Emissions related to hard coal mining

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1 Executive Summary (restricted)

This short study is meant to present emission data related to coal mining, to be used for calculation of emission impacts of Carbon Capture and Storage (CCS). The study mainly focuses on emissions related to hard coal mining. It is largely based on an in-depth study of Dones et al (2007), supplemented by a number of recent literature sources for some items. The data presented pertain to resource requirements, indirect energy user and material requirements (for mining infrastructure), land use, direct energy use (mining including cleaning and upgrading), emissions to air (in particular for coal mine methane), emissions to water, and accidental air emissions due to coal fires. The data presented may be used in a database enabling model calculations on environmental impacts of CCS chains to be developed in the Netherlands.

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Applicable Documents

(Applicable Documents, including their version, are documents that are the “legal” basis to the work performed)

	Title	Doc nr	Version date
AD-01	Beschikking (Subsidieverlening CATO-2 programma verplichtingnummer 1-6843	ET/ED/9078040	2009.07.09
AD-02	Consortium Agreement	CATO-2-CA	2009.09.07
AD-03	Program Plan	CATO2-WP0.A-D.03	2009.09.29

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Abbreviations

(this refers to abbreviations used in this document)

CBM	Coal Bed Methane
CMM	Coal Mine Methane
CCS	Carbon Capture and Storage
EPDM	Ethylene propylene diene monomer
HHV	Higher Heating Value
UCTE	Union for the Co-ordination of Transmission of Electricity
UNFCCC	United Nations Framework Convention on Climate Change

3 Emissions related to hard coal mining

3.1 Introduction

This short study provides an overview of emissions related to hard coal mining, largely based on Dones et al (2007), supplemented by a number of recent literature sources for some items. The contents of this short study are as follows:

- Resource requirements
- Indirect energy use and material requirements for mining infrastructure;
- Land use;
- Direct energy use (mining including cleaning and upgrading)
- Emissions to air, in particular of coal mine methane;
- Emissions to water;
- Accidental air emissions due to coal fires.

There are basically two types of coal mining: on the one hand open-pit mining or surface mining; on the other hand pithead mining with shafts (deep mines).The data presented may be used in a database enabling model calculations on environmental impacts of Carbon Capture and Storage (CCS) chains to be developed in the Netherlands.

3.2 Resource requirements

Dones et al (2007) address material requirements, land and energy use, and emissions of coal mining. Here, the focus is on *hard coal* mining. Table 1 shows the resource use of coal mining, i.e. the gross coal use per tonne of coal produced for various world regions. The rightmost column forms the basis for calculations on environmental impacts reported by (Dones et al, 2007).

Table 1 *Kg gross coal requirement per kg of coal produced in various world regions*

Country/Region	Gross coal equivalent [tonne/tonne coal equivalent] [a]	Higher heating value (HHV) [MJ/kg]	Produced coal equivalent [tonne/tonne coal equivalent] [a]	Relative resource use [b]	Gross coal requirement (Dones et al) [kg raw coal/kg product coal]
China	1.49	19.7	1.39	1.03	**1.106**
India	1.48	19.7	1.41	1.03	**1.106**
USA	1.52	19.3	1.16	1.01	**1.321**
Canada	1.50	19.3	1.05	1.01	**1.321**
South Africa	1.46	20.1	1.18	1.05	**1.304**
Australia	1.46	20.1	1.11	1.05	**1.381**
Russian Fed.	1.69	17.3	1.25	0.91	**1.228**
Poland	1.90	16.1	1.18	0.84	**1.358**
Ukraine	1.70	16.1	1.47	0.84	**1.358**
Germany	2.00	15.8	1.09	0.83	**1.526**
UK	1.69	15.8	1.22	0.83	**1.526**
Latin America	N/A	19.1	N/A	1.00	**1.245**
Average		19.1			

a The definition of tonne coal equivalent is a metric tonne of 29.31 GJ/tonne.
b Defined as HHV of country of interest / average HHV. The average HHV is 19.1 GJ.tonne.
Source: Dones et al, 2007.

3.3 Indirect energy use and material requirements

Dones et al (2007) also present data of indirect energy and material use for mining infrastructure, in particular for *hard coal* (product coal) (Table 2).

Table 2 *Material and energy use -for mining infrastructure- related to hard coal mining*

	Unit	Surface mining		Underground mining	
		Operation	Infrastructure	Operation	Infrastructure
Material use					
Rubber (EPDM)	[kg/t]	0.1			
Explosive	[kg/t]	1.2		0.1	
Copper	[kg/t]		0.003		0.002
Un-alloyed steel	[kg/t]		0.07	2.4	0.5
Low-alloyed steel	[kg/t]		0.03		0.1
Concrete, normal	[kg/t]		0.3		6.5
Plywood	[kg/t]		0.003		0.003
Timber, hardwood	[kg/t]				6.997
Energy use (construction)					
Electricity	[kWh/t]		0.3		0.4
Diesel fuel	[MJ/t]		4		6
Heat based on heavy fuel oil	[MJ/t]		4		6

Source: Dones et al, 2007.

3.4 Land use

Another parameter reported is the land use of coal mining. Table 3 provides the land use for *surface mining of hard coal* by country (Dones et al, 2007) – surface mining is open-pit mining. Dones et al assume an economic lifetime of 20 years for open-pit mining and another 100 years before the land may get another destination (e.g. agriculture). Table 3 shows that in 1999 the average land use for open-pit mining of hard coal (steam coal) amounted to 0.019 m^2/t raw coal.

Table 3 *Land use related to open-pit mining of hard coal by country/region based on data 1999*

Country/Region	Origin (1999)		% open-pit mining		Seam thickness	Land use	
			By country	Weighted for total worldwide coal production			Weighted for open-pit mining
	[Mt/a]	[%]	[%]	[%]	[m]	[m^2/t for open-pit mining]	[m^2/t total]
France	3.57	2.07	15	0.31	1.50	1	0.100
Germany	31.81	18.45	0	0.00			
Spain	8.71	5.05	15	0.76	1.50	1	0.100
Western Europe [a]	44.10	25.57		1.07			0.028
Poland	58.95	34.19	0				
Czech Republic	6.35	3.68	0				
Eastern Europe	65.30	37.87	0	0.00			0.000
Australia	7.69	4.46	68	3.03	20.0	0 [e]	0.034
East Asia [b]	6.98	4.05	3	0.12	25.0	0	0.001
North America	2.67	1.55	58	0.90	3.0	0	0.193
Latin America [c]	13.55	7.86	100	7.86	20.0	0	0.050
Russian Fed.	4.06	2.35	33	0.78	10.0	0	0.033
South Africa	28.09	16.29	50	8.15	30.0	0	0.017
Total	172.44	100.00		21.90			
Average [d]							0.019

a Excluding the United Kingdom and Scandinavia.
b China, India, and Indonesia.
c Columbia.
d The average has been determined based on the distribution of the coal sourced (2nd column), which is representative of hard coal imported by UCTE countries in 1994.
e Numbers in this column are presented as single-digit numbers.
Source: Dones et al, 2007.

For *hard coal pithead mines* – pithead mines are deep mines in contrast to open-pit mines – Dones et al present figures for land use ranging from 0.27 – 1.0 m^2 to 1.2 – 1.4 m^2 per tonne of product coal per year, with an average of 0.5 m^2 per tonne per year. Assuming 20 years of operation, this results in 0.025 m^2 per tonne of product coal. Table 4 gives the land use for *open-pit and pithead mines* (20 years of operation) (Dones et al, 2007).

Table 4 *Land use per tonne of raw hard coal for open-pit and pithead mines by country/region*

Country/Region	Total land use [m^2]	Land use (ibid.) without collapse [m^2]	Land use including return to greenfield [m^2a] [a]	Total land use, previous study Dones [m^2]	Land use previous study (without return to greenfield) [m^2a] [a]	Return to greenfield [m^2]
Australia	0.23	0.13	11	0.034	0.680	
East Asia	3.12	0.31	22	0.001	0.024	
Russia Fed.	0.50	0.15	11	0.033	0.660	
Eastern Europe	0.45	0.16	9.5	0.000	0.000	
Western Europe	0.60	0.14	11	0.028	0.557	0.036
North America	0.36	0.23	21	0.193	3.867	
Latin America	N/A	N/A	13	0.050	1.000	
South Africa	0.24	0.086	5.8	0.017	0.333	

a a = annum. Per tonne of coal per year; figures have to be divided by 20 to come up with m^2 per tonne of coal.
Source: Dones et al, 2007.

Finally, Dones et al (2007) give land use data for *hard coal* per kg of coal per year, based on figures presented before weighted per tonne of coal produced by country, as shown in the 2nd column of Table 3. Three categories are distinguished, i.e. 'transformation to industrial area', 'transformation to mineral extraction site' or 'transformation to dump', which sum up to the total land use (Table 5). The data presented are directly based on (Dones et al, 2007) and present an average land use by country of origin considering both types of coal mining.

Table 5 *Land use per kg of raw coal for open-pit and pithead mines of hard coal by region*

Country/Region	Transformation to industrial area [m^2/kg]	Transformation to mineral extraction site [m^2/kg]	Transformation to dump site (tip) [m^2/kg]
Australia	3.8E-05	4.4E-05	4.4E-05
East Asia	1.5E-04	1.1E-05	1.5E-04
Russian Fed.	7.1E-05	2.3E-05	5.7E-05
Eastern Europe	9.3E-05	0.0E+00	6.3E-05
Western Europe	5.8E-05	3.6E-05	5.0E-05
North America	6.6E-05	3.7E-05	1.2E-04
Latin America	7.4E-05	2.8E-05	7.2E-05
South Africa	4.5E-05	2.2E-05	1.9E-05

Source: Dones et al, 2007.

Assuming 20 years of use for industrial area and 120 years for mineral extraction and dump site (tip), Table 6 gives cumulative land use per annual kg of raw *hard coal* as used by Dones et al. The data presented are directly based on (Dones et al, 2007).

Table 6 *Cumulative land use per annual kg of raw coal for open-pit and pithead mines*

Country/Region	Transformation to industrial area [m^2a/kg] [a]	Transformation to mineral extraction site [m^2a/kg] [a]	Transformation to dump site (tip) [m^2a/kg] [a]
Australia	**7.5E-04**	**5.3E-03**	**5.3E-03**
East Asia	**2.9E-03**	**1.3E-03**[b]	**1.8E-02**
Russian Fed.	**1.4E-03**	**2.7E-03**	**6.9E-03**
Eastern Europe	**1.9E-03**	**0.0E+00**	**7.6E-03**
Western Europe	**1.2E-03**	**4.2E-03**	**6.0E-03**
North America	**1.3E-03**	**4.5E-03**	**1.5E-02**
Latin America	**1.5E-03**	**3.3E-03**	**8.7E-03**
South Africa	**9.0E-04**	**2.7E-03**	**2.2E-03**

a a = annum. The figures from Table 5 have been multiplied by 20 (years) or 120 (years), which is why 'a' is added in the unit.
b Dones et al present a figure of 5.3E-3, but this is apparently incorrect (1.1E-05 times 120 is 1.3E-03).
Source: Dones et al, 2007.

3.5 Direct energy use

Categories

Open-pit mines
In 1994, 28% of the *hard coal* used in UCTE countries (UCTE = Union for the Co-ordination of Transmission of Electricity) stemmed from open-pit mines, 93% of which originated from open-pit mines in Australia, North America, South America, and South Africa. In the USA, the seam thickness is at least 24 cm and usually 2 – 10 m, and the maximum depth of open-pit mines in the USA is usually approximately 100 m. The yield, i.e. the ratio between the amount of coal mined and the amount in-situ, is generally of the order of magnitude of 90 – 100%. Depending on the extent to which hard coal is cleaned and upgraded, losses in this stage entail 0 – 38% of the originally mined coal. Dones et al (2007) assume an average of 30%, which means that for production of one tonne of product coal 1.43 tonne of raw coal is needed. The balance (0.43 t) remains at the dump site (waste tip).

Pithead mines
Germany used to be an important country for pithead mining of *hard coal*. Seam thicknesses in that country range from 0.7 to 5 m. From an economic point of view, the minimum seam thickness is 0.7 m, whereas 2 to 3 m is considered economically optimal. The mining depth ranges from 100 m (South Africa) to above 1000 m (Germany). In Europe, pithead mines are deeper than elsewhere. Long-wall mining[1] is common in Europe, but 'room and pillar' mining[2] is applied on a large scale in the USA and South Africa. The yield, i.e. the ratio between the amount of coal mined and the amount in-situ, for long-wall mining is of the order of magnitude of 60 – 90%, and 45 – 50% or 45 – 70% for 'room and pillar' mining.

3.5.1 Mining including cleaning and upgrading

Coal cleaning (upgrading) includes desulphurisation with a yield (desulphurisation) between 30 and 75% (USA). Dones et al conclude that all coal destined for export is cleaned in order to enhance the heating value and/or reduce the sulphur content. The direct energy use of coal

[1] Long-wall mining is a form of underground coal mining where a long wall of coal is mined in a single slice (typically 1–2 m thick).
[2] Room and pillar mining is a form of mining extracting the coal across a horizontal plane while leaving 'pillars' of untouched material to support the roof overburden leaving open areas or 'rooms' underground.

mining and cleaning (upgrading) is depicted for *hard coal* open-pit mines and for pithead mines in Table 7 and Table 8, respectively. For open-pit mines (Table 7), scattered data are provided per tonne product coal for Russia, Eastern USA, South Africa and the world (the latter average data) which are depicted as reported. For pithead mines, Dones et al present data per tonne product coal for Russia, France, Germany (Western Germany), and Eastern USA (Table 8). The data presented are representative for the countries of interest, not weighted for coal production.

Table 7 *Direct energy use for open-pit mines including upgrading (hard coal)*

Region		Russia (Kuzbass)	Eastern USA	Eastern USA	Eastern USA	South Africa	World
Mining		Open pit	Open pit	Open pit	Open pit	Open pit	Average
Source of data		Astakhov et al, 1984	ORNL, 1980	Astakhov et al, 1984	DOE, 1983	Dohmen et al, 1980	
Waste : coal	[m^3/t]	2.7		10.75		5.52	
Water : coal	[m^3/t]	0.2		0.10	0.12		
Electricity	[kWh/t]	18	5	20	9.7	26.9	30
Diesel fuel	[MJ/t]	158.3		368	645		56
Other	[MJ/t]	5.4		380			

Source: Dones et al, 2007 (based on literature sources referred to above).

Table 8 *Direct energy use for pithead mines including upgrading (hard coal)*

Region		Russian Fed. (Donetsk, Kuznetsk, Karaganda)	France, Lorraine	Germany, former Western Germany	Eastern USA	Eastern USA	Eastern USA
Source of data		Astakhov et al, 1984	Astakhov et al, 1984	AGEB, 1991; DGMK, 1992	ORNL, 1980	Astakhov et al, 1984	DOE, 1983
Water : coal	[m^3/t]	0.2 / 1.2 / 3.9	8.5				0.56
Electricity	[kWh/t]	10.7 / 30 / 76.1	99	94.6-127.8	13	14 - 21	57.7
Light and heavy fuel oil	[MJ/t]			17.2			
Diesel fuel	[MJ/t]			11.9	40	4	7.8
Hard coal	[MJ/t]			32			
Cokes gas	[MJ/t]			34.8			
Heat	[MJ/t]			75.4			
Other	[MJ/t]	30 / 150 / 350					380

Source: Dones et al, 2007(based on literature sources referred to above) .

Dones *et al* (2007) calculated averages for direct energy and material use per tonne product coal from Tables 7 – 8 and by weighting open-pit and pithead mines in countries/regions based on Table 3 (Tables 9a – 9b). The data in Table 9a and 9b pertain to a tonne of product coal, i.e. made available for export.

Table 9a *Energy and material use and waste generated per tonne of hard coal by country*

Country		Germany	Poland	Australia	China
Representing		Western Eur.	Eastern Eur.	Australia	East Asia
% open-pit mines	[%]	0	0	68	3
Resources					
Water, general	[m^3/t]	1.58	1.69	1.30	2.63
Module					
Electricity	[kWh/t]	37.8	45.8	17.9	12.9
Heat, hard coal	[MJ/t]	110.0	110.0	35.2	106.7
Drinking water	[kg/t]	486	514	180	442
Explosives	[kg/t]	0.035	0.076	1.625	0.125
Diesel fuel	[MJ/]	5.8	22.3	65.5	24.2

Land fill	[kg/t]	461	271	309	155

Source: Dones et al, 2007.

Table 9b *Energy and material use and waste generated per tonne of hard coal by country*

Country/Region		USA	Latin America	Russian Fed.	South Africa
Representing		North Amer.	Latin America	Russian Fed.	South Africa
% open-pit mines	[%]	58	100	33	50
Resources					
Water, general	[m^3/t]	0.54	1.30	1.24	0.54
Module					
Electricity	[kWh/t]	25.1	10.0	93.0	13.9
Heat, hard coal	[MJ/t]	46.2	0.0	73.7	55.3
Drinking water	[kg/t]	355	200	503	206
Explosives	[kg/t]	1.131	2.000	0.767	1.480
Diesel fuel	[MJ/t]	33.7	120.0	41.8	48.3
Land fill	[kg/]	415	250	271	270

Source: Dones et al, 2007.

3.6 Emissions to air

3.6.1 Coal mine methane

Coal mining produces 8% of the anthropogenic methane emissions worldwide. Table 10 presents Coal Mine Methane (CMM) emissions from coal mining (Dones et al, 2007). CMM is gas released from coal or surrounding rock strata immediately prior to, during, or subsequent to coal mining activities. CMM differs from Coal Bed Methane (CBM), which refers to methane derived from coal seams that are not actively being exploited. Note that estimates of CMM emissions from South African coal mines have been significantly reduced in (Lloyd and Cook, 2004), which is why previous (notorious high) estimates are presented in italics in Table 10. Figure 1 (IEA, 2009a) and Table 11(US EPA, 2006a) show projections of CMM emissions.

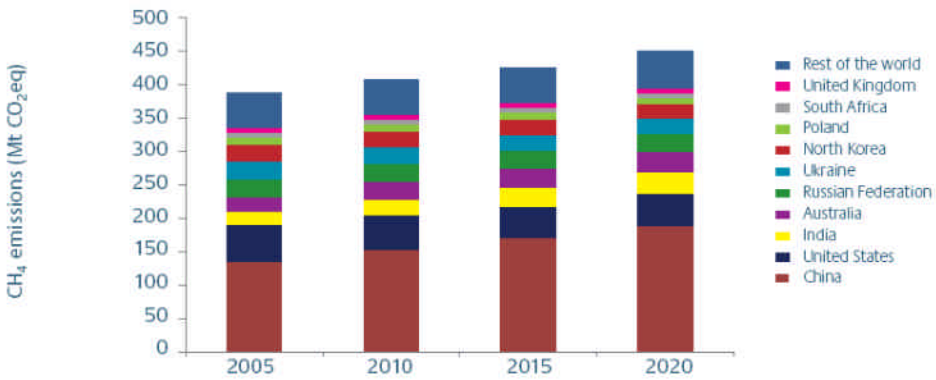

Figure 1 *Global coal mine methane (CMM) emissions 2005-2020*
Source: IEA, 2009a.

Table 10 *Emission factor coal mine methane (CH_4) in Nm^3 per tonne of product coal*

[Nm^3/tonne product coal]	Open-pit mines	Pithead mines	All types	Capture
Ökoinventare, 1996				
Belgium		25		
France	2	25		
Germany		18.2		
Spain	2	12.5		
Czech Republic		16.9		
Poland		12		
Australia	2	9.8		
China	2	11.5		
Canada	1.7	N/A		
USA	1.5	12.3		
Colombia	3	N/A		
Russian Federation	1.7	19.5		
South Africa	*2*	*9.9*		
Hinrichs et al, 1999				
Germany			7.6	3.3
Poland			3.1	0.7
Australia			4.0	0.0
East Asia			5.7	5.1
USA			7.8	18.0
Russian Federation			12.5	1.1
South Africa			*11.1*	*0.0*
IPCC, 1995				
Germany		22.4		
United Kingdom		15.3		
Czech Republic		23.9		
Poland		6.8 – 12.0		
Australia		15.6		
USA		11.0 – 15.3		
Russian Federation		17.8 – 22.2		
Lloyd and Cook, 2004				
South Africa			0.4 [a]	

a Based on an emission of 72,000 t/a ≈ 100 Mm^3/a of CH_4 and coal production of 245 Mt/a, which is far below the 317,000 t/a reported in the 1994 National Communication as acknowledged in (US EPA, 2009a).

Sources:Dones et al, 2007; Lloyd and Cook, 2004.

Table 11 *Projected baseline emissions coal mine methane (CMM) for selected countries*

[$MtCO_2$-eq]	2005	2010	2015	2020
China	135.7	153.8	171.8	189.9
USA	55.3	51.1	46.4	46.4
India	19.5	23.1	28.4	33.6
Australia	21.8	26.4	28.2	29.7
Russian Federation	26.3	27.5	26.9	26.3
Ukraine	26.3	24.5	23.8	23.2
North Korea	25.6	24.3	23.1	21.9
Poland	11.3	10.8	10.3	9.8
South Africa	7.4	7.2	7.1	7.4
United Kingdom	6.7	6.6	6.4	6.2
Germany	8.4	7.7	7.1	5.9
Kazakhstan	6.7	6.4	6.1	5.8
Colombia	3.4	4.0	4.7	5.5
Mexico	2.5	2.8	3.3	3.7
Czech Republic	4.8	3.9	3.1	3.0
Rest of the world	26.5	27.5	28.9	31.1

World total	388.1	407.6	425.6	449.5

Source: US EPA, 2006a.

3.6.1.1 China

China is the world's leading CMM emitter. In 2005, CMM emissions were in excess of 135 Mt of CO_2 equivalent – 35% of the world's total (Table 11); emissions are expected to increase in the future in tandem with increasing coal production. The selection of a suitable CMM gas drainage method is mainly determined by the source of methane, the type of coal, the coal extraction method and the geological conditions. Many coal mines are considered to have high gas content. All underground coal mines are required to use ventilation systems to keep in-mine methane concentrations below explosive limits and to provide fresh air to the miners. In China, mines with CMM having methane concentrations over 30% must augment their ventilation systems with drainage or degasification systems to remove methane (US EPA, 2006b).

Effective capture of coal-bed and coal-mine methane presents an opportunity for increased energy productivity and safety in China's coal industry. However, methane capture has not been extensively developed due to lack of transparency regarding resource property rights and lack of available technology. In 2008, Shanxi Electric Power Corp. officially commenced operation of the world's largest coal-bed methane power plant (120 MW, generating 840 GWh per year).

3.6.1.2 Russia

According to the UN Framework Convention on Climate Change (UNFCCC) GHG inventory data, methane emissions from Russian underground coal mines amounted to around 1.8 Bm^3 (26.9 $MtCO_2$-eq) in 2005 and 1.9 Bm^3 (28.5 $MtCO_2$-eq) in 2006. Nearly all the methane is released into the atmosphere. Not only will this contribute to global warming, but also high levels of methane are a critical issue for safety at coal mines. In 2009, 57 out of 98 mines were rich in methane (over 10 m^3/t), including some super-hazardous mines (over 15 m^3/t) and those with high risk of coal, gas and rock outbursts. However, less than 50% of the mines used degasification systems (see Table 12). Most fatalities at coal mines are related to methane (IEA, 2009b).

Russia's coal production has risen from a 1998 output of 221 Mt (including 141 Mt of hard coal) to 323 Mt (including 247 Mt of hard coal) in 2008 (IEA, 2009c). The increase in export volumes has led over the decade to a considerable rise in the share of coal that is treated to improve its quality – about 65% in 2005.

The high methane content of Russian coal and the associated risks during mining, referred to by some experts as the 'gas factor', remain key constraints to improving the efficiency of coal mines. Thus addressing CMM issues becomes an important prerequisite for Russia's coal sector to compete for energy market share domestically and on world coal markets. Table 12 shows the number of mines with degasification for Category 3 mines (>10 m^3 CH_4/t).

Table 12 *Russian mines with/without degasification (Category 3 and super-hazardous)*

Coal basin	Mines with degasification / Category 3 and super-hazardous mines (>10 m^3 CH_4/t)							
	1992		1998		2002		2009	
	- / -	[%]	- / -	[%]	- / -	[%]	- / -	[%]
Kuznetskiy	33/72	46	17/47	36	13/46	78	16/48	33
Pechorskiy	10/12	83	6/7	86	6/6	100	6/6	100
Donbass	4/4	100	1/4	25	1/1	100	1/1	100
Chelyabinskiy	4/6	100	2/2	100	2/2	100	2/2	100
Other	6/26	23	4/9	44	N/A	N/A	N/A	N/A
Total	57/120	47	30/69	44	22/55	40	25/57	44

Source: IEA, 2009b, based on (Ruban, 2009).

3.6.1.3 USA

In 2005, U.S. coal production amounted to 1,132 Mt, of which 763 Mt from open-pit mines and 369 Mt from pithead mines (US EPA, 2009a). The gassy coal seams of the U.S. are found in four geographic regions: the Appalachian Basins of the eastern U.S. (medium to high volatile bituminous and anthracite); the Illinois Basin in the Midwest (medium to high volatile bituminous); the Rocky Mountain Basins in the western U.S. (lignite, sub-bituminous to medium/high volatile bituminous); and the Gulf Coast and Anadarko Basins of the South/Southwest (lignite, sub-bituminous to medium/high volatile bituminous).

Table 13 shows the CMM emission from operating and abandoned U.S. coal mines. There are a limited number of CMM based power projects in existence or planned. CONSOL Energy and Allegheny Energy operate a combined power project in Virginia, the 88 MW power generation station based on two large turbines (the second largest CMM power plant in the world). Most CMM based power projects use small turbines or gas engines. CONSOL also recovers CMM from these mines to use in drying coal. CMM recovery and use projects are in place at some other U.S. mines too. In addition, there are 20 projects using gas from 30 abandoned U.S. coal mines in applications ranging from power generation to pipeline injection (US EPA, 2009a).

The U.S. is a signatory to UNFCCC and the Kyoto Protocol, but did not (yet) ratify the Kyoto Protocol. Therefore, it is not subject to Kyoto emissions targets. There are no alternative emission restrictions or regulations limiting CO_2 and other GHG emissions, but some states have begun establishing emissions limits. In addition, some firms are voluntarily engaging in the carbon market through self-imposed CO_2 emissions reductions or financial investments in greenhouse gas emission reductions. Utilities in 39 U.S. states offer their customers ‘green pricing’ in which customers opt to pay a premium on their electric bills to have a portion or all of their power provided from renewable sources. However, this does not include CMM.

3.6.1.4 Implementation of policies and measures to support CMM

Germany, Poland, the UK, Australia, the USA, and China have the largest physical CMM potential (Pilcher et al, 2008). Most of CMM demand comes from natural gas markets. For example, in the U.S. most CMM is sold via natural gas pipeline. Other applications are electricity generation (in the UK new CMM projects tend to be power generation projects), and heat generation and combined heat and power (CHP) (potential end usage in Germany).

Table 14 provides the status of implementation of policies and measures to support CMM recovery and utilisation (US EPA, 2009b). The UK, Germany, and Australia are among the countries that have most policies and measures in place to support CMM recovery and utilisation. In the UK, there are only five deep coal mines in operation. However, there are about 25 coalmine methane projects in operation in the UK, whereas the number of abandoned coalmines is more than 1,000 (IEA, 2008). Thus, there is a great potential to use CMM.

(ECE, 2010) and (Somers, 2008) provide the following salient data with regard to CMM:

- 14 countries have CMM drainage at active mines;
- 12 countries have CMM recovery and utilisation activities at active and/or abandoned mines;
- there are in excess of 200 CMM projects worldwide, delivering more than 3.8 billion m^3 of avoided methane emissions per year,
- the prevalent use for CMM is for power generation; other uses include boiler fuel, injection to natural gas pipelines, town gas, industrial gas, feedstock for conversion to vehicle fuels such as liquefied natural gas (LNG) or compressed natural gas (CNG), and coal drying.

Worldwide development potential for CMM can be realised to its fullest extent in the near term, but many formidable barriers remain (Pilcher et al, 2008). The most common barrier to development is the lack of comprehensive policies that not only encourage the development of CMM using the technology that is available presently, but policies and funding that cause new approaches to be taken and new technologies to be developed and used. Development of CMM projects can be encouraged by facilitating financial incentives gained through GHG emissions trading and from tax credits associated with unconventional energy resource development.

Table 13 *CMM emissions from operating and abandoned U.S. coal mines*

[million m^3]	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Operating mines												
Open pit	3,271	3,204	3,263	3,145	2,913	2,756	2,675	2,487	2,520	2,665	2,466	2,512
Pithead	806	832	851	884	871	861	922	897	871	905	931	982
Post-mining open-pit	485	503	523	519	480	468	477	448	450	465	450	439
Post-mining pithead	131	135	138	144	142	140	150	146	141	147	151	160
Total operating mines	4,693	4,674	4,776	4,692	4,407	4,225	4,224	3,978	3,982	4,183	3,997	4,092
Abandoned mines	577	606	568	483	490	515	469	431	417	406	389	378

Source: US EPA, 2009a.

Table 14 *Recent status of implementation of policies and measures to support CMM recovery and utilisation*

Country	Existence of major stakeholder categories	Institutional development	Increased use of new technologies	Feed-in tariff	Obligations	Utilization of existing economic incentives: Utilise existing economic incentives (except tax privileges)	Tax incentives	Grants	Lowering or eliminating tariffs and/or VAT or CAG imported equipment	Defined gas property rights	Unsubsidised free gas market	Education and information dissemination
Australia	+	+	+	-	+	+	-	+	-	+	+	+
Canada	+	+	+	-	-	+	+	-	-	+	+	+
China	-	-	+	-	N/A	+	+	-	+	+	-	+
Germany	+	+	+	+	-	+	-	-	-	+	-	+
India	-	-	-	-	-	+	-	-	-	- [b]	+	+
Poland	-	-	+	-	-	+	-	-	-	+	+ [b]	+ [b]
Russia	-	-	-	-	-	+	+	-	+	+	-	+
UK	+	+	+	-	-	+	+	-	-	+	+	+
USA	+	+	+	-	-	+	+ [a]	-	-	+	+	+

a Tax credits for CMM expired on December 31, 2002..
b Authors' assessment.
Source: US EPA, 2009b.

3.7 Emissions to water

In the following, emissions to water are reporter per tonne product coal. Water produced for pithead mines is 1.3 m^3/tonne product coal, and chloride 16.7 kg Cl/t (Dones et al, 2007). They present the following data for coal cleaning and upgrading (Table 15).

Table 15 *Emissions to water for coal cleaning and upgrading open-pit and pithead mines*

[g/tonne]	Open pit			Open pit	Pithead	Open pit US East/US West	Pithead		
	DOE 1989	DOE 1983	ORNL 1980	UNEP 1985	UNEP 1985	DOE 1980	DOE 1980	Brune et al, 1984	Dones et al, 2007
TDS [a]	1100	907	1100	493	10250	570/650	10700		**1000**
TSS [b]	18	16.5	19.88	9.5	440	11/63	47	<20	**15**
SO_4	700	495	620	338	4500	390/895	4800		**500**
Al		1.1	1.42			0.8/0.16	47		**1**
NH_3		1.1	1.68	0.5	7.5	0.55/5.5	8.2		**1**
Fe dissolved		0.16	0.24			0.01/0.14	0.55		
Fe non-diss.		1.6	2.19			0.11/0.55	5.5		
Fe total									**2**
Mn		0.8	1.19			2.7/0.55	2.7		**1**
Ni		0.08	0.09			0.05/0.03	0.55		**0.1**
Zn		0.11	0.17			0.05/0.14	0.55		**0.1**
Cl							350		**350**
F							2.7		**3**
Sr							5.5		**5**
$CaCO_3$							3800		
CSB [c]								<20	

a Total dissolved solids.
b Total suspended solids.
c Concentration of contaminant sorbed to bottom (bed) sediment.
Source: Dones et al, 2007.

3.8 Accidental air emissions due to coal fires

Dones et al (2007) also consider emissions to air from coal fires. Self-ignited, naturally occurring coal fires and fires resulting from human activities persist for decades in underground coal mines, coal waste piles, and unmined coal beds. These uncontrolled coal fires occur in all coal-bearing parts of the world and pose multiple threats to the global environment because they emit greenhouse gases – CO_2 and methane – as well as mercury (Hg), carbon monoxide (CO), and other toxic substances. The release of greenhouse gases from underground coal-mine fires depends on the mine fire temperature and the concentration of O_2 in the mine (Internet Source 1). The contribution of coal fires to global CO_2 emissions is little known but potentially significant (Kolker et al, 2009).

In China the main coal fire areas stretch along the coal mining belt, which extends for 5000 km from East to West along the North of the country. More than 50 coal fields affected by coal fires have been identified. At present in China an estimated 20 – 30 Mt of coal is burned by these fires each year (Internet Source 2). Acids, aerosols, and toxic-particulate matter released from coal fires may be transported over long distances. In China, such pollutants have adversely affected

88 cities, with the effects of acid rain spilling over into Japan, Korea, and the Philippines (Internet Source 3).
Dones et al present the following air emissions due to coal fires in the USA (Table 16).

Table 16 *Estimated emissions to air due to coal fires in the USA*

	CO	SO_2	VOC	NO_x	PM
[g/tonne]	2.2	1.1	0.4	0.4	1.5
[g/TJ]	85	42	15	15	58

Source: Dones et al, 2007.

4 Conclusions

This short study provides an overview of emissions related to hard coal mining. It is largely based on an in-depth study of Dones et al (2007), supplemented by a number of recent literature sources for some items. The data presented pertain to resource requirements, indirect energy user and material requirements (for mining infrastructure), land use, direct energy use (mining including cleaning and upgrading), emissions to air (in particular for coal mine methane), emissions to water, and accidental air emissions due to coal fires. The data presented may be used in a database enabling model calculations on environmental impacts of Carbon Capture and Storage (CCS) chains to be developed in the Netherlands.