2{}^0}\right) < 0 \tag{34}$$

Clearly overall emissions are reduced in scenario 1 compared to scenario 0 and all emissions are saved in scenario 2 which would have otherwise been lost in scenario 0.

So, the model above infers that if a country uses specialist services that make the process of selling to the end user more efficient, then that country is increasing the share it sells to the end user which in turn increases the revenue of that country. The other country is not only losing its gas to leakages but also losing a share which is a result of the market forces. From a country's perspective it can observe the price of the gas in the market, and it knows the value of emissions that can be potentially saved. Based on this, it will determine its willingness to pay for the specialist services which can also depend on its bargaining power relative to the provider for the specialist services.
Note that this study is from the perspective of the provider for the specialist services which relies on the price of the gas which is observable in the market, and the cost it charges for the specialised. This then allows to work back the value of the emissions saved.