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Determination of South African carbon dioxide emission factors for selected solid fuels

South Africa's National Climate Change Response Policy requires accurate reporting of greenhouse gas (GHG) emissions. To achieve this, the South African Department of Forestry, Fisheries and the Environment initiated a process to develop country-specific emission factors (referred to as Tier 2 factors by the Intergovernmental Panel on Climate Change (IPCC)) for fuels produced or used locally, which are more accurate than those currently used (Tier 1). In this work, we report on the development of such county-specific emission factors for the solid fuels most commonly produced and used in South Africa, based on the analysis of 107 samples. The samples received were classified into types based on the IPCC fuel classification method, which has some differences from that used in South Africa. The CO₂ emission factor for sub-bituminous coal, mainly used for power generation and in the liquid fuels/chemical sectors of South Africa, was found to be 97 807 kg CO₂/TJ. For 'other bituminous coal', the CO₂ emission factor was found to be 101 171 kg CO₂/TJ. These emission factors are higher than the IPCC default (also referred to as Tier 1) factors, which have been in use in South Africa to date. As solid fossil fuel use is a major contributor to South Africa's GHG emissions, this implies higher than previously estimated CO₂ emissions from this sector as well as a higher contribution to global emissions.

Significance:

- South African Tier 2 carbon dioxide emission factors for solid fuel use are reported for the first time, as required by South Africa's commitments under the United Nations Framework Convention on Climate Change and the Paris Climate Agreement.
- The Tier 2 carbon dioxide emission factors were derived from the analysis of over 100 South African solid fuel samples.
- Emission factors for the fuels used in the largest amounts are higher than the default Tier 1 factors previously used, leading to an increase in reported emissions for a similar fuel use.
- The main user of coal in South Africa, the power generation sector, uses sub-bituminous coal based on the IPCC classification system, which includes volatile matter as a classification criterion.
- Using the same IPCC criteria, the majority of samples from other South African industrial and commercial users are classified as 'other bituminous coal'.

Introduction

Climate change poses a significant risk to South Africa's development gains, exacerbating the existing national challenges of poverty, unemployment and inequality, whilst undermining the country's efforts to achieve the development goals of both the 2012 National Development Plan and the United Nations Sustainable Development Goals. The National Climate Change Response Policy of 2011 sets out South Africa's climate change response approach and cites accurate, complete and up-to-date data as the foundation of an effective response, positioning the National Greenhouse Gas (GHG) Inventory as a critical part of national climate action.¹ The Department of Forestry, Fisheries and the Environment in South Africa is responsible for the implementation of the country's mandatory GHG reporting regime, which forms the basis for the implementation and tracking of various climate change mitigation initiatives, informs policy formulation, and supports compilation of the country's national GHG inventory. The accuracy of the national GHG emissions estimate has a significant influence on the country's total GHG inventory and the concomitant policymaking and implementation initiatives, as well as GHG reporting by a range of stakeholders.

The National GHG Emission Reporting Regulations, under the *National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004)*, took effect in April 2017, establishing a single GHG emissions national reporting system to update and maintain the National GHG Inventory.² The regulations require that certain emission categories and activities make use of more accurate higher tier methods in quantifying GHG emissions after a period of 5 years from April 2017. The use of such higher tier methods (e.g. Tier 2) requires country-specific emission factors for solid fuels in use in the country, the development of which was the focus of this study.

In terms of a GHG inventory, a tier represents a level of methodological complexity. Three tiers are provided for. Tier 1 is the basic IPCC (Intergovernmental Panel on Climate Change) 2006 method using generic default emission factors. Tier 2 is of intermediate complexity using country-specific emission factors, whilst Tier 3 uses source- or facility-specific emission factors and is the most demanding in terms of complexity and data requirements.^{3,4} In this context, an emission factor allows the calculation of greenhouse gas emissions from a unit of activity, production or fuel use. Tier 2 and 3 methods are sometimes referred to as higher tier methods and are considered to be more accurate on condition that adequate data are available to develop, evaluate and apply the higher tier method. Countries often work to move to a higher tier to reduce uncertainty in reporting, especially for key activities.

Tier 2 emission factors for South African liquid and gaseous fuels have been previously determined⁵ and included in Methodological Guidelines issued by the Department of Forestry, Fisheries and the Environment that guide the development of the country's GHG inventory.⁶ The purpose of the study reported here was to facilitate a higher tier reporting for solid fuels. Samples of such fuels used in South Africa were thus taken and analysed for carbon content and calorific value to develop country-specific carbon dioxide emission factors for these fuels for the first time. The calorific value of the fuels allows for the classification thereof, as well as the calculation of emission factors for methane and nitrous oxide resulting from the combustion of the fuels, as emission factors for these gases are often calculated based on their energy content. The fuels which were included in this study are sub-bituminous coal, bituminous coal (referred to as 'other bituminous coal' in the IPCC classification scheme), anthracite, coking coal and coke. It must be noted that, although their emission factors are reported as part of this project, coke and anthracite are most frequently used in the metallurgical sector as reductants, rather than as fuels.

Methodology

Coal classification schemes

A number of formal coal classification schemes exist. These schemes classify coal by rank, or the level of geological maturity. In order of increasing rank or age, the categories are peat, lignite, sub-bituminous coal, bituminous coal and anthracite. In some classification systems, there are further sub-divisions within bituminous coal and anthracite. The most recent systems are based on, or include, vitrinite reflectance as a parameter^{7,8}, but the most commonly used systems, including those used by the IPCC and in South Africa^{3,9,10}, are based on moisture content, volatile matter content, carbon content and calorific value (CV) as the defining parameters. Due to the presence of multiple schemes, coal can be classified differently depending on the classification scheme. Many local users apply the South African scheme, and thus this formed the basis for sampling. However, national reporting as part of the country's international obligations uses the IPCC scheme, as summarised in Table 1, and results given here are based on this scheme.

South African solid fuel resources

Coal fields of varying grades or qualities occur over large areas of South Africa. Bituminous coal (both sub-bituminous and other bituminous in the IPCC classification) is used mainly for the generation of electricity and for the production of liquid fuels and other chemicals after gasification. The location of power stations and chemical factories that use this coal as feedstock is determined by the location of the coal resource. Some coal fields contain metallurgical coal (used for the production of coke in the steel industry) with specific petrographic characteristics, or anthracite (a solid fuel type with lower volatile matter content and/or higher carbon content), which is most often used as a reductant in the ferro-alloy industry.

Further particulars regarding the classification and use of South African coals for combustion are provided in Steyn and Minnitt¹¹, while a survey of physical and chemical characteristics of South African coals and the influence thereof on combustion is given in Falcon and Ham¹².

Analytical methodology

Sampling

The initial sampling strategy was to approach the major producers and importers of the various solid fuels through their representative industry bodies. As delays were experienced with this process, samples were simultaneously requested and received from some of the major users. Subsequently, samples were received from a number of suppliers of coal and coke, as well as users and importers of both coke and what the suppliers labelled as anthracite. As the final results are to be representative of the fuels used in South Africa, export coals were not taken into account, while samples of imports were obtained where possible.

Where samples were received uncrushed, these were crushed and reduced to a mass of approximately 1 kg by means of riffing. Both these, and samples received crushed or milled, were packed or re-packed in anonymous containers marked with serial numbers, the identifications of which were known only to project staff.

Analysis

The samples were sent for analysis at an external SANAS-accredited laboratory in South Africa, which analyses coal samples for major suppliers and consumers. The standard analytical methods employed are provided in Table 2.

Sample preparation at the laboratory was achieved using ISO 13909 Part 4 relating to the preparation of test samples by mechanical sampling (splitting). This included drying of samples before analysis in a calibrated oven set at 40 °C. The total moisture content of the samples was determined following ISO 589 using the one-stage method by oven drying in air after crushing to a nominal top size of 10 mm. The inherent moisture was found using SANS 5925 after air drying of samples under ambient conditions. Glass vessels with lids were used and samples were 1 g with particle size <212 µm. The oven was set to between 105 °C and 110 °C, and samples were dried to constant mass.

The total carbon content of samples (0.2 g nominal mass, <212 µm) was determined using ASTM D5373 using a Leco SC832 Sulfur and Carbon Determinator employing near infrared absorption detection (Leco Africa (Pty) Ltd, South Africa). Different masses of an accredited coal material supplied by Coal Concepts were used to construct a six-point calibration, and daily blank analyses were performed by means of an empty sample container. Quality control samples were analysed after every 10 runs. The overall measurement uncertainty for these total carbon measurements was 1.49%, expressed as an expanded uncertainty at the 95% confidence limit with coverage factor K = 2.

The CV at constant volume was determined according to the ISO 1928 standard (2020) employing calibration using certified benzoic acid supplied by Coal Concepts, with high purity oxygen supplied by Afrox. Samples were run in duplicate, either on a Leco AC600 (using 1 g of sample, <212 µm) or DryCal calorimeter (using 0.5 g of sample, <212 µm), and results were reported as the averages of the duplicate measurements.

The analysis of volatile matter of the solid fuel samples (<212 µm) was conducted using the procedure described in the ISO 562 (2010)

Table 1: Intergovernmental Panel on Climate Change (IPCC) coal classification parameter specification

	Volatile matter (%, dmmf)	Carbon content (%, dmmf)	Gross calorific value (MJ/kg, maf)	Approximate net calorific value (MJ/kg, dmmf)
Sub-bituminous	>31	–	17.435 – 23.865	16.70 – 23.25
Other bituminous	>10	<90	>23.865	>23.25
Anthracite	<10	≥90	>23.865	>23.25

Source: IPCC^{3,4}

dmm: dry, mineral matter free; maf: moist, ash free (the moisture referred to here is the inherent moisture after the sample has been air dried)

standard using lidded silica crucibles with a final furnace temperature of 900 °C held for 7 min. The limit of detection was 0.053% and the limit of quantification was 0.177%. The overall measurement uncertainty for the volatile matter analysis was 0.62%, expressed as an expanded uncertainty at the 95% confidence limit with coverage factor $K = 2$. Ash was determined by means of ISO 1171 using a 1 g sample ($<212 \mu\text{m}$), which was incinerated in a silica crucible using the temperature ramp rate specified in the standard until constant mass was achieved.

In addition to solid fuel samples from suppliers and customers, four certified reference materials (CRMs) were also submitted to the laboratory as quality control samples. Particulars of the CRMs, as well as the analytical results obtained, are given in the [supplementary material](#). In all cases, these standards were submitted 'blind' with distinguishing information removed and anonymised labelling.

Data interpretation

Use of valid samples

In total, South Africa produced approximately 230 million tonnes of all types of coal in 2022¹³, exporting approximately 64 million tonnes in the same year¹⁴, resulting in the domestic use of locally produced fuel of approximately 166 million tonnes. Due to the limited supply of metallurgical coal and anthracite in South Africa, additional requirements for these fuels are met by imports. The term 'metallurgical coal' refers to the properties of coal in the coking process and is not directly related to the classification systems described earlier. Similarly, the term 'anthracite' is used commercially for certain types of coal which would not be classified as such in these formal coal classification systems (Table 1).

Based on these data and additional information in the public domain¹⁵⁻¹⁷, it is possible to determine the percentages of the total South African coal production that is used for electricity generation, liquid fuel/chemicals production and by the metallurgical industry. The solid fuel usages of these major solid fuel consuming sectors were thus found to be in the proportion of 53%, 33% and 12%, respectively, with the remaining 2% used by various smaller users. Samples were received from all of these sectors.

Power generation is, by a considerable margin, the major user of coal in South Africa^{14,15,18} and sampling from coal-fired power stations in operation would therefore represent a similarly large proportion

of national coal use. For the coal used in electricity generation, the contribution of different mines to each of the power stations was not available, but as a quality control measure, daily samples are taken from the coal feed to all the coal-fired power stations and monthly composites of these daily samples are prepared using an in-house method. For a period of 3 months (July–September) during 2023, a portion of each composite sample was made available for this study. This provided a total of 40 composite samples for the power generation sector.

Similarly, the liquid fuels/chemical production sector provided duplicate monthly composite samples of the feed stockpiles to its plant for 3 months. This included a portion provided on contract by one of the major mining companies which formed part of the feed samples. The feed was divided into two screen sizes for different applications, and the over-and undersize of the screened material was sampled separately. Twelve samples were obtained from this sector (six oversize and six undersize).

The third largest use sector of solid carbonaceous material is for metallurgical applications. From the sources quoted earlier and from public domain data for the metallurgical sector¹⁹, it is possible to estimate the coal use for various purposes (coking, steam raising or as a reductant) in this sector. Petrographic properties not used in either of the classification schemes are required for some applications of these materials, such as coking or as a reductant. Most of the materials used for these purposes can therefore not strictly be classified as a solid fuel. Of the nine samples labelled as coal provided by this sector, three were classified as anthracite using the IPCC system, but only one was classified as anthracite under the South African system. Coal with metallurgical properties is also imported but is again not used as a fuel, although results for these coals are included in this report for completeness.

The major coal producers provided samples of the different types of coal produced, including samples of export coal. As the purpose of this study was to develop South African specific emission factors, the samples representing exports were not used.

Statistical analysis – test for normality

The method to calculate a single value to represent a property of multiple samples is determined by the statistical distribution of the values of the property for all the samples. If that distribution is normal, the mean can be used and the calculation thereof becomes a simple matter; otherwise, a parameter like the median must be used. A number of statistical tests with different levels of rigour to determine whether property values of a collection of samples are normally distributed are available. These include the Kolmogorov–Smirnov Test, the Shapiro–Wilk Test and the Anderson–Darling Test.²⁰ In all these tests, the null hypothesis is that the data are normally distributed. Each of these tests provides a p -value or significance level. When this value is larger than 0.05, the null hypothesis is accepted and the data can be assumed to be normally distributed.

Quantitative statistical tests (e.g. for normality) have the disadvantage of being not sensitive enough for a small number of samples or overly sensitive for large sample numbers. Graphical verification is therefore often used. The most usual method for this is the Q-Q (quantile-quantile) plot. The various quantiles of the observed distribution are compared with the theoretically expected (in this case normal) distribution.²⁰ On such a Q-Q plot, normally distributed data will appear as roughly a straight line, although the tails sometimes deviate.

Figure 1 provides the Q-Q plots for the carbon content of the sub-bituminous and other bituminous coal samples. The z-scores of the

Table 2: Analytical standards applied in the analysis of solid fuel samples

Description of analysis	Method of analysis
Sample preparation	ISO 13909
Calorific value	ISO 1928
Total moisture	ISO 589
Inherent moisture	SANS 5925
Carbon	ISO ASTM D5373
Ash content	ISO 1171
Volatile matter	ISO 562

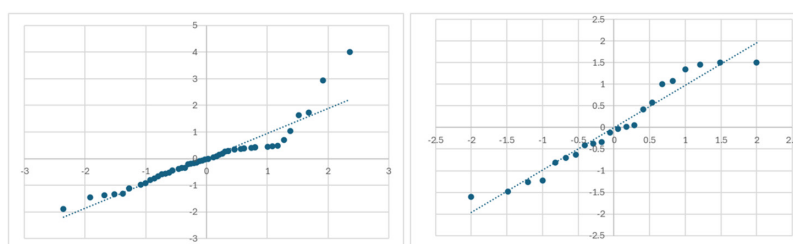


Figure 1: Q-Q plots for the carbon content of sub-bituminous coal (left) and other bituminous coal (right) based on the Intergovernmental Panel on Climate Change (IPCC) classification system.



actual data quantiles (vertical axis) are plotted against the z-scores of the normal quantiles. It is evident from this plot, as well as the plots for the fuels and properties not shown, that the assumption of the normal distribution of the values for these fuel types is valid, with only two deviations from sub-bituminous samples in the tail of that distribution.

For coke and anthracite, far fewer samples were available, making the tests for statistical distribution less dependable. The figures for these fuels are therefore not included here. The plots for these categories nevertheless indicated that there was no reason not to assume normality, especially using the IPCC classification.

Statistical analysis – weighted averages

As indicated previously, if the values of a property of a set of samples are normally distributed, the average is easily calculated. The variability around the average (often expressed as a standard deviation or as confidence limits around the average) can then also be calculated using well-known methods. In this study, the samples did not all represent similar production or usage volumes. For example, the samples from power generation are representative of a greater share of the country's coal usage than those from smaller users. Thus, to calculate the average emission factor for the country, different weightings must be applied to the property values of the different samples. The variability or standard deviation must then also take these weightings into account. This was done using the method of Bevington (quoted by Kirchner²¹) using the assumption that the variability of the individual samples is similar, but weightings assigned to samples differ. A discussion of the equations used to calculate the weighted averages and variance is provided in the supplementary material.

For the electricity generation results, weighting per station per month was done using the coal use for each station for each month. Weighting for the samples from the liquid fuels/chemicals sector was based on the 2023 usage volumes. For the samples received from producers, the production volumes in the months of sampling were used for weighting.

Compared to locally produced coke, the amount of coke imported (and used as a reductant in the ferro-alloy sector, not as a fuel) is relatively small. Most of the locally produced coke is used by the producer, with a limited amount being supplied to the market. Weighting for the three samples obtained was thus done according to the amounts imported by the ferro-alloy sector and made available to the market by the local producer, excluding the coke used by the major local coke producer itself, which includes imports.

To also account for the fuels used by smaller users, weighting was based on actual production or use volumes during the sampling period.

Calculation of emission factors

The CO₂ emissions for the different fuel types were determined from the carbon content in the fuel:

$$CO_2 \text{ emissions} = \text{Carbon content}_{\text{fuel}} \times \frac{\text{Molar mass}_{\text{carbon dioxide}}}{\text{Molar mass}_{\text{carbon}}} \quad \text{Equation 1}$$

where the emission values are given in g/kg, and the molar masses are given in kg/mol. The uncertainty of the carbon content and the emission factors given in this report should be taken into account in determining the overall uncertainty of the GHG emission inventories.²²

Results

Samples collected

The number of samples collected for each source are detailed in Table 3. Samples were given on condition of anonymity in reporting, and thus the names of the sources are not provided.

Solid fuel properties

Tables 4 and 5 provide the weighted averages for the properties of sub-bituminous coal, other bituminous coal, coke (using the IPCC classification), and the material that was labelled as anthracite.

Table 3: Solid fuel samples per sample source

Sample source	Number of total samples	Time period for collection
Major user A feed	44	Monthly samples for 3 months (July–September 2023)
Major user B feed	12	Monthly samples for 3 months (August–October 2023)
Metallurgical sector	18	Once-off samples (October/November 2023)
Major producer C	18	Monthly sample for 3 months
Major producer E	15	Monthly sample for 3 months

Table 4: Weighted average properties of sub-bituminous and other bituminous coal on an air-dry basis

Coal type using IPCC classification (number of samples)	Emission factor (EF), kg CO ₂ /kg fuel	% Relative standard deviation (RSD), EF	Net calorific value (NCV), MJ/kg fuel	% RSD, NCV	EF, kg CO ₂ /TJ	% RSD, EF	Carbon content (CC), %	% RSD, CC
Sub-bituminous (66)	1.80	11.40	18.43	12.44	97 807	2.95	49.06	11.40
Other bituminous (13)	2.59	10.28	25.87	7.19	101 171	3.85	70.61	10.31

Table 5: Weighted average coke and anthracite properties on an air-dry basis

Parameter	Coke		Anthracite*	
	Carbon content, %	Net calorific value, MJ/kg	Carbon content, %	Net calorific value, MJ/kg
Weighted average	81.74	24.43	77.75	22.56
%RSD	11.39	3.58	6.38	13.74

*These samples were labelled 'anthracite' by suppliers, but are not classified as anthracite by the classification of the Intergovernmental Panel on Climate Change (IPCC) or by South Africa.

With regard to the reference material (Supplementary table 1), the total %C results showed a positive bias with an overall error across all four reference materials of 4% (including duplicates of two of the CRMs), whilst the CV (MJ/kg) results had a negative bias of -3% overall. Upon comparing the total %C and CV of the CRMs to that of the averages for the different sample categories in Tables 4 and 5, it is noted that the carbon content and CV of the bituminous coal samples used by major users was far lower than that of the CRMs. Use of local CRMs for quality control purposes, as done by the laboratory, is therefore more appropriate in this regard. CRM ERM-EF411 (hard coal) was the closest in %C and CV to that of the bituminous coal used by the metallurgical sector, whilst the LECO 502-680 Prox-Plus coal had a similar %C to that of the coke samples (Table 5). The %C of the anthracite samples (Table 5) fell between that of the LECO 502-680 Prox-Plus coal and the ERM-EF411 CRM (hard coal).

Calculated emission factors for each fuel type

Table 6 provides the average emission factors determined for the solid fuels within the scope of this study. Comparative figures with the IPCC default values for the energy industries are provided in Table 7. The mass-based emission factors were converted to kg/TJ using the net CVs from this study (Table 8).

The average net CVs from this study (summarised for all types in Table 8) can further be used by facilities and government to calculate the emission factors for CH₄ and N₂O using Tier 3 methods based on the energy content of the fuels (given here) and plant-specific details. The variation around the average is given by the % relative standard deviation of the net CV value in each case, as provided in Tables 4 and 5. These are compared to the relevant IPCC defaults in Table 9.

Table 6: Average CO₂ emission factors for solid fuels on an air-dry basis

Fuel type (IPCC classification)	CO ₂ emission factor, kg/kg air-dry product ± %RSD	CO ₂ emission factor, kg CO ₂ /TJ ± %RSD
Sub-bituminous coal	1.80 ± 11.40%	97 807 ± 16.87%
Other bituminous coal	2.59 ± 10.28%	101 171 ± 12.54%
*Metallurgical coal	2.72 ± ND	100 500 ± ND
*Anthracite	2.85 ± 6.38%	126 400 ± 15.5%
Coke	3.00 ± 11.39%	122 700 ± 11.93%

*Fuels marked with an asterisk are formally classified as 'other bituminous coal' in the Intergovernmental Panel on Climate Change (IPCC) scheme but are given here separately because they are generally referred to in South Africa as metallurgical coal or anthracite. 'ND' signifies that the %relative standard deviation (%RSD) was not determined for this category as it is not a reporting category.

Table 7: CO₂ emission factors in kg CO₂/TJ for the energy industries, showing the results from comparing this study to the Intergovernmental Panel on Climate Change (IPCC) defaults. The average IPCC value is given with the lower and upper limits of the 95% confidence interval.⁷

Fuel type (IPCC classification)	CO ₂ emission factor (this study) Average ± %RSD	IPCC default lower	IPCC default average*	IPCC default upper
Sub-bituminous coal	97 807 ± 16.87%	96 100	92 800	100 000
Other bituminous coal	101 171 ± 12.54%	89 500	94 600	99 700
Coke	122 700 ± 11.93%	95 700	107 000	119 000

*The samples in this study were air dried and the IPCC emission factors are based on 'as received'.

RSD, relative standard deviation

Conclusions

For the first time, carbon dioxide emission factors were determined experimentally from samples representative of solid fuels used in South Africa. The emission factors were mainly based on samples from users of the fuels, as it was not possible to receive representative samples from all producers. The coal samples received were classified into coal type using two classification systems (South African and IPCC). Under both systems, all samples (excluding coke) were classified as bituminous or other bituminous coal, respectively, including samples received labelled as anthracite. In the analysis, those labelled as anthracite, as well as the coal used as a reductant in the metallurgical industries, were kept separate.

Table 8: Net calorific values for solid fuels on an air-dry basis

Fuel type (IPCC classification)	Net calorific value, MJ/kg Average ± %RSD
Sub-bituminous coal	18.43 ± 12.44%
Other bituminous coal	25.87 ± 7.19%
Metallurgical coal*	27.07% ± ND
Anthracite*	22.56 ± 13.74%
Coke	24.43 ± 3.58%

*Fuels marked with an asterisk are formally classified as 'other bituminous coal' in the Intergovernmental Panel on Climate Change (IPCC) scheme but are given here separately because they are generally referred to in South Africa as metallurgical coal or anthracite. 'ND' signifies that the %relative standard deviation (%RSD) was not determined for this category as it is not a reporting category.

Table 9: Net calorific values (NCV) from this study and Intergovernmental Panel on Climate Change (IPCC) default values for stationary combustion by the energy industries. The average IPCC value is given with the lower and upper limits of the 95% confidence interval.⁷

Fuel type (IPCC classification)	NCV, MJ/kg (this study) Average ± %RSD	IPCC default NCV, MJ/kg		
		Lower	Average	Upper
Sub-bituminous coal	18.43 ± 12.44%	11.5	18.9	26.0
Other bituminous coal	25.87 ± 7.19%	19.9	25.8	30.5
Coke	24.43 ± 3.58%	25.1	28.2	30.2

RSD, relative standard deviation

Country-specific carbon dioxide emission factors for sub-bituminous coal obtained in this study are higher than the IPCC average default values, and those for other bituminous coal and coke are above the upper confidence interval for the IPCC default values. This implies that future South African inventory reports will report increased CO₂ emissions even if fuel use remains the same.

In addition to these emission factors, the net CV results can be further used by facilities and the government to estimate N₂O and CH₄ emissions. The net CVs for sub-bituminous and other bituminous coal are very similar to the IPCC average default values, while for coke they are below the lower confidence interval for the IPCC default values.

In the application of the emission factors in reporting, the correct classification of the fuels is important. Classification of solid fuels is done on a dmmf (dry, mineral matter free) or daf (dry, ash free) basis, while reporting entities will most probably have analysis certificates containing results on an air-dry basis. In addition, analysis certificates will often contain only proximate analysis results giving fixed carbon content, while the emission factor for CO₂ is determined from the total carbon content given in the ultimate analysis. To ensure correct and uniform classifications for reporting purposes, results of the ultimate (rather than the proximate) solid fuel analysis are required.

The country-specific carbon dioxide emission factors for solid fuels, which have been determined for the first time and are reported here, enable the transition of South Africa to higher tier GHG emission reporting in line with international standards and trends, and will assist with the transition to a low-carbon economy in accordance with the United Nations Sustainable Development Goals.

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Data availability

Data from this study are not available due to commercial confidentiality requirements from sample providers.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

G.K.: Project leadership and management, methodology, investigation, sample analysis, formal analysis, writing – review and editing. P.F.: Supervision, investigation, sample analysis, formal analysis, writing – review and editing. R.G.: Supervision, formal analysis, writing – original draft, writing – review and editing. All authors read and approved the final manuscript.

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