Background document for Deliverable WP 4.3-D04

Coal Transport

Prepared by: J. van Deurzen
Reviewed by: H. Snoep
Approved by: R. Ybema

1 Executive Summary

This document is a background document to the CATO-2 Deliverable Work Package 4.3-D04, named Environmental monitoring and exchange database. It provides information regarding the emissions related to the transport of coal, to be used in a Life Cycle Analysis., This document, which is part of the environmental performance tool, describes part of the supply chain of the Carbon Capture and Storage technology performance.

Distribution List

(this section shows the initial distribution list)

External	copies	Internal	Copies
Internal list: Cato WP4.3 partners			

Document Change Record

(this section shows the historical versions, with a short description of the updates)

Version	Nr of pages	Short description of change	Pages
-	-	-	-

Table of Content

2 Applicable/Reference documents and Abbreviations

2.1 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

2.2 Reference Documents

(Reference Documents are referred to in the document)

	Title	Doc nr	Issue/version	date
Dones, R. et al	*Teil VI - Kohle, Data v2.0*. Ecoinvent Centre, Swiss Centre for Life Cycle Inventories, PSI, Villigen, Switzerland,			December 2007
Gon, D. van der, H.J. Hulskotte	*O Methodologies for estimation shipping emissions in the Netherlands*. Netherlands Environmental Assessment Agency, TNO, ECN, RIVM, Utrecht, the Netherlands		. http://www.rivm.nl/bibliotheek/rapporten/500099012.pdf	2010
Ritschel. W., H.W. Schiffer	*World market for hard coal*. W RWE Power, Essen-Cologne, Germany			2003
Schrooten, L., I. de Vlieger, L. in Panis, R.Torfs	*Forecasted Maritime Shipping Emisson for Belgium with an Activity Based Emission Model*. Proceedings of the TAC-Conference			June 26-29, 2006
Georgakakia, A. et al	*Maritime air pollutant emission modelling - TRENDS (Transport and Environment Database System)*. Technical University of Denmark (DTU)			12 July 2004
Vreuls, H.H.J.	*Nederlandse lijst van energiedragers en standaard CO_2-emissiefactoren.* Netherlands Environmental Assessment Agency, Utrecht, The Netherlands			2006

Internet sources

1.	Http://www.eurostat.com
2.	Http://www.portworld.com
3.	Http://www.distances.com
4.	Http://www.argusmedia.com; Http://web04.us.argusmedia.com/ArgusStaticContent/snips/sectors/pdfs/argus_coal_daily_intl.pdf
5.	Http://www.snsk.no/sales-of-coal.145615.en.html
6.	Http://www.clarksons.net/pubs/pubs.asp
7.	Http://www.tc.gc.ca/eng/programs/environment-ecofreight-about-voluntary-racemissions2007-5-341.htm#a5.1

3 Introduction

As part of the CATO-2 programme Work Package 4.3, life cycle analysis is part of the CCS chain research. The emissions that can be linked to transport of coal are subject of this paper. The emissions considered in coal transport merely stem from the use of heavy diesel fuel. Several studies over time have been dedicated to determining emissions from the use of marine diesel, which record the emissions $NO_{x,}$ CO, HC, $CO_{2,}$ $SO_{2,}$ and PM. Not considered in this note are emissions to water or risks to the environment due to water discharge or accidents. For emissions to water further literature needs to be awaited. Environmental impacts related to i.e. ballast water discharge and other risk factors are considered to be out of scope for this note.

The approach for determining the emissions due to the transport of coal to the Netherlands is as follows (Figure 1). The first category of interest is the origin of the coal: country (and region) of origin. The second category relates to the transport mode and distance, and the third category to the related fuel consumption and emission factors. These are governed by a fourth category, namely the ship or rail characteristics (dependent on transport mode). The final results are the emissions.

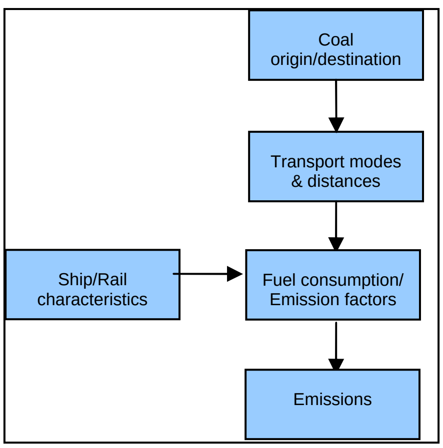

Figure 1 *Overview of the stages in determining transport emissions*

4 Coal origin/destination

The amount of coal that is used for electricity generation in the Netherlands is over 8 Mton per year over the period from 2005 to 2007. The exact origin of the coal i.e. the location of the mine is not publicly available. An assumption for the origin of coal used in Dutch coal-fired power plants is that the coal has the same origin as the European average as published in the Eurostat database (Internet Source 1). The total import to the Netherlands is recorded and published by Eurostat. As a reasonable approximation a general mix of imported hard coal is considered as the default for the Netherlands because export numbers do not suggest all import from one particular country is only used for export. The amount and underlying mix of imported hard coal per country depends on the reference year, but over the last 3 years (from 2005 to 2007) the main countries of origin for imported hard coal are the same. Figure 2 shows the import mix of hard coal to the Netherlands.

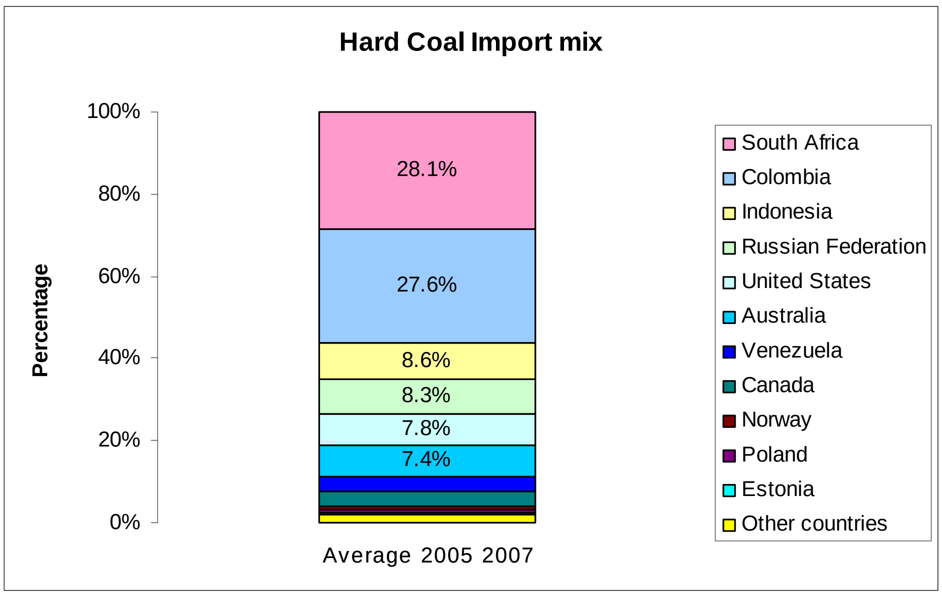

Figure 2 *Import mix of hard coal to the Netherlands*
Source: Eurostat.

The assumed geographical locations can be distributed over several regions within one country. In this way the transport distances can also vary significantly. There are studies that have produced a map for the geographical location of mining and world resources of coal. Given the countries of origin from the Eurostat database, based on Ritschel and Schiffer (2005), the region(s) of mining within the countries are known. Especially for countries such as Australia and Russia, there are multiple regions where coal is mined.

5 Transport modes and distances

Distances were calculated based on calculations (Internet Sources 2-3), as well as by comparison to existing literature. One of the leading databases in LCA research is the Ecoinvent database (Dones et al, 2007). Depending on the year of mining, the amount of coal transported per mine varies. Among other factors, that influences the use of ports and shipments and exact routes of coal transport. But considering the character and time span involved, the routes that exist today are expected to be more or less the same for the future. Therefore, typical routes that are being used were assessed by country in this study.

Based on surveys and verification of market information for bulk transporters (Internet Source 4), the most commonly used harbours by country of origin were used to determine the origin of one route. The point of destination for a bulk transport was set at the Rotterdam harbour. In terms of transport distance of coal from mine area to harbour, an average distance was used for clusters of mines in a region for supplying a harbour. Table 1 shows the transport distances for hard coal import to the Netherlands (Rotterdam).

Table 1 *Transport distances for hard coal import to the Netherlands (Rotterdam)*

Coal production			Destination Rotterdam	
Country	Region	Port	Shipping Distance [NM][a]	Rail distance [km]
South Africa	KwaZulu Natal	Richards Bay	7,025	240
Colombia	El Cerrejon	Puerto Bolivar	4,530	200
Indonesia	Borneo	Balikpapan	12,095	200
Russian Federation	Kemerovo	Ulst Luga	1,300	4,288
United States		Norfolk	3,514	400
Australia	New South Wales	Port Kembla	12,493	200
Venezuela	Paso Diablo	Maracaibo	4,543	200
Canada	West Canada	Vancouver	8,852	550
Norway	Spitsbergen	Longyearbyen	1,631	
Poland		Gdansk	771	250
Estonia		Riga	1,012	100

a NM = Nautical Mile.

6 Ship characteristics

In the same surveys of transport routes of hard coal, the capacity of ships was also published, among additional sources of information (Table 2) (Internet Source 5-6). There are two main types of ships, namely the Panamax type which is fitted to the maximum Dead Weight Tonnage (DWT) allowed for passing the Panama Channel, and the Capesize type. Table 2 shows that the DWT of these types differs by a factor two or more. This affects the freight tariff due to economies of scale.

Table 2 *Ship characteristics for hard coal shipping to the Netherlands (Rotterdam)*

Country	Port	Assumed ship type	Dead Weight Tonnage [DWT]	Payload [ton]
South Africa	Richards Bay	Capesize	170,000	112,000
Colombia	Puerto Bolivar	Capesize	170,000	112,000
Indonesia	Balikpapan	Panamax	70,000	68,000
Russian Federation	Ulst Luga	Panamax	70,000	65,000
United States	Norfolk	Capesize	140,000	98,000
Australia	Port Kembla	Capesize	170,000	112,000
Venezuela	Maracaibo	Panamax	70,000	58,000
Canada	Vancouver	Panamax	70,000	58,000
Norway	Longyearbyen	Panamax	70,000	58,000
Poland	Gdansk	Panamax	80,000	70,000
Estonia	Riga	Panamax	70,000	58,000

7 Emission factors

The emission factors study of the main joint knowledge consortia of the Netherlands (NEAA and ECN) was used (Van der Gon and Hulskotte, 2010). They report ship emissions per capacity category. The calculated emissions were compared to results from the emission study of the Technical University of Denmark called TRENDS (Georgakakia et al, 2004). In 2009, the Flemish institute for Technological research, VITO, performed a bottom-up study for determining the total amount of emissions in Belgian harbours (Schrooten et al, 2006). Their research included the latest emission legislation of the EU and the International Maritime Organisation (IMO). The emission factors from the VITO study differ from the emission factors of the TRENDS study for SO_2 (Table 3).

Main reason for using the NEAA/ECN study is that the main engine emission factors were derived from the emission factors of individual ships sailing through the Dutch Continental Shelf and field experiments in 2004. It published its results in selected categories of Gross Tonnage, whereas the TRENDS study uses a correlation function for fuel consumption for all ship categories. Although the study was done in about the same period (2003), it uses a more general approach and its input and assumptions are less transparent.

Table 3 *Emission factors for fuel use in bulk transport*

Bulk ship transport					Train transport
	Heavy fuel oil		NEAA/ECN study [main engines kg/GT.km]	NEAA/ECN study [main engines kg/GT.km]	Freight operations emissions intensity
Emission factor	TRENDS [kg/ton fuel]	VITO [kg/ton fuel]	GT 29999 - 59999	GT 60000 - 99999	kg/1,000 RTK[b]
NO_x	81.4		1.36E-04	9.56E-05	0.27
CO	6.91		1.89E-05	1.30E-05	0.03
HC	2.24		3.70E-06	2.59E-06	0.01
CO_2	3170	3110	4.58E-03	3.23E-03	17.75
SO_2	59.8	54 until 2006; 30 from 2006	6.75E-05	5.19E-05	0.01
PM	7.7		7.78E-06	5.95E-06	0.01

Revenu Tonne Kilometer

The emission factors for bulk transport per train are taken from the Locomotive Emissions Monitoring Program in 2007 in Canada (Internet Source 7).

8 Emissions

The total emissions were calculated by using the emission factors of the recent study of NEEA/ECN. The emission factors are given per Gt.km. This means that the assumed ship type is stated in Gross Tonnage instead of Dead Weight Tonnage. The DWT was divided by 1.83 to come up with the Gross Tonnage of a ship type (Georgakakia, et al, 2004).

Table 4 *Intermediate results for emission calculation of ship bulk transport*

	Dead Weight Tonnage	Gross Tonnage	# of Shipments	Gt.km
South Africa	170000	92896	61	1.4745E+11
Colombia	170000	92896	67	1.0443E+11
Indonesia	70000	38251	27	4.6269E+10
Russian Federation	70000	38251	37	6.8150E+09
United States	140000	76503	24	2.3898E+10
Australia	170000	92896	16	6.8779E+10
Venezuela	70000	38251	20	1.2873E+10
Canada	70000	38251	13	1.6304E+10
Norway	70000	38251	5	1.1552E+09
Poland	80000	43716	2	2.4969E+08
Estonia	70000	38251	2	2.8677E+08

By multiplying the Gt.km result with the appropriate emission factor, the total emissions can be calculated. In this calculation the total imported coal was set as 25,146 Mton. The emissions of the average imported coal mix emissions are as follows (Table 5).

Table 5 *Emissions from coal transport per Mton of coal*

Emission	Due to ship transport	Due to train transport	Emissions per average imported coal mix	
	[ton/Mton]	[ton/Mton]	[ton/Mton]	[kg/TJ]
NO_x	1,764	255	2,019	49,460
CO	241	28	270	6,604
HC	48	9	57	1,403
CO_2	59,550	16,749	76,299	1,869,330
SO_2	937	9	946	23,176
PM	108	9	117	2,865

The results of the emissions from coal transport can be presented in several ways, in terms of average imported tonnage as well as in terms of the energy content of the coal itself. The energy content for 2006 for bituminous coal was given a 24.5 MJ/kg (Vreuls, 2006).

9 Sensitivity analysis

Comparing the emission results was done by applying different emission factors of the above mentioned studies, with using the same input data. The TRENDS study follows an approach of first calculating the fuel use of a certain ship (engine) type and then multiplying with a different set of emission factors (see Table 3) as compared to the study of NEAA/ECN. The results of the TRENDS/VITO study were used when comparing the emission factors. An indication of the uncertainty from the methodologies and measurements for the ship transport emissions can be obtained in this way. PM emissions show the largest reduction, other emissions deviate between plus and minus 30%.

Table 6 *Emission deviation among studies*

Emission	NEAA/ECN study [ton/Mton]	TRENDS&VITO study [ton/Mton]	Differences between the total emissions [%]
NO_x	1,764	2,033	15
CO	241	173	-28
HC	48	56	17
CO_2	59,550	77,663	30
SO_2	937	749	-20
PM	108	192	79

Due to the large distance from the Kemerovo region to the Baltic ports, the vast majority (65%) of the coal train transport emissions are related to Russian coal transport. In general, the emissions from rail transport are much lower than those of ship transport.

The absolute values of the emissions are given in Table 5, where Table 7 gives their relative share. Generally speaking, the ship transport contributes 88% of the emissions per imported Mton of coal, where train transport is accountable the other 12%.

Table 7 *Emissions from coal transport per transport mode*

Emission	Due to ship transport [%]	Due to train transport [%]
NO_x	87	13
CO	89	11
HC	84	16
CO_2	78	22
SO_2	99	1
PM	92	8

When calculating the effect of one extra shipload coal from one of the production countries, the effect on the average of the imported coal mix can be either an improvement or a loss of the general intensity due to transport (Table 8). On average an increase in the total market volume of coal hardly impacts the average coal mix emission intensity. Calculated as an effect for all mentioned emissions, Table 8 shows that an increase in the mix of European and American coal will have a positive effect on the average emission intensity, whereas extra coal imported from Australia, Canada and Indonesia results in an increase of the overall emission efficiency.

Table 8 *Sensitivity analysis: When one extra shipload of coal is imported*

	% change in emissions per average imported coal mix		
	Average change over all emissions	Related to ship transport	Related to train transport
South Africa	0.04	0.08	-0.28
Colombia	-0.13	-0.11	-0.30
Indonesia	0.19	0.24	-0.18
Russian Federation	0.00	-0.20	1.50
United States	-0.17	-0.17	-0.14
Australia	0.39	0.48	-0.30
Venezuela	-0.05	-0.04	-0.16
Canada	0.13	0.15	-0.03
Norway	-0.16	-0.16	-
Poland	-0.23	-0.24	-0.17
Estonia	-0.19	-0.19	-0.19

10 Conclusions

The emissions related to the transport of coal to the port of Rotterdam are considered in this note, as part of a life cycle analysis of the CCS chain. Several assumptions have been made about the transport routes and the transport distances and modes. Each year market conditions, the total amount of coal used, and imported coal mix will have an effect on the total and average emissions. What is considered in this note are typical values that can be expected and used in a life cycle analysis involving transport of coal for use in a coal fired power plant in The Netherlands. Average values are given in Table 9.

Table 9 *Emissions from coal transport per Mton of coal*

Emission	Due to ship transport [ton/Mton]	Due to train transport [ton/Mton]	Emissions per average imported coal mix [ton/Mton]	[kg/TJ]
NO_x	1,764	255	2,019	49,460
CO	241	28	270	6,604
HC	48	9	57	1,403
CO_2	59,550	16,749	76,299	1,869,330
SO_2	937	9	946	23,176
PM	108	9	117	2,865

The results can be affected by several factors. The sensitivity of the average results can be affected by using ships with a larger DWT. But the use of the type of ships is constrained by local conditions of the route i.e. the use of the Panama Channel, or the harbour. Changes in the emissions per average imported coal due to a change in the average mix, are of a order of magnitude smaller than the variability related to outcomes of comparable studies. The sensitivity analysis suggests that to a large extent the choice of the method and the measurements considered in a study determine the amount of emissions that are related to coal transport. Therefore the results in the Table above should be considered with care of its variability.