Scenarios, Effectiveness and Efficiency of EU Methane Pricing in the Energy Sector

A STUDY COMMISSIONED BY
ENVIRONMENTAL DEFENSE FUND

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enervis

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1 Key Takeaways

This study analyzes the impacts of a methane emissions price implemented on all natural gas imported or produced in the EU and proportional to the methane emission intensity of gas production. The results show that

- an EU methane price can have a significant impact on global oil and gas methane emissions if it creates sufficient incentives for suppliers of gas to the EU to implement methane abatement measures;
- a price on upstream methane emissions can then significantly reduce the EU's methane footprint due to emissions from gas production in countries supplying gas to the EU;
- an EU methane price will be most effective if also other key global gas import markets implement methane policies to incentivize gas producers to mitigate their methane emissions;
- the impact of a methane price on EU household gas prices is likely to be small.

2 Executive Summary

Reducing anthropogenic methane emissions by half could lower global temperature rise by 0.2 degrees C by 2050. Current assessments indicate that the most cost-effective methane emission reductions can be achieved in the energy sector.

Methane emissions are a significant contributor to climate change and responsible for at least 25% of current man-made-warming (IPCC, 2013). Reducing anthropogenic methane emissions by half could lower global temperature rise by 0.2 degrees C by 2050. Current assessments indicate that the most cost-effective methane emission reductions can be achieved in the energy sector with upstream oil and gas operations in particular considered to offer reduction opportunities at very low cost. Estimates also indicate that the largest share of the European Union's (EU's) methane emissions footprint from its gas consumption comes from upstream emissions arising in the countries supplying gas to the EU (EC, 2020b).

In October 2020 the European Commission released its Methane Strategy, which for the energy sector includes a proposal to require improved detection and repair of leaks (LDAR) in gas infrastructure and consideration of legislation to prohibit routine flaring and venting practices in the EU. The Commission also committed to exploring possible standards, targets or incentives for energy imports to the EU as well as tools for enforcing them and to engage in a dialogue with its international partners to address methane emissions from energy imports (EC, 2020b).

The EU imported roughly a third of all internationally traded gas in 2019 and is projected to represent 9% of global gas demand in 2025 (bp, 2020b). The share of exports to the EU in total gas production in certain countries is substantial and tied to existing pipeline routes. For example, the EU's share of total gas production in Algeria was 33% in 2019 and in Russia 28% (Eurostat, 2020b). For these two major supply countries, the majority of the gas is delivered to the EU through pipelines. This indicates that incentives introduced by the EU to address upstream methane emissions from its gas supply chain could have a significant influence on certain gas suppliers, which – even though they can expand their LNG liquefaction capacities and alternative pipeline routes – are at least partially locked-in to supply gas to the EU through existing gas infrastructure.

In this study, we analyze the impacts of an EU price on upstream methane emissions from natural gas production on all gas imported into or produced in the EU.

A price on methane emissions has promising properties among the policy options under discussion for addressing upstream methane emissions from the EU gas supply chain. Such a methane price could take the form of a proportional penalty on natural gas that fails to meet a target upstream methane emission intensity. In this study, we analyze the impacts of an EU price on upstream methane emissions from natural gas production on all gas imported into or produced in the EU. It is beyond the scope of this study to assess legal options and consequences and the study therefore does not explore what specific policy or regulatory mechanism could be used to implement such a methane price.

This study analyzes pricing of upstream methane emissions on natural gas in the EU at the levels of 25 and 100 €/tCO_2eq in 2025. For both methane price levels – 25 and 100 €/tCO_2eq, respectively – we look at two different scenarios. In the first – which we call the "CH_4 Pricing with Producer Abatement Response" scenario – we assume an abatement response by gas producers to the EU methane price resulting in a 75% reduction in assumed baseline emissions for the gas volumes exported to the EU. This assumption is based on IEA analysis indicating that 70 - 80% of available abatement measures would be cost-effective at methane price levels at or above 25 €/tCO_2eq (IEA, 2020a). In a second scenario – the "CH_4 Pricing without Producer Abatement Response" scenario – we look at a case where no additional abatement is happening in response to an EU methane price. This second scenario represents a "worst-case" to assess the impacts of an EU methane price where the main channels for impacts on methane emissions are changes to EU gas demand and global gas trade flows rather than direct abatement of methane emissions. Additional sensitivity checks were conducted to explore the importance of the uncertainty in the assumed regional emission intensities.

Global oil and gas methane emissions are highly uncertain, both in terms of scale and location of emissions per country/region.

Global oil and gas methane emissions are highly uncertain, both in terms of scale and location of emissions per country/region. IEA estimates 82 million tonnes (Mt) of methane per year from the global oil and gas sector, with recent scientific studies pointing to a range of 80 - 140 Mt per year.[1] Data on methane emission levels and abatement costs is currently not granular enough to define clear volume trajectories for market-based policy options.

A broad range of scenarios and assumptions is considered to assess potential impacts on methane emissions, the EU gas supply mix and natural gas prices.

We look at a broad range of scenarios and assumptions to assess potential impacts on methane emissions, the EU gas supply mix and natural gas prices. All while bearing in mind the context of large uncertainty around actual methane emission intensities for gas imports from different supply regions. We present assumed ranges for methane emission intensities intended to represent the upstream methane footprint of natural gas from gas production fields serving the EU. These methane emission intensities – with the exception of the US – are based on IEA emissions data (IEA, 2020a) and expert judgement. US numbers are based on empirical estimates from Alvarez et al. (2018). Our main scenarios are based on assuming the central baseline emission intensities from these ranges and should therefore be considered illustrative only.

Under the CH_4 Pricing with Producer Abatement Response scenario, total global oil and gas methane emissions are

Under the CH_4 Pricing with Producer Abatement Response scenario, upstream methane emissions for the gas volumes exported to the EU decrease by about 2.5 Mt CH_4 (equivalent to 71 Mt CO_2eq with Global Warming Potential $(GWP)_{100}$ and 210 Mt CO_2eq with GWP_{20}). This is in comparison to a BAU scenario under the central baseline emission intensity assumptions. When varying the methane emission intensity assumptions for the major EU gas supply countries, the results indicate a reduction in total

[1] See: IEA (2020a); Saunois et al. (2020); Schwietzke et al. (2016) and Hmiel et al. (2020).

reduced by up to 4%.

global oil and gas methane emissions under this abatement scenario of up to 4%.[2] The extent of the methane emissions reduction at a methane price of 25 €/tCO_2eq is the same as at a methane price of 100 €/tCO_2eq in the Producer Abatement Response scenario, due to our assumption that 75% of baseline emissions are cost-effective to abate at prices at or above 25 €/tCO_2eq. A 2.5 Mt reduction in methane emissions corresponds to close to 2% of the EUs total domestic greenhouse gas emissions in 2018 for the EU27 (Eurostat & EEA, 2020) and would thus be substantial.[3]

If abatement could be extended beyond the volumes delivered to the EU from gas supplying countries (i.e., 75% reduction in assumed baseline methane emissions for all gas production in the supply countries) then global oil and gas methane emissions could be reduced by 15 - 25%.[4] This would be based on the plausible assumption that if producers were to implement methane mitigation activities at their production facilities these would not only apply to the share of the production delivered to the EU, but also extend beyond those gas volumes. In addition, if oil and gas producers in EU gas supply countries were also to abate 75% of methane emissions from their oil production facilities – e.g., in response to the adoption of comprehensive methane policies and regulations in oil and gas buying countries and/or in the supply countries themselves - the impact on global oil and gas methane emissions could potentially be twice as large.

A methane price of 25 €/tCO2eq has a relatively small impact on the EU gas supply mix. A methane price of 100 €/tCO2eq has a larger impact on the EU gas flows.

A methane price of 25 €/tCO_2eq has a relatively small impact on the EU gas supply mix with or without a producer abatement response based on our central baseline emission intensity assumptions. For example, if relatively lower methane emissions intensities are assumed for production in the Middle East, there is an increase in EU imports from that region, while if relatively higher methane emission intensities are assumed for Russia, US and North Africa, then a corresponding reduction in EU imports can be seen from those regions. Sensitivity checks show that the supply mix is susceptible to changes in assumed emission intensities. The overall effect on total gas production volumes in gas supply countries is smaller due to the redirection of liquified natural gas (LNG) volumes to markets other than those of the EU.

A methane price of 100 €/tCO_2eq has a larger impact on the EU gas supply mix but such impacts would be mitigated with a producer abatement response (because such an abatement response would proportionally reduce the methane price mark-up on EU gas import prices). These supply mix impacts are larger because the modeling assumes fungibility of gas shipped through pipeline and LNG infrastructure, i.e., that the market will redirect gas trade flows via flexible LNG in response to high methane emission prices. According to the modeling, producers with high methane emission intensity

[2] Using a range for global oil and gas emissions of 80-140 Mt per year based on Saunois et al. (2020); Schwietzke et al. (2016) and Hmiel et al. (2020).

[3] Based on GWP_{100} conversion factors to CO_2eq for non-CO_2 gases.

[4] Using the central baseline emission intensities and a range for global oil and gas emissions of 80-140 Mt per year based on IEA (2020a); Saunois et al. (2020); Schwietzke et al. (2016) and Hmiel et al. (2020). Applied to all EU relevant countries, regardless if they are exporting 50% or 1% of their gas to the EU.

would therefore deliver their gas elsewhere than to the EU, while producers with low methane emissions would redirect trade flows to the European Union. This modeling however, abstracts away from the details of existing long-term contract and trading structures and political or administrative constraints which may, in reality, constrain the opportunity to export gas to other markets than the EU in the short to medium term.

The impact of a methane price of 25 €/tCO_2eq on EU natural gas wholesale prices is low.

The impact of a methane price on EU natural gas wholesale prices is minimal except for the case of a methane price of 100 €/tCO_2eq without a producer abatement response. At the end-use level, the impact of an EU methane price on gas prices is smaller due to the large share of national taxes, levies, distribution and other price components in end-use prices. The methane price mark-up on the average EU residential gas price under the central baseline emission assumptions, is between 1% at 25 €/tCO_2eq and 5% at 100 €/tCO_2eq. Both numbers are significantly lower if producers are assumed to abate their methane emissions. Due to lower average end use prices for the industrial sector, the methane price mark-up has a greater influence on industry gas prices, resulting in potential price increases of less than 10%. These numbers would similarly be significantly lower if gas producers are assumed to abate their methane emissions in response to the EU methane price.

Given emissions data uncertainty our main scenario results should be viewed as illustrative examples of potential impacts of an EU methane price on the EU supply mix, gas prices and methane emissions.

Given emissions data uncertainty, our main scenario results should be viewed as illustrative examples of potential impacts of an EU methane price on the EU supply mix, gas prices and methane emissions. This is since they are based on assumed methane emission intensities for the gas fields serving the EU. We therefore performed additional sensitivity checks to explore the importance of the uncertainty in the assumed regional emission intensities. Our sensitivity checks focus on the uncertainty in the methane emission intensity of gas from the main supply countries of Russia and Algeria and indeed show that the size of the supply mix, gas price and methane emission impacts are highly sensitive to assumptions regarding the level and relative differences in methane emission intensities for different gas supply regions.

An EU price on natural gas proportional to upstream methane emission intensities can have an impact on global oil and gas methane emissions without significantly raising consumer gas prices in the EU.

The main conclusion from this study is that an EU methane price on natural gas proportional to upstream methane emission intensities can have an impact on global oil and gas methane emissions if it creates sufficient incentives for gas producers to implement abatement measures and could do so without significantly raising consumer gas prices in the EU. To maximize the global methane emission reduction potential of an EU methane policy, a coalition of oil and gas buying countries built through the Commission's energy diplomacy will be needed to incentivize individual producers to mitigate methane and motivate oil and gas producing countries to implement their own policies to address their methane emissions.

3 Introduction & Objectives

After carbon dioxide, methane emissions are the second largest contributor to climate change. The EU's methane emissions 'footprint' in gas supply countries could be three and up to eight times the domestic methane emissions from the EU gas supply chain.

The EU has the ambition to significantly reduce greenhouse gas emissions (GHG) in order to achieve the goal of climate neutrality by 2050. Various policies and regulations support the achievement of energy-related environmental and efficiency milestones for the years to come. Tightening European and global GHG reduction targets requires continual adaptation of regulations.

The public debate on climate change has so far mainly focused on carbon dioxide, with some attention paid also to non-CO_2 emissions. In this context, there has been recent increasing focus on methane, a greenhouse gas with an >80 times higher global warming potential than carbon dioxide over the first 20 years after it is released. Anthropogenic methane emissions account for roughly 60% of all global methane emissions, main sources being the energy, agriculture, and waste sectors. The remaining 40% come from natural sources such as wetlands (IEA, 2020a).

To acknowledge the importance of also addressing methane emissions for reaching European climate targets, the European Commission (EC) recently adopted its Methane Strategy. In the EU, methane makes up around 10% of domestic EU total greenhouse gas emissions (EC, 2020a).[5] While the largest share of domestic EU methane emissions comes from agriculture with 53% followed by 26% from waste,19% comes from the energy (oil, gas, and coal) sector which is considered to offer the most cost-effective methane reduction opportunities (EC, 2020b). Furthermore, these 19% of methane emissions from the energy sector only include domestic emissions (e.g., emissions from the production, processing, transmission and distribution of natural gas inside the EU). Importantly, non-domestic 'methane footprint' emissions in producer countries, related to production and transmission of natural gas for the EU market could be three and up to eight times the domestic emissions from the EU gas supply chain (EC, 2020b). Addressing the methane footprint of imported gas is therefore an important element of a successful EU methane strategy and something that the Commission acknowledged as a priority in its Strategy.

Supply countries have various options to abate methane emissions. The IEA estimates that around 75% of methane emissions from oil and gas production are technically possible to abate. Around half of the technical abatement potential is estimated to be available at negative or zero net costs and the majority of the potential available at costs of less than 600 €/tCH_4 (IEA, 2020a). Nevertheless, adoption of these cost-effective mitigation options appears to be limited so far. Part of the explanation may lie in the commercial

[5] Based on GWP_{100} conversion factors for non-CO_2 gases

value of lost gas being of secondary importance if the cost of gas transportation is high or if the local selling gas price is too low. It may also be due to still relatively limited knowledge on producers' part of their own methane emissions, their sources and related cost-effective mitigation opportunities. A policy that introduces a price on methane emissions could be an incentive that spurs adoption of both methane measurement and detection approaches as well as these cost-effective mitigation options. Against this backdrop, Environmental Defense Fund (EDF) asked enervis energy advisors GmbH to conduct a model-based impact assessment of the introduction of an EU methane price on natural gas in proportion to the methane emissions intensity of the gas production.

The objectives of this study are to analyze the impacts of methane pricing on gas flows to the EU and on EU natural gas prices as well as on global methane emissions.

This study analyzes the effect of methane pricing, not presuming what specific policy or regulatory instrument would be used to implement the methane price. We assume an introduction of a methane price without coordination with other gas importing countries. The required analysis is based on enervis' GasTracks load flow model. We use this model to examine how methane pricing could affect the gas flows to the EU and to what extent the change in the EU supply mix could cause a reduction in methane emissions in the EU and globally. We assume methane emission intensities for the different supply regions with corresponding uncertainties – as further explained in Section 5.3.2. We include sensitivity checks to test the robustness of these results.

Furthermore, this study looks at some of the economic impacts of methane pricing such as potential changes to EU natural gas prices in response to a methane price. It is beyond the scope of this study to assess legal questions and consequences.

4 Status Quo and Policy Framework

4.1 EU27 Natural Gas Markets (status quo and trends)

Global gas demand is forecasted to increase from just under 4000 bcm in 2019 to almost 4300 bcm in 2025.

4.1.1 Demand by Region

Natural gas has played an important role in the past and will continue to do so for the next decades. The global demand is forecasted to increase from just under 4000 billion cubic meters (bcm) in 2019 to almost 4300 bcm in 2025 (bp, 2020a) – see Figure 1 for projected gas demand by region. The EU's demand is forecasted to decrease by around 3% by 2025, when the EU's share of global gas demand is predicted at 9% (bp, 2020a).[6] The implementation of the European Green Deal, progress in energy efficiency and market growth of low carbon gases is forecasted to decrease natural gas demand in the industrial, residential and buildings sector.

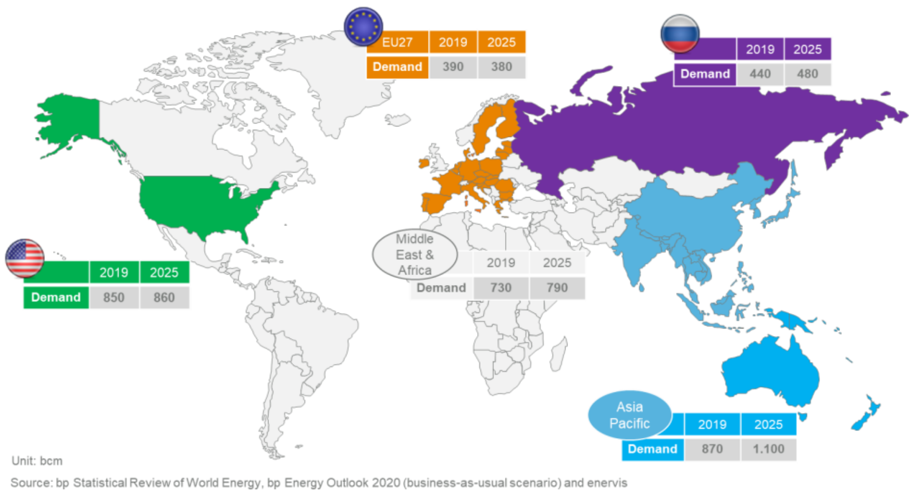

Figure 1: Gas Demand by Region

The main areas of natural gas use in the EU remain the power sector as well as the industrial heating and building sector. In the power sector, gas is expected to compensate for the decline in coal and nuclear capacities. As indicated in Figure 2, the 2019 to 2025 change in EU gas consumption share per sector is almost negligible.

[6] EU market after Brexit

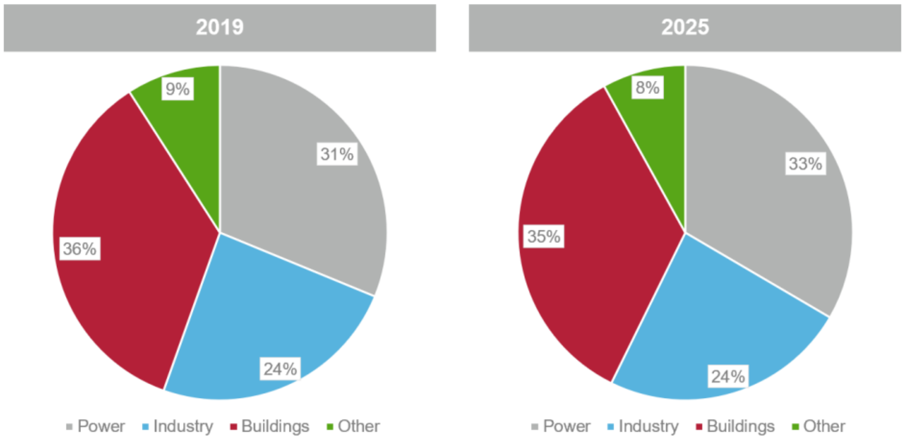

Figure 2: EU Gas Application (IEA, 2020b)

A strong decline in EU gas production is expected and therefore the EU's import dependency is increasing.

4.1.2 Forecasted Natural Gas Production in Europe

In 2019 around 15% of the EU's natural gas consumption was covered by domestic production (Eurostat, 2020a). The remaining 85% had to be imported from supply countries outside EU borders. Furthermore, a strong decline in EU production is expected. The Netherlands' decision to terminate production at the Groningen gas field by 2022 and reduce small field production by more than 90% by 2040 combined with the UK's exit from the EU will significantly hamper domestic production and increase the EU's dependence on imports (MEACP, 2019). France and Spain have a strong regasification capacity position which will lead to an increasing role for LNG imports in Europe. Even considering the projected decreases in future gas consumption, the EU's dependency on gas imports is set to increase.

Net natural gas imports are forecasted to decrease. Russia, Norway, Algeria, and Qatar are currently the EU's largest natural gas suppliers.

4.1.3 EU27 Import Structure

The EU is currently the world's biggest importer of fossil fuels, including natural gas (EC, 2020b). However, absolute natural gas import volumes are forecasted to decrease (bp, 2020a). Russia and Norway are currently the EU's largest natural gas suppliers (see Figure 3). Together with the EU's own production they account for around 75% of natural gas used in the EU. In 2019 Russia's exports accounted for 41% of the EU's total gas volumes while Norway's accounted for 21%. Algeria and Qatar exported 29 and 26 bcm of natural gas to the EU27 in 2019, respectively, which each accounted for 6% of total EU gas volumes (Eurostat, 2020b).

Ensuring gas supply security, flexibility and optionality, and diversification of sources is key. That includes not only the supply by different regions, but also the addition of flexible, traded liquified natural gas (LNG). The EU places a premium on flexible gas supplies that include uncontracted pipeline supply as well as uncontracted and divertible (i.e. option to redirect to more economical locations) LNG. This is secured through a variety of pipeline connections as well as LNG terminals that can be seen in Figure 4.

The biggest importers of natural gas in 2019 were Germany (23%), Italy (10%) and the Netherlands (10%) (Eurostat, 2020a). The total share of LNG in EU gas imports in 2019 was 22% (Eurostat, 2020b). Most of it was supplied by Qatar and Nigeria. In this context, Spain and France were the major LNG importers.

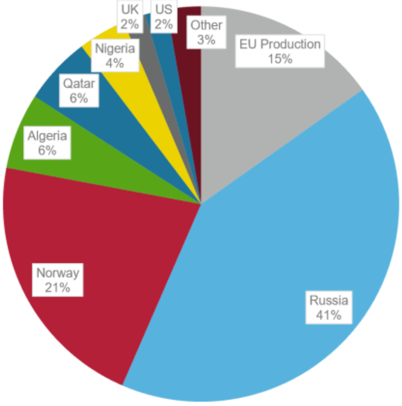

Figure 3: EU Natural Gas Import Structure 2019 (Eurostat, 2020a), (Eurostat, 2020b)

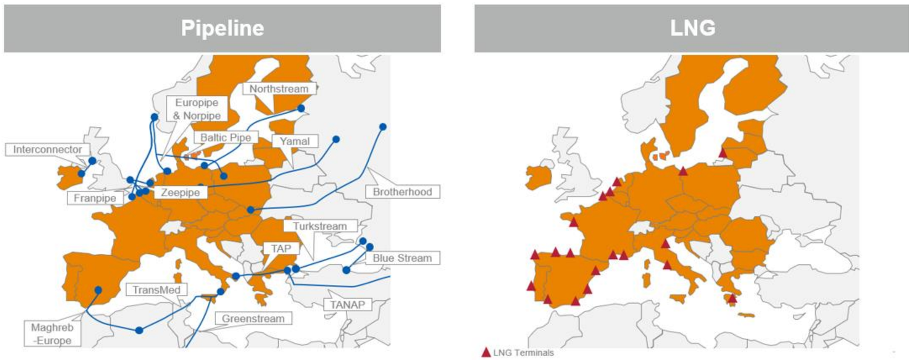

Figure 4: EU Entry Points – Per Pipeline and LNG (Assumptions for 2025 in GasTracks)

The EU share of export volumes is 68% in Algeria and 74% in Russia.

As can be seen in Figure 5, even though the EU's share of global gas demand is relatively small, various export countries are heavily dependent on their EU partnership. For example, Norway exports 86% of its total gas production to the EU (corresponding to 87% of all gas exports from Norway). Algeria exported approximately one third of its production to the EU (68% of Algerian gas exports), while Russia exported roughly one quarter of its total production to the EU (with the EU buying 74% of total gas exports from Russia). For these three major supply countries, the majority of the gas is delivered to the EU through pipelines, physically connecting production to consumption. This goes to show that EU decisions can have a significant influence on certain gas supply countries which – even if they decide to grow their LNG liquefaction capacities - are at least partially locked-in to supply gas to the EU through existing gas pipeline routes.

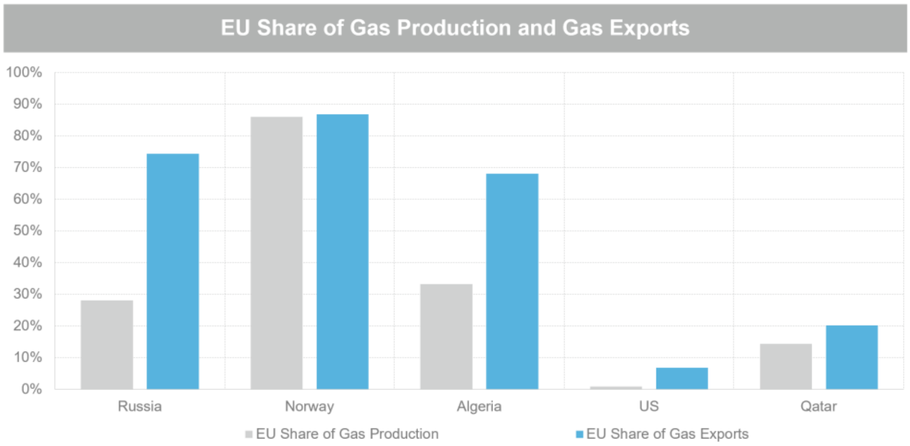

Figure 5: EU Share of Supplier Gas Production and Exports in 2019 (Eurostat, 2020b), (IEA, 2020b), (bp, 2020b)

4.2 EU Methane Strategy

In its October 2020 Methane Strategy, the European Commission committed to engage in a dialogue with its international partners and explore possible standards, targets or incentives for energy imports to the EU.

The EU Commission's October 2020 Methane Strategy recognizes methane emission reductions as essential to reaching European 2030 climate targets and the 2050 climate neutrality goal and relies on a holistic approach that combines sector-specific with cross-sectoral actions and promotes international cooperation. The recent Impact Assessment for the EU 2030 climate target plan found that major reductions in non-CO_2 emissions are necessary to reach the EU's climate goals and also highlighted that action in the energy sector is the most cost-effective in terms of methane emissions reduction potential. Estimates also show, that methane emissions from the gas and oil sector make up for more than half of total methane emissions in the energy sector (EC, 2020b).

The EU Methane Strategy includes various measures to decrease methane emissions in the EU but also includes responsibilities that are focused on the international market. Improving data quality by ensuring the application of more accurate data collection and reporting methodologies is one of the key cross-sectoral objectives. The Strategy states that companies should apply the measurement and reporting framework protocols provided by the voluntary initiative Oil and Gas Methane Partnership (OGMP). The newly developed OGMP 2.0 standard improves methane reporting by requiring companies to incorporate measurement-based emission estimates (instead of using simple emission factors) and also requires companies to report emissions on all their assets, including assets owned by the company but operated by another entity. Additionally, the EU's Copernicus program and other projects providing satellite-based methane quantification such as MethaneSAT are set to expand capacity to detect methane leaks across the globe and enhance data quality globally.

To collect, verify and publish anthropogenic methane emissions on a global scale, UNEP, the EC, and various partners are developing the International Methane Emissions Observatory (IMEO).

In this context, this independent observatory would among other things be tasked with the establishment of a methane supply index (MSI) to provide reliable information about the methane footprint of gas supply corridors to buyers or importers. To start, the MSI could be based on existing methane emissions data, provided by national GHG inventories, but with the ambition of continuous improvement in regards to future data quality on domestic and international supply chains.

To tackle emissions the focus of the Strategy lies on the prevention of venting and flaring as well as on improving data collection. The Commission will propose corresponding legislation for quantification and reporting standards, based on the OGMP2.0 methodology, in 2021. Additionally, the Commission plans to propose mandatory improvements in leak detection and repair programs for the entire European oil and gas infrastructure in addition to flaring efficiency standards (EC, 2020b).

The strategy also includes measures to improve international cooperation. This is an important factor, as estimates show that external methane emissions that are related to the EU's consumption could be 3 to 8 times higher in comparison to the EU's domestic gas supply chain emissions (EC, 2020b). Therefore, the EC is eager to improve accurate data collection in partner countries which could be possible through joining the OGMP or provisioning of technical assistance in mitigation, monitoring and reporting. The Commission also committed to engage in a dialogue with its international partners and to explore possible standards, targets or incentives for energy imports to the EU as well as the tools for enforcing them. Even though the proposed methane supply index could act as a potential starting point for methane pricing, so far, the Strategy does not explore options to put a price on methane emissions. Against this backdrop, this study explores the potential impacts of an EU methane price on upstream emissions for natural gas (but does not explore which specific policy or regulatory instruments could be used to implement such a price).

5 GasTracks Load Flow Model, Scenarios & Core Assumptions

This chapter establishes the scenario framework as well as core assumptions underlying the modeling.

5.1 enervis' GasTracks Load Flow Model

The marginal-cost optimization model of the global gas market derives load flows based on a large set of detailed assumptions and input data and takes gas pipeline capacity constraints into account.

The following figure shows a schematic overview of inputs, outputs and the method of enervis' GasTracks Load Flow Model.

The model is a comprehensive load flow model for the analysis of gas markets. It is based on wide-ranging fundamental data. Based on our experience from European markets, we apply our modeling approach to a wider geographic scope. Hence the model incorporates the relevant market drivers and provides a comprehensive view on future developments of load flows. Although GasTracks is capable of considering long-term gas contracts to a certain degree, we assume that production and trading happen according to economic signals. GasTracks' simulation works by balancing worldwide and European gas flows for the respective scenarios while taking gas transportation capacity (including pipeline capacity) constraints into account.

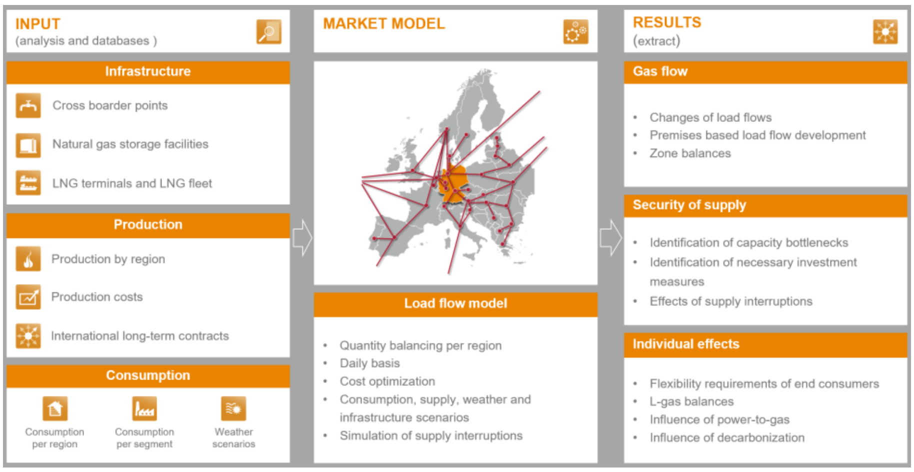

Figure 6: enervis' GasTracks Load Flow Model

5.2 Scenarios

We are looking at a broad range of scenarios and assumptions to assess potential impacts on methane emissions, the EU gas supply mix and natural gas prices.

For better interpretation of the results, the following table shows the assumptions for the modeling in the two policy scenarios and the business as usual (BAU) scenario, with the columns representing the scenarios and the rows the central premises. The assumptions where chosen based on discussions with EDF.

The scenarios focus only on upstream emissions, i.e. methane emissions that arise at gas production. The emissions caused by transmission or distribution of volumes are not considered in this study and are therefore not charged with a methane price, but would ideally be addressed with domestic EU regulations including LDAR regulations as well as measures to address gas transmission emissions outside EU borders.

Furthermore, we do not include methane emissions from coal and petroleum production and focus exclusively on gas production (i.e., gas production fields serving the EU with consideration given to the co-production of oil and gas in the US). The analysis includes the countries of the EU27, i.e. Brexit is considered.

	Business As Usual Scenario	CH_4 Pricing without Producer Abatement Response	CH_4 Pricing with Producer Abatement Response
MEANING	Baseline with no sector-specific policy on methane and no sustainability requirements on gas	Methane price proportional to upstream emission intensity implemented on all gas traded in the EU	Methane price proportional to upstream emission intensity implemented on all gas traded in the EU | Including 75% abatement response
METHANE PRICE	• No EU CH_4 price	• Focus: EU CH_4 price of 25 €/t CO_2eq (700 €/t CH_4) • Additional: Notional price of 100 €/t CO_2eq (2800 €/t CH_4)	
EMISSION INTENSITY (UPSTREAM)	• Central baseline emission intensity estimates in supplier countries range from 0.01% to 6.7%		• Abatement emission intensity estimates range from 0.0% to 1.7%
ABATEMENT RESPONSE	• None		• 75% in gas supply regions (focus on EU share)
EU27 GAS DEMAND	• 2025: 378 bcm (9% of global demand)	• Demand elasticity considered	• Demand elasticity considered

Figure 7: Overview of Core Assumptions

"Business as usual" functions as a baseline scenario for the assessment and does not include any sector-specific policy on methane nor sustainability requirements on gas. No price is introduced on methane emissions and there is no abatement response assumed. The upstream methane emissions relate to the central estimate baseline emission intensities assumed for each supply region and are presented in Section 5.3.2. which describes the assumptions regarding methane emission intensities for different gas supply countries.

The **"CH_4 Pricing without Producer Abatement Response"** scenario assumes the introduction of a methane price on all gas traded (both in the spot and long-term contract market) in the EU but without any abatement happening in response to an EU methane price. The upstream methane emissions are based on the assumed central estimate baseline emission intensities as in the BAU and presented in Section 5.3.2. To allow a broader range of impacts, we look at two methane price levels - 25 €/tCO_2eq and a notional price of 100 €/tCO_2eq, respectively.

The **"CH_4 Pricing with Producer Abatement Response"** scenario also assumes the introduction of a methane price on all gas traded (both in the spot and long-term contract market) in the EU but here we assume an abatement response of 75% reduction in baseline emissions for the EU share of gas production volumes in the gas producing countries. This assumption is based on IEA analysis and expert judgement indicating that 70 - 80% of methane emissions from gas production would be cost-effective to abate at methane prices of 25 €/tCO_2eq (with a GWP_{100} of 28 for methane) and above. 75% abatement below baseline emissions only for gas volumes produced for export to the EU is also a conservative assumption, since if companies adopt abatement measures, it would most likely affect a larger share of gas production volumes than just the EU share. The upstream methane emissions are based on the assumed abatement emission intensities as presented in Section 5.3.2. Similar to the previous scenario, we look at two methane price levels - 25 €/tCO_2eq and a notional price of 100 €/tCO_2eq. We do not assume additional abatement beyond 75% at the higher price level. The methane price is applied to every unit of emission above zero.

This scenario setup allows us to infer EU supply mix as well as gas price impacts of a methane price by comparing the CH_4 pricing scenarios with the BAU scenario depending on abatement levels and methane price levels.

An additional sensitivity analysis allows for a deeper assessment of the uncertainty in methane emission intensities and related supply mix effects through variations in these assumptions for two main supply countries, i.e. Russia and Algeria (see Section 7).

5.3 Core Assumptions

Up to 75% of upstream gas supply chain methane emissions are considered to be cost-effective to abate at methane prices of 25 €/tCO_2eq. and above.

5.3.1 Abatement Incentive and Potential

One key assumption for the CH_4 Pricing with Producer Abatement Response scenario is the abatement potential.

Based on IEA (2020a), methane emissions from gas production (i.e., upstream methane emissions from the gas supply chain) can with today's technologies be cost-effectively reduced by up to 75% at methane prices of 700 €/tCH_4 (equivalent to 25 €/tCO_2eq assuming a GWP_{100} for methane of 28). There is a high level of uncertainty surrounding the distribution of abatement opportunities across sources, categories and across countries. It may be technologically feasible to reduce more than 75%, but such measures may not necessarily be cost-effective, even at a high methane price.

Methane emissions occur along the supply chain of natural gas and oil (i.e. production, processing, transmission & storage, and distribution). To incentivize abatement, a methane price needs to be above abatement cost. Studies show that, to maximize social welfare, the emissions price should in principle be set at the level given by the social damage cost of methane emissions. The German Federal Environment Agency estimates a methane damage cost of around 5460 €/tCH_4 (195 €/tCO_2) for methane emitted in 2020 (UBA, 2020).[7] This estimate can be compared to the previously discussed assessment that up to 75% of upstream methane emissions from gas are cost-effective to abate at prices at or above 700 €/tCH_4.

Since a large part of abatement measures is estimated to already be possible at negative or zero net cost (e.g. blowdown capture), additional factors likely play a role in the possible abatement decision process, e.g. missing information on the magnitude of methane emissions per source, and which specific sources account for the majority of emissions for a given operator. This indicates that a

[7] German Federal Environment Agency is assuming a GWP_{100} = 28

portfolio approach in regards to policy choice to address methane emissions, including regulation, is useful, since the private value of capturing emitted gas alone does not seem to provide sufficient incentives.

The EC's Impact Assessment illustrates that a carbon pricing scheme for non-CO_2 emissions provides significant reduction potential, even at moderate price levels (EC, 2020a). Corresponding expectations regarding the low cost of abatement measures were also confirmed by further investigation into the mitigation potential for methane emissions from US gas production (Marks, 2019).

For our modeling, it can be concluded that there is a high abatement potential for methane emissions at relatively low cost, especially in the energy sector.

The uncertainty regarding methane emission intensities for different gas producing regions is high. This study only considers upstream emission intensities, i.e. methane emissions from the production stage of the gas supply chain.

5.3.2 Assumed Methane Emissions Intensities for Gas Production

One of the most important assumptions for all scenarios is the country specific methane emissions intensity, i.e. methane emissions divided by gross natural gas production. The data quality of methane emission levels is low, causing great uncertainty. The current emission intensities for the EU supply countries are largely based on simple, generic estimates (i.e., not on empirical data), with the exception of the US where recent scientific studies have updated emission estimates across the oil and gas supply chain based on direct measurements (see Alvarez et al. 2018).

The assumed methane emissions intensity ranges presented in Table 1 were provided by EDF. The ranges were developed to reflect data quality and uncertainty based on EDF expert judgment. The upper and lower bound emission intensities are intended to represent the uncertainty in emission intensities and form the limits for later sensitivity analysis in Section 7 which is focused on assessing the impact of different emission intensities on the results of our analysis.

The central baseline methane emission intensities in Table 1 are based on the IEA Methane Tracker database for upstream methane emissions attributed to gas production in each country, except for the US, where the estimates are based on empirically-based estimates from Alvarez et al. (2018). The US estimates reflect average methane emissions for US oil and gas production (i.e., representing co-production from oil and gas since gas exported to the EU could be coming from different basins across the US). The associated uncertainty for the US is significantly lower compared to other countries because of the recent empirical characterization of emissions (see Alvarez et al. 2018).

Upstream here refers to production facilities and does not include processing and gas transportation. The estimates in Table 1 are assumed to represent emission intensities for gas fields serving the EU except for the US where the national average methane emission intensity was used.

Table 1 also shows the 75% reduction in the central baseline emissions intensity as a result of cost-effective abatement in response to the methane price. This 75% below central baseline emissions represents already existing mitigation opportunities be it through technology upgrades or other mitigation measures which are cost effective at a price of 25 €/tCO_2eq or above based on IEA assessment (see preceding Section 5.3.1.).

Table 1: Assumed Methane Emission Intensity Ranges for Gas Production by Supply Country (EDF); descending sorted by quantity of gas volumes supplied to the EU (green = below 1% and red = above 2%)

	Central Baseline Estimates	Lower Bound Baseline Estimates	Upper Bound Baseline Estimates	75% Abatement Below Central Baseline Estimates
Russia	1.3%	0.0%	2.5%	0.3%
Norway	0.01%	0.01%	0.01%	0.0%
Algeria	1.6%	0.0%	3.2%	0.4%
Nigeria	1.2%	0.0%	2.5%	0.3%
Netherlands	0.01%	0.01%	0.02%	0.0%
US	2.2%	1.8%	2.5%	0.5%
Trin. & Tob.	0.3%	0.0%	0.7%	0.1%
Libya	5.1%	0.1%	10.2%	1.3%
UK	0.2%	0.1%	0.3%	0.0%
Romania	0.9%	0.0%	1.8%	0.2%
Eq. Guinea.	1.5%	0.0%	2.9%	0.4%
Egypt	1.1%	0.0%	2.2%	0.3%
Qatar	0.3%	0.0%	0.6%	0.1%
Yemen	5.3%	0.1%	10.5%	1.3%
Angola	6.7%	0.1%	13.4%	1.7%
U. A. E[8]	0.7%	0.0%	1.5%	0.2%
Oman	1.2%	0.0%	2.3%	0.3%

IEA (2020a) estimates 82 Mt CH_4/yr, with recent scientific studies pointing to a range of 80 - 140 Mt CH_4/yr of global oil and gas methane emissions.[9] This range illustrates the uncertainty in methane emissions from the oil and gas sector.

The methane price of 25 €/tCO_2eq is on the expected level of the EU-ETS price in 2025. A notional price of 100 €/tCO_2eq is also considered to extend the range of impacts.

5.3.3 Methane Price

The first examined price is 25 €/tCO_2eq which corresponds to 700 €/t of methane emissions.[10] This price represents a price level that corresponds to the expected level of the EU ETS price in 2025.

A second price of 100 €/tCO_2eq is introduced to represent a notional price level which extends the range of scenarios to include larger possible impacts and more forward-looking forecasts. Equivalent to 2800 €/tCH_4 when using a GWP for methane of 28, it is still lower than the German Federal Environment Agency's social cost of methane estimate of 5460 €/tCH_4 (UBA, 2020).

[8] United Arab Emirates

9 See: IEA (2020a); Saunois et al. (2020); Schwietzke et al. (2016) and Hmiel et al. (2020).

[10] Assuming GWP_{100} = 28

Comparing historical carbon prices and various estimates for future developments in Figure 8, the initial methane price of 25€/tCO_2eq is amongst low average expected 2025 carbon prices.

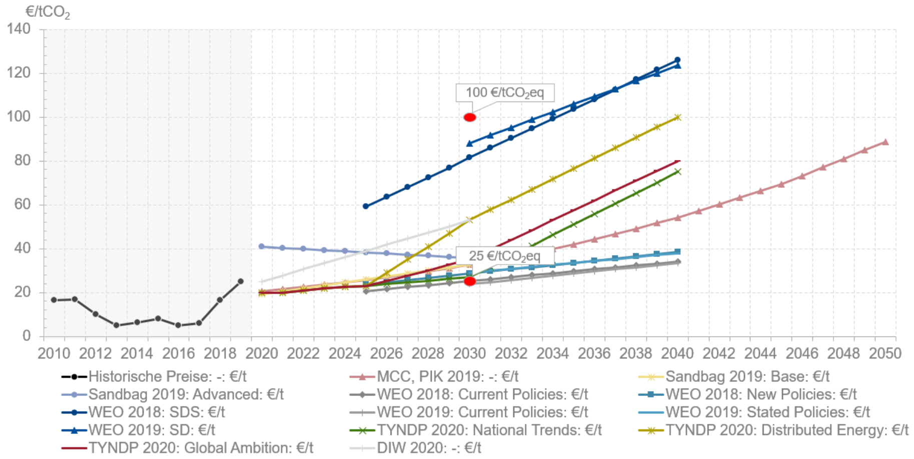

Figure 8: Literature Review Future CO_2 Price (enervis)[11]

The production costs of different countries vary greatly.

5.3.4 Costs of Production and Transport

Upstream gas production costs are determined by two components. Firstly, the extraction of natural gas directly incurs costs per unit lifted. This variable cost component is constituted of operating expenses, which are required to run the extraction facilities. Additionally, the facilities, infrastructure and equipment required to extract natural gas require large upfront and smaller recurring investments. These are allocated to the natural gas unit costs by a fixed component. Hence, we approximate the gas production costs by country based on the direct lifting costs and the investment environment in the country's natural gas industry (see Figure 9).

Data for our estimations is gathered from various sources. enervis collects information about operating expenses and the investment environment from natural gas upstream companies' annual and financial reports. We then combine this information with higher level industry reports from associations, and national or supranational agencies, then use academic literature to improve and verify our estimates. Where applicable, we moreover consider mineral extraction taxes to accurately represent country-specific production costs.

Countries in the Middle East, like Qatar, are located at the lower end of the cost range because of their vast and easily accessible natural gas resources and large-scale production. Similarly, North African countries, like Algeria and Nigeria, can extract natural gas at moderate costs. Average producer prices for developed countries with large natural resource extraction industries and accessible gas depots, such as Russia, the Netherlands and the US, are

[11] MCC, PIK 2019*: Optionen für eine CO2-Preisreform*; Sandbag 2019: *Sandbag, Halfway There - Existing policies put Europe on track for emission cuts of at least 50%*; WEO 2018/2019: *IEA, World Energy Outlook*; TYNDP 2020: *ENTSOG, ENTSO-E, TYNDP 2020 Scenario Report*; DIW 2020: *DIW, Klimaschutz statt Kohleschmutz: Woran es beim Kohleausstieg hakt und was zu tun ist*

estimated above North African producer price levels. Here, it is important to note that a large share of Russian upstream costs is due to the Mineral Resources Extraction Tax that applies to natural resource extraction on Russian territory. Lastly, states with difficult to access natural gas reservoirs, like Norway and the United Kingdom, are estimated to produce at high cost. EU production costs are rather irrelevant as production capacity is limited.

Transport costs to the EU border are estimated based on distances, available routes and load flows.

Transport costs are significantly different between LNG shipping and transmission by pipeline. Pipeline transmission is characterised by higher cost efficiency and is cheaper than LNG shipping. However, leaks and the need for propellant gas lead to more substantial losses compared to LNG shipping.

These underlying factors are used to calculate supply costs to the European borders. Here, transport routes and their distances are weighted with the load flows simulated in our model to represent actual transport distance and load, rather than theoretical minimum or average costs. Furthermore, pipeline routes account for indirect transport through intermediary countries, while LNG shipping is considered intermediary free.

Ultimately, aggregated transport costs from gas field to the EU border range from less than 1 €/MWh for nations in close proximity to the EU that utilise pipelines like the United Kingdom and Norway, to almost 6 €/MWh for the US or countries in Asia that rely on long distance LNG shipping.

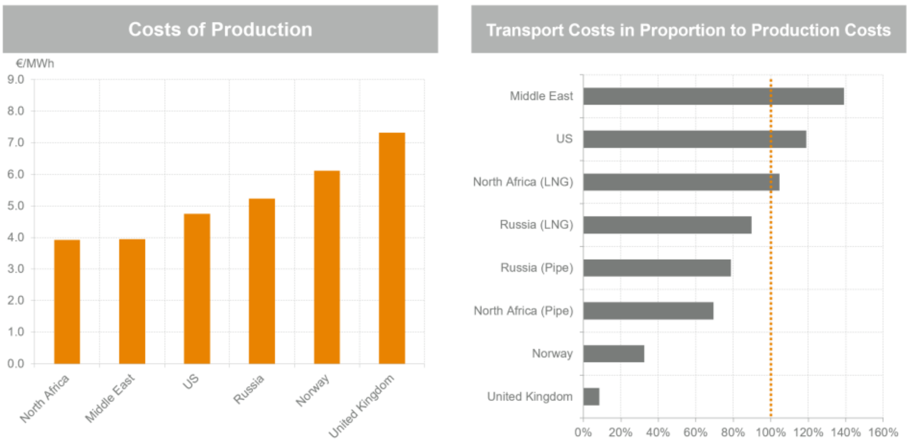

Figure 9: Costs of Production and Transport for Major Gas Suppliers to the EU

The effect of methane pricing on EU gas demand is estimated using an aggregate own-price demand elasticity for gas and is estimated to be rather small.

5.3.5 Demand Elasticities

The price elasticity of natural gas demand describes how variations in the natural gas price affect the demand for natural gas. It is important to distinguish between short term and long-term price elasticities because the demand for natural gas is related to energy infrastructure with long lifespans and high investment costs. Therefore, short term price changes, in general, do not diminish gas demand significantly. Since this study's time horizon is 2025, no major changes in infrastructure and asset base are expected and a short-term demand elasticity is used. By sampling academic literature about commodity and gas demand price elasticity, we find that the gas price elasticity is rather low and represented by an average elasticity of -0.2.[12] Thus, a 10% increase in natural gas price would reduce gas demand by 2%. We apply this on the wholesale gas price. Consequently, only minor reductions in EU gas demand are expected as a result of increased gas prices from applying a methane price. Resulting from these assumptions, the effect on gas demand by the application of a methane price of 25 €/tCO_2eq is quantified as a minor 0.8% demand decrease in the "CH_4 Pricing without Producer Abatement Response" scenario and a 0.4% decrease in the "CH_4 Pricing with Producer Abatement Response" scenario.

5.3.6 Additional Information

The results from the modeling are generated for predefined regions. The supply from Russia includes EU imports from Ukraine and Belarus, as these two countries purchase gas from Russia and trade it to the EU. Consequently, the source of production remains Russia. The region 'North Africa' includes the countries Algeria, Libya and Egypt while Qatar, Yemen and the United Arab Emirates are combined into 'Middle East'. The aggregate of all remaining countries, such as Trinidad & Tobago, Angola, Nigeria and Equatorial Guinea are referred to as 'Other'.

Norway already has a carbon tax in place that is applied to methane emissions that occur at the production of oil and gas. For 2021, the tax rate is proposed to be around 52 €/tCO_2 for the combustion of natural gas and 1376 €/t for methane leaked to the atmosphere (Norwegian Petroleum, 2020).[13] This methane price translates to 49 €/tCO_2eq for methane using a GWP_{100} of 28. Additionally, Norway is part of the EU Emissions Trading System since 2008. The fact that Norway already has a tax on methane emissions is neglected in the modeling because the used emission intensity for Norway as seen in Section 5.3.2 is very close to zero and by implication, so is the associated methane price mark-up on Norwegian gas.

All relevant LNG routes are considered and no extra conditions for future LNG use are in place.

This modeling abstracts away from the details of existing long-term contract and trading structures. However, price adjustment clauses could enable adaption to methane pricing and its consequences for gas volumes traded under long-term contracts. Furthermore, the modeling does not consider political or administrative constraints which may constrain the opportunity to export gas to other markets than the EU in the short to medium term.

[12] Liu (2004). *Estimating energy demand elasticities for OECD countries: A dynamic panel data approach.*
Sønstebø (2012). *The impact of natural gasexports from the U.S. to Europe.*
Asche et al (2008). *Natural Gas Demand in the European Household Sector.*
Andersen et al (2011). *How is demand for natural gas determined across European industrial sectors?.*
Bilgili (2014). *Long Run Elasticities of Demand for Natural Gas: OECD Panel Data Evidence.*
Bernstein & Madlener (2011). *Residential Natural Gas Demand Elasticities in OECD Countries An ARDL Bounds Testing Approach*.

[13] With 1 NOK = 0.095 € (Dec 2020)

6 Results

In this chapter we show the core results building on the scenarios and assumptions presented previously and the respective GasTracks model simulations.

6.1 Price Mark-Ups

Methane emission intensities for the gas supply countries are largely unmeasured (with the exception of US) and therefore very uncertain. Consequently, price mark-ups are characterized by uncertainty, too. Sensitivity checks are presented in Section 7.

First, we look at what the methane price levels of 25 €/tCO_2eq and 100 €/tCO_2eq imply in terms of mark-ups above gas production costs. The mark-ups due to the methane price are by construction proportional to the methane emission intensity of gas production. Figure 10 shows the gas price mark-ups as a function of the methane emission intensity for methane price levels of 25 €/tCO_2eq (grey line) and 100 €/tCO_2eq (blue line) respectively.

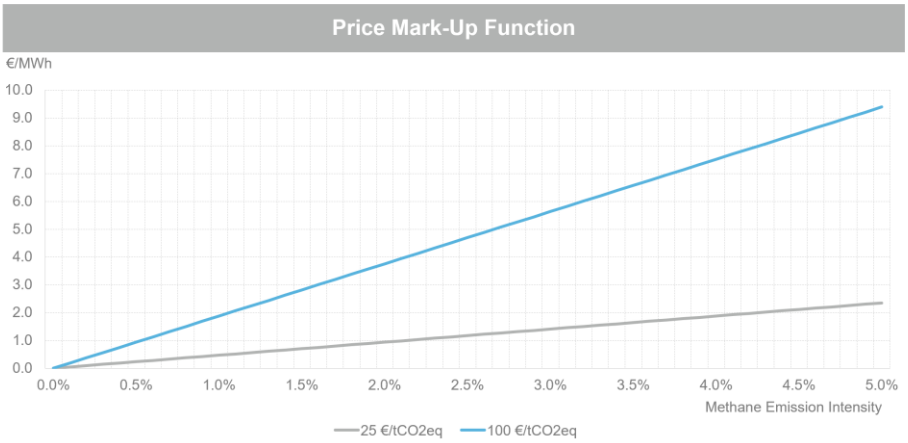

Figure 10: Price Mark-Up Function

Figure 11 shows the price mark-ups which result for the gas supply from each country based on the respective assumed central baseline emission intensities presented in Section 5.3.2. Countries with low emission intensities obtain low price mark-ups and vice versa. The error bars correspond to the upper and lower bound baseline emission intensities presented in Table 1.

The effect of the emission intensities at a price of 25 €/tCO_2eq is relatively low, with mark-ups above 1 €/MWh for production in Angola, Yemen, Libya and the US. Applying the upper bound baseline estimate emission intensities, mark-ups are above 4 €/MWh in Yemen and Libya and above 6 €/MWh in Angola, respectively.

In contrast, the price of 100 €/tCO_2eq has a much stronger impact, with most mark-ups being around 2 €/MWh and for some production regions at around 10 to 12 €/MWh using the central baseline emission intensities.

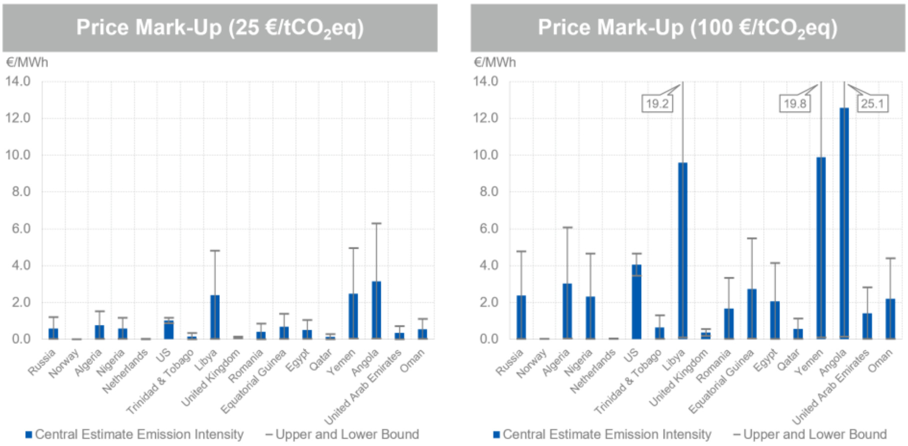

Figure 11: Price Mark-Ups (above gas production costs) at 25 €/tCO2eq and 100 €/tCO2eq; based on assumed central baseline emission intensity estimates and error bars indicating the range with the lower and upper bound emission intensities from Table 1; countries ranked by quantity of gas volumes supplied to the EU

Figure 12 shows the mark-ups which result for the gas supply from each country based on the respective assumed abatement emission intensities presented in Table 1, Section 5.3.2. With a reduced emission intensity, as a result of applied abatement measures, the methane price of 25 €/tCO2eq has almost no impact with most mark-ups being under 0.4 €/MWh. However, the 100 €/tCO2eq methane price leads to higher mark-ups despite lower emission intensities and closely corresponds to the mark-ups at 25 €/tCO2eq with no abatement assumed.

As one would expect, a methane price impacts regions with a higher methane emission intensity more strongly than regions with lower intensity. Due to the high uncertainty in methane emission intensities, the relative position of countries in Figures 13 and 14 is highly uncertain and only illustrative.

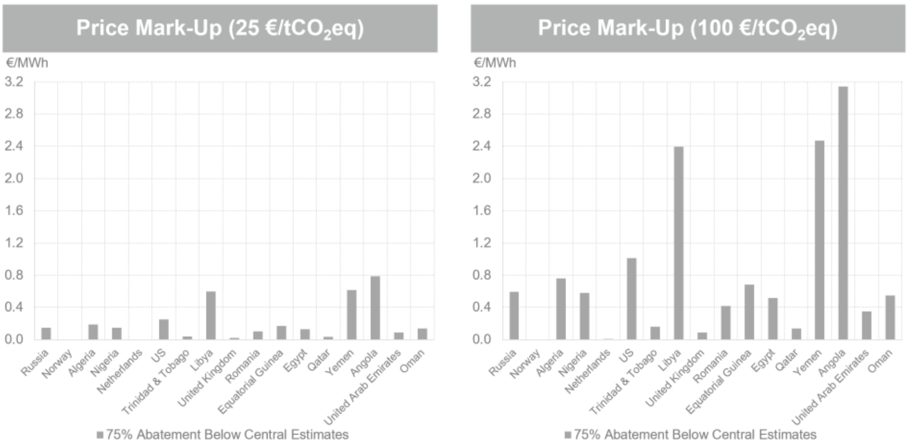

Figure 12: Price Mark-Ups (75% abatement below central estimates) at 25 €/tCO2eq and 100 €/tCO2eq; based on assumed abatement emission intensity estimates from Table 1; countries ranked by quantity of gas volumes supplied to the EU

6.2 Price-Wise Order of Supply Cost

With a methane price countries/ regions with lower emission intensities become more cost competitive in the EU market. Countries with higher emission intensities experience the opposite effect.

Based on the central baseline methane emission intensities we assumed in Section 5.3.2, we analyze the effect of a methane price on the cost competitive positioning of production regions. To do so, we look at an indicative merit order of supply cost. The position of a country represents competitiveness, the “further to the left” the better its competitiveness.

Calculations indicate that countries with lower emission intensities and therefore lower mark-ups become more cost competitive. As one would expect, countries with higher emission intensities experience the opposite effect. With abatement, this effect is significantly reduced.

The large uncertainty regarding relative emission intensities between supply countries leads to uncertainties regarding presented impacts on EU gas supply costs.

Figures 13 and 14 both include production costs, costs of transportation as well as methane price mark-ups. Hence, bundled EU supply costs include several elements: country of origin production costs, transport costs to the EU border, cost of lost gas, liquefaction and regasification costs (when applicable) and the price mark-up based on the assumed central baseline emission intensities presented in Table 1.

At 25 €/tCO_2eq the mark-up does not significantly influence cost-competitiveness and thus does not provide strong incentives for gas buyers to shift their gas supply. Later sensitivity checks confirm this statement to a large extent, except for countries with very high assumed emission intensities, e.g. Libya.

The mark-up share in total supply cost is significant at 100 €/tCO_2eq and with no abatement response. This high price favors countries with lower emission intensities and therefore impacts relative cost-competitiveness between supply countries. For example, at 100 €/tCO_2eq with no producer abatement response, methane pricing favors Norway.

The cost of EU production is not a factor in this case, as the production capacities in the modeling for 2025 are quite fixed at around 42 bcm in total.

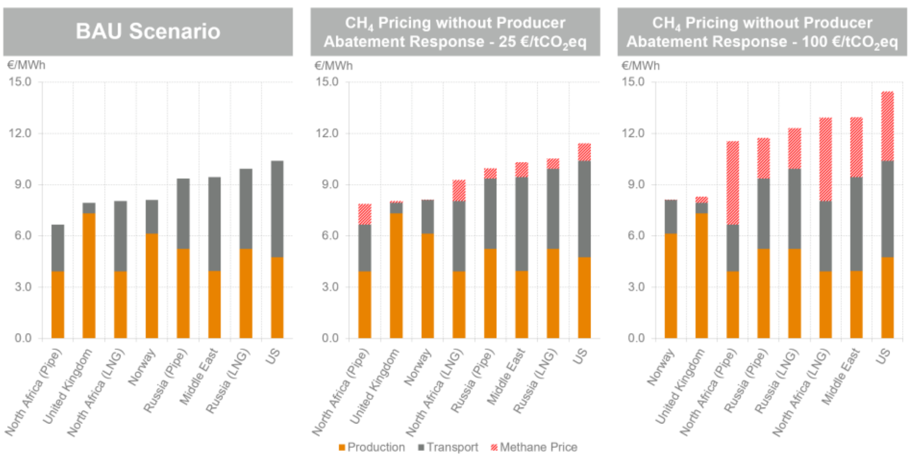

Figure 13: Price-Wise Order of Supply Cost (CH_4 Pricing without Producer Abatement Response)

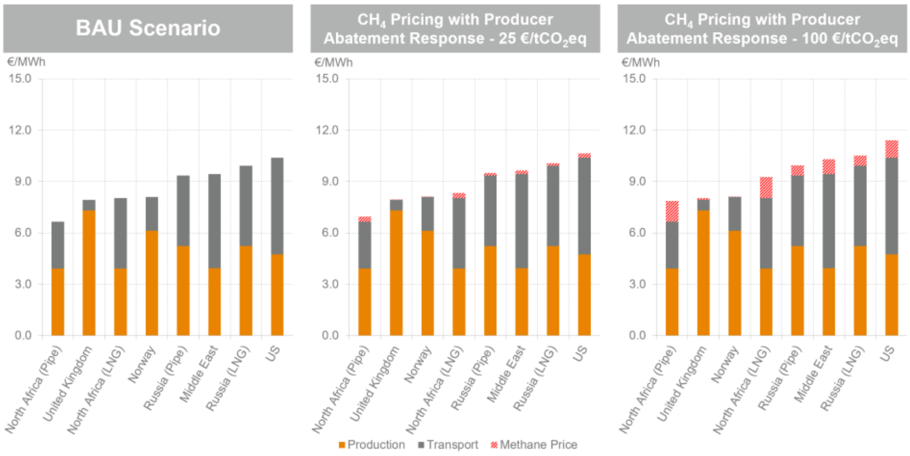

Figure 14: Price-Wise Order of Supply Cost (CH_4 Pricing with Producer Abatement Response)

6.3 Impacts on the EU Gas Flows

Methane pricing reduces EU imports from countries with high emission intensity, with effect almost negligible at 25 €/tCO_2eq and more significant at 100 €/tCO_2eq.

6.3.1 Supply Countries

Based on the central baseline methane emission intensities we assumed in Section 5.3.2, we here analyze the effect of a methane price on the import structure of the EU. Please note, that a reduction in imports from a country does not imply that production in that country is reduced accordingly.

The following figure shows a comparison of the EU supply mix in 2019 and 2025 in the BAU scenario. In contrast to the supply mix in 2019, the EU's own production, as expected, has decreased (see Section 4.1.2). Around 60% of the EU's natural gas demand is still provided by Russia and Norway. The LNG share has increased from 22% in 2019 to 28% in 2025, with Russia and Nigeria being the main supply countries for LNG.

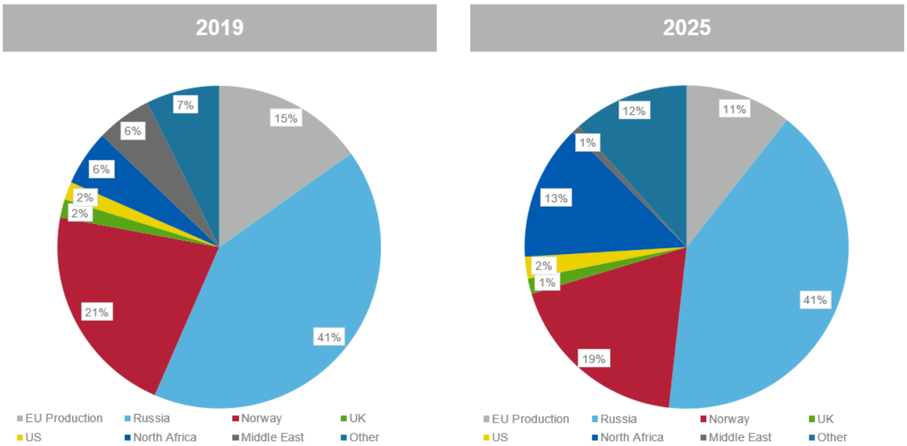

Figure 15: EU Supply Mix 2019 (Eurostat, 2020b) vs BAU Scenario in 2025 (enervis' GasTracks model)[14]

[14] The figure for 2025 shows results from cost-optimization in the GasTracks model and is therefore only partially comparable with the Eurostat figure for 2019. Furthermore, no long-term contracts were considered.

Figures 16 shows the EU supply mix under CH_4 pricing without producer abatement response. Results indicate that the 25 €/tCO_2eq methane price has a rather moderate impact on the import structure based on the assumed central baseline emission intensity estimates in Table 1. The supply regions most affected are Russia, the US and the Middle East. There is an increase in imports from supply countries with relatively lower assumed methane emission intensities and a reduction in imports from countries with relatively higher assumed emission intensities. If we assume emission intensities according to the central baseline estimates in Table 1, imports from Russia decline and imports from the US are completely eliminated, while imports from the Middle East increase. The EU's two main supplier countries remain Russia and Norway.

At 100 €/tCO_2eq with the assumed central baseline methane emission intensities, the supply mix effects are significantly amplified. The notional methane price of 100 €/tCO_2eq leads to a larger decrease in natural gas from supply countries with relatively higher emission intensities. In contrast, imports from countries with relatively lower methane emission intensities increase further compared to the 25 €/tCO_2eq. Supplies from Russia decline further, while imports from North Africa are also sharply reduced. The now missing quantities are largely compensated by the Middle East. Again, results here are dependent on the assumed central baseline emission intensities in Table 1 and are only illustrative given the uncertainties in baseline methane emission intensities.

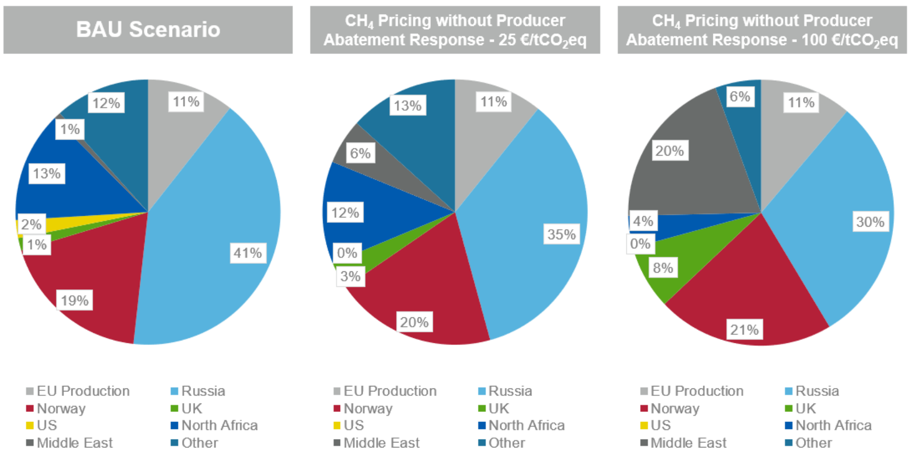

Figure 16: EU Supply Mix CH_4 Pricing without Producer Abatement Response (based on assumed emission intensities from the central baseline estimates in Table 1)

Figure 17 indicates that if gas producers respond to a methane price by abating 75% of their methane emissions, the mark-up due to the methane price is proportionally reduced compared to the CH_4 pricing scenario without a producer abatement response, and therefore the supply mix impacts illustrated in Figure 16 are mitigated as shown in Figure 17. If we assume 75% Abatement Below Central Baseline Estimates in Table 1, the top four supplying countries remain Russia, Norway, Algeria and Nigeria under both the 25 €/tCO_2eq and even the 100 €/tCO_2eq scenarios.

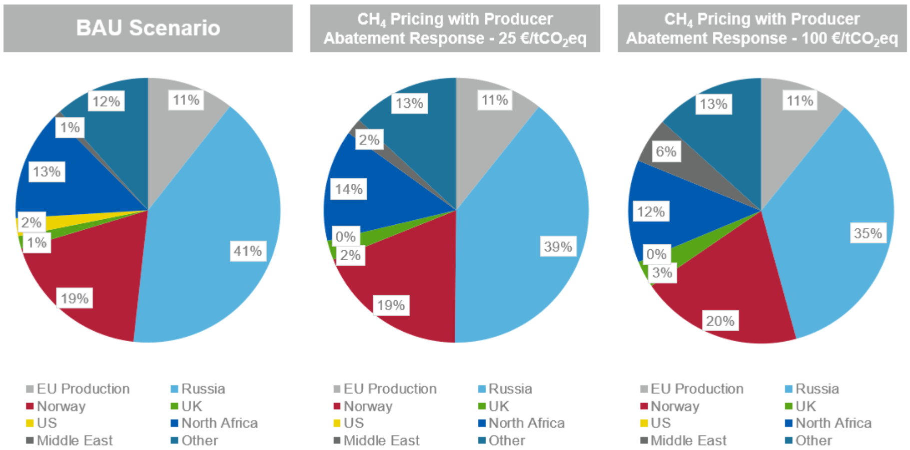

Figure 17: EU Supply Mix CH_4 (Pricing with Producer Abatement Respons); based on assumed 75% abatement below central baseline emission intensity estimatesin Table 1

The Asian market is modelled to absorb parts of the shifted volumes as a result of growing flexibility in international gas markets. China receives diverted volumes from the US due to EU methane pricing. Furthermore, volumes from the Middle East and Russia, originally intended for the EU, are instead exported to China.

Import countries without access to LNG terminals have less flexibility in shifting their gas supply.

6.3.2 Impacts in EU Gas Import Countries

Figure 18 shows an example of the effect of methane pricing on the share of Russian gas in Germany, France and the Netherlands - three EU member states with a large dependence on gas. Again, based on the central baseline emission intensity estimates from Table 1, Figure 18 indicates that under methane pricing without a producer abatement response, the share of Russian gas in these countries decreases. Germany still stays dependent on Russian imports while in contrast, at 25 €/tCO_2eq, France and the Netherlands reduce their shares of Russian gas and at 100 €/tCO_2eq cease to import Russian gas at all. Germany remains relatively dependent on Russia since, unlike France and the Netherlands, it is not assumed to have its own LNG terminals nor the associated increased flexibility. Furthermore, at 100 €/tCO_2eq Germany absorbs to a lesser extent parts of the omitted volumes from France and the Netherlands.

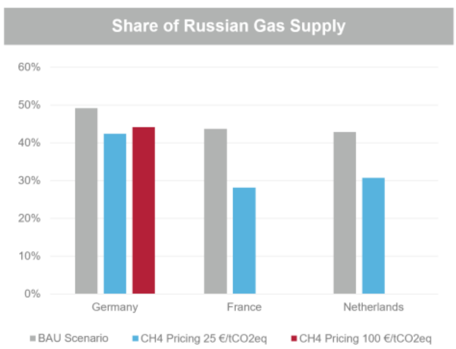

Figure 18: Russian Share of Gas Supply (CH_4 Pricing without Producer Abatement Response); based on assumed central baseline emission intensity estimates in Table 1

Italy continues to import most of its gas from North Africa, mainly from Algeria, at a methane price of 25 €/tCO_2eq. However, LNG volumes from Nigeria are replaced by lower methane emission intensity supply from the Middle East. At 100 €/tCO_2eq, supply from North Africa is further reduced and replaced by additional volumes from the Middle East and Europe.

Conclusion

- The methane price of 25 €/tCO_2eq has a rather small impact on the EU supply structure if there is a producer abatement response. If no abatement is assumed, 25 €/tCO_2eq causes a moderate effect on the import structure.
- In contrast, the notional price of 100 €/tCO_2eq causes more changes as countries with high emission intensities make use of possible flexibility to export elsewhere and direct their gas flows to other markets than the EU. With abatement response these effects stay moderate, without abatement response they become more noticeable.

6.4 Impacts on Global Production

Besides the gas flow analysis, the model assesses the changes in production in between scenarios.

Global production volumes are not significantly impacted because production volumes are predicted to be reallocated to other markets.

Based on the central baseline methane emission intensities we assumed in Section 5.3.2, we here analyze the effect of a methane price on global natural gas production. Effects on the global production mix are smaller than impacts on import gas flows to the EU. Since a methane price of 25 €/tCO_2eq only decreases EU demand by less than 1% (due to the low assumed EU gas demand elasticity), overall global gas production stays largely unimpacted and global gas production volumes are predicted by the model to be reallocated to other markets than the EU instead. On a regional level, production countries that have access to spare LNG liquefaction capacity can redirect their volumes to other markets. This is true so long as they were delivering gas to the EU in 2025 via LNG (US and partially Russia) or they have access to LNG liquefaction and/or regasification facilities.

The results at the regional level are only illustrative in the sense that they show that there are effects on countries with high and low methane emission intensities. Impacts on specific countries are highly uncertain due to the aforementioned ambiguity surrounding actual methane emission levels in the different supply countries. Uncertainty in emission intensities leads to uncertainty in methane price mark-ups and thus in corresponding production changes in global production and EU supply countries.

The following figure shows production changes relative to the BAU scenario. Partly due to the redirection of LNG volumes, production volumes only decrease by about 1%.

A price of 25 €/tCO_2eq leads to an increase in production in countries with relatively lower methane emission intensities and a decrease in production in countries with relatively higher methane emission intensities. If we assume the methane emission intensities in the central baseline estimates from

Table 1, methane pricing without a producer abatement response results in decreased Russian production which is compensated by increases in other regions, e.g. the US. Noticeable reduction can be found in Angola (-8%) due to the relatively high assumed methane emission intensity and the cost of exporting LNG to other markets.

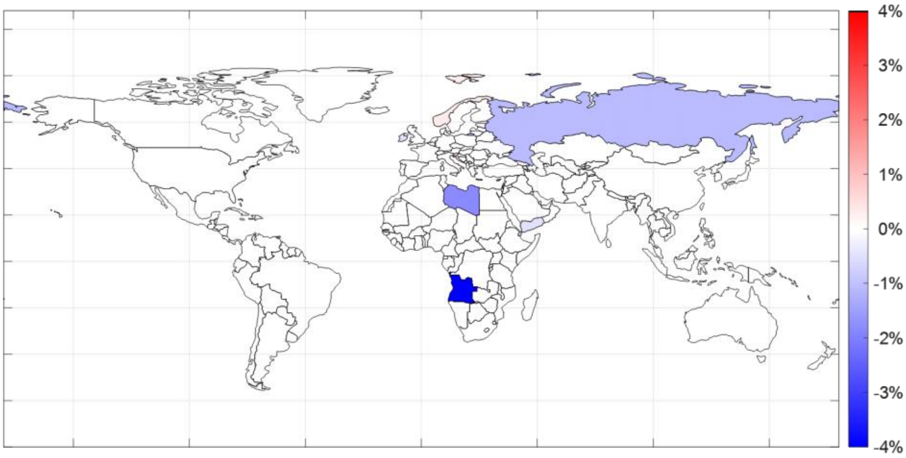

Figure 19: Global Gas Production in Relation to BAU Scenario (CH_4 Pricing without Producer Abatement Response at 25 €/tCO_2eq); based on assumed central baseline emission intensity estimates in Table 1

Figure 20 indicates that under the assumed central baseline estimates for methane emission intensities in Table 1, a price of 100 €/tCO_2eq without a producer abatement response leads to an increase in production in the US as well as in the Middle East. Contrarily, a decrease in production occurs in Algeria (-30%) and Libya (-24%) because of the relatively higher emission intensities assumed for gas production in these countries in the central baseline estimates.

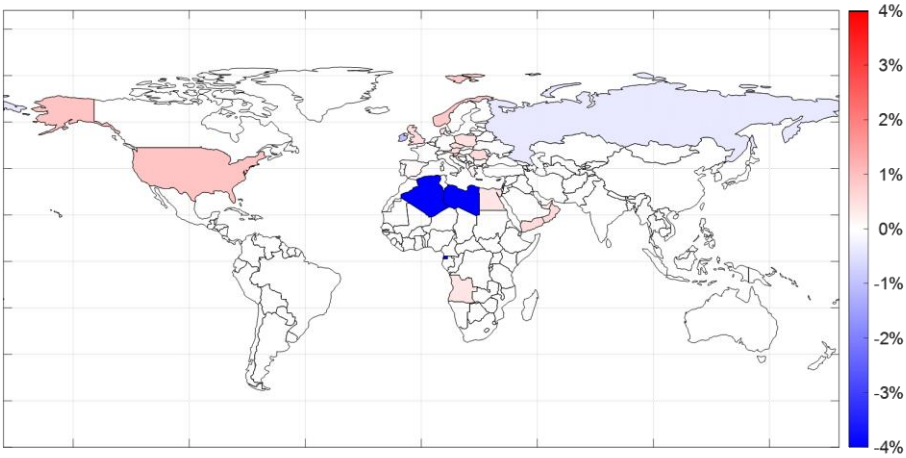

Figure 20: Global Gas Production in Relation to BAU Scenario (CH_4 Pricing without Producer Abatement Response at 100 €/tCO_2eq); based on assumed central baseline emission intensity estimates in Table 1

In the CH_4 Pricing with Producer Abatement Response scenario, and assuming a methane price of 25 €/tCO_2eq, the global production remains at a rather constant level (see Figure 21). Noticeable reduction can be found in

Angola (-8%) due to the still relatively high assumed methane emission intensity and the cost of exporting LNG to other markets.

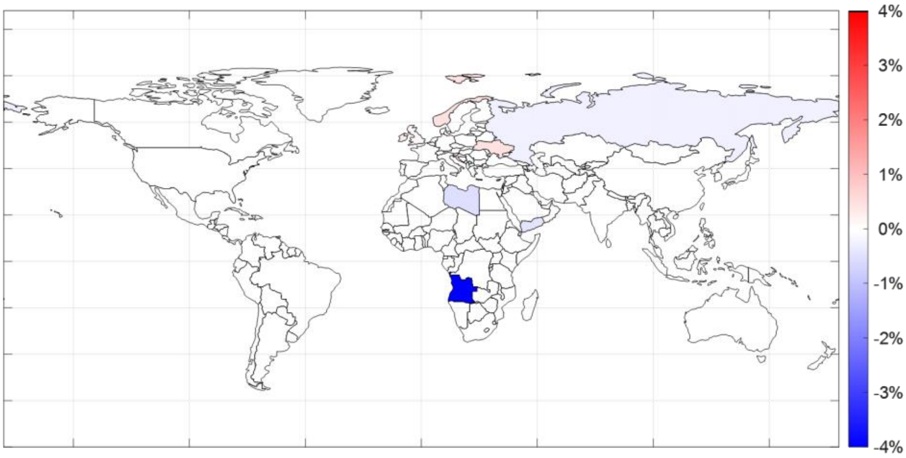

Figure 21: Global Gas Production in Relation to BAU Scenario (CH_4 Pricing with Producer Abatement Response at 25 €/tCO_2eq); based on assumed 75% abatement below central baseline emission intensity estimates in Table 1

The changes in production at a methane price of 100 €/tCO_2eq with producer abatement response correspond to the methane pricing without producer abatement response at a price level of 25 €/tCO_2eq (we therefore also omit a figure illustrating production impacts under CH_4 Pricing with Producer Abatement Response at 100 €/tCO_2eq).

Variation in methane emission intensity assumptions and related methane price mark-ups changes the modeled production impacts as one would expect. There is a direct connection between increases in assumed methane emission intensity and decreases in production and vice versa. This is confirmed by our sensitivity analyses presented in Section 7. Increasing the methane emission intensity for Russia or Algeria leads to a decline in the country’s production.

Key-assumptions driving these results are cleaner and cheaper production in the Middle East and in Trinidad & Tobago and therefore lower influence of methane pricing. Furthermore, LNG provides a flexible supply for the EU. Countries in close proximity to the EU such as Norway and the UK, are given an advantage by short and therefore cost-efficient transport, and have just as low methane emissions despite relatively high production cost.

6.5 Impacts on Methane Emissions

Besides the gas flow analysis, the model assesses the changes in methane emissions. This section analyzes the impacts on upstream methane emissions under the CH_4 pricing scenarios compared to the BAU scenario.

Assuming a 75% abatement response to an EU methane price leads to a significant reduction in the EU's methane footprint from upstream gas supply chain emissions.

6.5.1 Impacts on the EU's Methane Footprint from Upstream Gas Supply Chain Emissions

Based on the central baseline methane emission intensities we assumed in Section 5.3.2, we analyze the effect of a methane price on methane emissions from gas production attributed to the supply volumes for the EU27 (i.e. the EU's methane footprint from upstream gas supply chain emissions). In the BAU scenario, 3.25 Mt CH_4 are emitted during production of EU gas volumes in the gas supply countries according to our central baseline emission intensity estimates in Table 1. Please note, that changes to the EU's methane footprint don't necessarily correspond to similar changes in overall methane emissions.

Methane emissions are reduced by almost 0.6 Mt at 25 €/tCO_2eq and almost 1.6 Mt at 100 €/tCO_2eq, respectively, in the methane pricing scenarios without producer abatement response. Methane pricing therefore reduces the upstream methane emissions footprint of the EU's gas consumption by 18% and 48%, respectively.[15] This reduction in the EU methane footprint is due to a decrease in supply from countries with relatively higher assumed emission intensities and increases in supply from countries with relatively lower assumed emission intensities.

If methane pricing can trigger not only a change in the EU supply mix, but also a producer abatement response of 75% reduction in central baseline upstream emission intensities for the gas volumes exported to the EU, then upstream methane emissions decline by about 2.5 Mt (-78%) at 25 €/tCO_2eq and about 2.6 Mt (-79%) at 100 €/tCO_2eq. This is close to 2% of the EU's total domestic greenhouse gas emissions in 2018 (Eurostat & EEA, 2020).[16]

Sensitivity checks indicate, that results are highly dependent on the assumed relative emission intensities. With the application of the upper bound emission intensity in Table 1 on Russian production and all other emission intensities remaining the same, the EU's upstream methane emission footprint from the gas supply chain in the BAU increases by 0.2 Mt (+5%) and decreases by 2.2 Mt (-67%) with lower bound emission intensity. The former includes a decrease in Russian supply to the EU and the latter comprises an increase in Russian supply to the EU.

[15] In comparison to BAU scenario

[16] GHG emissions from EU27 countries (GWP_{100})

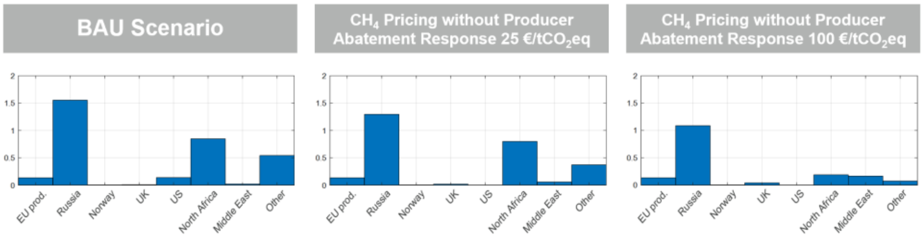

Figure 22: EU Upstream Methane Emissions Footprint (CH_4 Pricing without Producer Abatement Response); based on assumed emission intensities from the central baseline estimates in Table 1

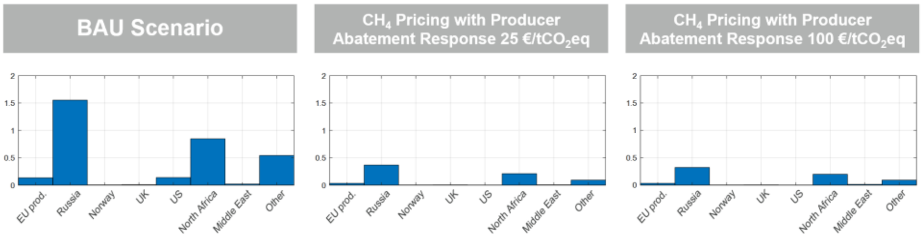

Figure 23: EU Upstream Methane Emissions Footprint (CH_4 Pricing with Producer Abatement Response); based on assumed 75% abatement below central baseline emission intensity estimates in Table 1

The reduction of global methane emissions is much lower than on the EU's share of upstream methane emissions due to redirecting of global gas trade flows.

6.5.2 Impacts on Global Oil and Gas Methane Emissions

Now we extend the scope of the analysis beyond the methane emissions directly related to the volumes delivered to the EU. Based on the results of the section on gas production impacts we can already expect the results of a methane price on global methane emissions to be much lower than on the EU's share of upstream methane emissions due to redirecting of global gas trade flows to other markets than the EU.

Here, we choose to relate our impact estimates to total global oil *and* gas supply chain methane emissions due to the difficulty in consistently separating oil and gas methane emission sources. The range we use for total global oil and gas supply chain methane emissions is 80 - 140 Mt CH_4/yr based on recent scientific studies.[17]

On a global level, without a producer abatement response, the decline in total oil and gas methane emissions amounts to less than 1% at 25 €/tCO_2eq and 1 - 2% at 100 €/tCO_2eq due to the previously described reshuffling of global gas trade flows. With producer abatement response, the 75% reduction in central baseline emission intensities only over the EU's share of the gas production in the supply countries, results in a reduction in global oil and gas methane emissions of around 2 - 3% at both 25 €/tCO_2eq and 100 €/tCO_2eq (since the level of abatement is assumed to be the same at both price levels). Varying the relative methane emission intensity assumptions for the major EU gas supply countries to account for uncertainty indicates a reduction in total global oil and gas methane emissions under this abatement scenario of up to 4%.

If abatement could be extended beyond the gas volumes delivered to the EU (i.e., extended to 75% abatement below central baseline emission intensities

[17] See: IEA, (2020a); Saunois et al. (2020); Schwietzke et al. (2016) and Hmiel et al. (2020).

on all gas production in the supply countries) then global oil and gas supply chain methane emissions would be reduced by around 15 - 25%. This would be based on the plausible assumption that if producers were to implement methane mitigation activities at their production facilities, these would not only apply to the share of the production delivered to the EU, but extend beyond those gas volumes. In addition, if oil and gas producers in EU gas supply countries were to abate 75% of methane emissions also from their oil production facilities – e.g., in response to the adoption of comprehensive methane policies and regulations in oil and gas buying countries and/or in the supply countries themselves - the impact on global oil and gas methane emissions could potentially be roughly twice as large.

The results are reliant on assumptions about upstream methane emission intensities for different gas supply countries for which there is currently very limited data and therefore significant uncertainty outside the US. We therefore conducted sensitivity analyses in Section 7 to provide information about the robustness of the modeling results. From that analysis, it can be concluded that results are sensitive to changes in assumed emission intensities.

Conclusion	
Conclusion	• Under the CH_4 Pricing with Producer Abatement Response scenario, upstream methane emissions for the gas volumes exported to the EU decrease by about 2.5 Mt CH_4. This is equivalent to a near 80% reduction in the upstream methane emissions footprint of the EU's gas consumption compared to a BAU scenario with assumed central baseline emission intensities. Varying the relative methane emission intensity assumptions for the major EU gas supply countries away from the central baseline emission intensities indicates a reduction in total global oil and gas methane emissions under this abatement scenario of up to 4%. • If abatement could be extended beyond the gas volumes delivered to the EU - i.e., extended to 75% abatement below central baseline emission intensities on all gas production in the supply countries - then global oil and gas supply chain methane emissions would be reduced by around 15 - 25%.

6.6 Impact on EU Natural Gas Prices

The impact on the average EU wholesale gas price is relatively small with a 25 €/tCO_2eq methane price.

Based on the central baseline methane emission intensities we assumed in Section 5.3.2, we analyze the effect of a methane price on wholesale market prices for gas. Implementing a methane price would imply an increase in the European wholesale gas market prices. The following figure shows the resulting impact of methane pricing on the wholesale market prices for gas.

The influence of the methane price on the average EU wholesale gas price is relatively limited at 25 €/tCO_2eq and/or with abatement response and remains within the range of historic price fluctuations.[18]

With a producer abatement response, the methane price mark-up impact on wholesale gas prices is significantly lower.

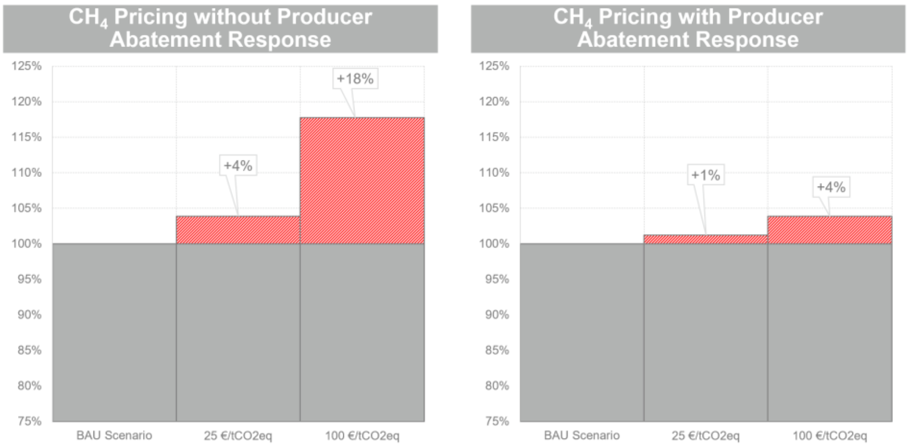

Figure 24: Average Wholesale Natural Gas Price Impact

The impact on residential gas prices is relatively small. This is due to the large share of taxes, levies, distribution and other price components.

The increase in the European wholesale gas prices would translate into effects on end-use prices. However, the impact on end user natural gas prices is lower than on wholesale prices, as can be seen in Figure 25.[19] This is due to the large share of taxes, levies, distribution and other price components in end-use gas prices. The mark-up on the average residential gas price amounts to between 1% at 25 €/tCO_2eq to 5% at 100 €/tCO_2eq without a producer abatement response. Due to lower end use prices for industry, the mark-up has a greater influence, between nearly 2% at 25 €/tCO_2eq and 8% at 100 €/tCO_2eq without a producer abatement response. With a producer abatement response, the methane price mark-up on both residential and industrial end-use gas prices is significantly lower.

[18] Example: average hub wholesale day-ahead prices in Europe in Q4 2019 between 12.5 and 15 €/MWh (EC, 2020c)

[19] Price effects on consumer level are calculated based on publications of EU28 prices based on latest publication for 1st half year of 2020 for residential customers (5 – 55 MWh) (Eurostat, 2020c) and medium-sized industry (27 – 277 MWh) (Eurostat, 2020d)

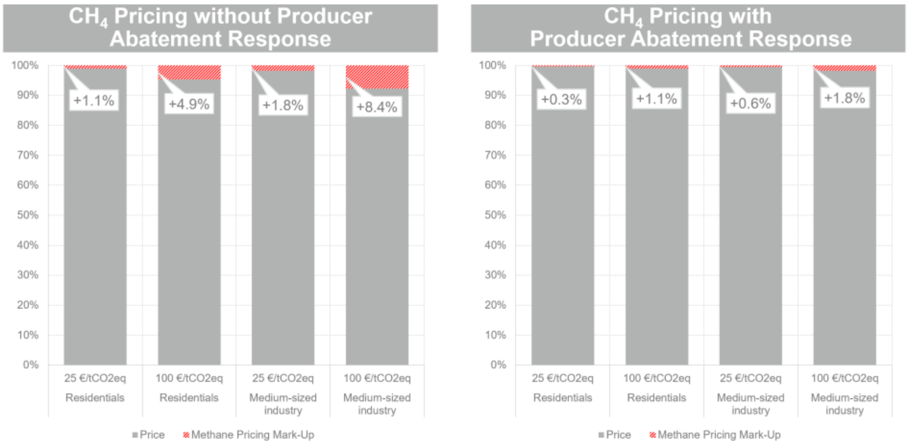

Figure 25: Average Consumer Level Impact

Variation in methane emission intensity assumptions and related methane price mark-ups away from the central baseline emission intensity assumptions, changes the modeled price impacts as one would expect. This is confirmed by our sensitivity analyses presented in Section 7.

Conclusion

- The influence of methane pricing on the EU residential gas prices is limited due to the large share of taxes, levies and other price components in end-use gas prices and stays below 5%.
- The impact on industrial end-use gas prices is on the order of up to 9% under a methane price of 100 €/tCO_2eq, but would be lower with a producer abatement response.

7 Sensitivity Analyses

To analyze the sensitivity of our results to the uncertainty in emission intensities, we ran additional model runs varying the assumptions for the scenario with methane pricing at 25 €/tCO_2eq without a producer abatement response. Hence, all parameters are kept equal as in the methane pricing without a producer abatement response scenario with central baseline emission intensities from Table 1 except for the emission intensities for Russia and Algeria, which are now taken from the upper and lower bound baseline emissions from Table 1. These countries are two main supply countries for the EU with relatively high emission intensities. This allows us to assess the extent to which the emission intensity has an effect on the results. This is important to know, as there are large uncertainties regarding the methane emission intensities. Emission intensity variations for other countries are only applied for the price-wise order review. We choose to focus on the scenario without abatement response since assuming abatement mitigates the price and supply mix impacts of methane pricing.

7.1 Sensitivity of the Price-Wise Order of Gas Supply

Changing the assumed methane emission intensities has immediate impact on the relative positions in the EU price-wise order of supply.

Methane pricing impacts production costs and ultimately the EU supply costs. Therefore, it is important to examine the robustness of the price-wise order of supply, as the main results are based on the central baseline emission intensity estimates in Table 1.

Figure 26 shows the impact of variations in emission intensities for Russia and Algeria in relation to the average supply cost in the given sensitivity scenario.[20] Algeria is already in the BAU able to supply more cost-efficiently than the average, while Russia is at the other end of the scale. Variations in emission intensities do not change the overall result. However, they indicate that a change in the emission intensity can eventually lead to repositioning within the price-wise order of supply. In the case that the upper bound emission intensity is applied to Algeria, its relative cost advantage is reduced and its position deteriorates somewhat. A similar influence can also be seen on Russian supply. The impact is weaker on Russian LNG supply compared to Russian pipeline supply as costs of LNG transportation already provide for a worse position.

Further variations in emission intensities on other countries show that the application of lower bound emission intensities, at 25 €/tCO_2eq and 100 €/tCO_2eq, does not change the price-wise order, as impact of methane pricing is low. In contrast, a change to higher bound emission intensities does have an impact. The effect is strongest for countries with already high central baseline estimates and at a price of 100 €/tCO_2eq. For example, Libya is under central baseline estimates below the average supply price, but worsens its relative cost position significantly with the application of the upper bound emission intensity.

[20] Average LNG and pipeline supply costs for Russia

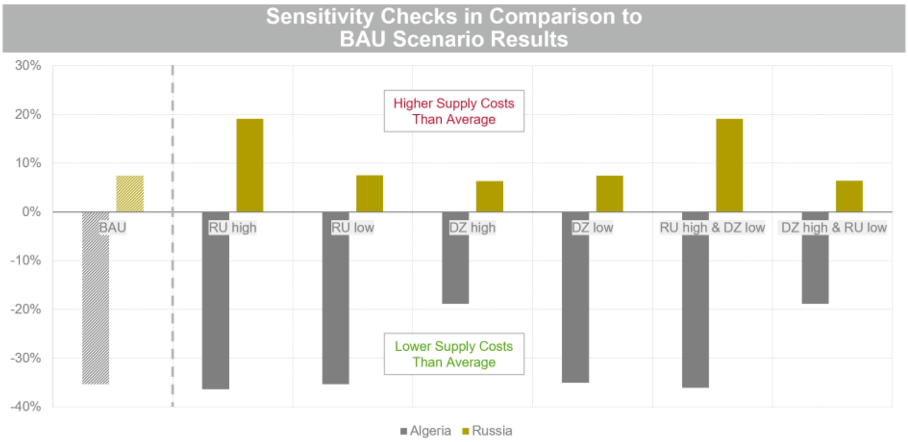

Figure 26: Variations in EU Supply Costs; changing the assumed methane emission intensities for Russia (RU) and Algeria (DZ) while keeping the rest on central baseline estimates (low = lower bound estimates; high = upper bound estimates) under methane pricing at 25 €/tCO_2eq without a producer abatement response

7.2 Sensitivity of Impacts on the EU Supply Mix

The sensitivity analyses indicate a strong dependency of supply mix changes on assumptions for methane emission intensities. Variations in emission intensities show that higher methane emission intensities result in lower import volumes to the EU and vice versa.

Results indicate a strong dependency of the supply mix on methane emission intensities. Variations in assumptions affect the results, thus the results based on central baseline methane intensity estimates in regard to regional effects are not very robust. Nonetheless, aggregated results (e.g. increased emission intensities lead to less imports) are robust to our sensitivity checks.

As previously discussed in Section 6, a change in central baseline emission intensities to lower or upper bound emission intensities results in corresponding changes for the EU supply mix. The following graphs show the differences in import volumes from Russia (blue bars) and Algeria (orange bars). Emission intensity variations are compared to the BAU scenario (left panel) and the methane pricing at 25 €/tCO_2eq without producer abatement response scenario with central baseline emission intensities for all countries including Algeria and Russia (right panel), respectively. We vary the emission intensities for Algeria and Russia to correspond to the upper and lower bounds in Table 1 while the remaining regions correspond to central baseline estimates from Table 1. The variations in emission intensities always show that higher methane emission intensities result in lower import volumes to the EU and vice versa.

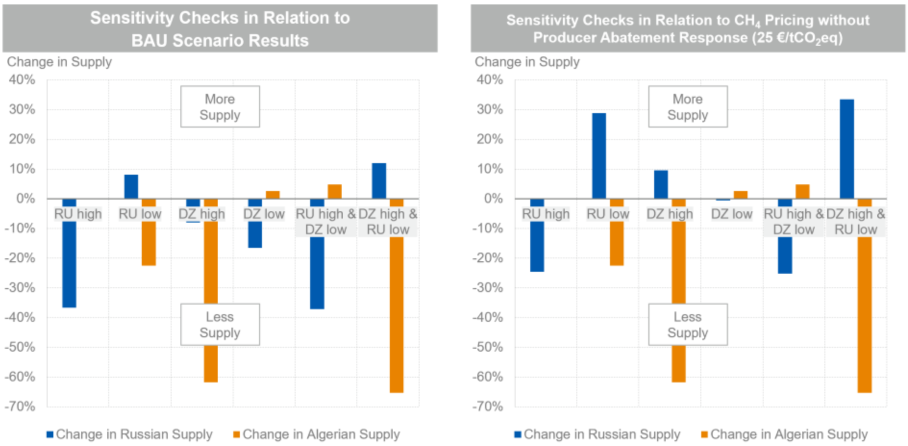

Figure 27: Variations in EU Supply Volumes; changing the assumed methane emission intensities for Russia (RU) and Algeria (DZ) while keeping the rest on central baseline estimates (low = lower bound estimates; high = upper bound estimates) under methane pricing at 25 €/tCO_2eq without a producer abatement response; left panel shows results compared to the BAU scenario and the right panel results compared to methane pricing at 25 €/tCO_2eq without producer abatement response scenario with central baseline emission intensities assumed for all countries including Algeria and Russia

Figure 28 indicates that the upper bound emission intensity from Table 1 for Russia leads to a strong decline in supply by around 37%, regardless of lower or central baseline estimate emission intensity for Algeria. Imports from the latter stay rather unchanged in this setup. Under these assumptions, the missing volumes from Russian supply are compensated by increased imports from the Middle East and the UK. Increasing the emission intensity of Algeria to the upper bound in Table 1, with simultaneous decrease in Russian emissions intensity to the lower bound results in a strong decrease of supply from Algeria, which is mostly compensated by imports from Russia. Additional changes in emission intensities from other supply countries would have further directionally similar effects. An increase or decrease in the emission intensity can provide the price change needed to take advantage of the existing, but still limited flexibility in the global gas market, where especially countries with LNG liquefaction capacities can divert their supply volumes to other importers than the EU.

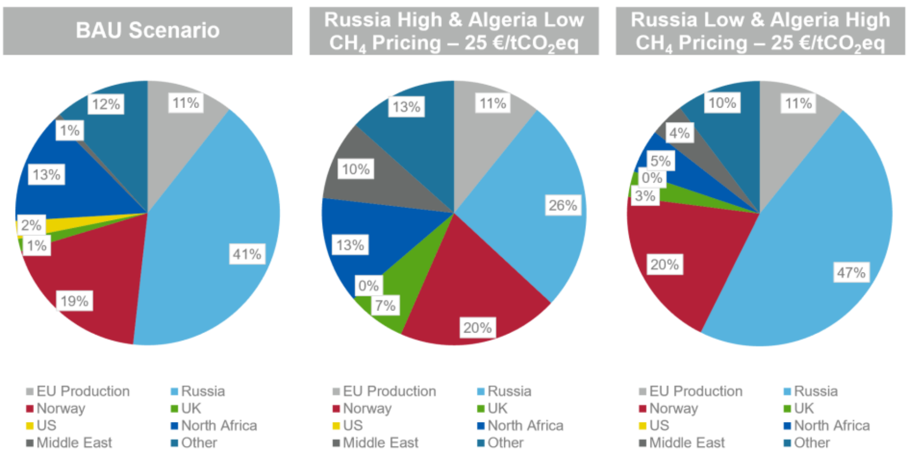

Figure 28: Supply Mix for Concurrent Variations for Russia and Algeria; based on assumed emission intensities from the central baseline estimates as well as lower and upper bound – no abatement response

Variation in methane emission intensity assumptions and related methane price mark-ups impact the production in regions considered as one would expect. Increasing the methane emission intensity for Russia or Algeria leads to a decline in the country's production and vice versa.

7.3 Sensitivity of Impacts on EU Methane Footprint

Our sensitivity checks show that the size of the supply mix, gas price and methane emission impacts are highly sensitive to assumptions regarding the level and relative differences in methane emission intensities for different gas supply regions.

The results for methane emission levels also indicate a strong dependency on assumptions regarding methane emission intensities for different supply regions. Note that here we only focus on methane pricing without a producer abatement response and hence do not, in this section, consider variations in the abatement assumptions or impacts which will by construction yield larger reductions and impacts on methane emissions.

Figure 29 shows the different emission intensity variations that are examined in relation to the BAU scenario and the methane pricing at 25 €/tCO_2eq without producer abatement response scenario, respectively. Green bars represent stronger declines in methane emissions in comparison to the BAU scenario and red bars represent the opposite. Lower and upper bound emission intensity variation in relation to the BAU results, lead to stronger declines, except in case of a sole change to a higher Russian methane emission intensity. In contrast, variations in comparison to the CH_4 Pricing without Producer Abatement Response scenario show more mixed results. A singular lower emission intensity in Russia or Algeria as well as coexisting higher emission intensity for Algeria and lower for Russia, result in less methane emissions compared to the methane pricing without producer abatement response scenario. In this case, central baseline emission intensities are assumed for all countries including for Algeria and Russia.

Figure 29: Variations in EU Suppy Emissions; changing the assumed methane emission Intensities for Russia (RU) and Algeria (DZ) while keeping the rest on central baseline estimates (low = lower bound estimates; high = upper bound estimates); left panel shows results compared to the BAU scenario and the right panel results compared to methane pricing at 25 €/tCO_2eq without producer abatement response scenario with central baseline emission intensities assumed for all countries including Algeria and Russia

A sole increase or decrease of emission intensity assumptions for Russia leads to 5% higher and 67% lower methane emissions, respectively compared to the BAU scenario based on central baseline emission intensities as seen in the left panel of Figure 29. In relation to methane pricing at central baseline estimates, EU's methane footprint is 27% higher and 60% lower, respectively, as seen in the right panel of Figure 29. The upper bound methane emission intensity for Russia and lower bound for Algeria result in a 12% decline in EU methane footprint emissions under the methane pricing without producer abatement response at 25 €/tCO_2eq compared to the BAU. As seen in the right panel, this corresponds to an increase of 6% compared to methane pricing without producer abatement response based on central baseline emission intensity estimates for all countries. If baseline emission assumptions for the two countries are inverted, EU methane footprint emissions decline by 66% compared to the BAU scenario and decline by 59% compared to methane pricing without producer abatement response based on central baseline emission intensity estimates for all countries.

Conclusion

- Varying the assumptions regarding methane emission intensities for Russia and Algeria strongly affects the modeling results, thus results based on assuming the central baseline methane emission intensity estimates from Table 1 should be taken as illustrative examples of the directional effects of methane pricing.
- This finding is intuitive and does not change the assessment that a unilateral EU methane price, even without a producer abatement response, can have an impact on the EU's methane footprint but does not impact net export countries significantly because they, according to our modeling, can divert their export volumes to other markets than the EU.

8 Bibliography

Alvarez, R. A., Zavala-Araiza, D., Lyon, D. R., Allen, D. T., Barkley, Z. R., Brandt, A. R., … Hamburg, S. P. (2018). *Assessment of methane emissions from the US oil and gas supply chain*. Science, 361(6398), pp.186-188.

bp. (2020a). *Energy Outlook 2020.*

bp. (2020b). *Statistical Review of World Energy 2020.*

EC - European Commission. (2020a). *EU 2030 Climate Target Plan Impact Assessment.*

EC - European Commission. (2020b). *EU Strategy to Reduce Methane Emissions.*

EC - European Commission. (2020c). *Quarterly Report on European Gas Markets.*

Eurostat & EEA - European Environment Agency. (2020). *Greenhouse gas emissions by source sector (ENV_AIR_GGE)*. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/env_air_gge/default/table?lang=en

Eurostat. (2020a). *Supply of gas - monthly data (NRG_103m)*. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_103m/default/table?lang=en

Eurostat. (2020b). *Imports - gas - monthly data (NRG_124M)*. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_124m/default/table?lang=en

Eurostat. (2020c). *Gas prices for household consumers (NRG_PC_202)*. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_202/default/table

Eurostat. (2020d). *Gas prices for non-household consumers (NRG_PC_203)*. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_203/default/table

Hmiel, B., Petrenko, V. V., Dyonisius, M. N., Buizert, C., Smith, A. M., Place, P. F., … Dlugokencky, E. (2020). *Preindustrial 14CH4 indicates greater anthropogenic fossil CH4 emissions*. Nature, 578(7795), 409–412.

IEA - International Energy Agency. (2020a). *Methane Tracker*. Retrieved from https://www.iea.org/reports/methane-tracker-2020

IEA - International Energy Agency. (2020b). *World Energy Outlook 2020.*

IPCC. (2013). *Climate Change 2013: The Physical Science Basis.*

Marks, L. (2019). *The Abatement Cost of Methane Emissions from Natural Gas Production.*

MEACP - Ministry of Economic Affairs and Climate Policy. (2019). *Natural resources and Geothermal energy in the Netherlands 2019.*

Norwegian Petroleum. (2020). *Emissions to Air*. Retrieved from https://www.norskpetroleum.no/en/environment-and-technology/emissions-to-air/

Saunois, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B., … *Zhuang, Q. (2020). The Global Methane Budget 2000–2017.* Earth System Science Data, 12(3), 1561–1623.

Schwietzke, S., Sherwood, O. A., Bruhwiler, L. M. P., Miller, J. B., Etiope, G., Dlugokencky, E. J., … Tans, P. P. (2016). *Upward revision of global fossil fuel methane emissions based on isotope database*. Nature, 538(7623), 88–91.

UBA - German Federal Environment Agency. (2020). *Methodenkonvention 3.1 zur Ermittlung von Umweltkosten - Kostensätze.*

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