European Commission

Environmental and Sustainability Assessment of Current and Prospective Status of Coal Mine Methane Production and Use in the European Union

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Abstract

The study provides an analysis of the coalmine methane (CMM) status and prospects (up to 2030) in the EU from the sustainability point of view, i.e. economic, environmental and social implications.
The study demonstrates the considerable potential for alternative price and regulatory drivers to encourage coal mine methane project developments. This is clear across the three scenarios considered (i.e., the existing market price scenario, the augmented price scenario, and a scenario that imposes a requirement for methane use/abatement to the extent that is technically feasible) as applied in this analysis to the three subject countries of Germany, Poland and the United Kingdom.
The most significant potential impact that CMM industrial development brings is the mitigation of greenhouse gas emissions, which occurs under all three scenarios. The costs of reducing greenhouse gas emissions through policies to promote coal mine methane projects is also very favourable.
The use of CMM will also provide some enhanced domestic supply of an energy resource. Although CMM should not be viewed as a critical strategic energy resource to the EU as a whole, as its maximum expected input into the European grid systems of gas and electricity would be small compared to the overall respective market sizes and would have very small impacts on energy prices, the analysis in this study shows that full use of existing and future CMM resources can contribute considerably to the energy mix of the local regions.

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NOTE TO THE READER

The overall goal of this study is to support the Joint Research Centre (JRC) of the European Commission in assessing the environmental impacts and sustainability of energy resources in the EU. In particular, it provides an analysis of the coalmine methane (CMM) status and prospects (up to 2030) from the sustainability point of view, i.e. economic, environmental and social implications. The study has been produced by Mr. Karl H. Schultz, www.climate-mitigation.com and Mr. Linus M. Adler, www.energy-edge.net, as external contractors and hence, it does not represent any formal position of the European Commission. The study was finalised in December 2014.

The study begins by outlining the set of methodologies developed to obtain, manage and calibrate quantitative data and also the approach to a qualitative analysis of these data and overall trends in the technical, economic, and environmental situation of CMM resource development and its economic, social, and environmental impact. The study uses separate analyses of three different scenarios of alternative incentives for the encouragement of CMM resource development as the basis for understanding how the resource could be treated, and the impacts, going forward.

Following this, the study considers the socio-economic implications of each scenario based upon stated assumptions regarding technology choice and market pricing structure. It analyses potential technology uptake for the alternative scenarios in terms of additional gas input and production. These then form the basis for an understanding of potential revenues, job creation, and energy supply implications of each scenario. The report analyses the marginal costs in Euros/tonne of carbon dioxide equivalent of abating greenhouse gas emissions. Macroeconomic energy price impacts are considered in a short section. What follows is a discussion of barriers to project uptake: namely, why experience in different countries indicates that purely economic drivers of CMM resource development often are insufficient for all viable potential to be undertaken. The study then considers some of the means of overcoming these barriers to resource development.

The following section details the environmental implications of the alternative scenarios, including greenhouse gas emissions and local environmental impacts (particularly local air quality).

Finally, the study concludes with some remarks on how the analyses could be useful in policy formulation, without making any suggestions as to what specific policies would be appropriate.

We would like to thank the following experts for their assistance and support in developing this study:

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EXECUTIVE SUMMARY

Methane (CH_4) is a gas formed as part of the process of coal formation – coalification. Two main categories of such coal seam gas are identified. Coal Bed Methane (CBM) is recovered from un-mined (virgin) coal seams. Coal Mine Methane (CMM) is recovered during mining activities as the coal is in the process of being extracted and thus emitting significant quantities of the gas. Besides these two main categories, Abandoned Mine Methane (AMM) is sometimes distinguished as well. AMM represents CMM, which is recovered from mines that have been abandoned following the completion of mining operations. Significant amounts of methane may remain trapped in the mine or may continue to be emitted from openings.[1]

Coal mine methane (CMM), in particular, constitutes a safety hazard and nuisance in underground mines, a source of powerful greenhouse gas (GHG) emissions, but also a potential resource for generating heat and power, as well as revenue from the sale of electricity and gas, and an opportunity to reduce GHG emissions at a lower marginal cost than many less mature technologies such as carbon capture and storage.

This study provides an analysis of the coalmine methane status and prospects (up to 2030) in the EU from the sustainability point of view, i.e. economic, environmental and social implications. It examines in particular CMM resources, usage and issues for the United Kingdom, Germany and Poland, and expands the analysis to provide a general assessment of EU-wide resource and use potential, and how these may impact energy supply, revenues, local environmental and social (i.e. job creation) impacts, and the contribution of CMM to reducing greenhouse gas emissions.

In each country, the hard coal mining industry is in a state of transition. As this study was commencing, UK Coal announced that it would be closing its two remaining deep mines, after which the employee-owned Hatfield Colliery would be the sole remaining underground mine in the UK. In Germany, the sole major operator of deep mines will be closing its three remaining underground properties by 2018, and at about the same time EU subsidization of the Polish coal industry is scheduled to end, leading to the likely shuttering of some properties in Poland.

The social impacts of a transitioning mining industry are reflected in higher than average unemployment rates in each of the mining regions studied.

Methane is a greenhouse gas, meaning that its presence in the atmosphere affects the earth's temperature and climate system. Methane is the second largest contributor after carbon dioxide to future warming of the earth and 34 times more potent over a 100-year time frame.[2] And while combusting methane produces CO_2, the net benefit of burning the gas – even if it is just flared, but not captured and then used – compared to venting methane is significant from a global warming perspective.

[1] Adapted from World Coal Association

[2] International Panel on Climate Change (2013) Fifth Assessment Report, p 714: the 100-year global warming potential (GWP) of methane is revised upward in IPCC 5AR from its previous value of 21.

Globally CMM emissions amounted to 589 million tonnes of CO_2 equivalent (CO_2e) in 2010, with emissions expected to increase to 784 million by 2030.[3] In the EU, CMM contributed to 38 million tonnes of CO_2e emissions in 2010. Underground coal mining in the EU is in steep decline owing to coal market factors, including the introduction of the EU's Industrial Emissions Directive, that are reducing coal demand and supply requirements from the EU coal sector. One result of this decline is that CMM emissions are expected to decline to 30 million tonnes of CO_2e by 2020 and further down to 28.5 million tonnes of CO_2e by 2030.

	Estimated annual CMM emissions by country in Mcm (top rows) and t CO_2e (bottom rows)		
	2010	2020	2030
Spain	27	9	5
	624,459	214,525	115,971
Romania	119	118	118
	2,747,216	2,716,076	2,714,000
Poland	794	785	785
	18,262,000	18,055,000	18,055,000
Italy	2	2	2
	35,075	34,678	34,500
Germany	294	101	55
	6,762,000	2,323,000	1,255,800
France	4	3	1
	89,006	75,051	17,311
Czech Republic	205	202	202
	4,709,600	4,656,207	4,646,000
Bulgaria	41	40	40
	932,634	922,063	922,300
UK	199	46	34
	4,577,000	1,055,700	782,000
Total	1,684	1,307	1,241
	38,738,991	30,052,310	28,542,882

Yet methane combustion also has negative environmental impacts. Aside from CO_2, the primary gaseous products of gas combustion and flaring are nitrogen oxides (NO_x). However, these emissions have to be considered in light of the alternative to using methane for energy use; in mining regions this is likely to be coal combustion, a fuel source that generally produces higher NO_x emissions and also produces at varying levels emissions of sulphur dioxide (SO_2), which is the primary cause of acid rain, as well as other pollutants such as mercury (Hg).

To date, the markets for the vast majority of coal mine methane employ standard, commercially available natural gas use technologies. In the EU the most common market is on-site power generation. Gas flaring is the lowest-cost technically feasible

[3] US EPA (2014) Global Mitigation of Non-CO_2 Gases 2010-2030: Executive Summary.

approach to reducing coal mine methane emissions from any drained gas that does not find an economic market.

The EU's Climate and Energy Package, enacted by the European Parliament and Council in 2009, sets policies for reducing greenhouse gas emissions by 20% in 2020 from a 1990 baseline. While it is an important tool for emissions reduction, the Emissions Trading System (ETS) does not currently cover coal mine methane and there are no other EU-wide regulations limiting coal mine methane emissions.

However, there are a number of EU initiatives and nationally mandated legislation that have been employed to reduce CMM emissions. In Germany, CMM (that is, gas liberated by mining activities only) is treated like a renewable resource and is eligible for a feed-in tariff (FiT) when used to generate electricity. In the UK, legislation has provided tax breaks for CMM projects, and during the UK Emissions Trading Scheme, incentives were offered for CMM projects, including flaring projects.

The study looked at three alternative scenarios for how the CMM resource may be developed up to 2030, considering economic costs and benefits, social benefits, particularly job creation, and environmental impacts, with a focus on greenhouse gas abatement.

The most significant potential impact that CMM industrial development brings is the mitigation of greenhouse gas emissions, which occurs under all three scenarios. While baseline emissions are expected to decline by 2030 owing to coal production decline, promotion of economically feasible projects without any price or regulatory incentive will still result in direct additional emissions abatement of 4.3 Mt CO_2e; a further policy imposed price signal may improve this to 11.4 Mt CO_2e, and all technically feasible abatement results in 14.3 Mt CO_2e in direct annual emission reductions by 2030. Calculations based on the per-unit economics of CMM use for various countries and regions assessed in this study reveal a wide spread of discounted marginal costs over the period 2015-2030.

While not of major impact on the national or EU-wide scale, promotion of CMM projects could result in considerable net revenues (up to 228 million Euros) and a direct job creation potential (associated with the entire project period) of between 2,300 and 6,670 for the mining regions of the EU as a whole (while indirect job creation could be higher by a factor of more than two). While from an EU scale these figures are modest, the potential for at least transitional job-creation from a regional development perspective is important, in particular considering the impact of further mine closures on regions already facing high unemployment rates.

Tax receipts would be enhanced and project developers could realize considerable revenues while projects remained viable. Local environmental impacts may include some marginal improvement in air quality in regions facing generally moderate to poor air quality with, in most likely scenarios, minimal impacts on land and water use.

The use of CMM will also provide some enhanced domestic supply of energy resource. While CMM should not be viewed as a critical EU-scale strategic energy resource, on the regional scale it can play an important contribution to energy resources while mining activities continue and for several decades or more following mine closure.

Realising these benefits requires relatively low investment levels. Even the most aggressive, technically feasible scenario estimates additional EU-wide capital costs of only EUR 78 million in 2020 declining to EUR 29 million in 2030.

However, the study also notes that experience around the world has shown that not all coal mine methane project opportunities that are economically viable will result in projects. As such, it is important to consider the barriers to economic development of projects and measures that have been successful to overcome these. The study highlights a variety of informational, legal, market and financing barriers and suggests that these may be overcome through policies and measures that provide unbiased information and analysis services, further research, development, and demonstration (including significant efforts to disseminate the findings), all of which can play an important role in encouraging increasingly effective coal mine methane projects. Energy and resource and regional development policies can play an important role in clarifying rights and market value in the use of CMM. Appropriate financial mechanisms (e.g. identification or even designation of specific funds, loan guarantees, and encouragement of an investment community and project development industry) may reduce market uncertainties and address barriers such as a lack of project finance.[4]

[4] It is important to note that such policies focus on CMM; that is, only promoting the recovery and use of gas resulting from mining activities, as the EU is committed to phasing out subsidies for fossil fuel production.

A. SETTING UP THE SCENE

Methane (CH_4) is a gas formed as part of the process of coal formation – coalification. Two main categories of such coal seam gas are identified. Coal Bed Methane (CBM) is recovered from un-mined (virgin) coal seams. Coal Mine Methane (CMM) is recovered during mining activities as the coal is in the process of being extracted and thus emitting significant quantities of the gas. Besides these two main categories, Abandoned Mine Methane (AMM) is sometimes distinguished as well. AMM represents CMM, which is recovered from mines that have been abandoned following the completion of mining operations. Significant amounts of methane may remain trapped in the mine or may continue to be emitted from openings.[5]

For many years, CMM was viewed in an unfavourable light. The mining industry considered it a nuisance and safety hazard that threatened lives, equipment and operations while inhibiting mine productivity. For natural gas exploration and production, CMM represented a resource that was difficult and expensive to produce. In a number of countries, the gas resource base is high but the low permeability and unique gas reservoir characteristics typical of many coal seams add a level of complexity that has not been cost-effective to overcome.

Even with these inherent difficulties, efforts to capture CMM began as early as the late 1700s when a British scientist drove a metal pipe into a coal seam and produced methane for use in his laboratory. This "well" is considered by some to be the birth of the modern industry. By the early 1900's several European countries were beginning to capture methane from coal mines. By the 1950's and 1960's coal mine methane recovery had begun in other countries. Today in many countries CMM is a significant resource for a host of uses such as gas pipeline injection, boiler fueling and electricity generation.

Technological advances, favourable government policies, concern over climate change, increasing fuel prices, and improved technology transfer and cooperation have all served to increase recovery of this valuable resource. No longer viewed as an annoyance or a cost-prohibitive resource, CMM is now thought of as economically viable source of energy that generates revenues or cost savings. Beyond project-specific economic benefits, CMM production yields other important benefits, ranging from reductions in greenhouse gas emissions to improved mine safety to enhanced mine productivity. For mining regions, CMM's recovery and use provide the basis for important economic and social development, further extending the benefits.

CMM IN THE EU

Globally CMM emissions amounted to 589 million tonnes of CO_2 equivalent (CO_2e) in 2010, with emissions expected to increase to 784 million by 2030.[6] CMM

[5] Adapted from World Coal Association

[6] US EPA (2014). Global Mitigation of Non-CO_2 Gases 2010-2030: Executive Summary.

represents about five percent of methane emissions in the EU, at 38 million tonnes of CO_2e in 2010. Underground coal mining in the EU is in steep decline owing to coal market factors, including the introduction of the EU's Industrial Emissions Directive, which is reducing coal demand and supply requirements from the EU coal sector. One result of this is that CMM emissions are expected to decline by 26% to 28 million tonnes of CO_2e by 2030, with the most of the decline occurring by 2020 – Table 1.

	Estimated annual CMM emissions by country in Mcm (top rows) and t CO_2e (bottom rows)		
	2010	2020	2030
Spain	27	9	5
	624,459	214,525	115,971
Romania	119	118	118
	2,747,216	2,716,076	2,714,000
Poland	794	785	785
	18,262,000	18,055,000	18,055,000
Italy	2	2	2
	35,075	34,678	34,500
Germany	294	101	55
	6,762,000	2,323,000	1,255,800
France	4	3	1
	89,006	75,051	17,311
Czech Republic	205	202	202
	4,709,600	4,656,207	4,646,000
Bulgaria	41	40	40
	932,634	922,063	922,300
UK	199	46	34
	4,577,000	1,055,700	782,000
EU Total	1,684	1,307	1,241
	38,738,991	30,052,310	28,542,882

Table 1 – Estimated and Projected CMM Emissions

The decline of coal demand is also causing a number of expected mine closures. However, abandoned coal mines continue to emit methane, often for considerable periods, following abandonment.

METHANE AND THE ENVIRONMENT

Methane is a greenhouse gas, meaning that its presence in the atmosphere affects the earth's temperature and climate system. Methane's chemically active properties have indirect impacts on global warming, as the gas enters into chemical reactions in the atmosphere that not only affect the period of time methane stays in the atmosphere (i.e., its lifetime) but also play a role in determining the atmospheric concentrations of tropospheric ozone and stratospheric water vapour, both of which are also greenhouse gases. These indirect and direct effects make methane a large contributor, second only to carbon dioxide (CO_2), to potential future warming of the earth and 34 times more potent over a 100-year time frame[7]. And while combusting methane produces CO_2, the net benefit of burning the gas – even if it is just flared, but not captured and then used – compared to venting methane is significant from a global warming perspective. Methane also contributes to tropospheric ozone problems and harms vegetation at high concentrations. Hence capturing and using or, if not technically and economically feasible, flaring coal mine methane may also alleviate local air quality problems.

However, methane combustion also has negative environmental impacts. Aside from CO_2, the primary gaseous products of gas combustion and flaring are nitrogen oxides (NO_x). NO_x, which in methane consumption can be formed from reactions between atmospheric nitrogen and oxygen at a high temperature flame front, are a pollutant that can cause regional air quality diminishment (with associated health effects) and, at a larger scale, contribute to acid rain. However, these emissions have to be considered in light of the alternative to using methane for energy use; in mining regions this is likely to be coal combustion, a fuel source that generally produces higher NO_x emission and also produces at varying levels emissions of sulphur dioxide (SO_2), the primary cause of acid rain, as well as other pollutants such as mercury (Hg).

CONVENTIONAL MARKETS FOR COAL MINE METHANE

To date, the markets for the vast majority of coal mine methane employ standard, commercially available natural gas use technologies. In the EU the most common market is on-site power generation using small scale (e.g., approximately 1 MW electric capacity) reciprocating engines. In other countries, natural gas pipeline injection (U.S.) and local heating and industrial demand (China) are the primary markets for coal mine methane. Almost all gas that has found a market comes from gas drainage systems and typically has at least 30% methane concentration.

Until recently, because of the very low concentration (typically below one percent) of methane in ventilation air, coal operators had no technically proven option to recover this gas for its energy value. However, over the past two decades technologies have been developed, adapted and deployed that offer the promise of mitigating most of these emissions at low cost. Perhaps the most promising group of technologies available utilise catalytic and thermal flow reversal reactions of ventilation air methane. These technologies may use up to 100 percent of all the methane from ventilation shafts, and the by-product, heat, may be used for the production of power or to satisfy local heating needs. In the EU, however, as ventilation is only undertaken in operating underground mines, the numbers of which are dwindling in the EU, there is limited potential for the use of such ventilation air methane methods.

Gas flaring is the lowest-cost technically feasible approach to reducing coal mine methane emissions from any drained gas that does not find an economic market. Flaring is standard practice in many industries worldwide for environmental, health

[7] IPCC (2013), 5th Assessment Report, P. 714.

and safety reasons. In contrast, in the coal mining industry, methane recovered from underground mines which is not utilized is typically vented directly to the atmosphere. Coal mines primarily vent gob gas, a gas of variable methane quality and quantity that is sometimes difficult or uneconomic to utilize. However, a number of projects developed in the last decade illustrate that mine operators can safely practice controlled gob gas flaring to benefit mining and the global environment.

Although it is preferable from both environmental and energy conservation perspectives to put coal mine methane to economic use, it is much better for the global environment to flare gas than to vent it to the atmosphere. As discussed above, the global warming potential of methane is approximately 34 times that of CO_2 (over a 100-year time frame), combusting methane released from mines by controlled flaring would result in emission of a significantly less harmful gas. Methane also contributes to tropospheric ozone problems and harms vegetation at high concentrations. Hence, flaring coal mine methane may also alleviate local air quality problems.

POLICIES IN THE EU

The EU's Climate and Energy Package, enacted by the European Parliament and Council in 2009, sets policies for reducing greenhouse gas emissions by 20% in 2020 from a 1990 baseline. While it is an important tool for emissions reduction, the Emissions Trading System (ETS) does not currently cover coal mine methane and there are no other EU-wide regulations limiting coal mine methane emissions. However, there are a number of EU initiatives and nationally mandated legislation that have been employed to reduce CMM emissions.

In particular, environmental impact assessments for coal mining operations require mitigation of methane emissions. The EU Directives and Regulations on Health and Safety are the main regulatory framework to reduce methane emissions. The EU has funded a number of research, development, and demonstration projects to introduce improved tools for methane emissions control, including the Coal Mine Methane New Solutions for Use of CMM-reduction of GHG Emissions (COMETH) and Low Carbon Mine Site Energy (LOCARB) initiatives, yet it remains that no EU legislation penalizes emitters of CMM.[8]

However, in Germany CMM is treated like a renewable resource and is eligible for feed-in-tariffs when used to generate electricity. In the UK, legislation has provided tax breaks for CMM projects and during the UK Emissions Trading Scheme (now subsumed by the EU Scheme), CMM was offered incentives for CMM projects, including flaring projects.

Reflecting the social impact of mine closures, a number of programmes have been adopted to encourage regional redevelopment and employment opportunities, such as the EU's LEADER programme to provide grants for developing tourism activity based on mining heritage.

[8] Global Methane Initiative (2013). European Commission Global Methane Reduction Actions, Ref. Ares (2013)2843722-06/08/2013.

PAPER GOALS AND OUTLINE

The overall goal of this study is to support the Joint Research Centre (JRC) of the European Commission in assessing the environmental impacts and sustainability of energy resources in the EU. In particular, it provides an analysis of the CMM status and prospects (up to 2030) in the EU from the sustainability point of view, i.e. economic, environmental and social implications.

The study begins by outlining the set of methodologies developed to obtain, manage, and calibrate quantitative data and also the approach to a qualitative analysis of these data and overall trends in the technical, economic, and environmental situation of CMM resource development and its economic, social, and environmental impact. The study uses separate analysis of three different scenarios of alternative incentives for the encouragement of CMM resource development as the basis for understanding how the resource could be treated, and the impacts, going forward.

Following this, the study considers the socio-economic implications of each scenario based upon stated assumptions regarding technology choice and market pricing structure. It analyses potential technology uptake for the alternative scenarios in terms of additional gas input and production. These then form the basis for an understanding of potential revenues, job creation, and energy supply implications of each scenario. The report analyses the marginal costs in Euros/tonne of carbon dioxide equivalent of abating greenhouse gas emissions. Macroeconomic energy price impacts are considered in a short section. What follows is a discussion of project uptake: namely, why experience in different countries indicates that purely economic drivers of CMM resource development often are insufficient for all viable potential to be undertaken. The study then considers some of the means of overcoming these barriers to resource development.

The following section details the environmental implications of the alternative scenarios, including greenhouse gas emissions and local environmental impacts (particularly local air quality).

Finally, the study concludes with some remarks on how the analyses could be useful in policy formulation, without making any suggestions as to what specific policies would be appropriate.

DISCUSSION OF METHODS

In order to better understand the range of sensitivities for the economic and social implications of CMM use, we developed three scenarios that attempt to span the spectrum of potential market environments from lower to higher market / price / regulatory interventionism. The scenarios – entitled, respectively, *Market Driven Feasibility*, *Price Augmentation*, and *Technically Feasible* – are described below and developed further in Section C.

The model works at the mine level, e.g. by using series of gas/electricity and carbon price equivalents assumed for each of the years 2015, 2020, 2025 and 2030 and specific to each country in order to derive a solution as to how or whether a given mine will use available gas for that year. In the Market Driven (projected energy market prices) and Price Augmentation (where an extra price incentive, such as a subsidy, is added) scenarios, these decisions are based purely on a series of present value analyses as to whether a project could produce sufficient positive economic value to a developer over a projected period of years given current-year and expected revenues and standard fixed and operating costs. In the case of the Technically Feasible scenario, market factors support a portion of the outcome, but there is also an added fact that residual emissions must be used (e.g. through flaring) down to a threshold value. Technology costs are assumed to be constant across the three scenarios, so what differentiates outcomes among scenarios is ultimately market price drivers (e.g. electricity or gas hub prices or possibly a carbon price) as well as externally mandated incentives (price, penalty or other) in the case of the Technically Feasible Scenario. From this, the net methane use for each country by technology and net emissions for each year 2015, 2020, 2025 and 2030 can be calculated as the sums of these figures from all of a country's mines.

In addition to net profits for gas producers and/or project developers, the implementation of a project can have significant impacts on local or regional economies in terms of businesses served and jobs created as well as transfer income implications for the owners of the gas (in the case of the three countries studied here, this is the national government) in terms of royalties. Employment activities over time will vary; in general, more jobs will be created at the beginning, capital-intensive phases of a project, while the declining quantities of gas from abandoned mines will eventually lead to complete project shutdown, although the entire lifetime of this process could unfold over decades. In any event, CMM projects offer the prospect of transitional employment for workers with appropriate skill sets who are located within regions facing job loss owing to mine closures.

A discussion of the environmental and climate change aspects (both positive and negative) of CMM utilization is deferred to the section on the environmental impacts.

SCOPE OF STUDY

This study provides an analysis and summary of mine data gathered in the companion data compilation effort covering three of the historically and currently major coal producing countries in the European Union: the United Kingdom, Germany and Poland. Combined, these countries produce approximately 357 Mt of coal annually, of which approximately 107 Mt is hard (high calorific value subbituminous, bituminous or anthracite coal),[9] which in the subject countries is typically produced from underground mines. All three countries – particularly Germany and Poland – mine significant volumes of coal from opencast mines. However, as opencast mining generally produces lower specific emissions (varying from nearly zero in German surface mines to about 2.5 m^3 of gas per mined tonne of coal in Poland) and, more importantly, approaches to capture and use the gas are very limited, this type of mining will be disregarded here.

[9] EURACOAL Country Profiles (http://www.euracoal.org), 2012 Statistics.

In each country, the hard coal mining industry is in a state of transition. As this study was commencing, UK Coal announced that it would be closing its two remaining deep mines – Kellingley and Thoresby – in 2015, after which the employee-owned Hatfield Colliery would be the sole remaining underground mine. In Germany, the sole major operator of deep mines will be closing its three remaining underground properties by 2018, and at about the same time EU subsidization of the Polish coal industry will end, leading to the likely shuttering of some properties in Poland.

Using 2010 as a baseline year, an attempt to produce actual and projected statistics for the major relevant coal mining sites in each country has been made. In some cases, information on minor properties (small, independently operated legacy or "drift" mines) has not been available through desk research and is omitted; however, comparisons of the bottom-up results obtained here with available previous year national emissions inventories suggests that this report accounts for more than 80-90% percent of emissions in each country in the baseline year. In all, 56 active, abandoned, and closing mines in Poland, Germany and the UK have been assessed. As is discussed in further detail following, emissions from abandoned mines can remain significant for many years following closure, so these produce a considerable part of existing and anticipated inventories.

INVESTMENT DECISION FOR NEW BUILD

Although in textbook cases a decision among a "basket" of potential investments would be determined by whichever has the highest return in terms of potential (present) value or internal rate of return, in practice mine developers – like many investors – tend to be biased toward secure returns and habit (e.g. continuing an established course). Thus, while the relative business cases for various technologies are taken into account, other factors, such as existing usage and project development time (which, taking into account permitting requirements, can in some cases stretch to years) must also be taken into consideration in the build decision.

CMM USE AND ABATEMENT TECHNOLOGIES – IN BRIEF

ELECTRIC POWER GENERATION

Although in the EU most natural gas-generated energy is produced in large scale (e.g. above 200 MW) open or combined cycle turbine power plants operated by major utilities, such facilities require large scale operational and capital expenditures as well as long planning times. As mentioned above, all known mine gas-sourced electricity in the EU is generated using small (1-8 MW electric power capacity) modular reciprocating gas engines, which can be installed quickly and on-site, and added to as needed in order to flexibly adjust operational size.

In the modelling used in this study, the basic unit of gas generator was assumed to be a 1.4 MW reciprocating engine with 40-47% heat-electricity conversion efficiency based on a unit type commonly used in all three countries within the scope of this report.

FLARING

Flaring of vented or drained mine gas is a fairly recent practice and is generally done to earn carbon credits through the destruction of high-global warming potential methane. In the UK, flares – which have since been decommissioned – were installed at several mines in the mid-2000s in order to combust excess gas produced by the drainage systems. Largely owing to the collapse of the EU Emissions Trading Scheme carbon price following the 2009 financial downturn, most CMM flaring projects in Europe are currently mothballed. In addition, several projects for earning credits through flaring in Poland were registered under the UN's Joint Implementation scheme prior to 2008. Since then, Joint Implementation's Emission Reduction Units are not awarded for CMM projects in the EU.

Flaring is generally cheaper in terms of capital and operational expenditure than other CMM technologies; under the business-as-usual scenarios developed, however, the study assumes no price signal for flaring, and thus, gas engines are preferentially installed. However, in scenarios, in which there are market or mandatory incentives to take up more marginal increments of gas, flaring becomes much more important.

OTHER GAS USES

VENTILATION AIR METHANE

As discussed above, the use of catalytic and thermal flow reversal engines to utilize extremely low concentration ventilation air methane (VAM) has become possible in recent decades. However, such systems remain relatively expensive (with capital costs about fifteen times higher per cubic meter of air treated than flaring) and difficult to operate, still requiring a minimum methane concentration (i.e. around 0.2% methane in air) to maintain operations. As such, VAM use does not play more than a marginal role in the modelling accompanying this study.

HEAT GENERATION

Another significant use of mine gas is the generation of boiler heat through the direct combustion of methane. Although this is occasionally used to feed district heat systems, more often the mines will use it for cogeneration purposes within their own workings. Owing to the localized nature of this energy resource, it is not generally included within the scope of the economic calculations but known facilities are accounted for within the gas usage balances.

PIPELINE INJECTION

Although it is possible to supply a general gas delivery system with CMM, in most cases the expenses involved with connection to the national grid and upgrading to pipeline quality (gas cleaning and flow maintenance) render this practice prohibitively expensive in general within the EU. Connection pipeline is expensive to build and site and the large (above 5 km) distance of all of the sites examined here from major gas trunk lines makes such uses unlikely and, as a result, the introduction of gas into overall EU flows does not play a role in the scenario analysis here.

INDUSTRIAL USES

In some cases, captured mine methane is used as chemical or industrial feedstock e.g. as a precursor to methyl-containing chemicals or in the production of steel. Once again, the viability of this use is limited by proximity and the expense of building and maintaining pipeline.

MINE GAS SUPPLY

For each mine, unique physical factors – including inherent coal properties such as gas content and permeability, location and depth of seams, and overall deposits – and operational parameters such as mining history and technique, current and planned utilization, and venting characteristics determine the amount of gas emitted. Although physical models based on chemical and morphological principles can be used to determine emissions, these require a depth of data and analysis outside of the present scope.

The emissions from an underground mine can be fairly well localized to either the mine's ventilation shafts (often the same as the mine mouth or entrance) or to specific drainage shafts. In the absence of specific location data from the mine, most of the emissions in the accompanying dataset are localized by identification of the "head" or "frameset" marking the main entrance, which is generally visible from satellite photographs. Typically, drainage locations depend on seam location can be offset somewhat (within a few kilometers) from the main shafts.

UNFCCC TIER METHODOLOGY

In the absence of direct measurement from the mines, which are outside the scope of this study, emissions are determined at three basic levels of accuracy based on an estimation methodology developed by the United Nations Framework Convention on Climate Change (UNFCCC).[10]

Generally speaking, the UNFCCC's methodology is based on determining or obtaining a ratio, called the specific emissions, between the annual emissions of a mine, group of mines, or even sets of mines in a broad basin and the amount of coal mined per year. Given that the emissions from a quantity of coal are generally tied to physical coal qualities, it is often reasonable to assume that, if coal production and CMM emissions can be determined for a given year, the resulting specific emissions ratio will stay relatively constant over time (to a degree of certainty that declines with scope of the measurement, e.g. from seam to mine to basin to country to worldwide figures). The UNFCCC Tier system is defined as follows:

[10] Intergovernmental Panel on Climate Change (2006). Annex A White Paper: Proposed Methodology For Estimating Emission Inventories From Abandoned Coal Mines.

- Tier I: this method, which is least robust, uses global emission factors (specific to general ranks of coal or even coal in general) and uses rough estimates of past mining activity based on model productivity curves;
- Tier II: uses country or basin emission factors specific to the type of coal mined and to country or basin-specific activity factors; and,
- Tier III: uses mine-specific information and measurements to arrive at emission factors; in this study, exceptional cases where directly measured mine emissions data are available are classified as "Tier III."

ABANDONED MINE METHANE

The mechanics of mine emission change abruptly once a mine is closed (abandoned), although the specifics vary as to whether the closed mine is ventilated for a period following closure, whether disused drainage or ventilation shafts are sealed, when and how quickly the abandoned mine floods and, if flooded, what the pumping costs would be, among other factors. [11]

In most cases, it is possible to treat the emissions of an abandoned mine over time as a hyperbolic decline curve (Figure 1) in which there is a rapid decline in the first few post-closure years followed by relatively constant annual emissions at low levels (at about 5-10% of maximum emissions within a decade of closure) thereafter until the mine floods through groundwater intrusion.

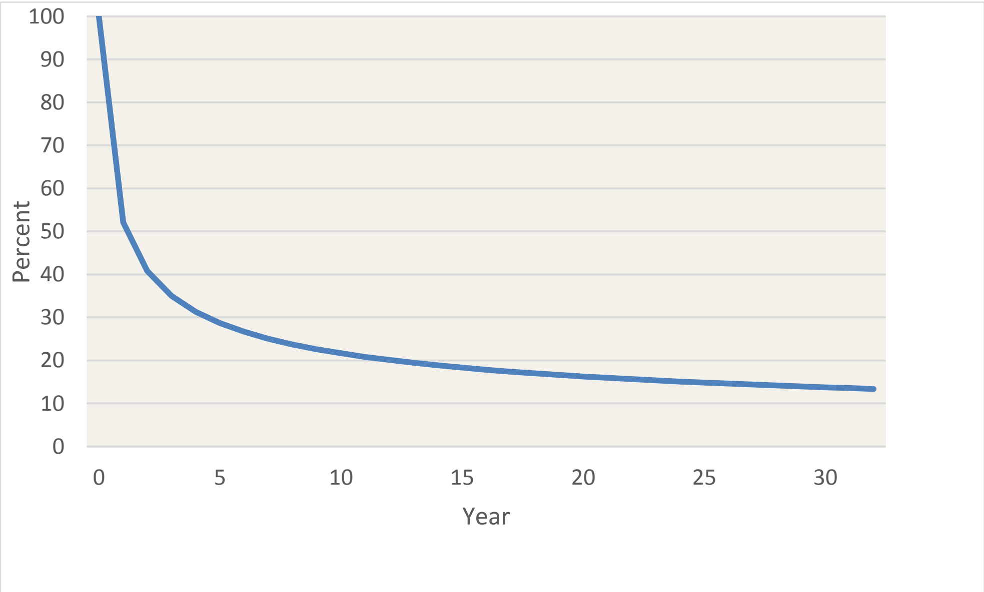

Figure 1 – Dimensionless Indicative Abandoned Mine Methane (AMM) Decline Curve[12]

[11] For Further Information, Refer To The World Coal Association Website: Abandoned Mine Methane Recovery And Utilisation: Http://Www.Worldcoal.Org/Coal/Coal-Seam-Methane/Abandoned-Mine-Methane/

[12] Adapted From Intergovernmental Panel On Climate Change (2006). Annex A White Paper: Proposed Methodology For Estimating Emission Inventories From Abandoned Coal Mines.

ECONOMICS

The net present value (NPV) of generation of electricity using a 1.4 MW gas engine is indicatively assessed in Figure 2 as a function of electricity price adjusted to kilowatt-hour equivalent gas volume. Although flaring can be performed to earn carbon credits, the lack of a significant EU Emissions Trading Scheme since 2008 has resulted in the shutting down of several flaring projects (although several others operating under the UN's Joint Implementation scheme have been registered), while electricity sales based on modular engine generation remain the dominant mode of use.

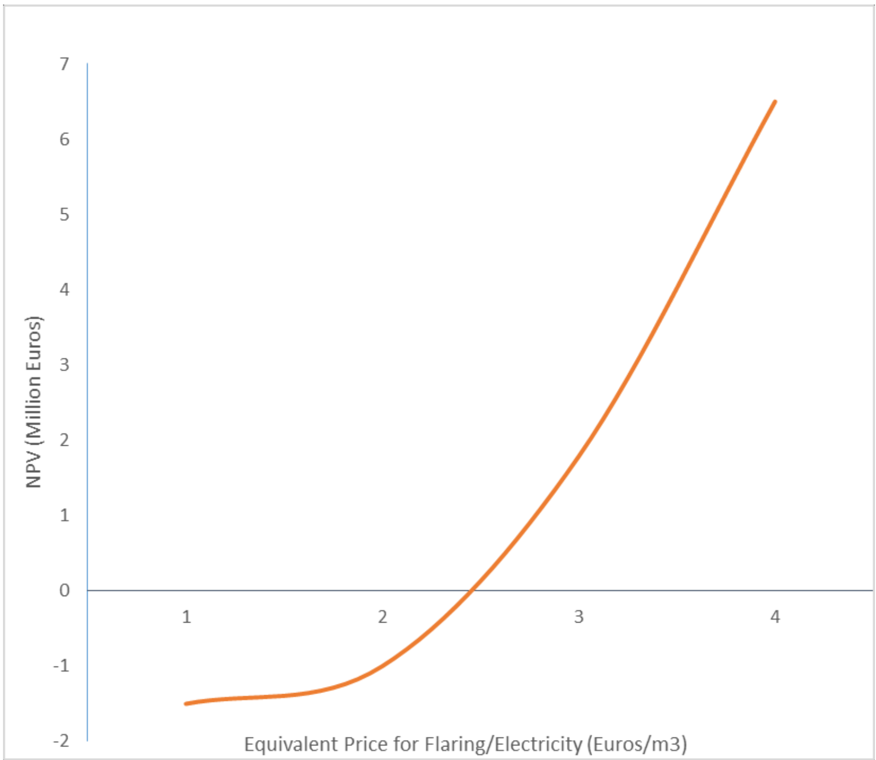

Figure 2 – NPV of gas generation at gas volume-adjusted price points

GENERAL ECONOMIC AND SOCIAL EFFECTS

It is important to assess the economic and social effects accruing at local, regional and national / EU levels that are associated with CMM use. These can be divided into two primary effects – specific local and regional economic impacts, and the potential larger scale impacts of fuel switching.

Environmental and climate implications of CMM production are addressed in further detail in Section C.

The study looks at mines sited in a wide number of locales associated with varying economic and social settings. However, coal mining communities in the EU generally face common challenges and advantages. These include:

- Economic and social stress owing to mine closure;

- Air, water, and land degradation owing to generally long-standing mine and associated industrial activities;
- Mining activities, however, have typically endowed such sites with an infrastructural legacy and a populace with applicable skillsets. Where mines are collocated with specific communities, such locales can be especially hard hit when production is cut or the mine is closed, but can also benefit from the presence of cheap proximate energy resources;

The production of coal mine methane requires significant input of capital and infrastructure, the provision of which can provide local and regional income in the form of jobs and capital/equipment rentals as well as income to gas resource owners (in Europe, this is generally the central governments) from royalties. It is difficult to accurately assess the magnitude of a specific employment stimulus, as this scales by the size and duration of the project, and varies depending on compensation factors associated with various skillsets employed. It should be noted that these directly created jobs would likely be highly paid primary jobs with economic spinoff potential.[13] The additional economic activity generated in this manner could have direct and significant positive impacts on localities and regions that, as a rule, continue to be adversely affected by the effects of mine closure.

As the range of salaries associated with gas production is wide, with top-line managers and highly skilled engineers potentially earning about twice what a roughneck or field earner would, no attempt will be made to quantify additional CMM-based income in this study; however, existing figures suggest that the mean salary in natural gas production can be as much as twice the provincial or national salary average.[14]

Considering the relatively high unemployment rates in mining regions, these jobs could contribute towards mitigating the social impacts of further mine closures. The net local income effects of CMM production can generally be positive in communities transiting away from coal production, as CMM activities can leverage highly paid employment based on many of the skillsets available in a well-trained mining workforce.

As discussed in Section C, changes in land use are often minimal, which reduces the conflicts in the form of lost jobs in other sectors such as agriculture. In addition, some of the organizational and technological skill sets needed for CMM production are often similar to those needed to run a mining operation, which aids in sourcing new or continued employment from the existing community.

FUEL SWITCHING

If gas producing mines have proper access to pipeline systems or local power generating plants or units, CMM-generated electricity can be integrated into regional or national power grids. As security of supply and cost containment are primary

[13] It has been estimated, for example, that each directly created CMM job could generate 2–3.2 jobs indirectly in various us regions (See US EPA (1994) The Environmental And Economic Benefits Of Coalbed Methane In The Appalachian Region, P. 19).

[14] See, for example SHALENET (2013). A Guide to Careers in the Oil and Natural Gas Industry.

pillars of EU energy policy and, particularly in the case of natural gas, the development of sufficient additional indigenous resources can reduce the need for imports and wholesale gas and electricity prices.

Nevertheless, it is important not to overstate the likely magnitude of this supply enhancement effect given the scope of the current study. For instance, although CMM is widely fed into pipeline networks in parts of the United States, this may represent an exceptional case owing to high mine mouth gas concentrations and quality and significantly higher quantities than are possible in the EU. Generally speaking, pipeline transport is dependent on the cleaning of associated gases (such as nitrogen oxides and carbon dioxide) from produced gas flows and the assurance of a steady supply of gas. In addition, proximity to existing pipeline networks is important to avoid excess capital expenditure on connecting pipeline build.[15] Finally, generally agreed upon mine methane production figures, as corroborated by the mine inventory exercise associated with this study, confirm that even total input of EU CMM emissions into the continental network would represent a marginal fraction of overall annual flow and thus contribute a negligible shift to hub price points (this point is addressed further in the discussion of EU social and economic effects in Section B. below.

ECONOMIC SCENARIO DRIVERS

SCENARIO ONE: MARKET DRIVEN FEASIBILITY

In this Scenario, income is assumed to be almost completely driven by sales into the power grid as remunerated to project owners based on a wholesale electricity price normalized to pence or Eurocents per cubic meter gas produced as a kilowatt hour equivalent. The price series represent exogenous outlooks based on figures provided, where possible, by central governing agencies. In the case of Germany, the gas price is fixed to reflect a constant feed-in-tariff rate based on current law.[16]

In some cases other uses of gas such as flaring, power generation using ventilation air methane emissions, or internal mine equipment such as boilers or co-firing is assumed to continue from the baseline year (2010) as long as available gas is left from power production. As there is no energy value created, flaring depends on a carbon price signal or a regulatory mandate, neither of which is present in the Market Driven Scenario.

SCENARIO TWO: PRICE AUGMENTATION

[15] Based on calculations from the US EPA (Coal Mine Methane Project Cash Flow Model), a capital figure of 8.7 EUR per meter of new pipeline is used here.

[16] Germany's Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2000). Act on Granting Priority to Renewable Energy Sources (Renewable Energy Sources Act). Support is granted only for gas that results from mining activities in order to ensure that there is no specific drilling taking place for the sole purpose of finding methane gas.

The Price Augmentation Scenario also assumes that net profitability factors will determine how and whether a mine will utilize its CMM; however, the market clearing price points are now assumed to be set by external policy instead of by hub prices. Such policies can be implemented via mechanisms such as the feed-in-tariff (FiT) for renewable energy under Germany's Renewable Energy Act of 2000. As this regulation recognizes CMM as a renewable source, all CMM electricity sold into the grid is compensated at a uniform rate equivalent to 50.8 Eurocent/m^3, policy that has already driven a broader utilization of modular generation sets at working and abandoned sites in Germany than either in Poland or the UK.

As the German renewable energy subsidy is the best established in Europe, it is assumed that, generally speaking, Germany's FiT level implemented in a Scenario would follow its general mechanics and equate to a universal real price to producers using renewable CMM.

The Market Feasibility Scenario does not provide a carbon price signal, which is a primary driver of the use of flaring. While the Price Augmentation Scenario does not make any assumptions on specific policy, it provides for an across-the-board flaring subsidy for the reduction of emissions; this provides a value to gas producers for flared gas, although this will be generally be done with residual gas that cannot be used in electricity generation. The effect of this on model output is that gas uptake is increased, net emissions go down, but potential electricity sales and generation remain unaffected.

SCENARIO THREE: TECHNICALLY FEASIBLE

In this scenario, it is assumed that a policy or equivalent driver is oriented toward using as much of the available emitted gas as possible and thus that, for the "final cubic meters" of production, marginal economic cost is not an issue. Although market forces, with price subsidies, will still drive investment, it is assumed that flaring is mandated as a means for using up any remaining emissions down to a residual "technically feasible" level.

B. ECONOMIC AND SOCIAL IMPACTS

In this section, the socio-economic implications of each scenario will be summarized based upon stated assumptions regarding technology choice and market pricing structure. Additional analyses of potential technology uptake in the form of discounted cash flow models will be used in conjunction with (possibly recreated) marginal abatement cost curves to develop scenario-driven schedules for additional gas input / production.

ECONOMIC AND SOCIAL IMPACTS BY COUNTRY AND SCENARIO

UNITED KINGDOM

Because the UK coal industry is shrinking and will continue to shrink, there is a declining emission and CMM resource base; however, there is room for introducing CMM projects with abandoned mine workings including a small number of flares. The modelling indicates that all three Scenarios result in very similar outcomes, with economic and energy outcomes for Augmented Price higher owing to increased electricity prices, with resulting increases in government revenues and energy supplied. The results of all scenarios, while small, are still favourable, with build and therefore capital costs occurring early, increasing net profitability in later periods.

UK SCOPE IN SUMMARY

The bulk of operating and recently closed deep UK coal mines are located in the northeast of the country, with many sites located in the Yorkshire-Nottinghamshire Coalfield, which stretches from the heavily industrialized region just west of the Humber Estuary in the north down to the border of Nottinghamshire and Leicestershire in the south. Other areas of interest include the mining region surrounding the Tyne estuary in the far northeast of England the Selby and Staffordshire fields to the northwest of the country, and South Wales.

UK coal production has decreased significantly since the 1980s, and by 2012 the country produced a total of 16.8 Mt while importing a further 44.8 Mt,[17] mostly from Russia, Colombia and North America. The pace of mine closure has accelerated since the turn of the Twenty First Century and, as of the baseline year of 2010, only five major underground sites were in operation. With the planned closure of UK Coal's last major underground properties – the Kellingley and Thoresby collieries – in 2015, the only remaining major deep mine in the country will be the employee-owned Hatfield Colliery.

Based in part on the scale of UK mine closures, the long-term employment outlook in UK coal mining regions is generally unfavorable. As of 2014, unemployment for those aged 16-64 varied from 6.5% in Wales, to 7% in Yorkshire-Humber, to 9.3% in the North East, according to the UK's Office of National Statistics.

[17] EURACOAL (2013).

UNITED KINGDOM ECONOMIC AND SOCIAL IMPACT OUTLOOKS – DATA

Table 2 below shows projected key infrastructure, use and economic indicators for the UK in 2020 and 2030 based on the Scenario modeling described in Section A. Because of dwindling resources, a high number of closed mines, and the relatively low levels of specific emissivity associated with UK coals, the total scale of available gas – and therefore usage – by Scenario is significantly smaller in the UK than in either Germany or Poland. Rapidly decreasing emissions from mines closed from 2000-2020 means that the build of generating capacity peaks early for each Scenario, with no new generation capacity added after 2020 and does not vary much among scenarios, from 16 added MW by 2030 under the Market and Technically Feasible Scenarios to 17 under the Augmented Price Scenario.

UNITED KINGDOM	2020 SCENARIOS			2030 SCENARIOS		
	Market	Augmented Price	Technically Feasible	Market	Augmented Price	Technically Feasible
Estimated Emissions (MILLION M^3)	51.3			34.6		
Projected Use (MILLION M^3)	46.7	48.2	49.8	30.8	32.8	33.6
Additional Generating Capacity Installed Since 2015 (MW)	16	17	16	16	17	16
Potential Total CMM Generating Capacity (MW)	72	73	72	72	73	72
Estimated revenues (based on gas/and or electricity sales) MILLION GBP	30.9	49.3	30.9	35.8	49.3	35.8
Total Costs M GBP	9.67	10.27	9.67	0.07	0.07	0.07

Table 2 – Scenario Modeling Outputs - UK

New job creation owing to new CMM activity is relatively small, amounting to about 50 jobs regardless of scenario. However, considering the relatively high unemployment rates in mining regions, these jobs could contribute towards mitigating the social impacts of further mine closures.

GERMANY

The modeling done here produced very little variance in additional electricity capacity build and added supply over the three scenarios. This result indicates that current German price support in terms of the FiT has been quite efficient at economically utilizing available gas. As discussed below, current CMM electricity generation capacity is high in Germany, and the modeling indicates that, despite decreasing availability of gas owing to mine closures, capacity should climb slightly through 2030.

GERMANY SCOPE IN SUMMARY

In 2012, German mines produced about 196 Mt of coal, although hard coal constituted only about 11 Mt of this, with the vast majority of production being lignite.[18] Most hard coal has been mined in the Ruhr-Ibbenburen basin in the northwest and in the Saar basin located to the southwest. The planned shutdown of Germany's remaining nuclear capacity by 2022, which was announced following the Fukushima plant disaster in 2011, implicitly commits the country to the maintenance of coal power and the expansion of mining, although following the planned shuttering of the remaining deep mines by 2018, surface-mined lignite will provide the entirety of the domestic supply.

As in the UK, the employment outlook in the German Saar and Ruhr regions is troubled owing both to deindustrialization and mine closure. Unemployment in the Ruhr in 2013 was above 6%, and the German Hard Coal Association has predicted that closure of German underground mines will add another 2 percentage points to this figure. [19]

GERMANY ECONOMIC AND SOCIAL IMPACT OUTLOOKS - DATA

Table 3 below shows projected key infrastructure use, and economic indicators for Germany in 2020 and 2030 broken out by Scenario. Owing in large part to the presence of a Feed-in-Tariff (FiT) for CMM-produced electricity and the anticipated value prior to the collapse of the EU ETS in 2006 and again in 2009 of carbon credits for CMM-derived projects, the baseline penetration of power generation infrastructure in German mines is high. Notably, the results in 2020 and 2030 in terms of generating infrastructure are identical across the three Scenarios. Although flaring differs somewhat by Scenario, the lack of difference in price signal for power generation owing to the constant FiT produced identical levels of growth in CMM power generation capacity. The likely maintenance of existing equipment under German incentive regimes and the high residual gassiness of a few abandoned mines results in moderate growth in generating capacity installation, with 26 MW added by 2020, regardless of scenario.

GERMANY	2020 SCENARIOS			2030 SCENARIOS		
	Market	**Augmen-ted Price**	**Technically Feasible**	**Market**	**Augmente d Price**	**Technically Feasible**
Estimated Emissions (MILLION M^3)	101.4			54.6		
Projected Use (MILLION M^3)	93.4	96.1	97.8	52.9	52.5	52.8
Additional Generating Capacity Installed Since 2015 (MW)	26	26	26	26	26	26
Potential Total CMM Generating Capacity (MW)	107	107	107	107	107	107
Estimated revenues (based on gas/and or electricity sales) MILLION EUR	91.1	91.1	91.1	91.1	91.1	91.1
Total Costs M EUR	19	19	19	0.1	0.1	0.1

Table 3 - Scenario Modeling Outputs - Germany

New job creation owing to new CMM activity is relatively small and does not increase significantly; the estimated figure for each Scenario is 450. However, considering the

[18] EURACOAL (2013).

[19] German Hard Coal Association (2007). Coal: Options for the Future.

relatively high unemployment rates in mining regions, these jobs could contribute towards mitigating the social impacts of further mine closures.

POLAND

Because Poland's coal industry is expected to remain active, both CMM emissions and resources will continue to be significant through 2030. Potential mine closures after 2018, however, could significantly reduce the level of emissions. The Augmented Price and Technically Feasible Scenarios both result in very significant supply changes, with large increases in uptake under both scenarios relative to the Market Scenario. The results of implementing price supports could have a significant effect on new generating capacity build, although there is the potential for supply bottlenecks from vendors to restrict large-scale deployment. [20]

POLAND SCOPE IN SUMMARY

In 2012, Polish mines produced 79.2 Mt of hard coal and 64.3 Mt of lignite,[21] with all of the hard coal production within the scope of this study taking place in the Upper Silesian Coal Basin located in the south of Poland in the border region with the Czech Republic. Like Germany, the country's energy growth relies strongly on new build of coal power plants, many of which will burn abundant domestic lignite.

Likely mine closures in Upper Silesia after 2018 would prove economically painful to the region, which has already suffered a profound and long-lasting economic downturn following the collapse of Communist rule in 1989. To put the overall situation into context, unemployment in the Silesian Voivodeship had risen to 20% by 2003, although limited restructuring has improved the current situation somewhat. According to EURACOAL, the Polish hard coal industry employed 113,000 people in 2012.[22]

POLAND ECONOMIC AND SOCIAL IMPACT OUTLOOKS – DATA

Although mine closures in Upper Silesia are likely as EU subsidies are scheduled for elimination after 2018, as of this assessment there are no specific closures announced for any mines. Because operating mines generally emit in proportion to annual production, the maintained emissions allow for a high level of added capacity relative to baseline (2010) across all three Scenarios, with 90, 90 and 91 MW added by 2030 under the Market, Augmented and Technically feasible Scenarios respectively – Table 4.

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[20] Bottlenecking brought up in this study is based on a discussion on new gen set ordering and installation logistics with a former officer of a company developing CMM projects in the Czech Republic. Where it is introduced, it loosely and conservatively reflects the fabrication and shipping capabilities of standard generating motor producers (e.g., GE Jenbacher). Although the supply chains for such equipment are rapidly evolving and growing in many markets outside of Europe, it is possible that a rapid change in demand in previously slowly growing markets could face at least initial supply stickiness; thus, this estimate is conservative and more capacity may be added at faster rate than is estimated here.

[21] EURACOAL (2013)

[22] EURACOAL (2013) Country Profile for Poland

POLAND	2020 SCENARIOS			2030 SCENARIOS		
	Market	**Augmented Price**	**Technically Feasible**	**Market**	**Augmented Price**	**Technically Feasible**
Estimated Emissions (MILLION M^3)	786.3			786.0		
Projected Use (MILLION M^3)	135.1	359.8	622.5	196.4	491.7	634.8
Additional Generating Capacity Installed Since 2015 (MW)	53	55	55	90	90	91
Potential Total CMM Generating Capacity (MW)	82	84	84	119	119	120
Estimated revenues (based on gas/and or electricity sales) MILLION EUR	49.6	71.5	50.8	95.7	101.3	72.6
Total Costs M EUR	40	42	42	28	27	27

Table 4 - Scenario Modeling Outputs - Poland

The high levels of sustained gas use and new infrastructure installation result in significant impacts in terms of job creation, particularly in the Scenarios with market intervention. The figure increases from 1,000 under the Market Scenario to 2,310 and 2,890 under the Augmented and Technically feasible Scenarios, respectively.

EUROPEAN UNION

By extrapolating the economic figures developed above for the United Kingdom, Germany and Poland, the economic and social impacts of coal mine methane can be roughly scaled up to cover potential three-scenario outlooks for the EU as a whole, as shown in Table 5. While the amount of available gas is in the low billions of cubic meters, the three countries assessed in this study constitute the bulk of EU CMM production and use, and aside from a fairly significant industry in the Czech Republic, there is no large-scale use of CMM in the EU outside of the UK, Poland and Germany. Nevertheless, the modeling done here suggests that a significant portion of EU CMM resources could be used under aggressive pricing and flaring regimes, creating thousands of jobs and producing hundreds of millions of Euros in electricity sales by 2030.

The emissions and gas use figures in Table 5 are extrapolated from the results calculated in this study for Germany, Poland, and the UK to the EU as a whole based on existing national inventories for previous years.[23] To produce a forecast of emissions, the major CMM producing countries in the EU were respectively determined to have mine closure "profiles" like those of Germany, Poland or the UK. Based upon this, their previous (2009 or before) emissions were scaled up or down for 2020 and 2030 projections. Because there is currently relatively little CMM utilization in the EU as a whole, Poland – the country within this study with the least developed CMM market – was used as a model to scale up the potential for overall EU development under various Scenarios.

[23] Figures used for this scaling up are combined latest available statistics for Bulgaria, The Czech Republic, Romania, Spain, Italy, France, Germany, Poland, and the UK collected by the Global Methane Initiative: https://www.globalmethane.org

EUROPEAN UNION	2020 SCENARIOS			2030 SCENARIOS		
	Market	Augmen-ted Price	Technically Feasible	Market	Augmen-ted Price	Technically Feasible
Estimated Emissions (MILLION M^3)	1,300			1,240		
Projected Use (MILLION M^3)	272	570	1,080	305	1,063	1,178
Additional Generating Capacity Installed Since 2015 (MW)	56	64	103	96	103	132
Potential Total CMM Generating Capacity (MW)	222	230	269	262	269	298
Potential households served (based on 4,000 Kwh/household and assuming net utilization factor of 75%)	1,458,540	1,511,100	1,767,330	1,721,340	1,767,330	1,957,860
Potential jobs added through 2030 (based on estimated 4.7 jobs/MCM)	2,050	3,240	6,140	2,300	6,040	6,700
Estimated revenues (based on gas/and or electricity sales) MILLION EUR	163.3	195.7	197.8	200.1	228.9	227.6
Estimated CAPEX (for new plants, based on 600 GBP/KWEL) M EUR	43	49	78	40	39	29
Estimated OPEX (based on 1 EUR/kWel yr) EUR	222,000	230,000	269,000	262,000	269,000	298,000
Total Costs M EUR	43	49	79	40	39	29
Other income: government royalties (32% of net profit) M EUR	39	47	38	51	61	63
Potential additional electricity into grid (vs 2015 baseline) based on total capacity derated to 75% availability (MWh)	367,920	420,480	676,710	630,720	676,710	867,240

Table 5 - Scenario Modeling Outputs Extrapolated EU-wide

As shown in Table 5, overall CMM use through power production can scale fairly significantly over the next decade and a half, with installed CMM electricity generating capacity increasing most under the Technically Feasible Scenario (by about a factor of 50% from 2015-2030). Although the total power capacity of 298 MW in 2030 is not large relative to the overall electricity market (the figure represents the equivalent capacity of a small combined cycle gas turbine plant) it represents the capacity to serve nearly 2 million households. Depending on the Scenario, a projected 2,000 – 6,100 and 2,300 – 6,700 jobs could be created through additional CMM activity by 2020 and 2030, respectively.

MACROECONOMIC PRICE EFFECTS

Overall, the maximum expected input into the European grid systems of gas and electricity is minuscule compared to the overall respective market sizes; from Table 5 above, for instance, the Technically Feasible Scenario might result in nearly 3 million additional MWh of electricity delivered into a continental power grid that carried more than 3 million GWh in 2012[24]. Adding this excess CMM generated electricity would thus represent an increase of 0.1 percent. Studies of the price elasticity of electricity

[24] Source: EUROSTAT.

of fuel suggest that each additional percent increase in supply in such markets would result in a decrease in price of between 1.5–2.7 percent[25], so even the largest potential influx of additional gas or electricity owing to CMM use would likely to have no more than a 0.2–0.3 percent downward effect on prices.

BARRIERS TO ECONOMIC DEVELOPMENT

The three scenarios presented show what level of CMM use would be viable considering a variety of market and, for the third scenario, regulatory signals. And while the great success of Germany's Renewable Law demonstrates that policy-driven market signals can bring about substantial uptake of projects, experience around the world has also shown that not all coal mine methane project opportunities that are economically viable will result in projects. As such, it is important to consider the barriers to economic development of projects and measures that have been successful to overcome these.

The development of any industry requires that broader market and technological conditions exist within which an industry may find a market. Fortunately, technologies to recover and use CMM have benefited from a considerable number of research, development and demonstration projects that have produced several technologies – from in-mine directional drilling of CMM, to use of flares and ventilation air methane – that have become established, commercially proven options. The use of ventilation air methane through oxidization of low-concentration methane, for instance, was introduced at a UK colliery in the 1990s. The European Commission has been involved in several bilateral technology pilot initiatives both within and outside of Europe, including: Advance Tools for Ventilation and Methane Emissions Control (AVENTO), in which various approaches to ventilation monitoring and control are being assessed; Coal Mine Methane New Solutions for use of CMM-reduction of GHG Emissions (COMETH), a programme for developing devices for use of CMM emissions; and Low Carbon Mine Site Energy Initiatives (LOWCARB), which sought to develop economically viable technologies for reducing the overall carbon footprint of coal mining.[26]

In some former mining regions, or regions where the industry is winding down, regional, national or EU-directed regeneration programmes have been instituted to provide assistance in the form of knowledge transfer or direct funding. For instance, the EU European Regional Development Fund's ReSource initiative has developed regional profiles for Poland, Germany and the Czech Republic that gather data such as employment and population dynamics, while the EU's Liaison Entre Actions de Développement de L'économie Rural (LEADER) programme has provided grants to regional authorities in Germany and elsewhere to develop tourism activity based on mining heritage.[27] In the UK, there are a number of government-instituted programmes to monitor and assist the coalfield regeneration process in England,

[25] See, for example, Johnson, Erik (2011). The Price Elasticity of Supply of Renewable Electricity Generation: Evidence from State Renewable Portfolio Standards.

[26] Global Methane Initiative (2013). European Commission Global Methane Reduction Actions, Ref. Ares (2013)2843722-06/08/2013.

[27] ReSource (2009). Central European Regional Profile Report.

such as the Coalfield Task Force. Although such efforts have generally had moderate success in aiding in the regeneration process, economic indicators in such regions remain poor overall and it is agreed that further work toward recovery will be required.

Commercial use of coal mine methane also requires that mine operators or other project developers have access to markets. These can be rights to use gas on-site as a substitute for other energy sources, or for sale to local users or in a grid as gas or electric power. However, the marginal abatement cost analyses employed in this study shows that deploying technically feasible use technologies, at today's market prices, would result in more methane use than is actually the practice in the three countries studied. In other words, more CMM could be economically viable under prevailing market conditions, than actually is used.

Why have economic projects not been developed? Barriers can be characterized as informational, resource, legal / property rights, market uncertainties, and finance. These are outlined below:

- Lack of Project Opportunity Information and Evaluation Resources: One of the problems that has slowed project development is that some coal mine operators did not have adequate information regarding coal mine methane projects. A related constraint has been that some coal operators simply do not have the time or resources to evaluate the information available on coal mine methane or to investigate the potential to develop a profitable project at their own coal mine.
- Lack of Market Understanding / Information by Broader Stakeholders: A thorough understanding of the market potential by all stakeholders (coal operators, local and national governments, foreign investors) is critical so that the full potential of the coal mine methane market may be developed.
- Technological Information: Technologies to employ increasingly large fractions of available coal mine methane, such as the dilute methane in ventilation air, are developing. It is important that the latest information on technical options will be available to potential project developers.
- Legal Constraints: Doubts as to the rights to the CMM resource and to energy revenue greatly increase the investment risk of projects and lower the prospects for successfully developing projects. Transparent methane ownership rights, licensing regimes, and energy prices and contracts are necessary.
- Market Uncertainties: In many European economies, restructuring of the coal industry is underway through the implementation of industrial or environmental policies. Clarity regarding the status and future of coal enterprises is important in identifying the best projects and coal operators to work with in developing projects.
- Financial and Development Resources: One of the greatest barriers to coal mine methane projects is a lack of champions of projects with adequate development resources. Expertise and funds for project development need to be identified and made available.

Policies and measures, including those that provide or foster unbiased information and analysis services, further research, development, and demonstration (including significant efforts to disseminate the findings) can play an important role in encouraging more and more effective coal mine methane projects. Energy and resource policies can play an important role in clarifying rights and market value in the use of CMM, and financial mechanisms (identification or even designation of specific funds, loan guarantees, and encouragement of an investment community and project development industry) may reduce market uncertainties and address barriers such as a lack of project finance.

There are a number of examples of successful initiatives to encourage economically viable coal mine methane developments. Outreach programmes and policies have been instrumental in developing the industry in countries as diverse as The United States, China, Russia and India. The European Commission, UK, Poland, Germany and other EU countries are active in the Global Methane Initiative, which gives participants opportunities to share information on successful projects, technological and policy instruments that have encouraged CMM developments.

C. ENVIRONMENTAL IMPACTS

INTRODUCTION

This section will outline environmental impacts by country studied and scenario. A subsection outlining likely impacts for other countries and the EU as a whole will also be included. The primary focus of the analysis will be on determining the net environmental (regional and global) benefits and/or costs resulting from Scenario-indicated changes in the following factors:

- land use
- air emissions
- greenhouse gas emissions

LAND AND WATER USE

Although the land use impacts of gas production can be significant in cases where new seams or deposits need to be explored and drilled (as is generally the true with shale or new coal seam projects), as a rule the coal mine sites within the scope of this study have been developed and used industrially for many years. While the well footprint of a project can be significant in some cases, virtue of CMM projects with respect to their land use is that the development has generally already taken place and the local impacts are well understood. In addition, unlike shale gas production or some coal bed methane projects, water use is not typically an additional problem as water treatment is already ongoing or even not necessary.

The infrastructure most often associated with the prospective projects covered in this study – gas powered engines and flares – is both compact and modular. Often it turns out that such equipment can be located directly on the mine or abandoned mine site. If remoter siting is required, generally this will be within five kilometers in order to spare pipeline expense, as the typically erratic concentration and poorer quality of the CMM produced makes longer distance pipeline transit impractical. Existing pipeline applications in Poland use 200 mm gauge pipe, so some easement planning for this (as well as for grid interconnection where power is produced) is required in the vicinity.

Based on manufacturer figures, the standard ground footprints of generator engines and flaring units discussed in this study are, respectively, 120 m^2 per MW for an engine (modular engine units range in size from about 1-8 MW) and 120 m^2 for a flare with a capacity of 2,000 m^3 per hour.

Mines adjacent or close to heritage areas or land protected by e.g. EU Natura 2000 legislation have been identified and mapped in the associated data analysis.

AIR EMISSIONS

As was discussed in the introductory sections of this study, although the ventilation and drainage of CMM originated primarily as an in-mine safety measure, other internal and external uses for the gas have evolved over time. With the recognition of the effects of methane as both a local / regional pollutant and as a powerful greenhouse gas, the uptake and use of CMM for emissions abatement has created environmental benefits for activities such as power generation and flaring.

FUEL SWITCHING EFFECTS

CMM-generated electricity can be integrated into regional or national power grids through either local generation or the supply of gas as fuel to existing power stations. This fuel switching effect can be beneficial if it results in a net reduction of the systemic grid emission factor, i.e. the weighted average GHG emissions per kilowatt-hour of the power grid, in cases where high emissions fossil fuels, such as coal, constitute a large portion of the generation mix. Even where gas power is not fed into the grid, local use can displace more polluting fuels, reducing GHG emissions and improving local air quality. The electric grid emission factor varies depending on country. For the EU as a whole, a weighted figure of about 1.06 is used.[28]

Table 6 below gives the appropriate factors by country used in the following section to derive grid emissions avoidance by country and scenario.

Country	Grid Emission Factor kg CO_2e/kWh Electricity Produced
United Kingdom	0.51
Germany	0.67
Poland	1.19
EU Weighted Average	1.06

Table 6 – National Grid Emission Factors

DIRECT ABATEMENT EFFECTS

As discussed previously, methane has a 100-year global warming potential[29] of 34, and applying this figure in conjunction with the volume of capture and use of mine emissions, allows for the calculation of reduced GHG emissions by mine and scenario in terms of avoided tonnes of CO_2 equivalent (t CO_2e). However, from this raw figure the smaller CO_2 emissions from electricity generation and flaring must be subtracted to get net emissions. For example, a gas engine releases about 750 g

[28] Brander Et Al., (2011). Technical Paper: Electricity-Specific Emission Factors For Grid Electricity: The figure of 1.06 for the EU is obtained as an average (weighted by country CMM emissions) of the grid emission factors for Bulgaria, The Czech Republic, Romania, Spain, Italy, France, Germany, Poland, and the UK.

[29] The global warming potential (GWP) of a gas is a dimensionless number that is a function of how well and over which portions of spectrum the gas absorbs infrared radiation as well as the amount of time a molecule of the gas typically persists in the atmosphere. The GWP carbon dioxide is set at a baseline of 1. As new measurements and research refine the understanding of the radiative forcing and atmospheric qualities of individual gases over time, their assigned GWPs can be amended; in the case of methane, the GWP has recently been increased to its current (2014) level of 34.

CO_2 for each kWh of electricity produced[30]; however, as the production of 1 kWh of electricity consumes about 0.25 m^3 of methane, the use of mine methane in a gas engine reduces net emissions by about 14,000 gCO2e for methane minus 4 x 750 g CO_2 = 11,000 g CO_2e net emissions reduction per cubic meter used.

For each country and scenario, the net reduction in GHG is shown in the subsection *Environmental Impacts by Country and Scenario* below.

OTHER EMISSIONS

Aside from CO_2, the primary gaseous products of gas combustion and flaring are nitrogen oxides (NO_x). NO_x, which in methane consumption can be formed from reactions between atmospheric nitrogen and oxygen at a high temperature flame front, include nitrogen dioxide (NO_2) and nitrogen monoxide (NO), which is often quickly converted into NO_2 in the atmosphere. NO_2 in particular is a pollutant that can cause regional air quality diminishment (with associated health effects) and, at a larger scale, contributes to acid rain.

Based on manufacturer figures, standardized emission figures of 0.5 and 0.7 g NO_x/m^3 can be assumed for gas engine and flare emissions, respectively, levels which are generally acceptable within the EU's legislation regarding plant emissions, the Industrial Emissions Directive (which, in any case, only dictates specific standards for units larger than 50 MW). Although a large number of technologies and combustion techniques can be employed to reduce NO_x emissions to minimal levels, these tend to be expensive and/or fuel intensive and are not generally applied at the project scale discussed in this report.

Despite moderate amounts of elevated NO_x emissions that can be produced at a local or regional level, CMM activity that results in the introduction of electric power into a national grid can actually have a net beneficial effect in terms of net emissions on a larger scale. This is because the grid electricity displaced will often have larger NO_x emissions factors than those associated with CMM electricity. In particular, countries with significant coal-fuelled power fleets can have grid emissions factors of up to five or six times that of a gas engine. This displacement effect, which is manifested most clearly on the international level and, to a certain extent depends upon wind patterns, is addressed below at the EU scale.

ENVIRONMENTAL IMPACTS BY COUNTRY AND SCENARIO

UNITED KINGDOM

Some of the major potential UK environmental and climate change impacts in 2020 and 2030 under the three Scenarios discussed in this study are shown in Table 7. The local pollution and land use effects of additional CMM use in the UK are relatively small, with negligible amounts of NO_x emissions adding marginally to

30 See for example International Energy Agency (2013). CO_2 Emissions from Fuel Combustion Highlights.

generally unhealthy background levels in current mining regions. On the other hand, displacement of grid electricity, which in the UK has a medium-high NO_x emissions factor of 750 mg/kWh,[31] with project-generated electricity could result in small net reductions in overall NO_x emissions from electricity production. In all scenarios, land use is negligible, although flare use under the Technically Feasible Scenario tends to multiply the used footprint by a small positive factor. Greenhouse gas emission reduction is relatively low in 2020 and decreases in 2030 owing to lower potential emissions from closed mines.

UNITED KINGDOM	2020 SCENARIOS			2030 SCENARIOS		
Change from 2015	Market	Augmen-ted Price	Technically Feasible	Market	Augmen-ted Price	Technicall y Feasible
GHG Abatement – net grid emissions avoided (t CO_2e)	113,783	112,658	104,536	75,072	78,551	75,072
GHG Abatement – CH_4 emissions abated (t CO_2e)	1,058,574	1,092,804	1,127,989	698,425	745,490	763,786

Table 7 - Environmental Impacts UK

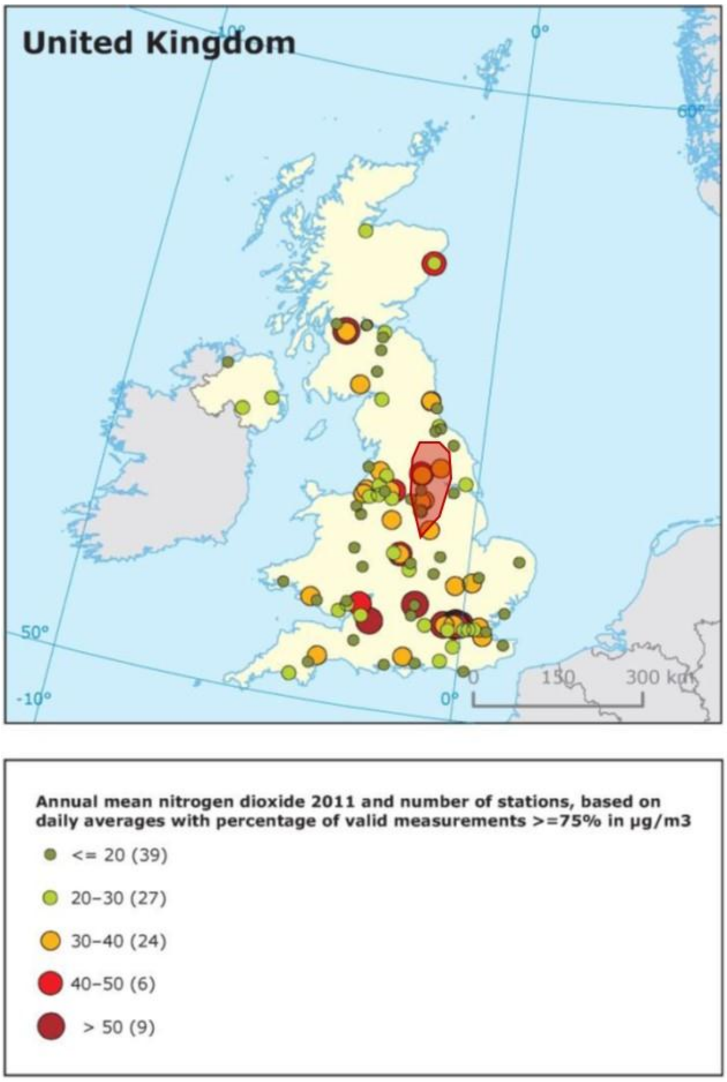
Most of the UK mines assessed in this study are located along a major coal deposit straddling the spine of the country in a general north-south direction from Yorkshire down to Nottinghamshire (the Yorkshire-Nottinghamshire Coalfield). The European Environment Agency estimated that, in 2013, exposure to NO_2 levels above the "acceptable" level of 40-60 µg/m^3 occurred 6-12% of the time on average nationwide, although the annual mean exceeded this figure in certain areas within the Yorkshire-Nottinghamshire axis (see Figure 3).[32] The additional combustion and flaring of CMM in UK mines, therefore, could contribute marginally to a generally unhealthy NO_x situation in certain localities within the region, including the urban complex centered on Sheffield-Rotherham that contains much of the country's deep mines.

In 2012, the latest year for which figures are available, estimated UK GHG emissions were 570 Mt CO_2e.[33] Based on the scenario analysis in Table 7 above, the grid and direct emissions effect of projected use of CMM in 2020 could reduce this figure by about 1.2 Mt CO_2e.

[31] Building Research Establishment Environmental Assessment Methodology (BREEAM) Website: Http://Www.BREEAM.Org/Breeamint2013schemedocument/Content/12_Pollution/Pol_02.Htm

[32] European Environment Agency (2013). Air Pollution Fact Sheet 2013 - United Kingdom.

[33] DECC (2013). 2013 UK Greenhouse Gas Emissions, Provisional Figures and 2012 UK Greenhouse Gas Emissions, Final Figures by Fuel Type and End User.



[34]

Figure 3 – NO_2 concentrations in the UK, 2011, with Yorkshire-Nottinghamshire coalfield shaded in red

GERMANY

Major environmental impacts for Germany by Scenario are outlined for 2020 and 2030 in Table 8 below. The local pollution and land use effects of additional CMM use in Germany are less than an order of magnitude larger than in the UK, with additional NO_x emissions not making much of a difference given the background levels in the regions studied. Although the average NO_x emissions of Germany's electricity grid are relatively low at 456 mg/kWh,[35] they are slightly higher than the emission factor associated with gas turbines (300 mg/kWh). The use of project gas to displace grid electricity could result in small national level net NO_x emissions reductions. In all scenarios, land use is negligible, although flare use under the Technically Feasible Scenario tends to multiply the used footprint by a factor of three. Greenhouse gas emission reduction of about 2.6 $MtCO_2e$ is achievable in 2020, although this decreases in 2030 to about 2 Mt owing to mine closures.

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[34] Source: European Environment Agency.

[35] Building Research Establishment Environmental Assessment Methodology (BREEAM) Website: Http://Www.BREEAM.Org/Breeamint2013schemedocument/Content/12_Pollution/Pol_02.Htm

GERMANY	2020 SCENARIOS			2030 SCENARIOS		
Change from 2015	Market	Augmented Price	Technically Feasible	Market	Augmented Price	Technically Feasible
GHG Abatement – net grid emissions avoided (t CO_2e)	363,749	363,749	363,749	191,144	191,144	191,144
GHG Abatement – CH_4 emissions abated (t CO_2e)	2,119,010	2,188,750	2,218,460	1,183,161	1,190,175	1,197,545

Table 8 – Environmental Impacts Germany

The operational and abandoned German mines assessed in this study are located in two major regions – in the Ruhr-Ibbenburen basin in the northwest (near the Dutch border) and in the Saar basin located to the southwest, near the borders with France and Luxembourg. Figure 4 indicates that some of these regions coincide with or are close to some of the highest NO_2 measurements in the country, and therefore additional combustion and flaring of CMM could contribute marginally to the generally unhealthy NO_2 situation in this highly urbanized and industrialized region.

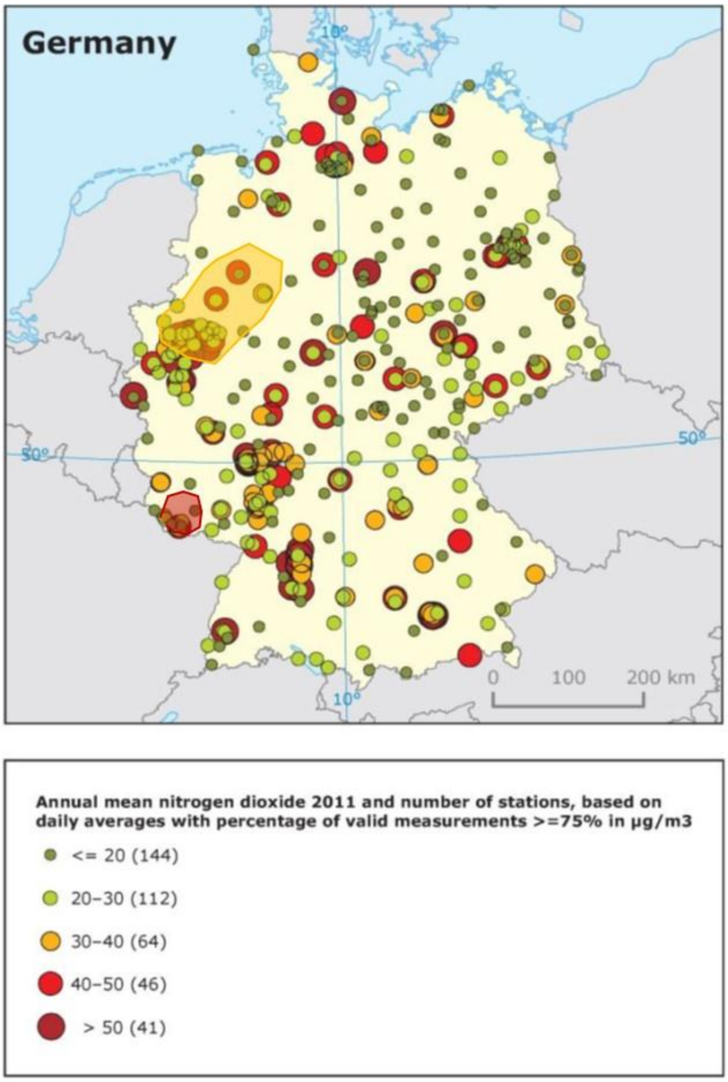


Figure 4 - NO_2 concentrations in Germany, 2011, indicating Ruhr-Ibbenburen (orange shading) and Saar (red shading) coalfields.

In 2011, estimated GHG emissions in Germany were 917 Mt CO_2e.[36] Based on the scenario analysis from Table 8, the combined grid and direct emissions reduction effects of projected use of CMM in 2020 could reduce this figure by about 2.6 Mt CO_2e.

POLAND

The main environmental impacts for 2020 and 2030 by Scenario are summarized in Table 9. There is a considerable increase in land use footprint – particularly in 2030, in the Augmented and Technically feasible Scenarios relative to the Market Scenario, which is the result of the larger scale use of flaring in these Scenarios. Nevertheless, both land use and NO_x production are relatively small, although background levels in the region studied are lower than the corresponding levels in the UK or Germany. Because the average NO_x emissions of Poland's electricity grid are relatively high (1,501 mg/kWh)[37], use of CMM to provide electricity for the grid could result in overall reductions of NO_x emissions that would more than compensate for the additional NO_x produced by project activities. Because more Polish mines are likely to remain open through 2030, potential reductions in GHG emissions are significant and likely to considerably improve under either a price support for CMM electricity or intensive flaring.

POLAND	2020 SCENARIOS			2030 SCENARIOS		
Change from 2015	Market	Augmented Price	Technically Feasible	Market	Augmented Price	Technically Feasible
GHG Abatement – net grid emissions avoided (t CO_2e)	1,164,534	1,187,399	1,187,574	1,319,003	2,102,706	1,703,617
GHG Abatement – CH_4 emissions abated (t CO_2e)	3,062,840	5,037,680	14,110,940	4,452,350	11,144,670	14,388,530

Table 9 - Environmental Impacts Poland

All of the Polish mines within the scope of this study are tightly placed within the Upper Silesian coal basin, which straddles the southern border of Poland with the Czech Republic – Figure 6. Although overall NO_2 concentrations are generally better in Poland than in the industrial areas of Germany and the UK, it can be seen that this basin overlaps to a certain extent with high (40-50+ µg/m^3) NO_2 concentration hotspots. In such areas, which in general are associated with industrial activity and large concentrations of road traffic, additional emissions from power generation and flaring would marginally worsen an already bad situation.

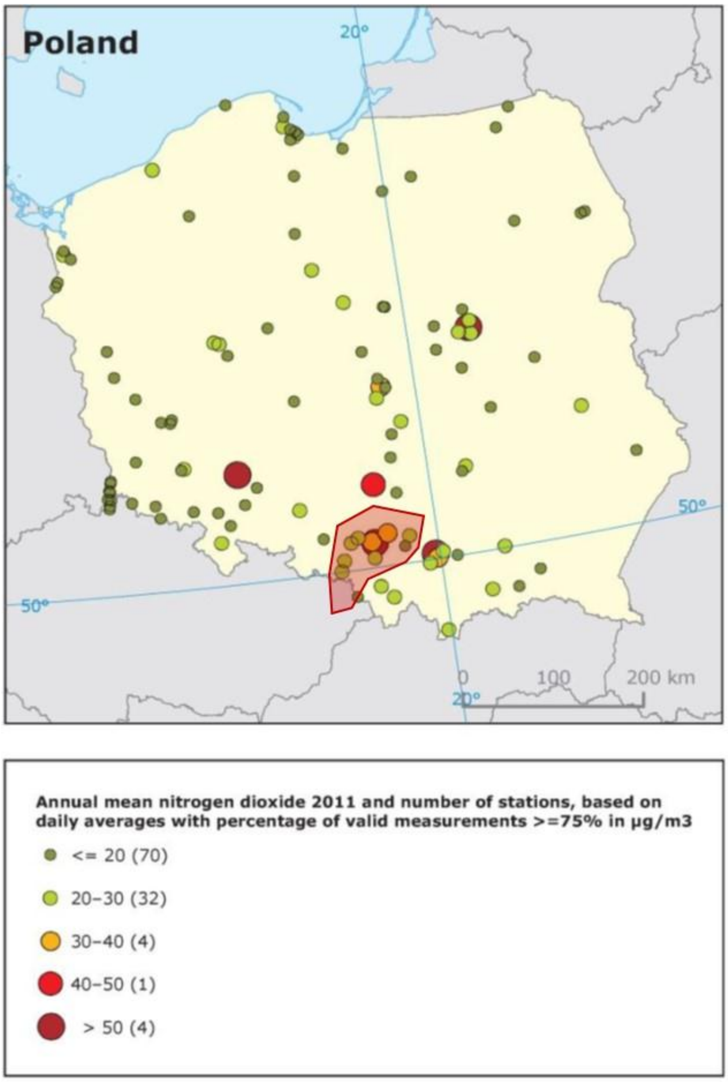
In 2011, estimated GHG emissions in Poland were 399 Mt CO_2e.[38] Based on the scenario analysis, the combined grid and direct emissions reduction effect of

[36] EEA (2013). Annual European Union Greenhouse Gas Inventory 1990-2011 and Inventory Report 2013 Submission to the UNFCCC Secretariat.

[37] Building Research Establishment Environmental Assessment Methodology (BREEAM) Website: Http://Www.BREEAM.Org/Breeamint2013schemedocument/Content/12_Pollution/Pol_02.Htm

[38] EEA (2013). Annual European Union Greenhouse Gas Inventory 1990–2011 and Inventory Report 2013 Submission to the UNFCCC Secretariat.

projected use of CMM in 2020 could reduce this figure by about 4.2 (Market) – 15.3 (Technically Feasible) Mt CO_2e (Table 9).



[39]

Figure 5 - NO_2 concentrations in Poland, 2011, indicating Upper Silesian Mining Region with red shading

EUROPEAN UNION

An extrapolation of the land use and emissions reduction figures from the environmental assessments of the three countries developed above produces a rough EU outlook, as shown in Table 10 below. While the impacts in terms of land use are larger by an order of magnitude or so, the effects are still small considering the EU's overall geographic scale. Although CMM activities would increase local and regional NO_x emissions near project sites, at the EU-wide scale the overall effects of grid electricity displacement result in net reductions in overall NO_x emissions. Further modeling to understand e.g. wind-driven plume patterns and acid rain deposition at a super-national level, is required in order to better understand the effects. While there is an enhanced potential to reduce GHG emissions through aggressive flaring

[39] Source: European Environment Agency.

(Technically feasible Scenario), the relatively lower generation build under this scenario reduces the potential for grid emissions displacement.

EUROPEAN UNION	2020 SCENARIOS			2030 SCENARIOS		
Change from 2015	Market	Augmented Price	Technically Feasible	Market	Augmented Price	Technically Feasible
Additional Land Use for CMM Infra-structure (m^2)	5,642	10,472	19,328	16,780	23,250	35,187
Additional annual NO_x emissions (t NO_x)	164	338	707	181	580	747
Net annual NO_x reduction from grid displacement (t NO_x)	590	1,217	2,545	686	2,198	2,831
GHG Abatement – net grid emissions avoided (t CO_2e)	1,950,402	2,020,687	2,298,622	2,084,016	2,363,325	2,795,739
GHG Abatement – CH_4 emissions abated (t CO_2e)	7,412,473	15,091,541	24,233,902	7,034,318	18,514,511	23,204,987

Table 10 – Estimated Environmental Impacts, EU-wide

The most significant potential impact that CMM industrial development brings is the mitigation of greenhouse gas emissions, which occurs under all three scenarios. While baseline emissions are expected to decline significantly by between 7 and 24 MTCO_2e in 2020 – Table 10. Although reduced coal production will cause baseline emissions to fall by 2030, promotion of economically feasible projects without any price or regulatory incentive will still result in direct additional emissions abatement of 7.0 Mt CO_2e; a further policy imposed price signal may improve this to 18.5 Mt CO_2e, and all technically feasible abatement results in 23.2 Mt CO_2e in direct emission reductions by 2030 – Table 10.

D. CONCLUDING REMARKS

This study demonstrates the considerable potential for alternative price and regulatory drivers to encourage coal mine methane project developments. This is clear across the three scenarios (the existing market price scenario, the augmented price scenario and the scenario that imposes a requirement for methane use / abatement to the extent that is technically feasible) as applied in this analysis to the three subject countries of Germany, Poland and the United Kingdom.

The costs of reducing greenhouse gas emissions through policies to promote coal mine methane projects is very favourable. Calculations based on the per-unit economics of CMM use for various countries and regions assessed in this study reveal a wide spread of discounted marginal costs over the period 2015-2030. Promotion of CMM projects could result in considerable net revenues (up to 228 million Euros) and a direct job creation potential of about 6,700 for the mining regions of the EU as a whole, under the most favourable scenario. While from an EU scale these figures may seem modest, the job-creation potential from a regional development perspective is important, in particular considering the impact of further mine closures on regions already facing high unemployment rates.

Tax receipts would be enhanced and project developers could realize considerable revenues. Local environmental impacts may include some marginal improvement in air quality in regions facing generally moderate to poor air quality with, in most likely scenarios, minimal impacts on land and water use.

The use of CMM will also provide some enhanced domestic supply of an energy resource. CMM should not be viewed as a critical strategic energy resource to the EU as a whole. Its maximum expected input into the European grid systems of gas and electricity would be small compared to the overall respective market sizes and would have very small impacts on energy prices. The analysis in this study, however, shows that full use of existing and future CMM resources can contribute considerably to the energy mix on the local / regional scale.

The choice of three alternative scenarios for the future development of EU's CMM resource may provide policy-makers with a view towards how different resource development, emission abatement and job creation goals could be met and at what opportunity costs. Yet even the most aggressive, technically feasible scenario estimates additional EU-wide capital costs of only EUR 78 million in 2020 declining to EUR 29 million in 2030.

However, the study also notes that experience around the world has shown that not all coal mine methane project opportunities that are economically viable will result in projects. As such, it is important to consider the barriers to economic development of projects and measures that have been successful to overcome these.

The study highlights a variety of informational, legal, market and financing barriers and suggests that these may be overcome through policies and measures, that provide unbiased information and analysis services, further research, development, and demonstration (including significant efforts to disseminate the findings), all of which can play an important role in encouraging increasingly effective coal mine methane projects. Energy, natural resources and regional development policies can play an important role in clarifying rights and market value in the use of CMM. Appropriate financial mechanisms e.g. identification or even designation of specific funds, loan guarantees, encouragement of investment communities and project development industry, etc. may reduce market uncertainties and address barriers such as a lack of project finance.[40]

[40] It is important to note that such policies focus on CMM; that is, only promoting the recovery and use of gas resulting from mining activities, as the EU is committed to phasing out subsidies for fossil fuel production.

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