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WORKING PAPER

A RECOMMENDED METHODOLOGY FOR ESTIMATING AND REPORTING THE POTENTIAL GREENHOUSE GAS EMISSIONS FROM FOSSIL FUEL RESERVES

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EXECUTIVE SUMMARY

In the Paris Agreement national governments committed to limit temperature rise to well below 2 degrees Celsius (°C) and pursue efforts to limit temperature rise to 1.5°C. To meet even a 2°C target, anthropogenic activities could only emit 986 $GtCO_2$ between 2011 and 2100. This number is our global emissions budget. Earth's coal, oil, and gas reserves are key to this budget. The potential CO_2 emissions from reserves currently held by the largest 200 public companies (by reserve size) is at least 1,541 $GtCO_2$, easily exceeding the budget. The degree to which these reserves are exploited will therefore help shape the severity of climate change.

Despite the importance of the potential CO_2 emissions from fossil fuel companies' reserves, they are not currently disclosed by any company. Financial reporting and industry management standards focus on reserve size and do not include methods for calculating greenhouse gas (GHG) emissions. At the same time, corporate GHG reporting standards focus on historical emissions and thus neglect the most material portion of fossil fuel companies' climate impact.

This working paper outlines a recommended methodology for the corporate accounting and disclosure of these emissions. The overall goal is the availability of transparent, credible, and consistent data on potential emissions that help illuminate companies' effects on the carbon budget and inform investment strategies and decisions to use reserves. While the methodology can be directly used by fossil fuel companies to disclose potential emissions data, other groups, such as civil society organizations, investors, and stock market listing authorities, can use the methodology indirectly to press for disclosure.

CONTENTS

Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback and to influence ongoing debate on emerging issues. Most working papers are eventually published in another form and their content may be revised.

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A number of technical issues affect the credibility of potential emissions data. For example, multiple emissions sources may influence overall amounts of potential emissions. While the downstream combustion of sold fossil fuels generates most of the potential emissions from most reserves, fossil fuel production and processing operations can also be important, depending on the reserve type and technologies used. Further, not all of the carbon in reserves is necessarily emitted to the atmosphere; some may be stored in long-lived products or underground through carbon capture and storage (CCS) projects. Reasonable estimates of potential emissions may therefore require looking beyond the sales quantities reported in reserves estimates.

In addition, the estimates are forecasts of the aggregate emissions that could unfold over periods as long as several decades. They are based on assumptions about economic and regulatory conditions, as well as technologies, which can easily change over the productive life of individual deposits. The estimates therefore have relatively high uncertainty and are subject to change.

This paper outlines a recommended methodology for how fossil fuel companies should take these issues into account when estimating and disclosing potential emissions from fossil fuel reserves. Key recommendations include the following:

- As a starting point, use the Petroleum Resource Management System (for oil and gas) and the Committee for Mineral Reserves International Reporting Standards template (for coal), or consistent national codes, to quantify the size of fossil fuel reserves.
- For oil and gas: Add in the amounts of fossil fuels used as fuel in internal operations.
- Add in the amounts of fossil fuels lost from internal operations through flaring, venting, and fugitive activities.
- Use calculation methods detailed in body of this paper to estimate the GHG emissions from fossil fuel combustion and the CH_4 emissions from leakage.
- Do not account for projected carbon storage from CCS projects.
- Separately report the potential emissions from proven and probable reserves.
- Report key assumptions and the sources of emissions factors used.

INTRODUCTION

The nature and importance of potential emissions

Potential emissions are the likely future emissions of carbon (in the form of CO_2 and CH_4)[1] that is currently stored in fossil fuel reserves (see Table 1) but that is expected to be released once those reserves are exploited in the future. Potential emissions have taken a large role in discussions of the global carbon budget, which is the estimated amount of carbon the world can emit while still having a likely chance of limiting global temperature rise to 1.5°C or 2°C over preindustrial levels. Beyond this threshold, the world will increasingly experience dangerously elevated amounts of sea-level rise, droughts, flooding, and other extremes. The scientific community estimates the carbon budget through 2100 to be 1 trillion tonnes of carbon, equivalent to 2,900 $GtCO_2$.[2] Of this budget, 66 percent had already been used up through 2011, leaving only 986 $GtCO_2$ to be emitted (IPCC 2014).

If extracted and consumed, the reserves of fossil fuel companies will cause the remaining budget to be exceeded. Preliminary estimates of the potential emissions from the existing proved and probable reserves of the largest 200 public coal, oil, and gas companies (by reserve size) already amount to 1,541 $GtCO_2$ or 156 percent of the remaining carbon budget (Carbon Tracker Initiative 2013).

Moreover, these reserves are being used and replaced at a very fast rate. For instance, based on current extraction rates in 2010, the largest 150 publicly traded oil and gas companies in the United States will exhaust their existing proved reserves within 12–14 years on average, if current trends continue (OGJ 2013). Comparable data are typically not calculated for the coal industry,[3] although Grubert 2012 estimated a value of 17 years for US coal companies. While current extraction rates may not accurately predict future rates because of possible changes over time in technologies and socioeconomic conditions affecting the energy industry, it is clear that the aggregate emissions from companies' reserves would easily surpass what is allowable for a 1.5°C or 2°C future.

In the Paris Agreement national governments committed to limit temperature rise to well below 2°C and pursue efforts to limit the rise to 1.5°C. A large portion of both corporate- and government-owned reserves must stay in the ground to meet these goals. Indeed, at least a third of all oil reserves, half of all gas reserves and over 80 percent of current coal reserves should remain unused through 2050 if the planet is to stay under the 2°C threshold (McGlade and Ekins 2015). Some portion of companies' reserves will therefore become unburnable and constitute "stranded assets." Under a stranded assets scenario, the valuations of public fossil fuel companies would decline steeply from a combination of stranded reserves and price declines for fossil fuels (see, e.g., HSBC 2013). These risks may not be priced into company valuations, posing risks to individual shareholders and also broader systemic risks to market stability (Carbon Tracker Initiative 2011, 2013). In response, an increasing number of shareholder resolutions have requested that companies report on the possibility of stranded assets. Investor initiatives and market analyses (ACCA and Carbon Tracker Initiative 2013; Carbon Tracker Initiative 2013) have also called on companies to publicly disclose their potential emissions and on stock market authorities to collect and aggregate these data. The absence of a consistent calculation and reporting approach has been identified as a primary barrier to the availability of such data (ACCA and Carbon Tracker Initiative 2013).

Table 1 | **Key terms**

Flaring	The controlled burning of fossil fuels without the production of useful heat or energy.
Fugitive emissions	Emissions that are not physically controlled but result from the intentional or unintentional releases of GHGs.
Potential emissions	The emission of carbon (in the form of CO_2 and CH_4) that is currently stored in fossil fuel reserves but is expected to be released once those reserves are produced in the future.
Reserves	While the oil and gas and coal industries have different definitions,* reserves can be broadly defined as the amount of fossil fuel that is currently in the ground and that a company is entitled to market or extract based on the application of economic, technical, or contractual criteria.
Probable reserves	The subset of a company's reserves that have the greatest likelihood of being produced.
Proved reserves	The subset of a company's reserves that have a lesser likelihood of being produced.
Venting	All controlled releases into the atmosphere of waste gas streams and process by-products.

* Petroleum- and coal-specific definitions for (probable/proved) reserves are provided in the Glossary.

Previously, estimates of potential emissions from fossil fuel reserves have been based on estimates of future emissions from the burning of fossil fuels by end users (e.g., at a power station or in a car). This approach is likely to result in underestimates, however, because it ignores emissions sources in fossil fuel production and processing operations, such as energy consumption during fuel extraction and processing, and fuel losses through flaring, fugitive releases, and venting. In an analysis of 30 different oil deposits, such sources accounted for between 5 percent and 37 percent (average: 15%) of life-cycle emissions (Gordon et al. 2015).

Scope and objectives of paper

This paper outlines a recommended methodology for estimating and reporting the potential emissions from the fossil fuel reserves held by coal, oil, and gas companies. It concentrates only on the carbon stored in reserves and attempts to account for the primary routes in which this carbon is expected to be released into the atmosphere, both during and after production. These routes include fuel use during fuel extraction and processing; flaring, fugitive, and venting emissions; and combustion of fuel products by end consumers.

Because the paper focuses on the carbon already contained in reserves, it is not concerned with GHG emissions that do not involve this carbon. Consequently, the N_2O emissions from fuel combustion are out of scope, although these are likely immaterial in any case. Similarly, the paper does not attempt to address other GHG emissions that occur during the life-cycle of fossil fuel production and use, such as those from the production of capital equipment and purchased energy. Nor does it recommend ways to conduct the assurance or verification of reported potential emissions data, as assurance requirements will vary by application (e.g., voluntary versus regulatory reporting).

The paper is also not intended as a stand-alone methodology for evaluating risks related to stranded assets. While potential emissions are one consideration in such risk analyses, they are but one factor among many, such as changes in tax and subsidy regimes and changes in technology (e.g., improvements in renewable energy generation and electricity storage). Finally, the methodology is not applicable to country- or region-level analyses since it is grounded on frameworks for disclosing company-wide reserve figures.

The objectives of this methodology are the following:

- Promote the transparent and consistent disclosure of the potential emissions from fossil fuel reserves.
- Draw attention to the importance of companies' potential emissions relative to the global carbon budget.
- Draw attention to the importance of fossil fuel extraction and processing operations in estimating potential emissions.
- Enable meaningful comparisons of potential emissions intensity across companies' fossil fuel reserves.
- Support the reporting of data that can be used as an input in evaluating risks related to stranded reserves.

The primary audience for this paper comprises fossil fuel companies responding to stakeholder requests for disclosure. Other groups can use this paper indirectly to press for disclosure; these organizations include the following:

- Civil society organizations asking for greater transparency about the reserves of fossil fuel companies relative to the global carbon budget and advocating to keep those reserves in the ground.
- Investors seeking to assess and incorporate future monetary risks of fossil fuel assets in their investment decisions.
- Stock market listing authorities (e.g., the World Federation of Exchanges and its members) seeking to require fossil fuel companies to report potential emissions data in annual reports or other disclosures.

Development process

A first draft of this methodology was prepared based on desk research and consultations with exchange regulators and reserves auditing firms. A second draft was developed based on feedback from 15 select experts and an open comment period during which 20 submissions were received. The experts were drawn from reserves auditing firms, the US Securities and Exchange Commission (SEC), fossil fuel companies, industry associations, voluntary reporting programs, nongovernmental organizations, and academia.

Outline of methodology

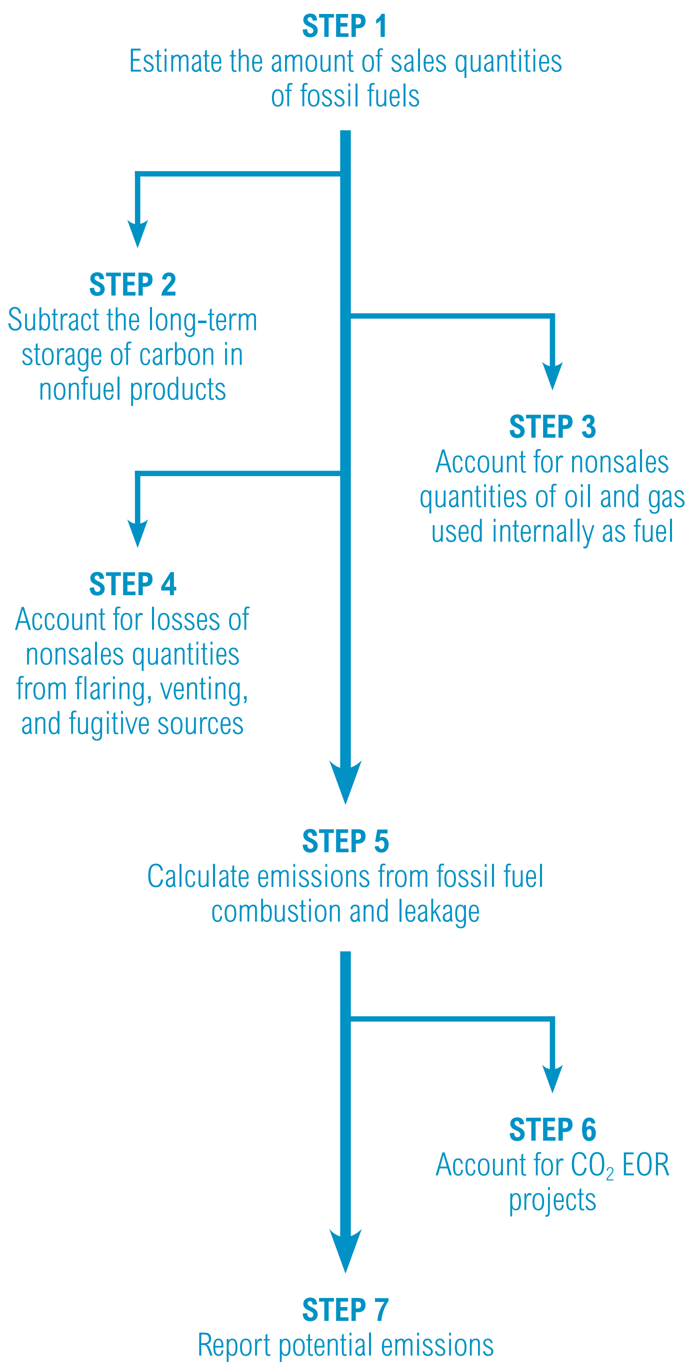
The methodology comprises multiple steps (Figure 1). The starting point (Step 1) is the determination of sales quantities, which represent the amount of fossil fuels potentially available for sale or transfer to other companies or business segments. Subsequent steps then adjust these sales quantities to reflect the long-term storage of carbon in nonfuel products (Step 2) and reflect nonsales quantities that can also contribute to potential emissions (Steps 3 and 4). The result is the amount of fuel that gives rise to potential emissions. Step 5 then entails estimating potential emissions based on this amount, while Step 6 involves correcting the emissions estimates for the storage of CO_2 in enhanced oil recovery (EOR) projects. Finally, Step 7 provides guidance on reporting potential emissions.

Companies' reserves are categorized and reported according to industry-accepted frameworks, which are discussed further in Step 1. These frameworks specify criteria for determining what portion of a company's overall stock of hydrocarbons can be recognized as reserves (and as sales quantities). In effect, a company's reserves represent the total amount of hydrocarbons it reasonably expects to extract in the future given commercial and technical considerations. Because potential emissions estimates are based on reserves figures, they represent the emissions from all future time periods reflected in the reserves estimates.

For each step in the methodology, this paper outlines background information and recommendations. It makes two different types of recommendations: core recommendations (denoted by "should"), which indicate actions that all companies should take, and ancillary recommendations (denoted by "may"), which indicate actions that companies may also wish to follow depending on their reporting objectives and business context. The distinction between the two types is based on the likely significance of an accounting step to the final results and the likely availability of the required data.

A summary of the steps and core recommendations is provided at the end of the paper.

Figure 1 | **Overview of the steps in estimating and reporting potential emissions**



STEP 1: ESTIMATE THE AMOUNT OF SALES QUANTITIES OF FOSSIL FUELS

Background

The first step in estimating potential emissions is to determine the overall quantities of fossil fuels in existing reserves that may be extracted and sold by a company in the future. This determination should use existing measurements that are readily available to companies and that have already been reported according to industry-specific classification systems.

The minerals (including coal) and oil and gas industries have independently developed widely used systems for categorizing and reporting fossil fuel deposits. These systems are industry-specific, such that neither covers both coal and petroleum, but they both categorize fossil fuel amounts based on the level of measurement uncertainty and the technical and economic likelihood of extraction. Approaches for actually measuring fossil fuel quantities are beyond the scope of this paper, given the complexities involved and voluminous technical guidance available (e.g., SPE et al. 2011).

The dominant categorization system for coal is the *International Reporting Template for the Public Reporting of Exploration Results, Mineral Resources, and Mineral Reserves*, published by the Committee for Mineral Reserves International Reporting Standards (hereafter, "CRIRSCO template"; CRIRSCO 2013). The dominant system for petroleum is the *Petroleum Resources Management System* (PRMS), published by the Society of Petroleum Engineers (SPE), the American Association of Petroleum Geologists (AAPG), the World Petroleum Council (WPC), and the Society of Petroleum Evaluation Engineers (SPEE) (SPE et al. 2007). These two systems have important bearing on many steps in the overall methodology for potential emissions and are discussed in more detail in this section.

Each system takes the form of a two-dimensional matrix that classifies deposits according to the commercial and technical certainty of their being produced. Both systems recognize proved and probable reserves as having the highest level of confidence, with proved reserves having the highest level of confidence. Proved and probable mineral reserves (CRIRSCO template) have the same general level of associated confidence as proved and probable petroleum reserves (PRMS). Beyond this broad similarity, several differences exist.

The PRMS identifies a third general category of reserves called possible reserves, while allowing for the further disaggregation of all reserves by whether they are developed (recovery through existing wells) or undeveloped (recovery through future investments). No equivalent categories exist in the CRIRSCO template.

Also unlike the CRIRSCO template, the PRMS distinguishes between conventional and unconventional resources. Conventional resources exist in discrete petroleum accumulations, are extracted through wellbores, and typically require minimal processing prior to sale. In turn, unconventional resources exist in petroleum accumulations that are pervasive throughout a large area and are not significantly affected by hydrodynamic influences, meaning they typically require specialized extraction technologies. Unconventional resources include extra-heavy oil, bitumen, tight gas, coal bed methane, shale gas, oil shale, and gas hydrates.

In addition, the two frameworks differ in terms of the permitted time horizons for assessing the commercial certainty of fossil fuel extraction and therefore the size of fossil fuel reserves. Under the PRMS, new extraction projects can generally be categorized under reserves provided that the projects will start within five years (with some documented exceptions), whereas the CRIRSCO template does not specify requirements in this regard.

Finally, while both systems use a reference point to determine which quantities get recognized as reserves, the exact definition of this point differs. Under the PRMS, oil and gas quantities are defined in terms of sales quantities measured at the reference point, which is typically the point of sale to third parties or where custody is transferred to the producing entity's downstream operations. In contrast, mineral reserves are based on unprocessed ore, usually measured at the point where the mineral ore is delivered to the processing plant. Still, the CRIRSCO template requires the disclosure of recovery factors, which are usually percentage estimates of the in-situ ore recovered after mining has taken place. These factors permit the derivation of sales quantities, and best practice is to report sales quantities of minerals. In addition, the PRMS requires that reserves estimates reflect any contractual arrangements and royalty obligations in effect at the time of the estimates. The CRIRSCO template includes no such explicit requirement.

Whatever differences exist, both systems enjoy extensive international use. For example, the CRIRSCO template is the basis for national reporting codes in Australia, Canada, Europe, Russia, South Africa, and the United States, a list that soon will also include China and Indonesia (SME 2011). Most listing authorities and stock exchanges refer to one or more of these minerals codes when specifying the reporting requirements for listed companies, at least in those jurisdictions that have formalized disclosure requirements. Likewise, many stock exchanges or listing authorities require the use of PRMS or reserves standards that are broadly consistent with PRMS. In both the coal and petroleum industries, regulators generally require that proved reserves be reported, but not all require that probable reserves be reported. Independent of regulatory requirements, though, companies would typically use the CRIRSCO template and the PRMS for internal planning purposes.

Recommendations

1. As the basis for calculating the potential emissions from sold products, companies should use estimates of sales quantities based on the application of the PRMS, the CRIRSCO template, and/or national codes that are consistent with either system.
2. Sales quantities should exclude royalties and interests owned by others and reflect contractual arrangements and royalty obligations in effect at the time of the estimate.
3. Coal companies should adjust reserve estimates using reported recovery factors to calculate sales quantities.

STEP 2: SUBTRACT THE LONG-TERM STORAGE OF CARBON IN NONFUEL PRODUCTS

Background

Not all sales quantities of fossil fuels are burned. A portion is diverted to the manufacture of nonenergy products, such as petrochemicals, asphalts and road oil, lubricants, waxes, and pigments.

Depending on the type of nonenergy product and how it is used, some or all of the carbon contained within it can enter long-term storage. Nonenergy uses vary greatly by feedstock type and composition (e.g., viscosity), refinery capabilities, petrochemical demand, and likely numerous other factors (Heede 2014). Consequently, there is a lot of spatial and temporal variation in the proportion of carbon that is stored, making it difficult to forecast actual storage rates.

Table 2 | **Estimated carbon storage rates for fossil fuels**

		US EPA 2013*	HEEDE 2014	MARLAND AND ROTTY 1984
Geographic applicability		USA	Global	Global
Carbon storage factors (%)	Coal	0.07%	0.02%	0.78–0.82%
	Oil and natural gas liquids (NGLs)	8.34%	8.02%	4.7–8.7%
	Natural gas	0.54%	1.86%	0–2%

* The US EPA values do not account for the losses of carbon from the incineration of nonenergy products as waste and so may overestimate storage rates in the United States.

Various studies have attempted to quantify storage factors for coal, natural gas, and oil at a national or global level (Table 2). Values vary and the relative accuracy of the studies is presently unclear. Still, a greater amount of the carbon in oil is stored (about 5 to 10%), compared with that in coal and natural gas (less than 1% and 2%, respectively). Because of the variation in storage rates, the use of global defaults may not closely approximate actual storage rates at the company level.

Recommendations

1. To remain conservative, companies may assume that there is no long-term storage of carbon in nonenergy products.
2. If storage is assumed, companies may calculate the amount of stored carbon using the following (in order of preference):
   a. Company-specific data on the fate of produced fossil fuels in tandem with published, product-specific storage factors.
   b. Storage factors sourced from recent, peer-reviewed scientific literature.
   c. The storage factors in Table 2 from Marland and Rotty 1984 or Heede 2014.
3. To correct fossil fuel sales quantities for long-term storage of carbon in nonenergy products, companies should use Equation 1:

   Equation 1: Correcting sales quantities for long-term storage in nonenergy products

   $$\textit{Corrected sales quantities} = F_j * (1 - SF)$$

   Where:

   F_j = Sales quantities of fossil fuel of type j, as determined using the PRMS or the CRIRSCO template, and measured in units of mass, volume, or energy (e.g., tonnes, bbl, scf, or MMBTU)

   SF = Storage factor, the fraction of carbon in the fossil fuel that is stored on a long-term basis in nonenergy products.

STEP 3 (FOR THE PETROLEUM INDUSTRY): ACCOUNT FOR NONSALES QUANTITIES OF OIL AND GAS USED INTERNALLY AS FUEL

Background

Under the PRMS, fossil fuels that are produced by the reporting company but subsequently used as fuel in production and processing operations (lease fuel) are excluded from or reported separately from sales quantities. These fuels support a wide range of activities, including driving pumps that produce petroleum; heating output streams to separate oil, gas, and water; producing steam for enhanced oil recovery (EOR) or bitumen extraction; and driving turbines to generate electricity and heat for on-site operations.

The intensity of these operations and corresponding GHG emissions depends on a range of interacting variables, such as the age, depth, and pressure of the producing field; the viscosity, density, and composition of the in-situ fossil fuels; and the project development type (e.g., onshore versus offshore) (ICCT 2010). Notably, the emissions from lease fuels are expected to compose a larger percentage share of potential emissions over time. This is because the energy intensity of oil and gas production is increasing—for example, by approximately one-third since 1980 in OECD countries (IPIECA 2013), despite heavy investments to improve efficiency. There are two main reasons for this (IPIECA 2013): (1) increased field age and reduced pressure and (2) declining conventional reserves and increasing reliance on less accessible conventional fields (e.g., offshore deep water fields) and unconventional deposits, such as oil sands and extra-heavy oil, which require more energy to extract and process and/or refine.

Recommendations

1. Companies should account for the nonsales quantities likely to be consumed as fuel in internal operations. These quantities should be the same as those calculated for the purpose of reporting sales quantities under the PRMS.
2. Companies should account for the emissions in proportion to their share of production from reserves (e.g., according to their share of production under production sharing agreements).
3. Companies should not account for imported energy (e.g., purchased fuel and electricity).

STEP 4 (FOR THE PETROLEUM INDUSTRY): ACCOUNT FOR LOSSES OF NONSALES QUANTITIES FROM FLARING, VENTING, AND FUGITIVE SOURCES

Background

A portion of the fossil fuels that are produced by the reporting company is subsequently lost through flaring and leakage (i.e., venting or fugitive CH_4 emissions) before the reference point. This portion is not available for sale and must not be included in reported reserves figures (i.e., sales quantities).

This is important because the emissions from flaring and leakage are considerable. For example, flaring in the oil and gas industry accounted for 0.43 percent of global anthropogenic emissions in 2010.[4] In turn, leakage of CH_4 from the overall natural gas system is a key factor influencing the potential emissions from natural gas reserves. Assuming a 1 percent leakage rate, leaked CH_4 would amount to 12 percent of the CO_2 emissions from the burning of the remaining gas, on a CO_2-equivalent (CO_2e) basis.[5] Actual measurements of leakage rates during the production phase vary widely, from 0.42 percent (Allen et al. 2013) to 11 percent (Karion et al. 2013), although neither extreme is likely to be representative of typical patterns (Brandt et al. 2014).

A portion of fossil fuels included in reported reserves figures will also be leaked prior to end consumption (i.e., a portion of sales quantities will be leaked downstream of the reference point). Downstream transmission and distribution systems account for about half of the methane lost from natural gas systems in the United States (US EPA 2013). Consequently, including this leakage in potential emissions estimates would help make those estimates more complete. However, quantities that are leaked from downstream operations are already reported in reserves figures and would have to be subtracted from those figures to avoid double counting.

Overall, great uncertainty surrounds methane leakage from natural gas systems, although a lot of research is under way to improve default industry emission factors and life-cycle estimates (Brandt et al. 2014).

Recommendations

1. Companies should account for the losses of nonsales quantities of oil and gas from venting, flaring, and fugitive sources. These nonsales quantities should be the same as those calculated for the purpose of reporting sales quantities under the PRMS.
2. Companies should account for these losses in proportion to their share of production from reserves (e.g., according to their share of production under production sharing agreements). In some cases, contracts might assign ownership of the emissions from flaring (and possibly venting/fugitive emissions) (IPIECA, API, and OGP 2011); such assignments should take precedence when estimating the potential emissions.
3. Companies may also account for the leakage of sales quantities from operations downstream of the reference point. If they do so, they should factor out the sales quantities involved from the reserves figures, estimate the losses using assumptions based on current operating practices and default industry emission factors (e.g., from the API Compendium [API 2009]), and report the assumptions used.

STEP 4 (FOR THE COAL INDUSTRY): ACCOUNT FOR LOSSES OF NONSALES QUANTITIES FROM FLARING, VENTING, AND FUGITIVE SOURCES

Background

CH_4 in coal seam gas is principally emitted during mining, although additional "postmining" emissions occur during the subsequent handling, processing, and transportation of coal (IPCC 2006). In underground mines, the seam gas may be burned for energy or flared (generating CO_2, as well as CH_4 from incomplete combustion) or vented (releasing CH_4).

These mining and postmining emissions can represent a significant fraction of the CO_2 emissions from coal combustion and tend to increase with the rank of coal and coal depth. For instance, the default emission factors for coal mining from the IPCC range from 0.2 to 16.7 kg CH_4 per tonne of coal, for surface and underground mines respectively (IPCC 2006). However, the emissions are not factored into estimates of reserves quantities under the CRIRSCO template. To calculate these emissions, it would therefore be necessary to make assumptions about changes in the treatment of seam gas over the productive life of coal deposits, which would carry considerable uncertainty. An alternative approach is to estimate emissions based on current operating practices.

Recommendations

1. Companies should account for both the methane emissions from the leakage and the CO_2 emissions from the combustion of seam gas.
2. Companies should estimate the emissions using assumptions based on current operating practices and report the assumptions used.

STEP 5: CALCULATE EMISSIONS FROM FOSSIL FUEL COMBUSTION AND LEAKAGE

Recommendations

Combustion emissions

1. The potential emissions from all fossil fuel combustion should be calculated by applying emission factors following the general approach in Equation 2 (for the use of sold products and the internal use of lease fuels; from Steps 1 and 3) and Equations 3 and 4 (for flaring; from Step 4).

   Equation 2: CO_2 emissions from fuel combustion.
   $CO_2\,(tonnes\ CO_2e) = H_j * OF * EF_j$

   Equation 3: CO_2 emissions from flaring.
   $CO_2\,(tonnes\ CO_2e) = H_j * OF * DF * EF_j$

   Equation 4: CH_4 emissions from flaring.
   $CH_4\,(tonnes\ CO_2e) = H_j * (1 - DF) * GWP_{CH4}$

   Where:
   H_j = Amount of burned fossil fuel of type j, measured in units of mass, volume, or energy (e.g., tonnes, bbl, scf, or MMBTU).

   OF = Oxidation fraction, the fraction of carbon in the fossil fuel that is completely oxidized during combustion. Companies should assume a value of 1.0, consistent with accounting practices for national (IPCC 2006) and corporate-level (API 2009) reporting in the industry.

   EF_j = Emission factor (tonnes CO_2 per unit amount of fossil fuel burned), specific to fossil fuel of type j.

   DF = Destruction factor, the fraction of fossil fuel that is destroyed during flaring. Companies should assume a value of 0.98, consistent with accounting practices for national (IPCC 2006) and corporate-level (API 2009) reporting in the industry.

   GWP_{CH4} = Global warming potential for CH_4, converting CH_4 emissions to a common currency (CO_2e). Companies should use a GWP value that is the same as that used for standard GHG inventory reporting purposes (e.g., regulatory or voluntary reporting). Companies should use GWP values expressed on a 100-year time horizon. The latest available GWP value from the IPCC (currently 28) is preferred.[6]

2. Combustion emissions should be calculated using any combination of the following sources of emission factors (listed in order of preference):
   a. Field-specific data. For convenience, companies with large numbers of holdings may choose to develop weighted average factors, based on, for example, the remaining proved reserves.
   b. National or subnational default emission factors for voluntary or regulatory reporting.
   c. International default emission factors (e.g., Tier 1 defaults in IPCC 2006; see Table 3).

Note that the use of default factors will require companies to disaggregate fossil fuel quantities by type. For instance, use of the default IPCC factors will require the separation of liquid petroleum reserves into natural gas liquids (NGLs) and crude oil components, and coal reserves into different ranks. Sometimes it will not be possible to separate fossil fuel reserves by type. For instance, under PRMS, if natural gas is sold wet (i.e., without the removal of NGLs), then the NGLs are included in the reserve estimate for natural gas. In such cases, companies may simply use emission factors for the reported reserve type (natural gas in this case).

CH_4 emissions from leakage

3. The CH_4 emissions from leakage (venting and fugitive losses) should be calculated following Equation 5.

Equation 5: CH_4 emissions from leakage.

$$CH_4\,(tonnes\ CO_2e) = H_j * F_{CH4} * GWP_{CH4}$$

Where:

H_j = Amount of gas leaked, measured in units of mass (e.g., tonnes), volume, or energy.

F_{CH4} = Fraction of CH_4 in natural gas. Companies may assume a mass fraction of 0.95, which is typical of processed natural gas.

GWP_{CH4} = Global warming potential for CH_4, converting CH_4 emissions to a common currency (CO_2e). Companies should use a GWP value that is the same as that used for standard GHG inventory reporting purposes (e.g., regulatory or voluntary reporting). Companies should use GWP values expressed on a 100-year time horizon. The latest available GWP value from the IPCC (currently 28) is preferred.[7]

4. The amount of gas leaked should be calculated using any combination of the following sources of emission factors (listed in order of preference):
   a. Field-specific data. For convenience, companies with large numbers of holdings may choose to develop weighted average factors, based on, for example, the remaining proved reserves.
   b. Industry default emission factors (e.g., those in API 2009).
   c. National or subnational default emission factors for voluntary or regulatory reporting.
   d. International default emission factors (e.g., Tier 1 defaults in IPCC 2006; see Table 3).

Figures 2 and 3 outline the general calculation approach for petroleum and coal, respectively.

Figure 2 | **Recommended calculation approach for oil and gas companies**

POTENTIAL EMISSIONS (Mt [megatonne] CO_2e) =

CO_2 FROM FOSSIL FUEL COMBUSTION (Mt CO_2e)

[(Carbon in sales quantities (Mt) x (1 - carbon storage factor)

– Carbon lost as CH_4 in leakages of sales quantities from downstream operations (Mt)

+ Carbon in nonsales fuel quantities burned on-site + Carbon in nonsales quantities of flared gas]

x 44/12

+

CO_2 AND CH_4 FROM OTHER LOSSES (Mt CO_2e)

CO_2 from venting and fugitive sources prior to the reference point (Mt)

+ (CH_4 from venting and fugitive releases of nonsales quantities (Mt) x GWP)

+ (CH_4 from venting and fugitive releases subsequent to the reference point (Mt) x GWP)

Figure 3 | **Recommended calculation approach for coal companies**

POTENTIAL EMISSIONS (Mt [megatonne] CO_2e) =

CO_2 FROM FOSSIL FUEL COMBUSTION (Mt CO_2e)		CH_4 FROM OTHER LOSSES (Mt CO_2e)
[(Carbon in sales quantities (Mt) + Carbon in flared seam gas (Mt)) x 44/12	+	(CH4 from venting and fugitive releases of seam gas (Mt) * GWP)

Table 3 | **Default IPCC Tier 1 emission factors provided on a mass and energy basis and, where possible, a volume basis**

TYPE OF FOSSIL FUEL[1]	ENERGY BASIS	MASS BASIS	VOLUME BASIS		
	TONNES CO_2 / TJ (LHV)	TONNES CO_2 / TONNE FOSSIL FUEL	TONNES CO_2 / bbl[2]	TONNES CO_2 / MILLION SCF_3[3]	TONNES CO_2 / BOE[4]
Petroleum					
Crude oil	73.3 (71.1–75.5)	3.1 (3.0–3.4)	0.4 (0.4–0.4)		
Natural gas liquids	64.2 (58.3–70.4)	2.8 (2.6–3.3)			
Shale oil	73.3 (67.8–79.2)	2.8 (2.6–3.6)	0.4 (0.3–0.5)		
Natural gas	56.1 (54.3–58.3)	2.7 (2.6–2.9)		53.4 (51.6–58.2)	0.3 (0.3–0.3)
Coal					
Anthracite	98.3 (94.6–101.0)	2.6 (2.5–3.2)			
Other bituminous coal	94.6 (89.5–99.7)	2.4 (2.3–3.0)			
Subbituminous coal	96.1 (92.8–100.0)	1.8 (1.8–2.6)			
Lignite	101.0 (90.9–115.0)	1.2 (1.17–2.5)			

Notes:
[1] Definitions used by the IPCC for these types of fossil fuels are provided in the Glossary.
[2] Assumes density values of 0.8 kg/l (crude oil) and 1 kg/l (shale oil) (GHG Protocol 2015).
[3] Assumes density value of 0.7 kg/m^3 (GHG Protocol 2015).
[4] Assumes 5798.62 ft^3 of natural gas per BOE.

STEP 6: ACCOUNT FOR CO_2 ENHANCED OIL RECOVERY (EOR), IF RELEVANT

Background

CO_2 enhanced oil recovery (CO_2 EOR) is a form of EOR that permits production of a greater share of the oil that remains after primary and secondary recovery. During CO_2 EOR, CO_2 is injected into the reservoir, where it dissolves in crude oil (under the right temperature and pressure conditions), increasing oil mobility. The injected CO_2 may be sourced from natural gas processing plants, natural CO_2 reservoirs, power plants, and industrial facilities. Most of the injected CO_2 is back-produced with the produced oil and then recovered for reinjection. However, a portion remains in the reservoir, typically about 0.3 tonnes CO_2 per barrel of produced oil (IEA 2013). Because the oil reservoir is bounded by an impermeable rock layer, this portion is effectively stored, provided that the well is properly sealed.

There has been only very limited deployment of carbon capture and storage (CCS) projects, and no commercial application, to date. As of 2012, the capacity of existing CCS projects (excluding CO_2 EOR) totaled only 6 million tonnes CO_2 per year (IEA 2013). The construction of all projects in advance planning would only increase this capacity to about 55 million tonnes CO_2 (Global CCS Institute 2015).

Recommendations

1. Companies may account for carbon stored in CO_2 EOR projects, but only if the injected CO_2 is planned to derive from fossil fuels the company will produce.
2. If CO_2 EOR is accounted for, companies should assume a storage rate of 0.3 tonnes CO_2 per barrel of produced oil (factor derived from IEA 2013).
3. Companies should not make any adjustments to estimates of potential emissions for CCS projects because of the expected very limited deployment of CCS projects worldwide.

STEP 7: REPORT POTENTIAL EMISSIONS

A credible emissions report presents information that is relevant, accurate, complete, consistent, and transparent. A key challenge is representing data uncertainty associated with potential emissions from fossil fuel reserves. Fundamentally, estimates of reserve size, as well as the amount of fossil fuel that is either used or lost in operations, can only be based on currently available information. As market, technical, and regulatory conditions change, these estimates may become outdated such that current estimates may over- or underestimate the actual emissions. Consequently, potential emissions estimates have high uncertainty, and this uncertainty is closely related to the type of deposit (e.g., proved versus probable reserve), the type of fossil fuel (e.g., conventional versus unconventional), and the type of emissions source (e.g., combustion of sales quantities versus leakage of nonsales quantities). Reports should therefore present the estimates and methodologies used with sufficient transparency to allow audiences to meaningfully interpret the reported information.

Recommendations

1. Companies should report the total potential emissions from all existing proved reserves.
2. Where companies publicly report probable reserves figures, companies should also separately report the total potential emissions from all existing probable reserves.
3. Emissions should be reported separately by gas (CO_2 and CH_4) and in combined CO_2e, on a million metric tonne (Mt) basis.
4. Companies should disclose whether potential emissions estimates have been adjusted to account for carbon storage in long-lived nonenergy products and/or CO_2 EOR projects.
5. Companies should disclose whether any emissions processes have been excluded from the estimates (i.e., the combustion of sales quantities, combustion of lease fuel, or losses of nonsales quantities through flaring and leakage).
6. Companies should disclose key assumptions, such as those pertaining to the use or loss of nonsales quantities and carbon storage. They should also report the source of emission factors.
7. If reported within a corporate GHG inventory report, potential emissions should be reported as a memo item outside of the scopes (see the GHG Protocol Corporate Accounting and Reporting Standard for further information).[8]
8. Oil and gas companies may further disaggregate potential emissions by the status of each reserve (developed versus undeveloped) and by the type of resource (conventional versus unconventional), using definitions provided by the PRMS.
9. Companies may further disaggregate potential emissions estimates by each of the activities described in this paper; that is, by the combustion of sales quantities, storage of carbon in long-lived sales quantities,

Box 1 | **Disclosure of potential GHG emissions from production of fossil fuel reserves**

	POTENTIAL EMISSIONS (MILLION TONNES, MT)		
TYPE OF RESERVE	**CO_2**	**CH_4**	**CO_2e**
Proved			
Conventional			
Unconventional			
Probable			
Conventional			
Unconventional			
Total			

Notes:

- Estimates have been adjusted to account for carbon storage in long-lived nonenergy products and/or CO_2 EOR projects.
- Description of main assumptions and sources of methodologies.
- Description of performance using GHG efficiency metrics. Example: the potential emissions amount to xx tonnes CO_2e/barrel oil equivalent in held reserves.

combustion of lease fuel, losses of nonsales quantities through flaring and leakage, and the CO_2 emissions stored through CO_2 EOR projects.

10. Companies may report GHG efficiency metrics to allow the tracking of a company's progress over time or comparisons across companies. Such metrics could include the potential GHG emissions per unit of sales quantities (e.g., tonnes CO_2e/tonne coal or tonnes CO_2e/bbl oil equivalent).

Box 1 provides a suggested template for disclosing potential emissions.

BRINGING IT ALL TOGETHER: SUMMARY OF RECOMMENDED METHODOLOGY

The extraction and use of the fossil fuels in companies' reserves would significantly exceed the remaining carbon budget for a 2°C temperature rise over preindustrial levels, leading to more frequent and severe extreme weather events, accelerated sea-level rise, and damage to infrastructure. In the Paris Agreement national governments committed to achieve net-zero greenhouse gas emissions in the second half of this century, limit temperature rise to well below 2 degrees 2°C, and pursue efforts to limit temperature rise to 1.5°C. Attainment of these commitments will require the fossil fuel industry to leave part of its reserves in the ground, at least in the absence of any commercially viable, large-scale carbon capture technology. It is imperative that fossil fuel companies, their shareholders, and other stakeholders have the information they need to make sound decisions in light of this need. Estimates of the potential emissions from fossil fuel companies' reserves is an important input into such decision-making, but no established methodology exists for estimating and disclosing these emissions. This paper presents such a methodology (Table 4), with the understanding that it is likely to be revised over time as companies become more practiced in applying it.

Table 4 | Outline of main recommendations

<table>
<tr><th rowspan="2">STEP</th><th colspan="2">INDUSTRY</th></tr>
<tr><th>OIL AND GAS</th><th>COAL</th></tr>
<tr><td rowspan="2">1. Estimate the amount of sales quantities of fossil fuels (pp. 5–6).</td><td>Use PRMS (SPE et al. 2007) and/or consistent national code.</td><td>■ Use CRIRSCO template (CRIRSCO 2013) and/or consistent national code.
■ Adjust reserve estimates using recovery factors to calculate reserve quantities.</td></tr>
<tr><td colspan="2">Exclude royalties and interests owned by others and reflect contractual arrangements and royalty obligations in effect at the time of the estimate.</td></tr>
<tr><td>2. Subtract the long-term storage of carbon in nonfuel products (pp. 6–7).</td><td colspan="2">No core recommendations.</td></tr>
<tr><td>3. Account for nonsales quantities used internally as fuel (pp. 7–8).</td><td>■ Account for the use of nonsales quantities as fuel.
■ These quantities should be the same as those calculated for the purpose of reporting sales quantities under the PRMS.
■ Do not account for imported energy (e.g., purchased fuel and electricity).</td><td>Not applicable</td></tr>
<tr><td>4. Account for losses of nonsales quantities from flaring, venting, and fugitive sources (pp. 8–9).</td><td>■ Account for venting, flaring, and fugitive losses of nonsales quantities of oil and gas.
■ These quantities should be the same as those calculated for the purpose of reporting sales quantities under the PRMS.
■ Account for losses in proportion to share of production from reserves.
■ Contracts that assign ownership of the emissions take precedence when estimating potential emissions.</td><td>■ Account for potential emissions related to coal seam gas.
■ Account for both the methane emissions from the leakage and the CO_2 emissions from the combustion of seam gas.
■ Estimate the emissions using assumptions based on current operating practices.</td></tr>
<tr><td>5. Calculate emissions from fossil fuel combustion and leakage (pp. 9–11).</td><td colspan="2">■ Calculate the potential emissions from all fossil fuel combustion—use of sold products, internal use of lease fuels, and flaring—using the general approach in Equations 2–4 and using emission factors from (in order of preference) field-specific data, national or subnational defaults, or IPCC international defaults.
■ Assume an oxidation factor of 1.0 and a destruction factor of 0.98 during flaring.
■ Calculate the potential emissions from leakage using Equation 5 and leakage rates from (in order of preference) field-specific data, industry defaults, national or subnational defaults, or IPCC international defaults.
■ Use a CH_4 GWP value that is expressed on a 100-year time horizon and the same as that used for GHG inventory reporting purposes (e.g., regulatory or voluntary reporting).</td></tr>
<tr><td>6. Account for CO_2 EOR and CO_2 projects (p. 12).</td><td colspan="2">Companies should not take CCS projects into account.</td></tr>
<tr><td>7. Report potential emissions (pp. 12–13).</td><td colspan="2">Disclose:
■ The potential emissions from proved reserves.
■ The potential emissions from probable reserves, where these reserves are publicly reported.
■ Emissions from proved reserves separate from those of probable reserves.
■ Emissions separately by gas (CO_2 and CH_4) and in combined CO_2e, on a million metric tonne (Mt) basis.
■ Whether emissions estimates have been adjusted to account for carbon storage in long-lived nonenergy products and CO_2 EOR projects.
■ Whether any emissions processes have been excluded from the estimates (i.e., the combustion of sales quantities, combustion of lease fuel, or losses of nonsales quantities through flaring and leakage).
■ Key assumptions, such as those pertaining to the use or loss of nonsales quantities and carbon storage, as well as the source of emission factors used.
■ Potential emissions outside of the scopes as a memo item, if reported within a corporate GHG inventory.</td></tr>
</table>

Note: Additional (ancillary) recommendations exist for many of the methodological steps involved and are outlined in preceding sections.

ABBREVIATIONS

bbl	barrel
BOE	barrel of oil equivalent
CCS	carbon capture and storage
CH_4	methane
CO_2	carbon dioxide
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
EOR	enhanced oil recovery
GHG	greenhouse gas
$GtCO_2$	one billion metric tonnes of CO_2
GWP	global warming potential
MMBTU	million British Thermal Units
NGL	natural gas liquid
Mt	megatonne
PRMS	*Petroleum Resource Management System*
scf	standard cubic foot

ENDNOTES

1. Because it is only concerned with tracking the fate of carbon contained in reserves, this paper does not consider N_2O as part of potential emissions.
2. 1 $GtCO_2$ equals 1 billion metric tons of CO_2.
3. "Unlike the oil and gas sector, reserve replacement rates are rarely used, except occasionally as referencing points for undeveloped assets. This is because mineral reserves tend to require significant additional capital and operating costs before they can be converted into earnings, and the timing and economics of this can be uncertain. Assets therefore tend to be valued on known or planned production rates discounted over the life of an asset" (HSBC 2012).
4. Based on global GHG emissions data from the EDGAR database (EC, JRC/PBL 2009) and flaring CO_2 emissions from the Carbon Dioxide Information Analysis Center (Boden, Marland, and Andres 2013).
5. These calculations assume the following: 100% combustion efficiency, the IPCC Tier 1 heating value and carbon content for natural gas, a density of 0.7 kg/m^3 (GHG Protocol 2015), and a mass fraction of 0.95 for CH_4 in natural gas.
6. IPCC Fifth Assessment Report, http://www.ipcc.ch/pdf/assessmentreport/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf.
7. IPCC Fifth Assessment Report, http://www.ipcc.ch/pdf/assessmentreport/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf.
8. http://www.ghgprotocol.org/standards/corporate-standard.

GLOSSARY OF TERMS

Anthracite coal – A type of coal used for industrial and residential applications. It has generally less than 10 percent volatile matter and a high carbon content (about 90% fixed carbon). Its gross calorific value is greater than 23,865 kJ/kg (5,700 kcal/kg) on an ash-free but moist basis. (IPCC 2006)

Bituminous coal – Coal characterized by higher volatile matter than anthracite (more than 10%), with lower carbon content (less than 90% fixed carbon). Its gross calorific value is greater than 23,865 kJ/kg (5,700 kcal/kg) on an ash-free but moist basis. (IPCC 2006)

Carbon budget – The cumulative amount of carbon emissions that can be released to have a likely chance of limiting warming to 2°C (or other temperature target).

Carbon capture and storage (CCS) – The process of capturing CO_2 from an emission source, converting it to a supercritical state, transporting it to an injection site, and injecting it into deep subsurface rock formations for long-term storage. CCS is sometimes referred to in the literature as carbon dioxide capture and sequestration.

Conventional (petroleum) resources – Resources that exist in discrete petroleum accumulations related to localized geological structural features and/or stratigraphic conditions, typically with each accumulation bounded by a downdip contact with an aquifer and significantly affected by hydrodynamic influences such as buoyancy of petroleum in water. (SPE et al. 2011)

CO_2-equivalent (CO_2e) – The universal unit for comparing emissions of different GHGs, expressed in terms of the global warming potential (GWP) of one unit of CO_2.

Crude oil – A mineral oil consisting of a mixture of fossil fuels of natural origin. It is yellow to black in color and of variable density and viscosity. It also includes lease condensate (separator liquids), which is recovered from gaseous fossil fuels in lease separation facilities. (IPCC 2006)

Developed reserves (petroleum) – Reserves expected to be recovered from existing wells, including reserves behind pipe. Improved recovery reserves are considered “developed” only after the necessary equipment has been installed, or when the costs to install it are relatively minor compared to the cost of a well. Developed reserves may be further subclassified as producing or nonproducing. (SPE et al. 2007)

Enhanced oil recovery (EOR) – One or more of a variety of processes that seek to improve recovery of fossil fuels from a reservoir after the primary production phase.

Flaring – The controlled burning of fossil fuels without the production of useful heat or energy.

Fugitive emissions – Emissions that are not physically controlled but result from the intentional or unintentional releases of GHGs.

Global warming potential (GWP) – The change in the climate system that would result from the emission of one unit of a given GHG compared to one unit of CO_2.

Lease fuel – That portion of produced natural gas, crude oil, or condensate consumed as fuel in production and lease plant operations. (SPE et al. 2007)

Lignite – A nonagglomerating coal with a gross calorific value of less than 17,435 kJ/kg (4,165 kcal/kg) and greater than 31 percent volatile matter on a dry mineral matter–free basis. (IPCC 2006)

Liquids – Crude oil, natural gas liquids, and condensates.

Natural gas – The portion of petroleum that exists either in the gaseous phase or in solution in crude oil in natural underground reservoirs, and which is gaseous at atmospheric conditions of pressure and temperature. Natural gas may include some amount of nonhydrocarbons. (SPE et al. 2007)

Natural gas liquid (NGL) – A mixture of light hydrocarbons that exist in the gaseous phase at reservoir conditions but are recovered as liquid in gas processing plants. NGL differs from condensate in two principal respects: (1) NGL is extracted and recovered in gas plants rather than lease separators or other lease facilities; and (2) NGL includes very light hydrocarbons (ethane, propane, butanes) as well as the pentanes-plus (the main constituent of condensates). (SPE et al. 2011)

Possible reserves (petroleum) – Those additional reserves that analysis of geoscience and engineering data suggests are less likely to be recoverable than probable reserves. (SPE et al. 2007)

Potential emissions – The emissions of carbon (in the form of CO_2 and CH_4) that is currently stored in fossil fuel reserves but is expected to be released once those reserves are produced in the future.

Probable reserves (minerals) – The economically mineable part of an indicated and, in some circumstances, measured mineral resource. The confidence in the modifying factors applying to a probable mineral reserve is lower than that applying to a proved mineral reserve. (CRIRSCO 2013)

Probable reserves (petroleum) – Those additional reserves that analysis of geoscience and engineering data indicates are less likely to be recovered than proved reserves but more certain to be recovered than possible reserves. (SPE et al. 2007)

Proved reserves (minerals) – The economically mineable part of a measured mineral resource. A proved mineral reserve implies a high degree of confidence in the modifying factors.

Proved reserves (petroleum) – Those quantities of petroleum that, by analysis of geoscience and engineering data, can be estimated with reasonable certainty to be commercially recoverable, from a given date forward, from known reservoirs and under defined economic conditions, operating methods, and government regulations. (SPE et al. 2007)

Recovery factors – Percentage estimates of the in-situ mineral ore recovered after mining has taken place.

Reference point (minerals) – The point at which mineral reserves are defined, usually the point where the mineral ore is delivered to the processing plant. (CRIRSCO 2013)

Reference point (petroleum) – A defined location within a petroleum extraction and processing operation where quantities of produced product are measured under defined conditions prior to custody transfer (or consumption). Also called "point of sale" or "custody transfer point." (SPE et al. 2007)

Reserves – Estimates of an entity's entitlement to marketable/extractable quantities derived from a deposit by applying a development plan taken to its economic, technical, or contractual limit. (CRIRSCO and SPE 2007)

Sales quantities (petroleum) – Petroleum quantities that are equal to raw production minus (1) nonsales quantities such as petroleum consumed as fuel, flared, or otherwise lost in processing, and (2) nonhydrocarbons that must be removed prior to sale. (SPE et al. 2007)

Scopes – Categories of direct and indirect emissions determined by application of operational boundaries.

Shale oil – Oil contained in the cracks or pores of shale rock.

Stranded assets – The fossil fuel energy and generation resources that, at some time prior to the end of their economic life (as assumed at the investment decision point), are no longer able to earn an economic return (i.e., meet the company's internal rate of return) as a result of changes in the market and regulatory environment associated with the transition to a low-carbon economy. (http://www.carbontracker.org/resources/)

Subbituminous coal – Nonagglomerating coal with a gross calorific value between 17,435 kJ/kg (4,165 kcal/kg) and 23,865 kJ/kg (5,700 kcal/kg), containing more than 31 percent volatile matter on a dry mineral matter–free basis. (IPCC 2006)

Unconventional (petroleum) resources – Resources that exist in petroleum accumulations which are pervasive throughout a large area and not significantly affected by hydrodynamic influences (also called "continuous-type deposits"). Examples include coal bed methane (CBM), basin-centered gas, shale gas, gas hydrate, natural bitumen (tar sands), and oil shale deposits. Also termed "nonconventional resources" and "continuous deposits." (SPE et al. 2007)

Undeveloped reserves – Quantities expected to be recovered through future investments: (1) from new wells on undrilled acreage in known accumulations, (2) from deepening existing wells to a different (but known) reservoir, (3) from infill wells that will increase recovery, or (4) where a relatively large expenditure (e.g., compared to the cost of drilling a new well) is required to (a) recomplete an existing well or (b) install production or transportation facilities for primary or improved recovery projects. (SPE et al. 2007)

Venting – All controlled releases into the atmosphere of waste gas streams and process by-products.

Viscosity – The resistance of a fluid to shearing flows, where adjacent layers move parallel to each other at different speeds.

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity and human well-being.

Our Challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision
We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.