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COAL MINING IN THE NETHERLANDS; THE NEED FOR A PROPER ASSESSMENT

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(8 figures and 6 tables)

ABSTRACT. In the Netherlands several billion tonnes of mineable coal remained after closure of all mines in 1974. Mining activities in Dutch Limburg were suspended relatively early in comparison to surrounding basins, of which only DSK's Ruhr mines are still producing. In retrospective this saved the costs of uneconomic exploitation and limited further depletion. On the other hand, associated knowledge base and mining expertise virtually disappeared from the Netherlands. Almost 30 years later this may arise some fundamental questions: How far is coal depleted in the Netherlands? How do the remaining inland reserves benchmark compared to other basins? What factors determine technical, environmental and economic feasibility of coal production? How are productivities developing with the progress of automation? How do applicable production costs relate to market prices and what are the expected trends in future? Which production costs are fundamental (e.g. of geological origin) and which may be overcome by technological progress? After giving a concise overview of the "old" basin and its exploitation history, the remaining coal-bearing areas in the Netherlands are briefly described with regard to their technical mineability. Some factors affecting the current economic, technical and environmental boundary conditions of coal mining are discussed.

Keywords: mining, coal, energy resources, reserves, depletion, Netherlands, Limburg, Staatsmijnen.

1. Introduction

Until 1967 Dutch coal production varied between 12 and 14 million tonnes (Mt) per year (Geologie en Mijnbouw, 1971). In this period a remaining (geological) coal reserve of approximately 5500 Mt was already identified (Petrascheck, 1961). From roughly the second half of the 20th century, oil, natural gas and nuclear power gained an increasing share of the energy market. In 1975, when all Dutch mines were closed, the market for coal almost disappeared, especially due to the large-scale introduction of natural gas. Besides that, increasing labour costs decreased the viability of the mines. At that time only the Hoogovens steelworks consumed approximately 3.5 Mt per year for the production of metallurgical cokes. The majority of power came from gas-fired stations. The oil crisis of 1973 led to the opinion that a diversification of primary energy sources was desired, with as target an approximately equal share of natural gas, coal, and nuclear power. Since 1975 price fluctuations on the oil market, the steady depletion of inland gas reserves and the reluctance to expand nuclear capacity led to a gradual re-introduction of coal as a primary source of energy. In 2002 Dutch coal consumption amounted approximately 12 Mt per year, of which 8.2 Mt was used for power stations. The remainder is mainly used by the steel industry (European Commision, 2002).

Inspired by the oil crisis of 1973, already before the scheduled final closure of the last Limburg mines, the ministry of economic affairs ordered to investigate the re-start of mining operations (Weehuizen, 1974). In 1978 however, it was concluded that long term prospects were unfavourable and the shafts of the state mine Emma, which had been preserved until then, were definitely closed in 1978 (Messing, 1988). Again inspired by high oil prices in the early eighties and the increasing demand for coal, the ministry of economic affairs ordered the Dutch Geological Survey (DGS) to start an exploration campaign to study the remaining Dutch coal reserves (van Leeuwen, 1987). The Geological Bureau in Heerlen, a separate branch of the DGS, carried out this investigation between 1980 and 1986. On the basis of several new core drillings and on new geophysical data, much additional information about the Limburg coal reserves and especially about the Achterhoek reserves was obtained (Krans, 1986). It was established that the mineable Peel reserves are not significantly different from the extend that was already known from earlier exploration. Large coal reserves, previously unknown, were discovered within the Deventer-Hengelo-Winterswijk triangle in Gelderland, bordering the never developed Gelria concession of the early 20th century. In the late eighties coal prices decreased again. It was advised to the ministry of economic affairs to suspend further exploration. A restart of coal mining has not been studied since then. The current situation on the energy market makes a short-term renewal of inland coal production unlikely. However, prohibiting economic conditions may not always last, either due to a changing market and/or due to emerging new technologies.

This study provides an overview of the current knowledge of the remaining Dutch coal reserves that can be exploited with conventional underground mining methods. The available geological exploration data of the unexploited South Limburg reserves, the reserves in the Peel area of Central Limburg and in the Achterhoek area of the province of Gelderland are reviewed regarding state-of-the-art underground mining technology. This study aims to provide an overview of the available data for an international audience: the available literature regarding this subject is sometimes difficult to access, often relatively old and in the Dutch language. In addition, some developments and boundary conditions related to underground coal mining are discussed.

2. History of coal mining in the Netherlands

Though around the town of Kerkrade coal mining had already taken place since medieval times, the opening of the Oranje Nassau mine in 1899 in Heerlen marked the beginning of systematic industrial development of the South Limburg coal reserves (Engelen, 1989b). In difference to some other large industrialised European nations, where large-scale mining marked the start of the industrial age, coal mining in the Netherlands commenced far away from the political and economical centre. Also, it was developed relatively late and primarily on initiative of foreign investors. The Dutch Government became involved only later to prevent too much foreign influence on inland coal production (Messing, 1988). Between approximately 1925 and 1967 the four State Mines, and eight private mines produced between 12 and 14 Mt yearly (Fig. 1). Since 1958 the market for industrial coal decreased, while labour costs strongly increased. On top of this, domestic coal demand diminished gradually. The discovery of the huge Slochteren natural gas field in Groningen speeded up the transition to natural gas as the dominant and strategically important fossil fuel. In addition to the poor viability, this further threatened the continuation of coal mining. At that time a viable inland production seemed no longer possible. In 1965 the Dutch government decided to close all mines. Production costs were too high and future prospects negative. The mines were closed within a 10-year program. The last operating mines in Limburg, the Oranje Nassau I and the Laura/Julia suspended production in December 1974. At that moment, the total amount of coal produced in Limburg added up to approximately 575 Mt. Subsequently all surface facilities were pulled down and shafts were closed. The region underwent an unprecedented redevelopment program ("*from black to green*") and new industries replaced the former mining industry. The Dutch State Mines were transformed into an international chemical enterprise. Just a handful of small monuments actually memorises the mining industry that once employed over 60000 workers (Fig. 2).

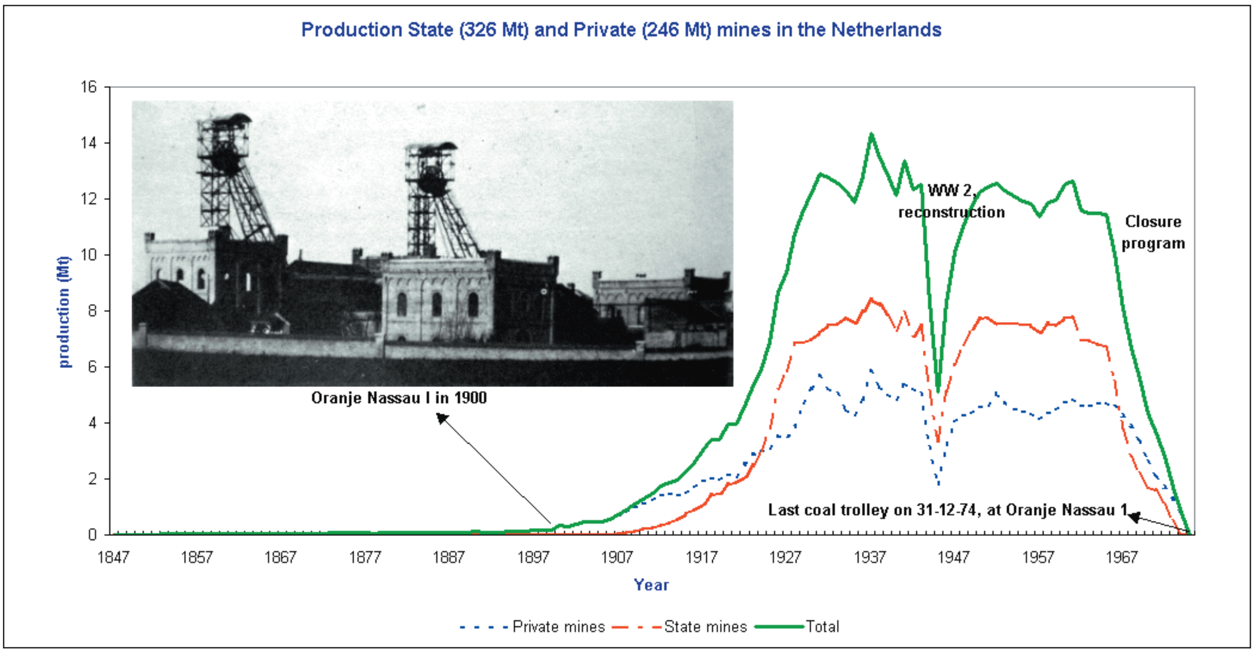

Figure 1. Yearly production of the Dutch private and state mines between 1847 and 1975.

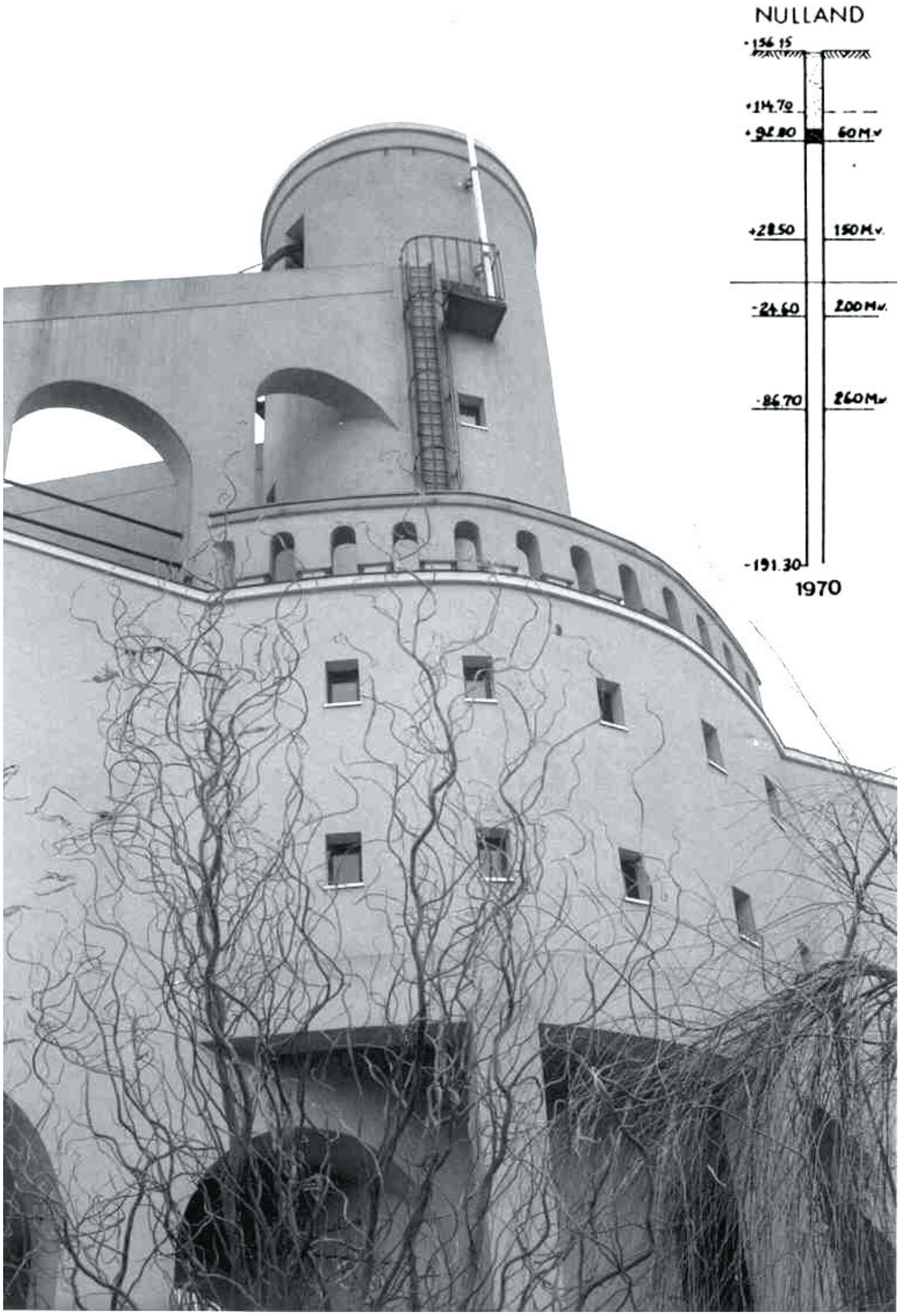

Figure 2. The restored Nulland shaft of the former Domaniale mine (Kerkrade, the Netherlands). At the top, right, a cross section of the shaft with the depths of the former levels. The upper level is filled with a concrete plug at –60 m depth. The closure year was 1970. (Photograph R. van de Laar, 1995)

In 1955 the Dutch State Mines started the development of the Beatrix coal mine in the Peel region of central Limburg by sinking two shafts into the Carboniferous. The construction of the newly planned mine was never completed and further shaft sinking was suspended in 1962. Both shafts, each already over 700 meters deep and penetrating approximately 300 meters of coal bearing Carboniferous strata, have been preserved since then and are flooded with water.

Lignite mining took place around the towns of Eygelshoven and Hoensbroek since approximately 1915 by means of surface mining (Engelen, 1989a). The mined deposits are a Northwest extension of the large lignite deposits in Germany, west of Cologne that are exploited by Rheinbraun AG (van Rooijen, 1989). The production of the various concessions amounted typically between 100000 and 200000 tonnes per year from, for lignite, relatively shallow seams of several meters thickness (e.g. 7 meters near Eygelshoven). Lignite mining was suspended in 1968 by the closure of Carisborg, the last remaining operator. Their new 140 ha concession that was granted in 1959 near the village Ubach over Worms never came into production.

3. Present situation

Currently there are no exploration and development activities in order to investigate future coal exploitation by means of underground mining. All former shafts in South Limburg are sealed with concrete and filled (Fig. 2). Virtually all surface facilities were pulled down, except two small monuments: Oranje Nassau I's shaft 2 in Heerlen and the Nulland shaft of the Domaniale mine in Kerkrade (Fig. 2). The shafts of the never completed State Mine Beatrix near Herkenbosch (Peel area) are conserved. These shafts are closed by means of heavy concrete lids. Re-opening of the other un-depleted "old" mines is unlikely, given both the extensive, predominantly urban, redevelopment and the complete disappearance of any coal related infrastructure, let alone the formidable water and subsidence problems. A fair safety distance to the old workings should be maintained in case of future exploitation of the remaining reserves.

4. Review of mineable coal reserves in the Netherlands

Van Tongeren presents an overview of the coal bearing of the Dutch Carboniferous (van Tongeren, 1989a). In the Netherlands presently three major coal-bearing regions are known that in principal are accessible by conventional mining methods: Achterhoek, the Peel region, and the remaining fields in South-Limburg (Fig. 3). It is not possible to determine a general definition that identifies what fraction of a specific coal bearing area can be regarded as mineable (Petrascheck, 1961; Hartman, 1987). Coal bearing and geology determine the value and extend of coal reserves and their exploitation costs. The geography dictates possibilities for access to the coal, as well as the planning of preparation, storage and transport facilities. Apart from geological factors, economical, political and social factors determine the production costs, e.g. coal market, tolerated levels of ash and contaminants, availability of labour, safety regulations, environmental regulations, subsidence risks, tax, subsidising etc. In addition, all these factors can vary with time and are often hard to predict on the long term. Despite the necessity to establish the mineability of coal reserves on a case by case basis, some key geological factors can serve as a rough guideline and enable bench-marking of the different coal fields, e.g. seam thickness, uniformity and disturbance, lateral extend, depth, geology of the overburden and volatile matter content.

In this overview coal bearing strata are regarded as technically mineable if they have a package of well coal-bearing strata of at least several hundreds of meters thick above –1500 meters and with coal seams ≥50 cm pure coal thickness[1]. As a result of various exploration campaigns by the former mining industry and later by the Dutch Geological Survey, the Carboniferous of the Limburg regions is mapped in considerable detail. Detailed study of the reserves in the Achterhoek region is problematic

Figure 3. Locations of the Mijnstreek (1), Peel/Beatrix (2) and Achterhoek (3) reserves.

[1] The real thickness (seam opening) can be higher, depending on ash content and the presence of shale bands.

because of the limited data available. In this section the known reserves, as well as the remaining prospects in each of these regions are concisely described, as far as presently known and relevant for underground mining operations.

4.1. Mijnstreek, South Limburg

In South Limburg only reserves that have a fair safety distance to the old mining works are considered for future exploitation, in order to avoid uncontrolled water flooding and surface subsidence (Fig. 4). The reserves of this area are located north of the former mines, however some small reserves at moderate depths are located towards the south (van Leeuwen, 1990).

4.1.1. SM-Emma-north field in Brunssum

A largely unexploited coal-bearing block is the north field of the concession of the former State Mine Emma. Both structure and coal bearing of this block are described in the inventory report of the Dutch Geological Survey (Krans, 1986). The area between the towns Sittard, Geleen, Hoensbroek and Brunssum covers an area of approximately 23 km^2. The sites of the former State mines Emma and Hendrik are located towards the southeast. The coal bearing of the remaining seams of SM-Emma-north is given in Table 1. Part of the shallower south side of the area has been worked before 1974. De Man investigated subsidence of the area as a result of the former mining activities and its related water drainage (de Man, 1988).

In this area there is an average of about 8 Mt/km^2 of ≥100 cm pure coal seams down to 1200 m and of about 11 Mt/km^2 down to 1500 m. The coal type ranges from 35% VM near the Carboniferous subcrob till c.a. 20% at progressing (stratigraphic) depths. Seam continuity as well as the considerable reserves of coking coal at moderate depths makes it one of the most interesting reserves of the former mining area. The Carboniferous subcrop is relatively shallow and lies between 250 and 450 meters below the surface.

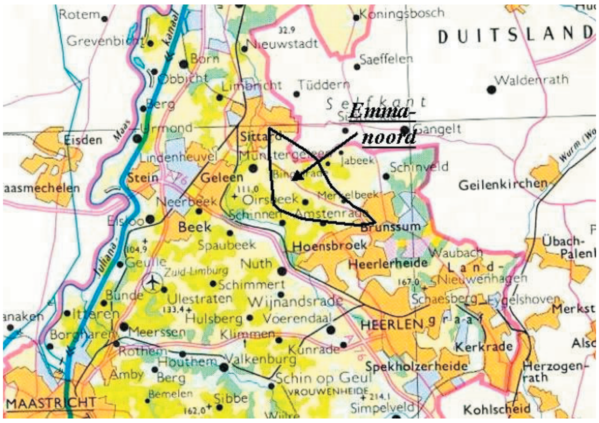

Figure 5. Outline of the SM-Emma-north field.

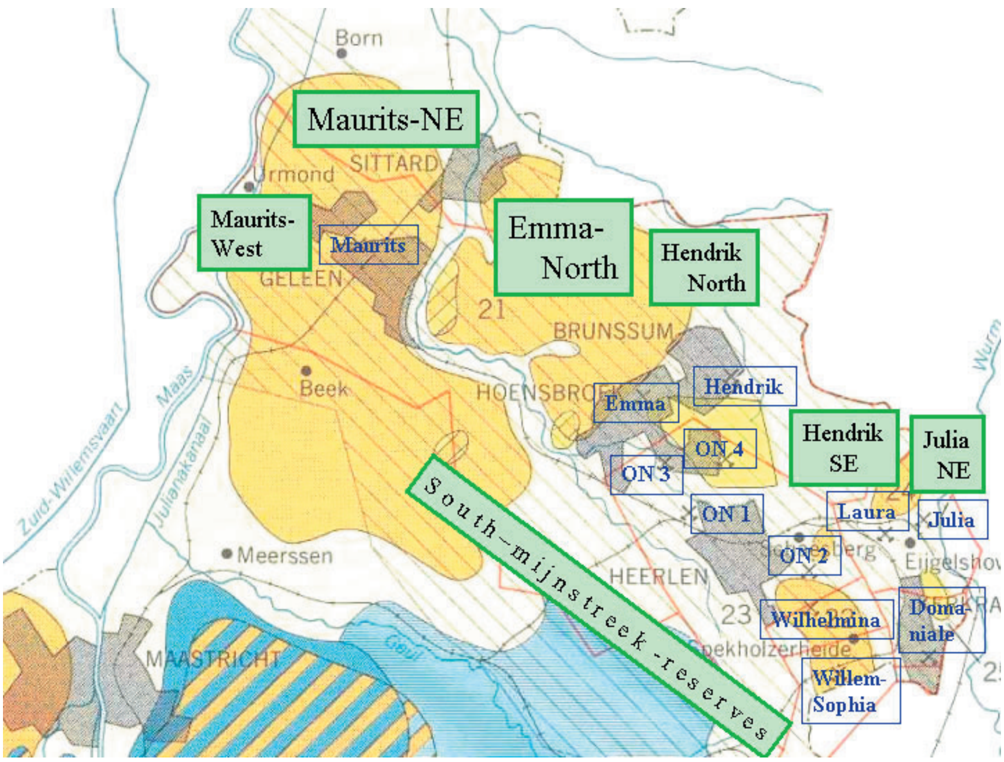

Figure 4. Location of the former mines (transparent boxes) and remaining reserves (closed boxes) in South Limburg (Mijnstreek). ON: Oranje Nassau mines.

SM-Emma-north			Geological reserves > 100 cm				
				depth m-NAP			
Layer ID	**Thickness**	**Type**	**TC / 900**	**900 / 1200**	**1200 /1500**	**TC - 1500**	**Relative**
GB	**cm**	**VM%**	**Mt**	**Mt**	**Mt**	**Mt**	**share**
84	130	>30	2.0	0.0	0.0	2.0	
80a	111	>30	6.9	0.5	0.0	7.4	
56	115	>30	14.1	6.1	4.1	24.3	
44	101	25-30	13.1	7.5	4.6	25.2	
42	117	25-30	13.8	10.1	6.9	30.8	
41	121	25-30	13.9	10.1	7.3	31.3	
39	125	20-25	4.3	5.7	6.2	16.2	
37	122	20-25	9.5	11.3	8.0	28.8	
36	108	20-25	4.5	6.3	4.3	15.1	
32	122	20-25	3.1	13.5	9.4	26.0	
27	206	20-25	1.5	21.1	17.5	40.1	
12	106	20-25	0.0	0.0	6.6	6.6	
		Total >100 cm	86.7	92.2	74.9	253.8	43%
		80 - 100 cm	90.7	31.7	25.8	148.2	25%
		50 - 80 cm	117.2	41.5	30.5	189.2	32%
		Total >50 cm	294.6	165.4	131.2	591.2	100%

Table 1. Coal reserves of seams ≥100 cm of the SM-Emma-north area, as determined by the Dutch Geological Survey (Krans, 1986). Indicated seam thickness is pure coal (actual thickness can be higher depending on the presence of shale bands and related in-seam ash content).

Development of a modern mine for the SM-Emma-north field, based on technology in use for underground mines in Germany and the United Kingdom, has been investigated in some earlier publications (van Leeuwen, 1988; van Leeuwen, 1990; Bremmer et al., 1989). Van Leeuwen concludes that maximised automation and selective mining of the most favourable seams still does not lead to competitive prices for the concept that was studied. The principal problems that are mentioned are the relatively high release of methane, the relatively low seam heights, and possible rock-mechanical problems.

4.1.2. Other South-Limburg reserves

Besides the SM-Emma-north field, remaining unexploited areas are both present north and south of the former mines (van Leeuwen, 1990; Wolf et al., 1997). Their location is given in Fig. 4. In quantity only the areas NE of SM-Maurits, the area N and SE of SM-Hendrik and NE of the former Julia mine have remaining coal seams of ≥100 cm pure coal and reserves of any significance. The geological coal reserves (≥100 cm) down to 1500 m add up to 369 Mt (Table 2). In the SM-Emma-north field the reserve ratio between the 50-100 cm and ≥100 cm coals is approximately 2.3. If a similar ratio is assumed for the other remaining South-Limburg fields, all ≥50 cm coals add up to approximately 860 Mt.

The areas south of the former mines SM-Emma, Oranje Nassau and Willem Sophia contain coals with low gas content (anthracites) in an area between 20 and 30 km^2. The majority is present as ≤100 cm thick seams. The depth of the Carboniferous subcrop varies between -50 and -200 meters. These coal bearing strata are confined by the bordering unproductive Namurien rocks towards

Geological reserves >100cm coal down to 1500 m					
depth:	TC-850	850-1200	1200-1300	1300-1500	Total
Maurits W	?	68	19	?	97
Maurits NE	40	60	20	40	160
Hendrik N	19	34	10	24	87
Hendrik SE	5				5
Julia NE	15	4	1	0	20
Total	79	166		64	369

Table 2. ≥100 cm pure coal reserves of the South-Limburg reserves, excluding the SM-Emma-north reserves that are given in Table 1 (Data from the Dutch Geological Survey, van Leeuwen, 1990).

the SW. Reserves and geology might not permit operations on a significan industrial scale. The relatively shallow depth however, as well as the low gas and ash content could make some of these locations of potential interest for smaller scale enterprises ("Mini-mines" or "Kleinzechen").

A quantitative estimation of lignite reserves is not given in this overview. Van Rooijen points out either their great depth or their low seam height as main reasons for their limited economic relevance (van Rooijen, 1989).

4.1.3. Summary of the South-Limburg coal reserves

Disregarding ≤100 cm pure coal reserves, the geological potential down to 1500 m of the unexploited South-Limburg reserves adds up to approximately 623 Mt. The most favourable block is the SM-Emma-north, which has a geological potential of 254 Mt. The majority coal quality will be medium VM (coking) coal.

4.2. The Peel coal fields, including the Beatrix concession

The Peel coalfields are located between the towns Venlo and Roermond and border the former German mine Sophia-Jacoba (Fig. 6). The Peel fields, including the Beatrix concession, cover approximately 385 km^2 in an elongated field in NNW-SSE direction.
DSM's Beatrix concession of 130 km^2 that comprises the SE part of the Peel fields is located east from Herkenbosch and is situated for 23 km^2 on Dutch territory and for 107 km^2 on German territory. In 1952 the Dutch State Mines, in co-operation with the governmental Peel committee started and extensive exploration campaign of the non-Beatrix fields, resulting in a detailed report (Peelcommisie, 1963). The shaft sinking of the Beatrix mine during 1955 and 1962 provided additional geological data (Kimpe, 1973). In 1984 the Geological Bureau in Heerlen acquired geophysical data about the coal reserves (Krans et al., 1986). Both structure and coal bearing of the most important parts of these reserves are rather well known.

4.2.1. Beatrix concession

In the most southern part the Meynweg national park borders the site of SM-Beatrix. As mentioned above, two flooded shafts with a depth of 700 meters are still present. The location of the shafts is remote and presently only accessible via a road crossing the Meynweg Park or via a small road from the German side. Until 1997 the German mine Sophia-Jacoba produced anthracite in the SSE extension of the coalfield. Its former shaft number 5 is located approximately 3 km south of the Beatrix concession. In 1980 Velzeboer proposed development of the Peel fields from the Sophia-Jacoba (Velzeboer, 1980), but this option disappeared because of the closure and abandonment of this mine in 1997. The reserves of the Beatrix concession, including the German territory, are described by Kimpe (1973) and are given in Table 3:

Assuming an approximate 4000 meters maximum distance from the production pillars to the shafts, about 40% of the Beatrix area would be accessible without delving new surface shafts. Compared to Emma-Noord, a

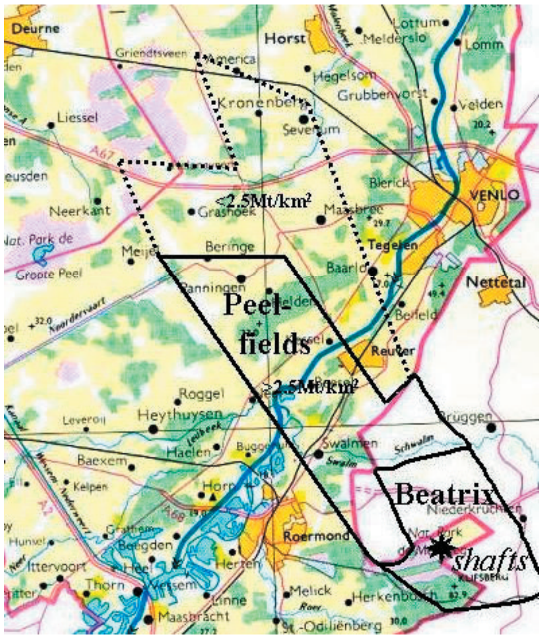

Figure 6. Location and geography of the Beatrix concession (SE) and other Peel fields (middle and NW), totalling approximately 385 km^2, of which the Beatrix concession comprises 130 km^2, and of which the remaining Peel fields with more than 2.5 Mt/km^2 comprise 123 km^2, (closed outline) and with less than 2.5 Mt/km^2 comprise 132 km^2 (dotted outline).

Seam thickness)		Depth (m below NAP):		
pure coal (cm)		TC / 950	950 / 1200	TC / 1200
50-80	30.6%	190	64	254 Mt
80-100	15.8%	98	33	131 Mt
>100	53.6%	333	113	445 Mt
50	100%	620	210	830 Mt

Table 3. Reserves of the Beatrix concession (TC=Top Carboniferous). The data are from Kimpe, 1973.

higher proportion of the reserves is in ≥100 cm (pure) coal layers, and layers are more flat lying. About one third of the reserves are low volatile bituminous or coking steam coal, the rest has a semi-anthracite to anthracite quality. Coal reserves average around 3.5 Mt/km^2 for all ≥100 cm pure coal seams down to 1200 m.

4.2.2. Non-Beatrix Peel fields

The Peel commission studied the non-Beatrix area of approximately 260 km^2 on coal bearing and defined 12 sub-areas (Peelcommisie, 1963). In Table 4 only reserves of the areas with more than 2.5 Mt/km^2 of ≥100 cm pure coal layers are listed. They are found within the closed contour of Fig. 6[2]. The remaining areas have a coal bearing between 1.0 and 2.5 Mt/km^2 of ≥100 cm pure coal.

The reserves range from semi-anthracites to low VM coking coal. VM varies between 10% and 20%. Area III with VM between 20% and 25% is the highest in VM% as well as in absolute reserves (361.4 Mt of ≥100 cm pure coal down to –1500 m, or 5.1 Mt/km^2). It comprises roughly all ≥2.5 Mt/km^2 area on the left side (NW) of the river Maas (Fig. 6).

4.2.3. Summary Peel coalfields in North Limburg

Disregarding ≤100 cm pure coal reserves, the geological potential of the total 385 km^2 Peel/Beatrix area add up to approximately 1200 Mt, adding the TC / -1500 of the Peel and the TC / -1200 of the Beatrix reserves[3]. This is low VM coal, the majority being between 10% and 20%. Viability of mining operations in the former Beatrix concession or Peel fields has not been studied in recent years. However, with regard to ventilation requirements, the relatively low VM content of the Beatrix reserves would make production more favourable than the reserves of the SM-Emma-north field (van Leeuwen, 1990). Another advantage is the presence of the conserved shafts, which will considerably reduce investment costs, risks and development time of new operations. For such relatively deep coalmines that have a considerable water bearing overburden, in this case of almost 400 meters, access by means of these vertical shafts instead of inclined roadways (ramps) is still considered as the most economic method (Reuther et al., 1980; Hartman, 1987).

4.3. Achterhoek (Deventer-Hengelo-Winterswijk)

The Achterhoek reserves are the largest in extend and roughly located between the towns Deventer, Zutphen, Winterswijk, and Hengelo, in the provinces of Gelderland and Overijsel (Fig. 7). Apart from some old boreholes

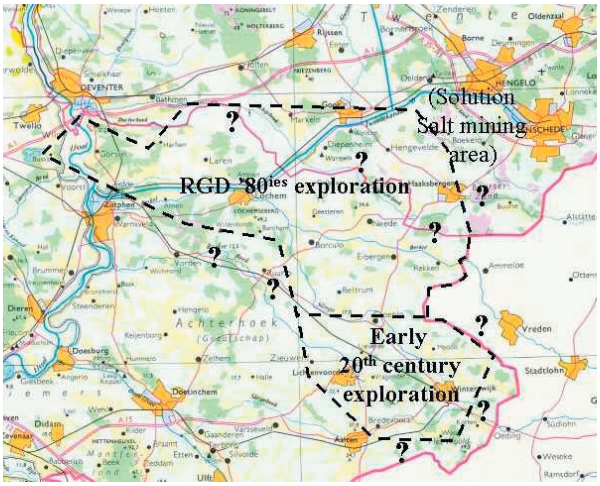

Figure 7. Approximate outline of the Achterhoek reserves that are technically mineable (TC at a maximum of –900 m to –1000 m).

		TC-950		950-1200		TC-1500		
		Mt/km2		Mt/km2		Mt/km2	Mt	Mt
Area	km2	>100cm	%VM	>100cm	%VM	>100cm	>50cm	>100cm
III	70.6	1.8	24	2.1	20	5.1	1143.3	361.4
VI	28.2	3.8	19	1.7	13	6.8	438.7	192.9
VII	1.8	4.1	19	1.9	13	6.1	29.4	11.1
VIII	3.2	3.0	17	0.4	11	6.2	54.0	19.6
X	7.4	7.0	16	4.3	11	12.8	161.6	94.7
XI	6.0	7.3	15	2.4	11	10.8	108.6	64.6
XII	6.2	2.4	12	0.9	9	3.9	48.4	24.5
TOTAL	123.4						1984.0	768.8

Table 4. Reserves of the >2.5 Mt/km^2 (≥100 cm pure coal) Peel areas, excl. Beatrix concession (TC=Top Carboniferous. The data and related areas are presented in the Peelcommissie report (Peelcommissie, 1963).

[2] For their precise location is referred to the Peelcommissie report (Peelcommissie, 1963)

[3] This estimate is conservative, since the reserves of the Beatrix concession between –1200 m and –1500 m are disregarded. The reserves deeper than –1200 m have not been described quantitatively in this review. It has been indicated in earlier studies that in the Beatrix concession coal bearing decreases with depth (Kimpe et al., 1973) .

in and around the Gelria concession of the early 20th century, most sub-recent information has been obtained from the exploration campaign of the Dutch Geological Survey in the period from 1984 to 1987 (Krans, 1986; van Tongeren, 1987; van Tongeren, 1989b). Three newly cored boreholes as well as a geophysical exploration program were carried out. Here only a coarse estimation of the coal bearing of the reserves can be provided.

The southern area with the early 20th century exploration boreholes covers a surface of a little over 200 km^2, while the northern part, discovered by the exploration in the 1980's, covers approximately 650 km^2; making a total of 850 km^2. However, these are indicative values only, as the exact extend cannot be established from the data. Typically the TC is between –800 m and –1000 m, but on more favourable locations - notably at the NW side of the former exploration area - around –700m (Harsveldt, 1963). Considerable lime, sandstone and rock salt strata can be expected above the Carboniferous, as well as unconsolidated top strata. In some areas the unconsolidated top layer is rather shallow (<100m), and even marginal to absent in some parts east of the town Winterswijk. In the area around Hengelo and Boekelo salt is produced by means of solution mining from deposits on top of the Carboniferous subcrop. Just east of Winterswijk there are limestone quarries.

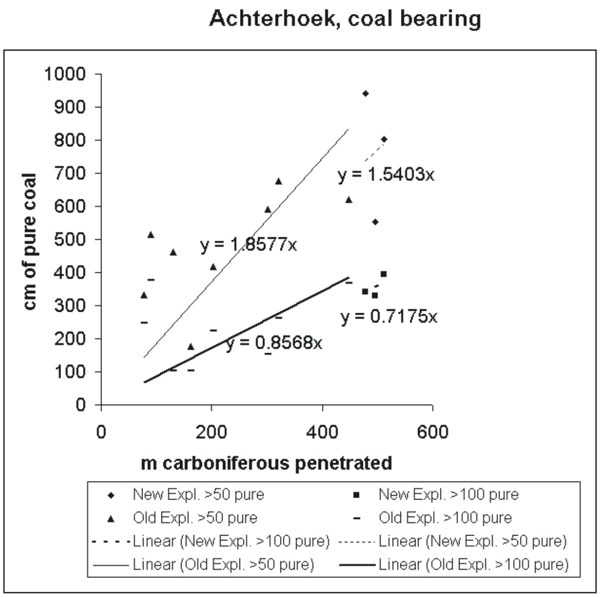

Figure 8. Thickness of seams ≥50 cm pure coal and seams of ≥100 cm pure coal as function of the distance of the Carboniferous that was penetrated by the Achterhoek coal exploration boreholes.

Compared to the Peel and South Limburg coalfields, geological knowledge is relatively poor in this region. Average depth of the shallowest ≥100 cm pure coal layers is much deeper than in Limburg and extends to -800m and deeper. In the north of the newly investigated area, an extensive ≥200 cm layer between –1000 m and –1500 m represents a major part of the initially estimated reserves. The real extend of this coal seam is only approximately known. In general the coal seams appear rather flat lying and well extended. VM of the coal varies between 33% and 38% for the first few 100m's below TC, and between 24% and 30% for the deeper parts, down to –1500 m. In addition, the VM increases towards the northeast direction. For the northern part of the new exploration, in an area of 157 km^2, the Dutch Geological Survey estimates a geological reserve of 693 Mt, considering ≥50 cm pure coal seams down to approximately 1500 m. This results in 4.4 Mt/km^2. Based on the boreholes Joppe and Hengevelde, an average of 46% of this coal is present as ≥100 cm pure coal, which leaves 319 Mt, or for this area 2.0 Mt/km^2 of ≥100 cm pure coal reserves.

Necessarily the estimations for the total area are somewhat speculative, since there are an insufficient number of boreholes. In the new exploration area, there are only 3, in the old area there are 8, which are less deep. Some do not even reach –1000 m. Of all boreholes mentioned in the data, the total thickness of ≥50 cm and of ≥100 cm pure coal seams are plotted as function of the total meters of Carboniferous that was penetrated (Fig. 8).

For technical reserve estimation we consider at least a package of 400 meters of Carboniferous to be exploited. With current technology this is assumed to be present within the indicated areas of Fig. 7. Conditions are that the top Carboniferous is at –1000 m or less, and the deepest shafts are not deeper than approximately 1500 m[4].

	km^2	m. prod.	Corr. Factor	cm >50	Mt/km^2	Mt geol.
Old >50cm	200	400	1.86	744	9.7	1934
Old >100cm	200	400	0.86	344	4.5	894
New > 50cm	650	400	1.54	616	8.0	5205
New >100cm	650	400	0.72	288	3.7	2434
					Total >50cm	7140
					Total >100cm	3328

Table 5. Reserve estimation of the reserves in the Achterhoek region based on linear least squares approximation of the data given in Fig. 8 and relating to the areas in Fig. 7 ("Old": early 20th century exploration area, "New": Geological Survey exploration area of the 1980's). The estimation of the author is based on data and geological maps from the Dutch Geological Survey that estimates a ≥50 cm reserve of 693 Mt in only a part of the area (Krans, 1986).

4 -1500 m is not the technical limit for underground mining, however there are no borehole data from deeper strata in this region. The north shaft of coal mine Ensdorf, in the Saar basin in Germany, has a depth of 1730 meters.

Carboniferous strata in the "old" Gelria concession were Westphalian A and/or lower B, while strata recovered in the newer RGD wells were Upper Westphalian B / Lower Westphalian C (Joppe, Hengevelde), and Lower Westphalian B / Upper Westphalian A (Ruurlo). The coal bearing of the old and the new area were approximated with 4 different linear least squares approximations: separate for the old and new areas, and separate for the cumulative ≥50 cm and ≥100 cm seam heights of pure coal (Fig. 8). The approximations of the coal bearing were used for the reserve estimation, assuming a 1.3 g/cm^3 density of pure coal (Table 5).

The reserve estimation of Table 5 lacks sufficient basis for thorough evaluation, and can solely be used to indicate the potential of the area. It must be stressed that a structural geological interpretation and considerable additional exploration would be necessary to confirm the given estimates within acceptable error margins. This could result in somewhat different figures. In 1978, before the new RGD exploration data became available, Dozy estimated a total reserve of 4300 Mt down to 1500 m (Dozy, 1978; 1979). Based on the new exploration data, Krans et al. estimate a reserve of 693 Mt for only a part of the area, and only considering 3 seams (1987). For an 851 km^2 area NITG-TNO estimates a geological reserve of ≥50 cm pure coal seams down to 1000 m at 1376 Mt and down to 1500 m at 10470 Mt, which is almost 50% more than the estimate of Table 5 (NITG-TNO, 2000). The reserve estimate of Wolf et al. of 5236 Mt for a 594 km^2 area would result in a reserve of 7493 Mt of ≥50 cm pure coal for an 850 km^2 area (Wolf et al., 1997). This is rather close to the estimate of Table 5. In respect to conventional mining the relatively great depth relative to the Limburg areas is unfavourable, despite the fact that fields of similar depth are currently producing in the German Ruhr and Saar basins.

5. Evaluation of the reserves in a European perspective

In 2002 the Dutch market for power coal amounted 8.2 Mt and for industrial coal 3.8 Mt (mainly steel industry). In 2002 the total hard coal consumption in the European Union amounted approximately 250 Mt, of which 77 Mt (this is 31%) was produced within the current EU (European Commision, 2002). When a production capacity of approximately 4 Mt will be developed, the Netherlands would rank average regarding the proportion of domestic versus imported coal. Table 6 summarizes the remaining Dutch coal reserves. Investigations that include adequate geological data of each part of the deposits as well as a thorough knowledge regarding modern mining technology and economy are necessary to estimate whether these reserves could be economically exploited by means of conventional mining.

The extraction rate of a long wall mine could locally reach 75% and more in a relatively flat seam of considerable lateral extension (Hartman, 1987). On the other side, in case of a relatively disturbed geology and when parts of the reserves are inaccessible due to excessive subsidence risks, faulting or water-bearing, extraction could be well below 25%. Even when a relatively unfavourable extraction rate is assumed (e.g. below 25%), it is apparent that the remaining Dutch coal reserves are potentially significant. In a relatively unfavourable scenario 12.5% of the ≥50 cm reserves and 25% of the ≥100 cm reserves add up to a mineable quantity of 2717 Mt, while in a more favourable scenario 25% of the ≥50 cm reserves and 50% of the ≥100 cm reserves add up to 5434 Mt. The average, approximately 4 billion tonnes, could be taken as a preliminary estimate for the remaining Dutch coal reserves that are technically mineable. The majority of higher VM steam coals (30% - 38%) are present in the SM-Emma-north field and in the fields located in the Achterhoek region. Low VM coals and (semi) anthracites (VM 20% and less) are found in the Peel region.

The value of the reserves, or even the question if the known resources can be considered as reserves (being that portion of the geological resources that can be economically mined), depends on the expected mining costs. On its turn these are mainly (but not exclusively) determined by the mine productivity; the mine production per quantitative unit of labour input. Comparable data of mine productivity of operations both within Europe as well as globally are available in the literature (e.g. Hessling, 1991; Walker, 1996). Hessling discusses the factors that

Reserves TC - 1500m	>50 cm	>100 cm	pure coal
Emma-North	591	254	Mt
Other South Limburg	860	369	Mt
Beatrix	830	445	Mt
Other Peel	1984	769	Mt
Achterhoek	7140	3328	Mt
TOTAL	11404	5165	Mt
12.5% mineable	1426	646	Mt
25.0% mineable	2851	1291	Mt
50.0% mineable	5702	2582	Mt

Table 6. Overview of estimated Dutch coal reserves down to a depth of –1500 m. The mineable reserves are taken as 12.5% (minimum scenario), 25% (average scenario) and 50% (maximum scenario) of the geological reserves.

influence mine productivity. Geological, geographical and political factors are pregiven and therefore unrelated to a specific mining practice. Some relevant factors are mentioned below and where possible put into a Dutch/ European perspective.

5.1. Geological factors

- *Coal reserves*. The identified coal reserves of a given area should be sufficient for decades of continuous production in order to justify the significant investments related to mine development. Especially for the remaining reserves in some parts of the former mines in South Limburg the identified quantities could be of insufficient size.
- *Number of seams.* Multi-seam mines have in general considerably lower productivities compared to single seam mines. This is due to their more complex underground infrastructure, increased need for development works, and possible interference (the disturbance of the mining process by extraction of nearby seams, e.g. by subsidence). This problem is mentioned as one of the reasons for the relatively low productivities of the German Ruhr mines, and the relatively high productivity of single seam mines in the United Kingdom. The many different seams, especially in the Limburg reserves, may cause similar problems. The higher aerial extend and lower disturbance of the Achterhoek reserves may be more favourable for single seam extraction.
- *Seam thickness.* Between 1 and 3 meters seam thickness no clear relation with mine productivity is observed. Though a higher seam results in a higher output of the same face crew, labour and costs of most other sections are approximately proportional to the mine output. This is damping out the benefits of the thicker seams. Productivity becomes significantly less below 1-meter thickness because of difficult working conditions and/or the need to produce floor or roof rock for sufficient space.
- *Mining depth.* Increased depth has an unfavourable effect on productivity, due to increased stress and strata pressure (maintenance, support, safety), increased temperature (larger ventilation requirements, larger openings, cooling, reduced shift lengths), and increased vertical lift of coal, personnel and materials (winding cycle times). In this perspective, a significant part of the Limburg reserves, and especially the south Limburg reserves are more favourable than the Achterhoek reserves. From the former Dutch mining industry it is known that until depths of approximately 750 meters no significant effect on labour effectiveness was observed for the mining methods employed at that time (Peelcommissie, 1963).
- *Aerial extension*. A large aerial extension, and hence low surface use, increases transport as well as preparation and reclamation work, and generally has a negative effect on productivity.
- *Seam dip*. Practically all European mines exclusively produce from relatively flat seams. The majority of Dutch reserves falls into this category. Working of steep seams is however possible, but only at lower productivity.

Other geological factors that are especially relevant for the productivity and economy of underground mining operations are material hardness, grade of disturbance, roof and floor quality, methane content, presence of water bearing strata, and coal quality.

5.2. Geographical factors

Topography, availability of markets, labour and supplies, as well as the availability of infrastructure (railways, waterways, roads, power lines) can, in general, be considered favourable for the Dutch reserves. On the other side, the density of settlement and restrictions on land use may be a significant restriction in the densely populated areas of South-Limburg and the Beatrix concession, which is bordering the Meynweg National Park.

5.3. Political factors

Important political factors are taxes, labour regulations, safety regulations, environmental regulations and subsidies. Besides these factors themselves, long term stability in them is of equal relevance for a mining enterprise.

5.4. Technology and engineering factors

Double drum face shearers with hydraulic roof support, flexible armoured conveyors, in combination with integrated road headers and roof bolters are currently providing the highest underground productivities, on condition that local geology permits their application (Walker, 1996). Alternative exploitation methods for coal can be either based on conventional access via shafts and/or roadways, or alternatively via boreholes. Despite numerous studies, only few methods other than automated long wall extraction or Room & Pillar mining have reached some economic perspective (Wood, 1980). They are Auger mining, chain cutters, scraper ploughs, and hydraulic mining by monitor. Borehole methods, including underground gasification, still remain in a conceptual and experimental stage, despite considerable research effort in the last several decades (van Tongeren, 1989b).

5.5. Underground mining productivity in European perspective

Berding states that, more than any other factor, a much simpler underground infrastructure may bring viable exploitation within reach (Berding, 1979). This is illustrated by recent production figures of underground coalmines in Germany and the United Kingdom, expressed in tonnes saleable production per employee and per year (Jahrbuch

2002, IEA 2002). A typical UK mine never has more than two coalfaces, whereas larger German mines are of higher average depth, and usually have 4 or more operational faces. The dominance of the infrastructural factor on mine productivity is also demonstrated by the performance of "Grube Hirtel", a German "mini" mine in the Saar basin that has a straightforward single level and single face infrastructure, with direct surface access via inclined roadways. Despite the narrow seam of 90 cm average height (and hence necessity of producing 10 cm of floor or roof for sufficient space in the seam), the relatively high ash content, its relatively low production (1 production shift per day, 143,000 t/y), and older manually controlled face equipment, with approximately 2000 tonnes per employee per year it was in 2000 the most productive underground coal mine in Germany (Jahrbuch 2002). Total depths of over 600 m and face–entry distances over 3000 m have been reached with this method (Ney, 2002).

For the economy of mining operations productivity figures are important, but indicative only. They are not always comparable and do not cover all factors mentioned. Mine by mine variations in the average worked shifts per year, absenteeism, holidays, activities of sub-contractors, overhead, ash level and calorific value in the saleable product may need further correction for a true comparison, e.g. following the approach of Walker (Walker, 1996). Besides, lower productivities in terms of production per employee-shift may be partly compensated by lower investment and equipment costs, and in some cases even result in lower costs per tonne produced.

6. Discussion

At an average sales price of 40.-/tonne, the 4 billion tonnes of estimated Dutch coal reserves represent a present value of approximately 160 billion Euros. Even if in the next several decades only a small fraction of this could be utilised, it would provide a significant economic stimulus for the involved region, as well as for the European coal industry and its suppliers as a whole. However, before coal production can be considered, it must be thoroughly investigated whether for the Dutch situation, now or in future, exploitation costs can principally approach market prices. If this seems possible, despite the generally more favourable geological conditions of non-European basins, domestic production can be justified economically as well as environmentally. It saves considerable transatlantic and inland shipping, and provides a stable base-load supply that is relatively insensitive for currency fluctuations. Besides, it has a positive effect on trade balance and development of supply industries and services.

On the other side, the current supply security of solid fuel imports and the relatively strong price fluctuations of coal and other energy carriers discourage long term investments in new production capacity. It may be important to know if this unfavourable perspective, which prevails since the 1960's, is fundamental (e.g. of geological origin), or has been, or will be overcome by technological progress. Experience from surrounding basins indicates that when favourable geological conditions permit minimised and straightforward underground infrastructures, production costs may approach market prices. In retrospective, the relatively early closures between 1967 and 1975 saved the remaining Dutch coal reserves from further uneconomic depletion, which may appear favourable for the relative economic potential of the Dutch reserves in comparison with some other European basins.

For a longer term prospect continuation of research to alternative exploitation methods remains useful if they have potential to out-perform long-wall mining in productivity, cost price and quality. Besides, in a European context especially environmental, social, and safety aspects must be strictly regarded for any existing or new method. Alternative exploitation methods can be based on conventional access and mining methods, as well as on borehole methods. The possibility to attain an optimised control and benefit from economy of scale in any part of the mining, preparation and conversion process is an important advantage of the conventional utilisation chain above (borehole) in-situ conversion methods. The current trend of increased integration of primary and secondary combustion (bio-mass and waste-to-energy), combined with the increased need for an accurate control in order to meet the highest thermodynamic efficiency and environmental demands (e.g. reducing emissions, CO_2), may favour developments towards novel mechanical extraction methods above underground conversion. Even when the future availability of considerably improved control methods for underground conversion is assumed, it seems likely that the controlled conditions and economy of scale in dedicated surface installations will become hard to approach by in-situ processes. In-situ processes are only favourable when the attained cost savings on imported fuel are not overrun by efficiency losses or other additional costs.

In the foreseeable future underground mining is likely to remain the only available method for utilisation of a significant part of the remaining Dutch reserves. By means of comparison with state-of-the-art operations in comparable basins, evaluation of present and past operational experience, and adapting that knowledge to local geological conditions, the reserves can be benchmarked in a European and global perspective. This study would comprise geological, economical, and engineering aspects. In this way, conclusions regarding the value of the Dutch reserves and viability of coal mining need no longer to be based on studies carried out several decades ago during the closure period of the former mines in the 1960's and 1970's.

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