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Preface

This paper presents a contribution to the 'Regional Material Balance Approaches to Long-Term Environmental Policy Planning' project (IND project). The policy compound of this project - the Ruhr/Katowice Policy Comparison - aims at providing better understanding of policy options for cleaning up the Black Triangle (cf. Blazejczak 1995). The comparison focusses on the Ruhr Area and on the Katowice voivodship which have both been identified as heavy metal pollution hot spots. The Ruhr/Katowice Policy Comparison comprises a historical analysis of the Ruhr Area. It draws heavily on the evidence collected in IIASA's previous Rhine Basin study and investigates previous policies to reduce heavy metal pollution in this area (cf. Stigliani et al. 1993; Stigliani/Anderberg 1992).

This investigation covers the time period 1955 to 1988. Special emphasis is placed on a description of those determinants of intrasectoral change within the iron and steel production sector in the Ruhr Area, Northrhine-Westfalia, which have contributed to the reduction of atmospheric heavy metal emissions since the early seventies. The driving forces behind these intrasectoral changes are also investigated. The aim of this paper is a description, as well as an assessment, of key elements of atmospheric point source and diffuse emission reduction policies related to the iron and steel industry. This investigation is based on earlier research by de Bruyn and Schucht (1996) which showed that intrasectoral change has been the most important factor in the reduction of atmospheric heavy metal emissions from industrial point sources.

Abstract

This working paper describes those determinants of intrasectoral change within the iron and steel production sector in the Ruhr Area, Northrhine-Westfalia (NRW), which have contributed to the reduction of atmospheric heavy metal emissions since the early seventies, as well as the driving forces behind these intrasectoral changes. The aim of this paper is a description, as well as an assessment, of key elements of atmospheric point source and diffuse emission reduction policies related to the iron and steel industry. It constitutes part of the Rhine/Black Triangle Policy Comparison Study at IIASA.

Intrasectoral changes pertaining to the reduction of atmospheric heavy metal and dust emissions are shown to have consisted, firstly, of process changes whose main characteristics were a replacement of older crude steel production processes, reductions and changes in fuel input and an increased recycling of residues. The second most important development was the application of gradually improved off-gas collection and cleaning technologies.

There were four major factors behind the intrasectoral change:

- developments in legal requirements,
- financial support from public institutions,
- economic motivations of the entreprises and
- cooperative approaches.

List of Figures and Tables

Glossary

APR - Aktionsprogramm Ruhr	Action Programme Ruhr
Arbeitskreise Umweltschutz	Environmental Protection Working Groups
Ausgleichsmodell	compensation model
BAT - Stand der Technik	best available technology
Belastungsgebiete	areas of high pollution
Betriebsbeauftragter für Immissionsschutz	plant representative for 'Immissionsschutz'
BImSchG - Bundesimmissions-schutzgesetz	Federal Law Concerning the Protection against Harmful Effects on the Environment through Air pollution, Noise, Vibration and Similar Effects
DIN - Deutsches Institut für Normung	German Standards Institute
Dynamisierungsklausel	dynamization clause
Emissionskataster	register of assessment for emissions
ERP - Europäisches Wiederauf-programm	European Recovery Programme
EStDV - Einkommensteuer-Durchführungsverordnung	income tax implementation regulation
EStG - Einkommensteuergesetz	income tax law
Gewerbeaufsichtsamt	State Trade Supervisory Office
Gießhallenentstaubung	casting house dedusting
Hüttenvertrag	the contract guaranteed German steelworks a supply of German coke at world market prices and bound them to cover their coke input with German coke
IFP - Immissionsschutzförder-programm	guide-lines for promotion of measures eliminating or reducing air pollution, noise and vibration

Immissionsschutz	protection against harmful effects on the environment through air pollution, noise and vibration
Interministerieller Ausschuß für Umweltschutz	interministerial committee for environmental protection
Konjunkturprogramm	Economic Policy Programme
KRL - Kommission Reinhaltung der Luft im VDI und DIN	Commission for Maintenance of Air Quality
Landesbeirat für Immissionsschutz	NRW council on pollution control
LIB - Landesanstalt für Immissions- und Bodennutzungsschutz	state authority responsible for monitoring air quality
LImSchG - Landesimmissionsschutzgesetz	State Law Concerning the Protection against Harmful Effects on the Environment through Air pollution, Noise, Vibration and Similar Effects
LIS - Landesanstalt für Immissionsschutz	state authority responsible for monitoring air quality; previously LIB; since 1994 part of the LUA
LRP - Luftreinhalteplan	Clean Air Plan
LUA - Landesumweltamt	'main' State Office for Environmental Protection
Luftreinhaltegesetz	Clean Air Law
Mitnahmeeffekt	used for the situation of entreprises not really in need managing to be financially supported
Nachbarschaftsbeschwerde	complaints from local residents
NRW - Nordrhein-Westfalen	Northrhine-Westfalia
Regional- und Bauleitplanung	regional planning
Sektorale Verbesserungsprogramme	sectoral amelioration programmes
Sonderverwaltung	technical and administrative responsibilities for clean air protection both allocated to the State Trade Supervisory Offices

Staatliche Ämter für Arbeitsschutz Staatliche Umweltämter	State Offices for Health and Safety at Work State Environmental Offices
Subventionswettlauf	subsidy competition
TA Luft - Technische Anleitung Luft	Technical Directive for Air
TÜV - Technischer Überwachungs-verein	Technical Control Board
UBA - Umweltbundesamt	Federal Office for Environmental Protection
VDI - Verein Deutscher Ingenieure	Association of German Engineers

1. Introduction

The aim of this paper is to investigate the restructuring process relevant to airborne heavy metal emissions (cadmium, lead and zinc) of the iron and steel industry in the Ruhr Area, NRW. Iron and steel production are amongst the major industrial point sources of atmospheric heavy metal emissions.

1.1. Study Background

Emissions of all three heavy metals considered in this study are strongly linked to the development of *iron and steel production*, because the metals occur as natural impurities both in coke and iron ores. An important source for zinc and cadmium emissions is also the use of scrap galvanized steel (zinc- and cadmium-coated) in the production of secondary steel (Stigliani et al. 1993; UBA 1982).

Figures 1.1. to 1.3. show atmospheric emissions of lead, zinc and cadmium from industrial point sources in the Rhine Basin area of NRW between 1955 and 1988[1].

Heavy metal emissions decreased considerably between 1955 and 1988, with the major decreases occuring during a relatively short period of time from 1965 to 1980. With respect to *lead emissions* we find, that the iron and steel industry was most important for both, the amount of industrial heavy metal emissions and their decline since the early 70s. With respect to *zinc emissions* the iron and steel industry was also most important, but whereas the overall industry's zinc emissions declined since the mid 60s the emissions caused by iron and steel production increased until the early 70s and then declined considerably.

[1] The emission data is the average values for 5-year periods. For the sake of simplicity time periods are denoted by their mid-value, e.g. 1955 denotes the period from 1953 to 1957.

Figure 1.1.

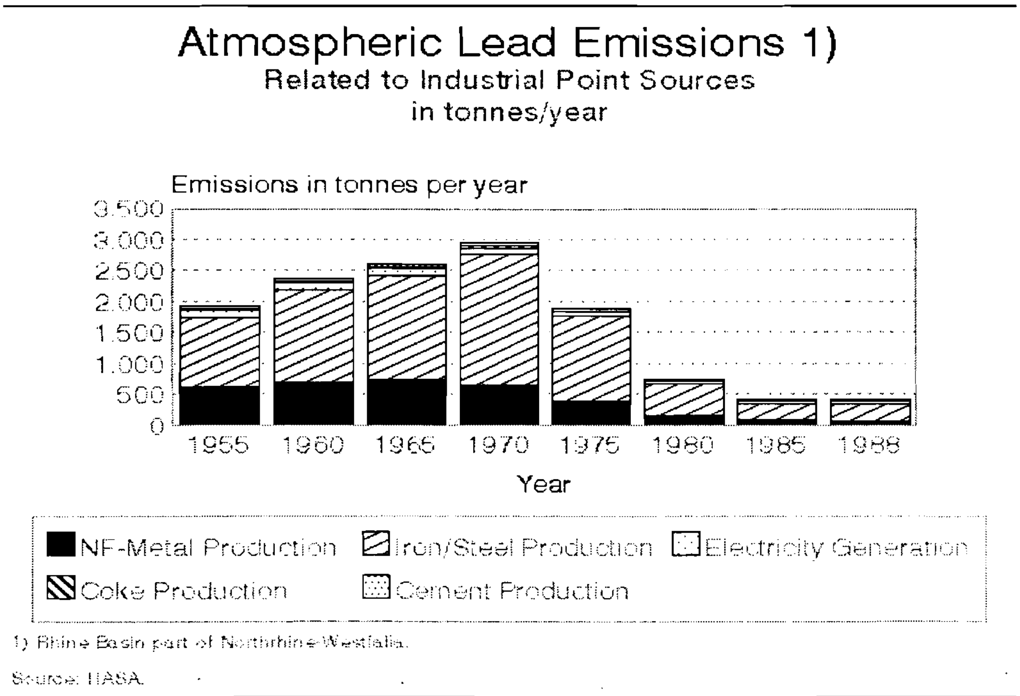
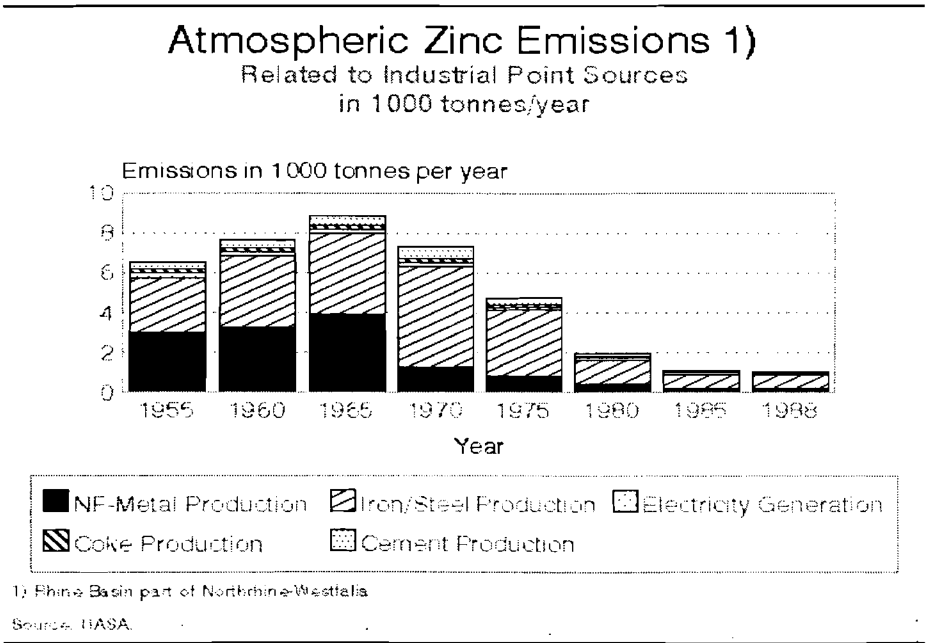


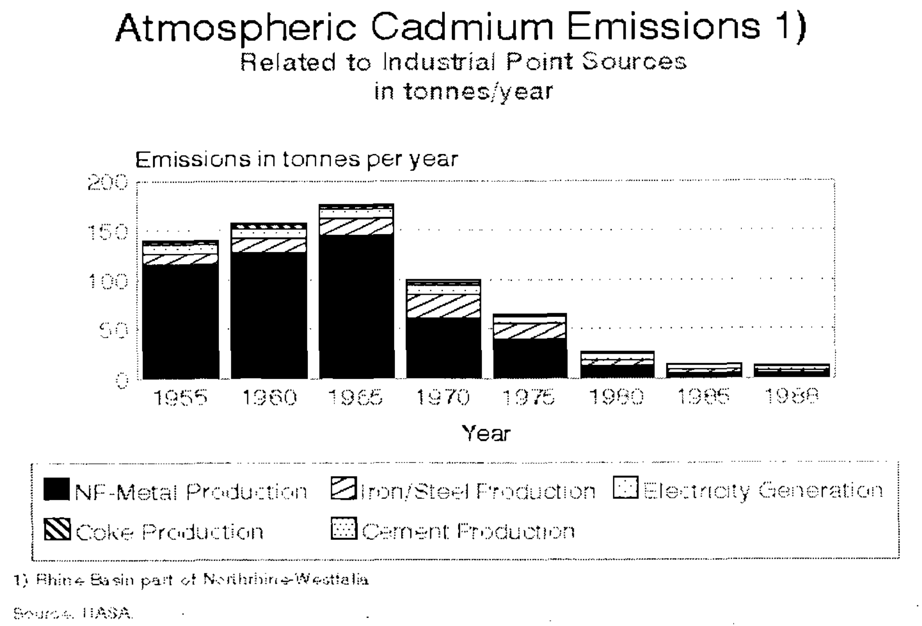
Figure 1.2.



With respect to *cadmium emissions*, iron and steel production was the second most important - behind non-ferrous metal production. Industrial lead emissions declined since the mid 60s, those caused by iron and steel production since the early 70s.

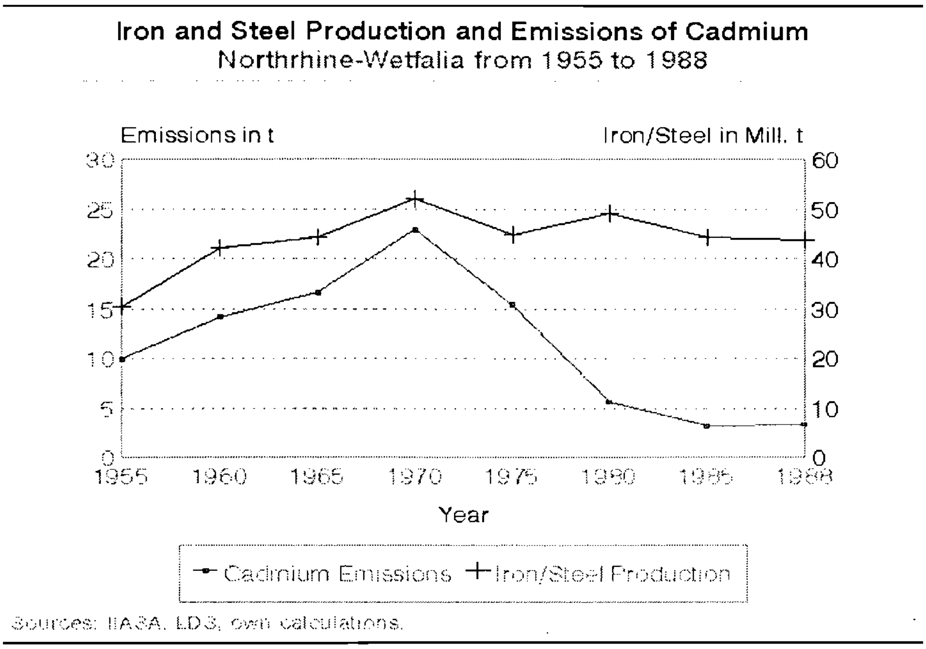
Figure 1.4. indicates that the development of cadmium emissions[2] related to *iron and steel production* was influenced by intersectoral, as well as by intrasectoral change. Between 1955 and 1970 both, iron and steel production and the related cadmium emissions, increased. However, until 1970 the increase in emissions was greater than the increase in production. While emissions continuously decreased between 1970 and 1985, production remained more or less constant and - between 1975 and 1980 - even increased. Until 1975 cadmium emissions related to iron and steel production seem to have been mainly influenced by the growth of production. Between 1970 and 1980 the decrease in emissions was, however, greater than the decrease in production. Since the decoupling of the development of emissions and production around 1970, technical influences, that is intrasectoral changes, have been the major factor of emission reductions.

Figure 1.3.



[2] As emissions of the three heavy metals related to iron and steel production and considered in this study developed in a rather similar way, only the example of cadmium emissions is presented in this figure. A further reason for the choice for cadmium emissions is their particular environmental toxicity (UNEP 1984).

Figure 1.4.



1.2. Research Aims

In order to determine, which factors of industrial change have led to the distinct decline in the iron and steel industry's emissions of cadmium, lead and zinc since the early 70s, the focus of the present study will be on an investigation of the various factors of intrasectoral change within the iron and steel sector, as well as on the driving forces behind these changes.

The following table gives determinants of *intrasectoral change.*

Table 1.1.

Classification of Determinants of Intrasectoral Change (De Bruyn/Schucht 1996):
- improvement in end-of-pipe technologies, - substitution of inputs (including the use of recycled inputs), - process-related technological changes, - product related technological and structural changes.

Driving Forces behind intrasectoral change include: developments in the legal framework with respect to pollution control and technological requirements as set by federal or local authorities, promotion programmes, increasing public concern about pollution and economic developments (e.g. changes in the demand for products or in international competition).

Finally the study presents an evaluation of clean air policies, including a description, as well as an assessment, of *key elements* of atmospheric and diffuse (dust blow) emission reduction policies related to the iron and steel industry. The evaluation uses the criteria of ecological and economic efficiency and effectiveness, as well as of administrative efficiency and practicability.

1.3. Plan of the Paper

In a *first part* of this study a brief overview of the development of the iron and steel industry in NRW and of the significance of the iron and steel industry within Northrhine-Westfalian industry as a whole is given. In a *second part*, intrasectoral changes in this sector are investigated. Emphasis is placed on those technological changes that are relevant to heavy metal pollution.

The *main part* of this study comprises the description of driving forces behind, as well as an assessment of, clean air policies related to the iron and steel industry in NRW. Further consideration is given to the question of whether a conjunction of environmental and economic requirements has been met by the restructuring of the iron and steel industry in the Ruhr Area (NRW). This question refers to the OECD concept of policy integration, aimed at the exploitation of opportunities for simultaneously achieving environmental and economic objectives (Blazejczak 1997).

2. Economic Background of the Iron and Steel Industry in NRW

NRW is characterized by a high density of industry. This is particularly true for the Ruhr Area. The industrial structure of the Ruhr Area is dominated by old industrialized sectors (heavy industry) that are characterized by a below-average economic growth (Heinze et al. 1992). The economic origins of NRW's industry are within the 'Montan sectors' (coal, iron and steel industries), with an interlinked economy of coal and steel. By the end of the 19th century the chemical industry and electricity generation had been added. The Ruhr Area in particular is characterized by a high degree of interlacing between the Montan sectors and their suppliers and the down stream operating industries (mechanical engineering, steel construction, electrical engineering).

2.1. Economic Development Since 1945

After the Second World War the Ruhr Area's economic structure (the interlinkage of coal and iron and steel) was reactivated with State support in order to avoid energy imports and to secure export proceeds. This reactivation, forced by destruction and dismantlement, made technical modernization and the replacement of destroyed or dismantled plants by modern plants possible (Hamm/Wienert 1990). From the demand side the region profited from the reconstruction of West Germany. As the steel-intensive infrastructure, as well as the capital stock had to be re-produced, the Ruhr Area's products such as iron, steel and coal were urgently required (Welsch 1988). This, combined with a reactivation of industrial structures supported by the government, led to growth rates above German average and an enlistment of additional workers from other regions. Consequently, wages, as well as prices for business sites, also rose above German average and added to a preservation of sectoral structures (Heinze et al. 1992).

Even though it had become obvious in the early 50s that the dominance of coal and steel represented a risk for the Ruhr Area as it might lead to structural problems, the industrial structure of the Ruhr Area was hardly diversified at all at that time. Coal and steel were supported by new subsidies and the structural adjustment was politically hindered. Later problems in the Ruhr Area are, to a large extent, due to investment and capacity increases with long-term effects as reaction to a short term increase in demand (Welsch 1988).

2.2. Development of the Iron and Steel Industry

On the input side the mining crisis at the end of the 50s resulted in the iron and steel industry losing the price advantage in the purchase of coal, thus an important location advantage. During the 60s the sector also came under pressure from the supply side (Heinze et al. 1992). Owing to declining transport costs and the Japanese steel location close to the coast, the Japanese steel industry became a strong competitor. Furthermore, petrochemical product innovations led to an increase in plastics production and to a substitution of steel (Heinze et al. 1992; Hamm/Wienert 1990).

With state support the economic pressure on the steel industry decreased: The 'Hüttenvertrag' guaranteed German steelworks a supply of German coke at world market prices and at the same time bound them to cover their coke input with German coke. The difference between German and world market prices was reimbursed by the state (Welsch 1989).

Since the worldwide economic depression during the mid 70s the steel industry has been suffering from a structural crisis[3]. As steel consumption is highly dependent on investment activity, the overall economic weakness led to a marked decline in steel consumption. This process was intensified by technological innovations, that made it possible to produce steel in local centres of consumption (mini steelworks) and changes in the foreign trade pattern of steel at the expense of the traditional exporters[4] (Welsch 1988; Hamm/Wienert 1990). Process and product related technological changes reduced the down stream operating industries' demand for steel. Furthermore, the 'subsidy competition' (Subventionswettlauf) within the European steel market forced the more competitive steel industries, such as the German steel industry, to higher adjustment processes, than would otherwise have been necessary.

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[3] Owing to rationalization of production processes, the work force had, however, already been reduced during the 60s.

[4] Since the end 70s several developing countries had built up their own steel industry in order to cover their own demand as well as to secure export proceeds. The latter holds true especially for South Korea, Mexico and Brasil (Kerz 1991). As these countries' share in the world steel market increased, the share of the traditional industrialized countries, such as the European Community, declined (Demgenski 1990).

Since 1975 the international steel markets are characterized by an enduring weakness in demand, distortions of competition due to the subsidies and numerous protective obstacles to trade (Wienert 1987). Between 1980 and 1988 the steel producers Mannesmann, Hösch, Klöckner, Thyssen and Krupp reduced their work force by 80,000 people (Heinze et al 1992). Between 1970 and 1988 the work force of the Ruhr Area steel industry was reduced by almost 200,000 people (Ruhrverband 1988). The steel boom in 1988 brought about a slight relief in the pressure to discharge jobs, but this was, however, only a temporary phenomenon.

Development of Plants

Technical and economic reasons originally led to an establishment of large steel production plants at locations of industrial density with an advantageous infrastructure, with respect to: existence of ores and energy, opportunities for manufacturing the products or transport possibilities for raw materials and products. That the importance of these pre-conditions has grown over the past two decades, is shown in that:

a) integrated steelmills without access to waterways stopped first their pig iron production and later the entire metallurgical production, and

b) locations situated close to a strong manufacturing industry, such as the steelmills in the Duisburg and Dortmund area, were strenghened (Philipp/Theobald 1993).

Table 2.1.

Number of Plants in West-Germany

	1975	1991
Blast furnaces	85	45
Oxygen converters	49	38
Electric arc furnaces	93	40

Source: Philipp/Theobald 1993.

This process was accompanied by development leading to an effective use of large-scaled plants (see table 2.1.) and to a replacement of less effective processes by more efficient ones: Thomas- and Siemens-Martin-steel processes in Germany were abandoned at this time (see table 3.1.).

3. Technological Development within the Iron and Steel Industry

3.1. Introduction: Iron and Steel Production and Emissions

The important sources of emissions in the production of crude steel from ore, as well as within the secondary production (recycling of iron and steel scrap) are the thermic processes (Angrick 1993). In the iron and steel production dust and heavy metals are predominantly emitted in the following production steps (Schade/Gliwa 1978; Angrick 1993):

- ore crushers and separators
- sinter plants
- blast furnaces
- steel production
    - Siemens-Martin furnaces
    - Thomas converter
    - Oxygen steelworks (e.g. LD and LDAC)
    - Electric arc furnaces
- Flame-treatment of crude steel blocks

3.2. Ore Crushers and Separators

In the mid-sixties ore crushing and separating plants were only equipped with mechanical dedusting facilities, operating with an average dedusting efficiency of 85% of the original dust content in the raw gas. As the goods were rarely moistened high dust contents of the raw gas had to be taken into account. In subsequent years, however, a moistening of the input material became common and more effective dedusting facilities were installed (Schade/Gliwa 1978). The authors estimated that all the plants would have been dedusted by the mid seventies. By the end of the 80s it was common that - where necessary - reloading points were encapsulated and cleaned from dust by suction. Storing sites were moistened and, in order to prevent tertiary emissions[5], streets used to transport ores were cleaned and moistened (Philipp 1989).

3.3. Sinter Plants

The sinter process leads to dust and gaseous emissions. The dust contains, amongst other things, lead, zinc and cadmium, the gas contains sulphur dioxide and nitric oxide. Sinter plants are also relevant for dioxine production (Angrick 1993).

During the 50s and 60s sinter plants were equipped with zyclones. These performed only rough dedusting[6] (Philipp et al. 1987). In later years dedusters of different kind and size were used (multyzyclones, electro filters[7]), depending on size and age of the plants. Emissions from sinter plants decreased continuously between the mid 60s and mid 70s, as a switch from zyclones to electrostatic separators became necessary in order to meet the deposition standards[8] for dust set in the 'technical directive for air' (Technische Anleitung zur Reinhaltung der Luft, TA Luft[9]) 1964 (Schade/Gliwa 1978; Rosenstock/Weber 1983). Today sinter plants are encapsulated (Finke 1988; Philipp 1989) and the collected dust is fed back into the process. The use of membrane filters

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[5] *Primary emissions* (process emissions) occurring in the actual processing, *secondary emissions* occurring for example with reloading of materials, *tertiary emissions* describing unspecific emissions that cannot be associated directly to plants, such as dust blown away from open storage are distinguished.

[6] The equipment of ore sinter plants with electrofilters for room (including conveyor belts) and off-gas dedusting in NRW was, however, already mentioned at the beginning of the 1960s (Jahresbericht 1961). While modern plants were equipped with electro filters, the majority of the older plants was only equipped with mechanic filters (zyclones). With these the standards set in the technical directive for air were not attainable. NRW, therefore, set up an amelioration programme for these plants (Jahresbericht 1964; see also chapter 4.3.).

[7] Electro filters were used for bigger plants and achieved a higher dedusting efficiency than zyclones.

[8] In this paper the term 'deposition' is used for the German term 'Immission', generally covering depositions and ambient air concentrations.

[9] See chapter 4.

currently being tested would further reduce emissions of dust and therefore of heavy metals, as well as of dioxine (Angrick 1993). Parallel to the development of the dedusting technology, the specific fuel consumption of sinter plants was cut by half by the end 80s (Philipp et al. 1987), which contributed to a reduction in SO_2 and CO_2 emissions (Philipp/Theobald 1993).

3.4. Blast Furnaces

For blast furnaces, dust emissions containing heavy metals such as cadmium, lead and zinc occur at various production steps (Schade/Gliwa 1978; Angrick 1993):

- with transport and storage and processing of input materials, such as ore, coke, sinter,
- with the blast furnace casting,
- with reloading of pig-iron,
- at the dedusting facility for the mixture of ores,
- with loading of the blast furnace,
- at the iron runner,
- with the inlet in the ladle,
- with the top charging operation,
- at chimneys of the hot-blast stove,
- through losses of blast furnace flue gas in the crude gas net,
- through drifts at the slag sites.

Development up until the late 70s shows that emissions of diffuse sources decreased because of decreases in the required input of coke and burden (ore mixture) per tonne of pig-iron. Until the mid 70s suction boxes in the area where pig iron is tapped[10] (Bereich des Abstichs) - though planned - were not installed. Losses of dust carrying blast furnace flue gases, however, were reduced over the years with help of double- and triple-bell-hopper arrangements (Schade/Gliwa 1978).

Modern blast furnaces are virtually sealed units (Finke 1988). Today for technological reasons - i.e. in order to avoid abrasion - the blast furnace flue gas is cleaned to such an

[10] Here the 'brown smoke' is emitted (Philipp 1989).

extent, that dust emissions are of minor importance. Dust and gaseous emissions from burden of blast furnaces are collected and fed to the blast furnace flue gas. The latter is cleaned using multi-stage high efficiency wet separators. Emissions occurring within the blast furnace casting house are almost completely collected (Angrick 1993). Within the blast furnace process, the 'casting house dedusting', using suction hoods, was in 1983 regarded as the most significant development of dedusting technology up to this time (Rosenstock/Weber 1983). Previously membrane filters were used for cleaning. Recently the development switched to dry electro filters, as these use considerably less energy. In many blast furnaces this technology is used today. Installation of this technology can amount to additional costs of about DM 30 million per blast furnace (Philipp 1989). By the end of the 70s membrane and electro filters, as well as wet dedusters were used in NRW (Jahresbericht 1978). By the early 80s 80% of the pig iron plants situated in the Ruhr Area were equipped with secondary dedusting facilities (Jahresbericht 1982).

Changes in the raw material input, process and metallurgical measures led to a decrease in the specific coke cunsumption from 850 kg/tonne pig iron in 1960 to 500 kg/tonne pig iron in the early 1990s, thus reducing emissions (Schulz 1992; Philipp/Theobald 1993).

3.5. Steel Production

3.5.1. Development of Steel Production Processes

The four major steel producing technologies are the Thomas-, Oxygen-, Siemens-Martin- and Electro steel processes. Their share in the total production changed over time. The Thomas converters and Siemens-Martin furnaces were initially replaced by Oxygen processes. Electro steel processes were also increasingly used (Schade/Gliwa 1978). Effective dedusting became possible with the introduction of oxygen blowing processes. In West-Germany, the last Thomas-steel plants were closed down by the end 60s, the last Siemens-Martin-steel plants were closed down by the early 80s (Schulz 1992; Philipp/Theobald 1993).

The following table shows the development of steel production and steel processes used in NRW.

Table 3.1.

Steel Production in ktonnes
Northrhine-Westfalia

	1960	1965	1970	1974	1979	1984	1992
Siemens-Martin steel	12084	11834	8584	6944	3201	0	0
Thomas steel	9852	6483	0	0	0	0	0
Oxygen steel	759	5430	18087	24365	22790	20206	18147
Electro steel	1539	2520	3132	3256	2802	3940	2606
Crude Steel	24234	26267	29803	34565	28793	24146	20753

Source: Jahresbericht 1967; Schade/Gliwa 1978; StaBu FS4, Reihe 8.1.

Brown smoke is produced in processes where oxygen is blown into the system (Thomas and Oxygen converters). The development of processes using oxygen allowed increases in production and quality. Opposite to these processes, only small amounts of oxygen are used within Siemens-Martin and electro steelworks. Measures to reduce brown smoke were, therefore, in the first place directed at oxygen blowing processes (Jahresbericht 1967).

3.5.2. Dedusting Technologies

a) Siemens-Martin Process

The oldest scrap smelting process is the Siemens-Martin process (Jeschar et al. 1996). The possibility of using large amounts of scrap material constitutes an advantage of this process. However, the use of scrap material can lead to high concentrations of heavy metal emissions in the off-gas. Off-gases are drained off through chimneys (Schade/Gliwa 1978). While Siemens-Martin steelworks had previously not been dedusted, the dedusting of the remaining plants was enforced in the mid 70s, though it was clear that the end of this technology being used was approaching (Philipp et al. 1987). Although this process was characterized by a relatively low consumption of energy, it was replaced by other processes. The reasons were high production costs and times (Jeschar et al. 1996).

Refitting measures started in Northrhine Westfalia in 1974. In this year the first dry electro filter in a Siemens-Martin steelworks within Germany was installed in NRW. With this technology it was possible to reduce emissions to the set standard of 150 mg/Nm^3. It was planned that by 1979 all Northrhine-Westfalian Siemens-Martin furnaces would be dedusted (Jahresbericht 1974; Jahresbericht 1975). The last Siemens-Martin furnace in NRW, however, was closed down in the early 80s.

b) Thomas Converters

In Thomas steelworks oxygen is blown into the converter, in order to reduce by-products such as carbon, silicon and phosphorous. With help of oxygen these elements are burned and partly bound to slag (Jeschar et al. 1996). The use of oxygen, however, leads to the emission of brown smoke. Owing to the high temperatures of the off-gas, the application of dedusting-facilities would require a cooling of the gases before feeding them to dedusting systems. Although dedusting with electro filters would have been feasible, it was - for technical and economic reasons - hardly pursued (Schade/Gliwa 1978; Rosenstock/Weber 1983; see also chapter 4.6.).

However, in 1960, 3 out of 54 Thomas converters in NRW, were roughly dedusted, reaching dust contents of 2000 mg/Nm^3 in the off-gas (Jahresbericht 1967). Furthermore, dedusting of a 40-t-Thomas converter had been developed in a pilot project supported by the European Community[11], and set up in 1959, reaching

[11] In 1954 all German Thomas steelworks had joined in order to build this pilot plant.

remaining dust contents of 100 mg/Nm^3 off-gas. However, owing to limited space in existing Thomas-steel plants, this technology could not easily be applied on a larger scale. As it became obvious that no new Thomas steelworks would be built, the dedusting activities were only directed at existing plants (Jahresbericht 1964; Jahresbericht 1967). In 1965 the economic efficiency of LDAC-converters was proven. A further pilot project, aimed at the reduction of brown smoke from Thomassteel plants, was therefore no longer pursued as it became clear that the Thomas steelworks would be replaced by Oxygen steelworks (Jahresbericht 1965; Jahresbericht 1967).

c) Oxygen Processes

The oxygen process uses pig iron as input and can, in general, handle an additional scrap input of up to 30% (Jeschar et al. 1996). This process leads to considerably lower specific amounts of off-gas than the Thomas converter. For cleaning of converter gases wet separators and dry electro filters[12] were used by the end of the 70s (Schade/Gliwa 1978). Oxygen converters, the process with the highest productivity of steel production, have, right from the beginning, been equipped with primary dedusting systems (Philipp 1989).

Currently technology most commonly used to clean converter off-gases of Oxygen steel plants is a two steps wet cleaning. While previously the converter gas was flared after being cleaned, for energy economical reasons the development for Oxygen steel plants now points at the installation of plants for a recovering of the CO as fuel. This, however, leads to insignificant further reductions of dust emissions. More difficult and expensive is the secondary dedusting - necessary to reduce dust, consisting mainly of ferric oxides - from the reloading of pig iron, as it requires cleaning of high volumes of air, in order to capture the dust. While previously membrane filters were used, now electrostatic separators are more widely used, as they require less energy (Philipp 1989). Dust captured by off-gas cleaning is fed back into the process (Philipp/Theobald 1993).

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[12] Dry electro filters currently clean off-gases to dust contents under 10 mg/m^3. The replacement of wet dedusting systems by dry electro filters leads to a considerable reduction in energy input and in the amount of off-gas (Schulz 1992; Philipp/Theobald 1993).

In NRW the construction of Oxygen steel plants equipped with added dry and wet electrofilters started in the early 60s[13] (Jahresbericht 1961). In the mid-seventies, secondary dust emissions resulting from the breaking out of the converter lining were reduced with help of material changes. While previously a mixture of tar and dolomite had been used for the lining from the mid 70s on pre-burned sinter dolomite stones were used (Jahresbericht 1974). Measures for secondary source dedusting then gained importance. New converters were completely encapsulated, equipped with suction hoods, and off-gases were fed into dedusting facilities. In existing plants measures for secondary dedusting were also installed (Jahresbericht 1975; Jahresbericht 1977; Jahresbericht 1980). By 1982 70% of the oxygen steelworks in the Ruhr Area were equipped with secondary dedusting systems (Jahresbericht 1982).

d) Electric Arc Process

Together with the Siemens-Martin furnace the electric arc furnace is the major scrap utilization process. Among the four major steel producing processes this showed the greatest reduction in specific dust emissions. This was due to various measures, such as the closure of not dedusted electro steelworks, dedusting of plants that had not previously been dedusted, replacement of technologically obsolete dedusting facilities, improvement of dust collection during specific phases of the batch process, and metallurgical process changes[14]. Dry and wet electro filters, Venturi dedusters, disintegrators and membrane filters are options for dedusting. The share of membrane filters[15] increased continuously between the mid 60s and mid 70s, due to increasing

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[13] It was planned that with the start of these plants, Thomas steel production would be reduced. The remaining Thomas-plants, at that time, were planned to be equipped with dedusting facilities. For the actual development see chapter 3.5.2. b).

[14] Conversion to a) AOD-process, b) vacuum-fining (Frischverfahren) or c) continuous addition of reduced iron ore or shredder scrap.

[15] The standard set for dust emissions in the technical directive for air is stricter for electro steel than for oxygen steel. As membrane filters are more effective their application increased within electro steelworks. However, because they can only treat off-gas temperatures up to 150° C, some modern oxygen steel plants partly use the less temperature sensitive electro filters (see 3.5.2. c)). In the Duisburg area, for example, for primary dedusting of oxygen steelworks

environmental standards. The emission of cadmium, zinc and lead in this process depends, as in the Siemens-Martin process, on the amount of contaminated scrap material used (Schade/Gliwa 1978).

In NRW, the dedusting of electric arc furnaces began in 1962. Facilities to suck off the off-gases and dry electro filters were installed[16] (Jahresbericht 1962). In the following years wet electro filters, memabrane filters and Pease-Anthony-plants were also installed (Jahresbericht 1964; Jahresbericht 1965). Until the early 70s optimization of production - i.e. the replacement of smaller and lower efficiency plants by ultra high-power plants reaching a higher output per hour, and increasing input of oxygen - increased dust emissions considerably. Additional dedusting facilities (suction hoods and additional membrane filters) which had been investigated in the USA since the early sixties, were able to reduce dust to 40 mg/Nm^3. In several plants within NRW this new 'best available technology' (BAT) was required, and in 1972 the first completely dedusted plant of Germany was opened in NRW (Jahresbericht 1971). During the following years improved technology was installed in further plants, some achieving dust contents lower than 0,5 mg/Nm^3 (Jahresbericht 1974). By 1982 all electric arc furnaces in the Ruhr area were equipped with secondary dedusting systems. The share of this process in total NRW steel production, compared to the share of oxygen steel, is still relatively low.

Currently off-gases produced by electric arc furnaces are collected, through suction and encapsulation. Encapsulation allows the capture of up to 95% of the off-gas. For dust-separation, membrane filters are used for 80% of the German electric arc furnaces, in some furnaces electro filters are still in use (Angrick 1993). The separation of primary and secondary dust is mostly achieved with a single filter (Philipp 1989).

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currently only electro filters are used, while, for secondary dedusting, both electro and membrane filters are used (interview with Mr. Kochskämper, Umweltamt Duisburg).

[16] In 1962 two 20-t-furnaces were dedusted reducing the dust contained in the cleaned gas to 60 mg/Nm^3. The costs of the cleaning facilities amounted to DM 600,000.

3.6. Residues

While residues occurring within steel production during the early 40s amounted to about 1200 kg per tonne crude steel (Philip/Theobald 1993), currently, integrated steelworks produce on average 575 kg per tonne crude steel as residue. 80% of these residues consist of slag which can be re-used, 8% of dust and sludge from filters, 6% of roll sludges. In some plants up to 90% of the latter two are re-used. In general the dry-separated dust from sinter plants, blast furnaces, oxygen and electro steel plants is re-used, either within the steel industry itself or in other industries, such as the non-ferrous metal industry[17] (Angrick 1993). With respect to water, the closing of cycles and re-use in several production steps considerably reduced both water input and the need to clean waste water (Philipp/Theobald 1993).

4. Driving Forces Behind Intrasectoral Change

4.1. Legal Framework

The most important legal basis for air pollution control is the 'Bundesimmissionsschutzgesetz' (BImSchG)[18] of 1974[19] together with its amendments of 1985 and 1990 (Finke 1988; Angrick 1993) and the standards based on the requirement to use the BAT for both old and new plants. The technical directives for air of 1964, 1974, 1983 and 1986 are also important, as is the 'ordinance for large combustion plants' (Großfeuerungsanlagenverordnung) of 1983.

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[17] In NRW currently 80% of the dust produced in the steel production is re-used (Philipp/Theobald 1993).

[18] Federal Law Concerning the Protection against Harmful Effects on the Environment through Air Pollution, Noise, Vibration, and Similar Factors.

[19] The steel industry had however already put effort into reducing emissions of process off-gases from chimneys (Finke 1988).

4.1.1. Development of Legal Framework

Before 1964 technical standards for plants were determined by the 'industrial code' (Gewerbeordnung) (Rosenstock/Weber 1983). Since 1964 the technical directives for air have been the legal basis[20]. According to the technical directives for air 1964, 1974, 1983 and 1986 *new plants* are only to be authorized, if

a) they are equipped with the BAT for the limitation of emissions,

b) the deposition standards are not exceeded due to the new plant and

c) those emissions which, even using the BAT, are unavoidable are adequately dispersed.

Exceptions with respect to the BAT are possible, if it is guaranteed that the deposition standards are not exceeded by other means e.g. other technologies, higher chimneys, different fuel input, diminution of the plant or a reduction of emissions from other plants run by the applicant or third persons (TA Luft 1964; TA Luft 1974).

New federal legislation in force since June, 1960, enabled authorities, for the first time, to require technically feasible and economically reasonable measures for *existing plants*. Plants affected were listed in an ordinance[21] of August 1960. Based on this 'clean air law' (Luftreinhaltegesetz), the first technical directive for air was enacted in 1964, requiring the BAT, as defined in the VDI-guide-lines[22]. In 1962 NRW enacted its

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[20] In the technical directive for air for the first time deposition standards were set. This had a severe impact on authorization. In areas where the deposition standards were already exceeded, special demands with respect to emissions had to be met.

[21] Verordnung über genehmigungsbedürftige Anlagen (ordinance for plants subject to authorization).

[22] Guide-lines from the 'commission for maintenance of air quality' (Kommission Reinhaltung der Luft im VDI und DIN, KRL). Association of German Engineers (Verein Deutscher Ingenieure) and German Standards Institute (Deutsches Institut für Normung).

'Landesimmissionsschutzgesetz' (LImSchG)[23] designed to reduce pollution from those plants not covered by federal legislation (Blazejczak 1995; Brennecke 1994).

According to the BImSchG 1974 and the technical directive for air 1974, 'clean air plans' (Luftreinhaltepläne, LRP) are to be produced for areas in which detrimental effects on the environment due to air pollution exist or where they are to be expected. These plans consist of information on the expected air pollution, its effects on the environment, the sources of air pollution and proposed measures to reduce emissions (TA Luft 1974). Clean air plans exist in addition to the technical directives for air and are not based on them. In areas in which high depositions were identified, the plants potentially causing emissions were inspected and respective measures were set up[24].

In 1985 the criterion for commands on existing plants was changed. The criterion was no longer that the changes be 'economically reasonable' but rather 'proportional' to the desired effect on the environment. A new instrument, the 'dynamization clauses' (Dynamisierungsklauseln), was introduced in the technical directive for air 1986. This instrument enables the administration to systematically tighten standards according to improving BAT (Brennecke 1994).

Implementing Authorities

State authorities are responsible for achieving standards and measures required by federal law (technical directives for air, BImSchG) and by state schemes (LImSchG, clean air plans, amelioration programmes). These were previously the 'State Trade Supervisory Offices' (Staatliche Gewerbeaufsichtsämter), and are now the 'State Environmental Offices' (Staatliche Umweltämter).

The State Trade Supervisory Offices have traditionally been responsible for overseeing technical installations in industry in order to prevent accidents. In other federal states this was their main domaine up to the end 50s when the industrial code

[23] State Law Concerning the Protection against Harmful Effects on the Environment through Air Pollution, Noise, Vibration, and Similar Factors.

[24] Interview with Mr. Krüner, Umweltamt Hagen.

(Gewerbeordnung) was amended, however in NRW State Trade Supervisory Offices since the late 40s have been active in pollution control.

The State Offices' responsibility with respect to clean air policies is the control of plants and their emissions, the authorization of plants[25] and participation in regional planning (Regional- und Bauleitplanung). With respect to regional planning they are responsible for ensuring that planning is compatible with environmental protection. For this they cooperate with the planning authorities (MAGS 1974), thereby integrating various policy fields (Fachpolitiken). In NRW their function also covers the allocation of financial support from the state budget[26] for environmental investment. With technical and administrative responsibilities for clean air protection both allocated to these administrations (Sonderverwaltung) in NRW, which is unique in Germany, they were given a high degree of independence.

Previously there had been 22 State Trade Supervisory Offices in NRW. They were assigned to the 5 governmental presidents (Regierungspräsidenten) who supervised (Fachaufsicht) the State Offices (Buck-Heilig 1989). In the late 80s responsibilities for 'health and safety at work' (Arbeitsschutz) and the protection against harmful environmental effects (Immissionsschutz[27]) were separated and assigned to individual departments within each State Office (Buck-Heilig 1989). During the early 90s, however, a reorganization took place. Health and safety at work and environmental protection were allocated to separate authorities. Currently 12 State Environmental Offices and 12 Offices for Health and Safety at Work (Staatliche Ämter für Arbeitsschutz) exist in NRW (Jahresbericht 1993).

Monitoring air quality is a prerequisite for tightening clean air legislation and for its implementation. In 1963 NRW established the 'Landesanstalt für Immissions- und

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[25] The number of plants to be authorized by the State Offices has increased considerably over time.

[26] Immissionsschutzförderprogramm (IFP), see also chapter 4.4.3.

[27] Protection against Harmful Effects on the Environment through Air Pollution, Noise and Vibration.

Bodennutzungsschutz' (LIB), a special authority to monitor air quality. The LIB was founded with the specific aim of supporting the State Trade Supervisory Offices in questions of environmental protection (Immissionsschutz), to provide the scientific basis for their work and to advise them in the implementation of legal requirements (MAGS 1974; Arbeits- und Sozialminister NRW 1969). In a similar way this institution was based on a previously existing structure (Kohlenstoffbiologische Forschungsstation), which was founded in 1946 and originally researching in the field of nutrition. From the early 50s on, the institute was concerned amongst other things with the maintenance of air quality. With increasing significance of clean air maintenance it was reorganized in 1960 (Forschungsinstitut für Luftreinhaltung) and in 1963 turned into a state institute (LIB), now specializing in the effects of air pollutants and in the definition of standards (Koch 1983). Since the mid 70s this institution has been shortly called 'Landesanstalt für Immissionsschutz' (LIS). The LIS has set up a complete network of measurement and monitoring stations. It was also involved in setting up the clean air plans. The LIS in 1994 was absorbed into the newly formed 'State Office for Environmental Protection' (Landesumweltamt, LUA).

4.1.2. Bundesimmissionsschutzgesetz

The Bundesimmissionsschutzgesetz (BImSchG) of 1974 enables the German government and, in individual cases, also the state governments to enact ordinances and administrative regulations. This led to the '4th ordinance for the accomplishment of the BImSchG', which is relevant to the steel industry as it enlarged the catalogue of plants that had to receive approval. It also led to the amendment of the technical directive for air in 1974 (Rosenstock/Weber 1983).

The BImSchG 1974 comprised and improved the previously scattered state and federal law and also transformed the State Trade Supervisory Offices into general 'Immissionsschutz' authorities responsible not only for industrial entreprises but for all activities causing depositions (Jahresbericht 1974; Jahresbericht 1975). Furthermore, this law requires that areas of high pollution (Belastungsgebiete) be determined. This serves as further basis for targeted clean air strategies. For these areas registers of assessment for emissions (Emissionskataster) are set up, and clean air plans are developed (Jahresbericht 1975). With this, the BImSchG 1974 constituted a switch from sectorally to more regionally oriented clean air policies (RISP 1982). In 1975 NRW enacted an ordinance to determine areas of high pollution and determined the first 5 of these areas (Jahresbericht 1975).

4.1.3. Landesimmissionsschutzgesetz

The state Trade Supervisory Offices were previously responsible for plants subject to authorization. Then, with the setting up of the Northrhine-Westfalian Landesimmissionsschutzgesetz (LImSchG) in 1962 they became responsible for the 'Immissionsschutz' of almost all industrial plants. Clean air policies were the focus of interest (Jahresbericht 1962). In this early law standards for dark smoke from combustion plants were already set (LImSchG 1962). An amendment of the LImSchG was adopted in 1975 (Jahresbericht 1975).

4.1.4. Technical Directives For Air

Deposition standards for dust and gases were fixed in the *TA Luft 1964*, however, heavy metal depositions were not mentioned at that stage. Standards for dark smoke from combustion plants were also set. In order to limit dust emissions specific minimum demands with respect to the iron and steel industry were set for: hard and brown coal combustion, for plants producing pig iron, for blast furnaces and for fining processes using oxygen within the steel production (TA Luft 1964). Technologies capable of reducing the emissions to the specified standards are presented in the VDI-guide-lines.

Specific emission standards for lead, copper and cadmium in dust were first set in the *TA Luft 1974*[28]. The standards for dust emissions were also tightened (Rosentock/Weber). In order to reduce dust emissions various, mainly organizational-technical[29] measures are required by *TA Luft 1974 and 1983*. These measures cover activities such as storage, transport, conveyance, discharge, and maintenance of

[28] In this amendment BAT was defined by emission standards for the first time.

[29] For more specific information on organizational technical measures see Schucht 1996.

moisture level for dusty comminution materials, goods and production residues, as well as the collection of waste gases containing dust. Special requirements with respect to dust, gaseous, CO and SO_2 emissions were imposed for various facilities. These facilities include those producing pig iron, iron ore sintering plants, facilities melting pig iron (cupola plants) and facilities producing steel in converters, electric arc furnaces, vacuum melting systems and top blowing converters, electroslag re-melting plants, facilities for the machine flame-treatment of steel and iron and steel foundries (TA Luft 1974; TA Luft 1983). In *TA Luft 1986* standards for emissions were tightened. Additionally standards were set for SO and SO_2 emissions from facilities for rolling of metals, heating furnaces and heat-treatment furnaces (TA Luft 1986).

4.2. Clean Air Planning in NRW

In addition to the federal legislation, given in the BImSchG and technical directives for air, relevant to iron and steel production in the Ruhr Area (NRW), NRW has its own clean air planning. As stated above, clean air plans are to be set up for highly polluted areas. Owing to its high density of heavy industry, several regions within NRW and especially within the Ruhr Area have this problem.

Previously the state government of NRW had tried to reduce air pollution from industrial dust and sulphur dioxide emissions with help of sectoral amelioration programmes[30] (focussing, for example, on steel converters, sinter, cement and coking plants). More recently, in connection with the BImSchG 1974, the concepts were extended to give a regional focus (RISP 1982), by setting up clean air plans including all sources of air emissions (all industrial sectors, households, traffic) and all other kinds of emissions (MURL 1989). In this respect the clean air plans also differ from the technical directives for air, which only focus on industrial plants and, moreover, do not cover all industrial activities. An example where the clean air plans exceed the technical directive for air are reloading sites: The technical directive for air only states possible measures to be taken in order to reduce dust emissions, but does not set any standards.

[30] See chapter 4.3.

The clean air plans set the measures to be taken in individual cases and to be reinforced by the State Offices[31].

Clean air plans consist of (TA Luft 1974; RISP 1984):

a) an inventory of depositions and emissions (Emissions- und Immissionskataster),
b) the expected development of pollution,
c) its effects on the environment,
d) registers of assessment (Wirkungskataster) in which causal relationships between depositions and polluters (sources and effects) are specified and
e) a catalogue of proposed measures to reduce emissions.

Clean air plans were set up for 3 regions within the Ruhr Area: Ruhr Area West, East and Centre. The first generation of these plans covered the years 1976 to 1982, the second, the years 1983 to 1988 (MURL 1989). Currently the third generation of these plans is under development. The area most affected by heavy metal emissions is the western part of the Ruhr Area. Examples of measures that were to be taken in the period 1978 to 1982, as specified in the clean air plan for Ruhr Area West and related to the iron and steel industry are: a dedusting of tapholes and tap runners in order to reduce brown smoke, a separate desulphurization of pig iron with added dedusting facilities, the collection and separation of brown gas - produced by the reloading processes in blowing and Siemens-Martin steelworks - aimed at a reduction of dust emissions and the dedusting of Siemens-Martin furnaces. In order to reduce dust and SO_2 emissions a conversion from coal and oil combustion to blast furnace gas combustion was planned, and a conversion from permanent-mold casting to continuous casting in steelworks was aimed at the reduction of dust emissions. Dust emissions caused by the regular cleaning of heating surfaces of steam boilers were to be reduced by improved electro filters for off-gas cleaning (MAGS 1977).

During these years the actual reduction in dust emissions was more than double what had been aimed at in the first clean air plan. Still, several measurements showed that

[31] Interview with Mr. Kochskämper, Umweltamt Duisburg.

depositions of lead, zinc and cadmium were higher in some areas than allowed by the standards. The aim of the second clean air plan for Ruhr Area West was therefore to reduce dust emissions and their heavy metal content in order to meet these standards. Concrete measures were, however, not specified in the literature (MAGS 1985).

Relevant measures to be taken in the period 1979 to 1983 as specified in the clean air plan for Ruhr Area East (MAGS 1978) were, firstly the installation of dedusting facilities in Siemens-Martin steelworks. There was a programme for dedusting Siemens-Martin furnaces, running from 1974 to 1978 which was carried out with an investment expenditure of DM 100 million. With its completion a reduction of dust emissions by 90% from 3 Siemens-Martin steelworks was expected. Secondly the installation of additional suction hoods collecting secondary source dust emissions from oxygen steel plants, as well as their removal with help of electro filters[32] was required.

The third generation of clean air plans constitutes a switch in the approach. Owing to high improvements with respect to dust, SO_2 and NO_x emissions, future measures were to focus stronger on substances that occur in smaller amounts but have potentially serious - toxic, cancerogeneous or accumulative - effects (hohes Wirkungspotential) (Jahresbericht 1988; LIS 1994).

The success of this instrument - at least with respect to the first two generations of plans - has been questioned, because it lacks legal binding force with respect to the realization of the measures recommended (Trute 1994). NRW, however, promoted the realization of measures by granting financial support. State support for the required measures was available from the 'small and medium-sized businesses credit programme' (Mittelstandskreditprogramm), the 'Immissionsschutzförderprogramm' (IFP)[33], the 'Action Programme Ruhr' (Aktionsprogramm Ruhr, APR) and the 'Federal Programme for Refitting Older Plants' ('Altanlagensanierungsprogramm des Bundes', UBA) (see section 4.4.; RISP 1982). Further criticism is directed at these programmes for setting

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[32] Using in part those filters already installed for primary source dedusting.

[33] Promotion programme for protection against harmful effects on the environment through air pollution, noise and vibration.

the focus on averting hazards in highly polluted areas instead of on general precaution (Trute 1994).

4.3. Amelioration Programmes of the NRW State Government

Sectoral amelioration programmes (sektorale Verbesserungsprogramme) were based on an emission-sided approach. Measurements were made at plants to evaluate possible focusses for amelioration[34], aimed at providing these plants with up to date technology. The experience with these programmes, however, was that improvements were carried out without significantly improving the environmental situation with respect to depositions. From that point of view improvements at different plants might have been more useful, as deposition also depends on other factors such as the hight of chimneys. This experience, amongst other things, caused the focus to be switched in later years to a more regional approach and clean air plans (see above) were set up[35].

The reasons for the decision on a sectoral approach for these programmes, however, were that (Jahresbericht 1967):

a) it could focus on specific production processes, as emissions depend heavily on the processes used,
b) an orientation on sectoral aggregation helped to foster cooperation with the relevant industrial associations,
c) a simultaneous treatment of whole sectors made the state offices' work easier than the case of simultaneously examining and dealing with various plants and technological problems, which would be necessary in a regional approach,
d) the greatest effect on heavily polluted areas was expected when improving the most important industrial emission sources first.

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[34] Considered as subject to amelioration were plants emitting more than twice of the standards required for new plants and plants leading to detriment of neighbours (Jahresbericht 1973).

[35] Interview with Mr. Stöcker, referent at the NRW Ministry for the Environment, regional planning and agriculture (Ministerium für Umwelt, Raumordnung und Landwirtschaft).

There was basically no financial support available for the amelioration programmes. Financial support for clean air measures, however, was availabe from two promotion programmes[36]:

- the European Recovery Programme (ERP)
- the 'Immissionsschutzförderprogramm' (IFP).

For information on support granted under these programmes see section 4.4.3. to 4.4.5.

Steel Converters

In 1960 54 dust emission intensive Thomas converters were in use in NRW. An amelioration programme was set up by the state government of NRW in 1961 with the aim of reducing the brown smoke and high dust emissions caused by these plants by refitting them with end-of-pipe technologies (Arbeits- und Sozialminister NRW 1969; IHK 1973; Jahresbericht 1967) and, thus, adjusting the technology to the latest VDI-guide-lines (Jahresbericht 1962). An experimental plant had been built up in 1959 to test dedusting technologies and by 1962 technology to keep back the dust had been developed (Arbeits- und Sozialminister NRW 1969). However by that time it was already clear that no new Thomas-steel converters were going to be built, but that they would be replaced by dedusted LD and LDAC converters (Oxygen-steel) equipped with dust removing technologies[37] (Arbeits- und Sozialminister NRW 1969; IHK 1973; Jahresbericht 1963). The focus of the amelioration programme, therefore, was switched to the replacement of Thomas converters (process related technological change).

Though the programme was originally supposed to be completed in 1967, its accomplishment was delayed by organisational changes, that is concentration processes within the steel industry which were taken into consideration by the authorities responsible for the implementation of clean air legislation. The replacement of Thomas-steel converters was also delayed by accelerated economic growth which extended the

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[36] Interview with Mr. Krüner, Umweltamt Hagen.

[37] See also chapter 3.5.2.b), as well as 4.6.

lifetime of these plants. By the end of 1969 50 out of the 54 Thomas-steel converters employed in 1960 had been replaced by LD- and LDAC-converters (Jahresbericht 1969). Between 1962 and 1969 20 LD- and LDAC-converters (basic oxygen) with a capacity of 3000 t and equipped with modern dedusting facilities went into operation (Jahresbericht 1969). In the following years further means of dust control were installed in several enterprises. These included electro filters and covers to collect exhaust gas arising from converters and dust arresters in auxiliary facilities (IHK 1982; Initiativkreis Ruhrgebiet 1992). From 1970 there was no more Thomas-steel production in NRW (Schade Gliwa 1978).

There were no sectoral amelioration programmes aimed at refitting Siemens-Martin- and Electro steel plants with dedusting equipment[38]. Nevertheless, there had been a trend to replace Siemens-Martin furnaces by dedusted oxygen-steel plants since the early sixties (Arbeits- und Sozialminister NRW 1969). Also Electro steel production increased. These plants were also equipped with various filters in order to reduce dust emissions (IHK 1973).

Sinter Plants

In order to reduce dust and SO_2 emissions from sinter plants the state government of NRW set up an amelioration programme in 1965 (Arbeits- und Sozialminister NRW 1969). 26 ore sinter plants needed improvements (Jahresbericht 1973). The aim was room and conveyor belt dedusting, to achieve values of 150 mg dust/Nm^3. Also dust emissions from reloading and storage were to be reduced. Furthermore the necessary height of chimneys was to be examined in order to sufficiently dilute SO_2 emissions (Jahresbericht 1967).

Until 1969 7 of 37 plants were closed down. 19 out of the remaining plants reached, with respect to conveyor belt and room dedusting, dust contents lower than 300 mg/Nm^3 and were, therefore, no longer subject to the amelioration programme

[38] In the mid-seventies, however, a dedusting of the remaining Siemens-Martin furnaces was required within the clean air planning.

(Jahresbericht 1969). In order to reduce the dust emissions various filters were installed (end-of-pipe technology), such as electro filters and mechanic dedusters (zyclones) (Jahresbericht 1967). 11 of the remaining 30 sinter plants in operation in 1969 still required improvements to their dedusting facilities (Arbeits- und Sozialminister NRW 1969; Jahresbericht 1969). While in the following years several obsolete plants were closed down, the remaining sinter plants were improved through changes in the raw material and fuel input, process changes, and the installation of dedusting facilities (Jahresbericht 1973).

Only during the early 70s the problem of heavy metals being concentrated - due to materials from sinter and blast furnace processes being re-fed to these plants - became known. This led to high concentrations of heavy metals in dust emissions from sinter plants. At that time, special attention was also paid to desulphurization of sinter off-gases (Jahresbericht 1973).

4.4. Financial Support

Clean air measures and pilot projects had already been financially supported by NRW, as well as by ERP-credits and by means of depreciation allowances in the early 60s (Jahresbericht 1962; Jahresbericht 1966). In the following years specific promotion programmes were set up at both state and federal levels. Being directly linked to the industrial investment activity and, therefore, to the overall economic situation, the volume of financial support differs considerably over the period investigated. On the other hand the amount of clean air investment and, therefore, of the financial support is influenced by requirements for clean air measures to be taken, as set for example in clean air plans (Jahresbericht 1978). Figures for federal and state financial support are given in tables 4.1. to 4.4.

4.4.1. Investment Programme Aimed at the Reduction of Pollution

The 'Federal Office for Environmental Protection' (Umweltbundesamt, UBA) claims that development of technologies aimed at the avoidance of emissions has frequently been advanced by its promotion of investment projects (Angrick 1993).

The UBA has, since 1979, carried out a programme supporting investment aimed at the reduction of pollution[39], firstly on behalf of the German Ministry for Inner Affairs and later on of the German Ministry for the Environment. Projects are promoted which investigate the feasibility and expense of adopting modern procedures to avoid and reduce pollution on a commercial scale. Alternative products and raw materials are also investigated. Integrated technologies are favoured and special attention is paid to minimizing waste and to the utilization of heat (Angrick 1993).

Measures supported by the investment programme must have a pilot project character. Measures required by law or authorities cannot, in general, be supported. The support is granted for the reconstruction of existing plants, either as soft loans or as investment grant[40]. The Ministry for the Environment, in cooperation with the UBA, decides about the level of support paid for individual projects (MAGS 1985; Angrick 1993).

According to the BImSchG authorities are empowered to command technically feasible and economically reasonable measures for existing plants. This poses significant problems with respect to inspection and proof on the licensing authorities, which make it difficult to enforce rapid improvement where there are emissions. The investment programme was also set up in order to create a better basis for these subsequent orders by financially supporting the refitting of existing plants. With the help of commercial demonstration projects the possibilities for adjusting existing plants to the BAT with respect to the reduction of gaseous and dust emissions, can be shown. This also sets a standard for similar plants and enables the operator to aim at compliance with this standard himself[41] (UBA 1982).

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[39] Programm zur Förderung von Investitionen zur Verminderung von Umweltbelastungen. In the following referred to as the 'investment programme'.

[40] Loans can be reduced at interest rates up to 70% of the promotable costs, investment grants can be granted up to 30% of the promotable costs.

[41] The financial support granted under this programme was also expected to be economically advantageous for the respective sectors as it encourages further investment.

The results of this programme are an important basis for the amendments to the legal framework, such as the technical directives for air. They also serve as guide-lines for authorizing bodies and licensing authorities (Angrick 1993).

The total volume of the investment programme was DM 560 million for the years 1979 to 1985 (Fiebig/Hinzen 1985), DM 120 million of which were provided for demonstration projects in the Ruhr Area supplementing the 'Action Programme Ruhr'[42] (see below). Cooperation between federal and Northrhine-Westfalian state authorities ensured that the total APR of over DM 700 million was used in a consistent concept. Within the investment programme in general the share paid by the entreprises had to amount to at least 50%. The decision about which projects are to be supported is taken by the UBA in cooperation with the local 'Immissionsschutz' authorities. Between 1979 and 1981 174 projects with an investment of DM 829,6 million were supported by this programme in NRW (UBA 1982).

Clean air measures within the metal producing industries have played an important role in this programme. In 1979 there were 92 projects in the whole of Germany within the domaine of iron and steel and non-ferrous metals with an investment of about DM 525 million. The focus was on dedusting of steelworks. By 1981 the number of projects increased to 130, with an investment of almost DM 750 million. At that time the focus had switched to the reduction of heavy metal emissions, reaching values for emissions considerably lower than required by technical directive for air 1974. In 1983, 159 projects (investment of DM 915 million) were supported, with a focus on diffuse sources of emissions, particularly in the non-ferrous metal industry. In 1986 the focus was on an application of membrane filters for dedusting and the possibility of re-using the dust that has been collected. There were 180 projects (investment of DM 1,16 billion). In recent years the focus of the support has gradually switched to the avoidance and re-use of waste-materials, the re-use of heat and the reduction of dioxine emissions (Angrick 1993).

[42] This DM 120 million count as 'federal funds' within the 'Action Programme Ruhr' (Institut für Stadtforschung 1980).

Specific projects supported within the iron and steel industry up until the early 80s included dedusting measures for plants, such as casting houses, oxygen steelworks, electric arc furnaces and foundries, as well as plants for ferro alloys. For the non-ferrous metal industry, the dedusting measures supported focussed on primary and secondary aluminium production, as well as on secondary copper and lead production (UBA 1982).

4.4.2. Aktionsprogramm Ruhr

In 1980 the 'Action Programme Ruhr' (APR) was set up by the NRW government for the years 1980 to 1984 (Landesregierung 1979). Its aim was to support the Ruhr Area as this region was particularly affected by economic and structural problems. Within this programme, financial support was provided for the refitting of highly polluting plants, such as smelting, iron and steel, power and combustion plants (MAGS 1985; MURL 1987).

The financial support aims at reducing the state Trade Supervisory Offices' difficulties in implementing measures required for existing plants, as these have to be technically feasible and economically reasonable. The high investment costs, for example, required for secondary dedusting in the iron and steel industry, would frequently have resulted in the changes not being economically reasonable (RISP 1984). The programme put an emphasis on promoting those measures that would have otherwise failed because they did not meet this criterion. The measures supported by the APR focus, rather, on added technology than on integrated technology.

The programme amounts to DM 585 million for clean air measures (UBA 1982). Through this it was possible to realize several measures suggested by the clean air planning, for which there would have been no legal basis due to the requirement that measures be economically reasonable (MAGS 1985; MURL 1987).

DM 535 million was granted for the secondary dedusting of iron and steelworks, a desulphurization programme, amelioration of coking plants and plants in the chemical industry, as well as for measures to reduce noise. Another DM 50 million was planned for the mining sector. While originally support up to 50% of the costs involved had been granted in order to intensively promote particularly problematical cases, the support had to be reduced to 30% in order to meet EC-rules (RISP 1984).

By 1982 the conceded support amounted to DM 101 million (MAGS 1985; MURL 1987). By the end of 1983 DM 223 million had been granted, supporting 38 projects, 32 of which promoted clean air measures, the remaining 6 were measures to reduce noise. The total investment amounted to DM 732 million. 51% of the financial support was paid for improvements to coking plants and the chemical industry. 25.3% was paid for secondary dedusting in mills and steelworks, 21.3% for desulphurization. From a regional point of view the main part of the financial support was paid in the Duisburg-district (RISP 1984).

The following table gives information on financial support paid for secondary dedusting of steelworks, on the number of measures supported and on the total investment.

Table 4.1.

Financial Support for Mills and Steelworks
Action Programme Ruhr
in million DM

	Projects	Support	Total Investment
1980	7	91.2	
			52.4
1981	7	25.5	74.2
1982	3	0.9	3.2
1983 (*)			
1984	9	23.0	151.5
1985	4	9.3	36.9
1986	9	55.1	184.4

(*) Owing to a reduction in the NRW budget within the APR no financial support was conceded in 1983 (RISP 1983).

Sources: Jahresbericht. Several volumes.

4.4.3. Immissionsschutzförderprogramm

In January 1974 NRW published a circular, setting out the guide-lines according to which financial support[43] was to be granted for measures eliminating or reducing air pollution, noise and vibration (Jahresbericht 1974; Jahresbericht 1975). With this 'Immissionsschutzförderprogramm' (IFP), the previous guide-lines for promotion (from 1967 and 1968) were renewed and adjusted to current budgetary regulations (Jahresbericht 1973). This programme was again amended in 1980 (Jahresbericht 1980).

With the IFP, financial support was provided for plants not covered by the APR. This took the form of investment subsidy, interest rate subsidy (soft loans) or low tax credits for projects aimed at the reduction of dust or gaseous emissions (MAGS 1985). Investment subsidies are granted up to 20% of the pollution control investment. As the German government offers support up to 50% of the investment costs[44], NRW granted further financial support in the APR (RISP 1982). For information on credits and grants paid for clean air measures from the NRW state budget see tables 4.3. and 4.4.

4.4.4. Further Financial Support

Depreciation Allowances

The 'German ordinance for the modification of the income tax implementation regulation' (Deutsche Verordnung zur Änderung der Einkommensteuer-Durchführungsverordnung, EStDV) was adopted in 1958, limited in time at first until December, 31st 1960. Tax relief was granted for air pollution control facilities (Guthmann 1961). This ordinance was prolonged several times. Until 1974 the legal basis for depreciation allowances was §§82 and 82e EStDV. In later years it was §7d EStG (Jahresbericht 1975). In 1980 the EC-Commission extended this regulation until 1990 (Jahresbericht 1980). Furthermore, the possibilities for depreciation were improved.

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[43] Credits and grants.

[44] See 'Altanlagensanierungsprogramm'/'Investment Programme' (UBA).

Table 4.2.

Depreciation Allowances (*) for Clean Air Measures in million DM

Iron and Steel Industry		Metal Production and Manufacturing	
until		in	
1965	120.30	1981	13.6
in		1982	79.4
1965	4.63	1983	17.6
1966	35.03	1984	19.8
1967	51.63	1985	50.3
1968	6.13	1986	127.8
1969	23.43	1987	108.9
1970	19.33	1988	35.6
1971	33.93	1989	461.6
1972	14.13	1990	134.9
1973	22.13		
1974	26.50		
1975	88.70		
1976	28.10		
1977	79.50		
1978	159.40		
1979	22.90		
1980	36.20		

(*) According to §82 EStDV. From 1975 on according to §7d EStG und §82 EStDV. From 1986 on according to §7d EStG.

Sources: Jahresbericht. Several volumes.

The amount of depreciation allowances granted gives an indication of investment in clean air measures pursued by industry[45] (Jahresbericht 1967). It also gives an indication of the economic state of industry, as this instrument of financial support can only be applied to entreprises achieving sufficiently high profits. Table 4.2. gives information on depreciation allowances granted to the Northrhine-Westfalian iron and steel industry for clean air investment up until 1980. For later years data is only available for the total metal producing and manufacturing industry.

European Recovery Programme

In addition to the NRW state budget, credits were also available from the European Recovery Programme (ERP). With these special measures, such as measures within the programme aimed at dedusting of Siemens-Martin-furnaces[46], were supported (Jahresbericht 1975). Financial support from the ERP is included in the data given in table 4.3.

Financial Support after 1986

NRW set up a promotion programme aimed at a rapid realization of the standards set in technical directive for air 1986[47]. Entreprises starting the refitting of plants within the lapse of time set by technical directive for air were granted soft loans[48].

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[45] It should be noted, that tax relief was only available for refitting measures in existing plants (Jahresbericht 1967).

[46] For this reason high financial support was granted by the ERP in 1975.

[47] There was practically no other public financial support granted for accomplishing the technical directive for air 1986. The necessary measures - which are now widely accomplished - had to be financed by industry itself (interview with Mr. Krüner, Umweltamt Hagen).

[48] Interview with Mr. Kochskämper, Umweltamt Duisburg.

4.4.5. Financial Support in Numbers

Table 4.3. gives an overview over financial support paid to the Northrhine-Westfalian industry for 'Immissinsschutz' measures between 1965 and 1987[49]. The data covers both federal and state financial support.

Table 4.3.

Financial Support Paid for Clean Air Measures in NRW in 1000 DM 1965 to 1987		
1965........ 10351	1975 86198	1985 74656
1966........ 26255	1976 29661	1986 100150
1967........ 18955	1977 31233	1987 55228
1968........ 19995	1978 56991	
1969........ 19165	1979 42961	
1970........ 21706	1980 66338	
1971........ 27663	1981 95983	
1972........ 24737	1982 98999	
1973........ 25795	1983 89099	
1974........ 44464	1984 64000	
Sources: Jahresbericht. Various volumes.		

[49] Comparable data on earlier and later years was not available.

The data includes credits and grants from the NRW budget (IFP), credits from the ERP budget[50] and support from the federal and state Economic Policy Programmes[51] (Konjunkturprogramme).

Table 4.4. shows Northrhine-Westfalia support paid to the steel industry between 1977 and 1984 for 'Immissionsschutz' measures. Unfortunately the aggregation of sectors differs between the years.

Table 4.4.

Sectoral Division of Financial Support for 'Immissionsschutz' Measures from the NRW Budget (*) Steel Industry Clean Air Measures (in 1000 DM)

	Projects	steelworks		metal- and steelworks		Total Investment
		credits	grants	credits	grants	
1977	4	1500	9741			163950
1978	5	-	5817			57506
1979 (**)						
1980	6			525	20745	351954
1981 (**)						
1982	1			-	121	619
1983	1			400	-	2989
1984	1			-	675	3552

(*) Excluding financial support granted for the APR.
(**) No data given in official statistics.
Sources: Jahresbericht. Various volumes.

50 ERP support is included in the data for the years 1965 to 1969 and 1971 to 1978.

51 Support from the federal Economic Policy Programme is included in the data for the years 1967 and 1968 and from the state Economic Policy Programme for the years 1974 to 1976.

4.5. Cooperation between Industry, Industrial Associations and Government

Standard Setting

In Germany the setting of environmental technical standards is pursued by the state (federal and state authorities) as well as by private standard setting associations, such as the 'Association of German Engineers' (Verein Deutscher Ingenieure, VDI) and the 'German Standards Institute' (Deutsches Institut für Normung, DIN). The standard setting association 'Commission for the Maintenance of Air Quality in the VDI and DIN' (Kommission zur Reinhaltung der Luft im VDI und DIN[52], KRL) is particularly important for clean air standards. Sectoral industrial associations are also involved in the setting of rules and standards. The 'Technical Control Boards' (Technische Überwachungsvereine, TÜV) are also relevant for the setting of standards. They are involved in control and measurement of emissions and depositions and provide both industry and the administration with expert opinions. They maintain their own committee 'Maintenance of Air Quality' which has a close relationship to the KRL (Brennecke 1994).

The background to this cooperation between the state and private associations is the fact that in the BImSchG 1974 the legislator set neither specific technological requirements for plants subject to authorization nor specific emission standards. The BImSchG demands solely the application of 'best available technology', a term that has to be specified by standard setting authorities.

The function of the KRL is to find out the BAT with respect to the maintenance of air quality and especially to the reduction of emissions and depositions. Apart from documenting technologies, the commission sets technically feasible emission standards and scientifically justifiable deposition standards, as well as standards for measuring

[52] While the commission (founded in 1957) was originally an independent institution of the VDI it merged in 1990 with the 'standard setting association on maintenance of clean air' (Normausschuß Luftreinhaltung) of the DIN.

instruments. Its committees consist of experts from industry, science and administration. While the state implementation authorities (the State Trade Supervisory Offices/State Environmental Offices) are not directly involved in the setting of standards, they are represented by members of the 'State Office for Environmental Protection' (LUA) joining the association committees of the KRL as experts (Brennecke 1994).

Implementation of Legal Framework

The emission and deposition standards set, for example, in the *technical directives for air* have to be transformed into measures to be taken by the respective entreprises. For that purpose previously the State Trade Supervisory Offices and currently the State Environmental Offices set up 'multiple directives' (Vielanordnungen), which leave the choice of measures to be taken in order to meet the standards to the entreprises. After the entreprises and state offices have reached agreement on measures to be taken, the latter ensure that these measures are implemented by administrative directive. However, should the entreprises wish for faster realization, they can ask the State Offices for a directive, directly setting the measures to be taken by the entreprise[53].

For execution of the measures stated in the *clean air plans* the State Trade Supervisory Offices discussed the measures and possibilities for implementing them with the facility operators (RISP 1982). While the second clean air plan for Ruhr Area Centre emphasizes that the entreprises were cooperative and that all requested measures had been carried out (MURL 1987), the second clean air plan for Ruhr Area West states that in some cases in which there was a disparity of views with repect to measures to be taken, these measures had been enforced by a formal directive. In most cases, however, an agreement was eventually reached in hearings (MAGS 1985).

According to a *BImSchG* ordinance of 1975 entreprises subject to authorization had to determine representatives for 'Immissionsschutz' (Betriebsbeauftragte für Immissionsschutz) (Jahresbericht 1975; Jahresbericht 1993). The experiences with this institution were, at first, good. The representatives ensured particularly in large

[53] Interview with Mr. Kochskämper, Umweltamt Duisburg.

entreprises that the interests of 'Immissionsschutz' were considered to a greater extent. Training programmes for the representatives were offered by the state authority responsible for monitoring air quality (Landesanstalt für Immissionsschutz, LIS) (Jahresbericht 1975). For cooperation between entreprises and the State Offices it was advantageous that these representatives be experts both with respect to their entreprise and to questions of 'Immissionsschutz' (Jahresbericht 1978). By the end of the 80s the assessment of this institution was less enthusiastic. While no specific problems were encountered with respect to the institution of entreprise representatives, there were also no indications as to their special effectiveness (Jahresbericht 1987).

4.6. Economic Motivations

The *reduction of emissions* caused by the iron and steel industry is closely related to technological developments, that have been induced by reasons other than pollution control standards (Finke 1988). Examples are:

- The number of aggregates has been considerably reduced. Plants were enlarged, thus the number could be reduced, and the emissions concentrated (IHK 1982).
- Modern blast furnaces are virtually sealed units.
- The decisive reduction of dust emissions was achieved by the replacement of Thomas- and Siemens-Martin[54] steelworks by dedusted Oxygen- and Electro steelworks. From 1970 there was no more Thomas steel production in NRW. The last Siemens-Martin furnace in NRW was closed down in the early 80s.

The conversion of processes is explained by both the entreprises' need of profitability and by pollution control requirements. The fast diffusion of the oxygen process and the decreasing share of the Thomas-steel was influenced by tightened requirements for the maintenance of air quality in the early 60s (Jeschar et al. 1996). Clean air policies at that time cover the LImSchG adopted in 1962, the sectoral amelioration programmes on NRW level and new VDI-guide-lines for the limitation of dust and off-gases

[54] In remaining Siemens-Martin steelworks dedusting facilities were installed.

(Jahresbericht 1962). The volume of off-gases per tonne of steel is four times higher for Thomas-converters than for oxygen blowing processes. The facilities for dedusting Thomas-converters would, therefore, have been so huge, that it was not possible to install them in the entreprises (Jeschar et al. 1996). While the dedusting of Siemens-Martin furnaces was possible, the specific costs related to this were high.

Though there were no specific standards set for electric arc furnaces by technical directive for air 1964, they were equipped with process dedusting systems. This was brought about by the technological development and general demands (Rosenstock/Weber 1983).

Being by far the largest industrial energy consumer, the availability of energy and its price have been of special significance for the iron and steel industry. Consequently, the iron and steel industry has taken significant measures to *reduce energy consumption* (Höffken et al. 1984). Measures to reduce energy consumption, especially coke consumption, were already pursued during the 1960s (Feddersen/Kruck 1982). Measures were applied in various production steps. The specific energy consumption was reduced by means of process optimization and improvements in production processes. The trend to a higher share of high-graded steel within total steel production was also important (Enquete-Kommission 1990; Prognos 1991). The use of by-product and waste energy[55] also reduced energy consumption. An example is the recovery of energy contained in converter gas from oxygensteel plants, as pursued in the Thyssen BOF shop (Höffken et al. 1984). A further example is the above mentioned (see chapter 3.3.) reduction of coke input in sinter plants by almost 50%. Also within blast furnaces process and metallurgical measures cut the consumption of coke from 850 kg/t pig iron in 1960 to between 350 and 500 kg/t today. Apart from a direct reduction of emissions from steel plants, the reduced coke consumption also led to decreases in emissions from coking plants (Schulz 1992). The process technology employed is also relevant to the consumption of energy: Electric arc furnaces require more than 50% less energy than the production of crude steel in the production line blast furnace and oxygen steelworks.

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[55] The use of waste energy was facilitated by the closely linked production steps of modern integrated steelworks (Brüninghaus/Bleilebens 1995).

The introduction of continuous casting, replacing the old ingot plants, reduced the specific energy consumption, because less scrap was produced (Altgeld/Schneider 1992; Brüninghaus/Bleilebens 1995).

However, the reduction of energy consumption was also encouraged by the state. In the 70s the Northrhine-Wetfalia state government set up a number of programmes supporting specific sectors. The 'technology programme steel' (Technologieprogramm Stahl) supported the introduction of new technologies, in the first place aiming at improving the steel industry's competetiveness. Special goals were the minimization of energy and raw material consumption as well as an improvement in the products' quality (Heinze et al. 1992).

5. Evaluation of Clean Air Policies

Gas cleaning technologies, with an emphasis on process off-gases from chimneys, were applied within the iron and steel industry even before the clean air legislation was set up in Germany (Eickelpasch et al. 1980). However, in the 50s heavy dust emission was still common for steel production. The main reasons were the Thomas- and Siemens-Martin steelworks, in which no dedusting facilities were used. The drastical reduction of dust emissions was mainly brought about by the replacement of Thomas- and Siemens-Martin steelworks by oxygen blowing and electric arc steelworks and the refitting of the remaining Siemens-Martin steelworks with dedusting facilities. While the specific dust emission of German steelworks amounted to more than 15 kg/tonne crude steel in 1950, they were reduced to less than 2 kg/tonne by the end of the 80s (Philipp 1989; Finke 1988; Eickelpasch et al. 1980). Currently the specific emissions amount to considerably less than 1 kg/tonne crude steel (Philipp/Theobald 1993; Thyssen 1995; Schulz 1992).

5.1. Environmental Effectiveness and Economic Efficiency

The most marked reductions in specific dust emissions took place up until around 1974. This led to a decline in total dust emissions, even though steel production had increased. In later years the specific dust emissions could only be reduced slightly, despite the 'secondary dedusting' installed in steelworks. Improvements of present dedusting systems, as required by the technical directive for air 1986, were expected to lead to only slight emission reductions (Philipp 1989). But these measures put high economic pressure on the entreprises, both for investment and running costs. In the Ruhr Area dedusting activities had already reduced depositions to values as set by technical directive for air 1986 by 1975. Measures to reduce dust emissions were highly effective until the mid 70s. Since then there have only been small reductions.

Since 1964 primary dedusting systems have been installed in coking plants, blast furnaces, sinter plants, blowing converters and electro steelworks (Rosenstock/Weber 1983). The dedusting of primary emission sources was already widely completed by the mid 70s[56] and led to a distinct mitigation with respect to depositions. Since then the aim is to fulfill the respective standards set by the technical directive for air with respect to collection and dedusting of secondary emission sources (Finke 1988; Rosenstock/Weber 1983).

The technologies to collect diffuse emissions and emissions from secondary sources require particularly high investment as large volumes of air have to be cleaned in order to collect the dust. With respect to dust collected within electric arc steelworks, currently 95% of the dust stems from primary emission sources, while only 5% stems from secondary sources. The required volume of suction, however, is 5% for primary dust and 95% for secondary dust (Philipp 1989).

The specific costs of dedusting, as well as the energy input required, increase exponentially (Finke 1988; Philipp 1989). A refitting of sinter plants as required by technical directive for air 1986 to reduce dust contained in off-gas to 50 mg/m^3 led on average to specific investment costs of several 100,000 DM per kg dust reduction/h and only to a small reduction of dust emissions. But of even greater importance for the economic situation of a steelworks are the running costs caused by pollution control. Secondary emission source dedusting causes high energy consumption, required by the ventilators used for the removal by suction of the large volumes of air and its cleaning (Philipp 1989; Finke 1988). Refitting of already installed dedusting systems can amount

[56] The only exception being the Siemens-Martin furnaces (Philipp et al. 1987).

to over 1 million DM/tonne avoided dust (Philipp 1989). The greatest specific electricity consumption within the iron and steel industry is in the steel production process. This is, to a large extent, caused by secondary dedusting. Within an integrated steelworks measures to reduce air pollution cause an energy consumption of about 62kWh/tonne crude steel or of 12,000 kWh/tonne collected dust (Philipp 1989; Finke 1988). Secondary dedusting systems, installed since 1974, cause - compared to primary dedusting - a ten times higher energy input and four times higher costs in order to separate the same amount of dust (Rosenstock/Weber 1983). Estimates at the end of the 80s established the result of over 1 billion kWh per year for secondary source dedusting (Eickelpasch et al. 1980). Given the fact that these measures do not have a marked effect with respect to depositions, the authors question whether this is a sensible strategy, even more as the energy itself is produced at the expense of high pollution[57] (Eickelpasch et al. 1980; Philipp 1989; Finke 1988).

There are, however, also more positive estimates of the efficiency of secondary dedusting. Representatives of the NRW State Environmental Offices and the Ministry for the Environment point out that:

a) Secondary dedusting, though expensive, still leads to collection of considerable amounts of dust that would otherwise be emitted. Furthermore secondary dedusting costs are low when compared to the total plant value.

b) Secondary dedusting serves various purposes at the same time: With respect to, for example, suction within plants, these measures serve not only environmental but also health and safety requirements for workers.

c) Furthermore, the collected dust containing metals is fed back into the process. This increases the economic efficieny as raw materials are substituted - even though only to a small extent. One plant within the Ruhr Area[58], however,

[57] Electricity consumption of a casting house dedusting causes for example emissions of 7 to 10 kg CO_2/kg dust. Measures for diffuse emission source dedusting can lead to even more unfavourable ratios (Philipp/Theobald 1993).

[58] DK Recycling und Roheisen (previously Duisburger Kupferhütte) situated in Duisburg.

exclusively uses only residues for its pig iron production and is paid for the dust residues it accepts by the delivering plants[59].

d) The importance of secondary dedusting is underlined by the aim of reducing dust in small particles and, even more, of substances with high (for example toxic) effects, such as dioxine. It might be more sensible to develop integrated technologies completely avoiding these substances instead of applying costly end-of-pipe technology. The development of new technologies, however, involves uncertainties with respect to its effects, as well as to the time needed for its development and commercial diffusion[60].

Intergration of Economic and Environmental Objectives

In addition to the conversion of crude steel production processes since the early 60s, contributing to economic and environmental improvements[61], an integration of economic objectives and ecological benefits is particularly clear with respect to measures reducing energy input, residues and water consumption. Since the early sixties the iron and steel industry has taken measures to reduce energy consumption, particularly coke consumption (see chapter 4.6.). A further means of reducing energy input was the re-use of waste energy. With the development to integrated steelworks this was made considerably easier. Less energy input not only reduces costs but also emissions caused by energy-generation and by its use within the steel production processes. The reduction of energy consumption was also supported by promotion programmes, such as NRW's 'Technology Programme Steel'. Residues resulting from steel production have also been considerably reduced (see chapter 3.6.). This was partly due to more efficient process technologies, such as the continuous casting, leading to a higher output per unit of input material. Partly it was due to recycling. Currently about

[59] Interview with Mr. Kochskämper, Umweltamt Duisburg.

[60] Interview with Mr. Stöcker, referent at the NRW Ministry for the Environment, regional planning and agriculture (Ministerium für Umwelt, Raumordnung und Landwirtschaft).

[61] The conversion of processes allowed for improved dedusting and increased productivity of steel production.

90% of the steel industry's residues are recycled[62]. The share of recycling with respect to water amounts to over 80% (Philipp et al. 1992). In some plants it even amounts to 97%. These measures serve economic purposes in two ways: They reduce input and deposition costs and lead to increased returns if residues or by-products can be sold.

5.2. Administrative Efficiency and Practicability

Administrative practicability was increased with the BImSchG 1974. With this law - and in this respect it was the opposite of the previous law - the plant operator had to prove that measures were not economically reasonable. This considerably reduced the number of investigations that had to be carried out by the authorities (Jahresbericht 1974). The possibility, given in the BImSchG, of prosecuting non-compliance with rules and directives as administrative offence is also seen as advantageous for a fast and effective implementation of measures. The imposition of fines is, in many cases, considered as more effective than initiating a prosecution or the enforcement of compulsory administrative measures (Jahresbericht 1975).

The State Environmental Offices regard the procedure for transforming legally set standards (technical directive for air) into specific measures to be taken by the entreprises and of implementation as being highly efficient. The measures taken in order to meet the required standards are mainly chosen by the entreprises themselves. They can choose the measures that are most cost effective and adequate for their respective plant. With respect to technical directive for air 1986 there were only very few cases of disagreement between authorities and entreprises, and the realization of requirements was, in many cases, finished before the date set by law. This was partly due to financial support offered to entreprises starting with their refitting before the final date set by technical directive for air. The entreprises had no interest in delaying their measures. This contributed to a better and faster accomplishment of technical directive for air 1986[63].

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[62] Approximately 70% is sold to other industrial sectors and about 20% is re-used within the steel industry itself.

[63] Interview with Mr. Kochskämper, Umweltamt Duisburg.

According to technical directive for air[64] 'compensation models' (Ausgleichsmodelle) would have been possible, i.e. to pursue additional measures reducing emissions from other plants than the one concerned. This possibility would have offered greater economic efficiency, however, it was never carried out, as it turned out to be too complicated. Instead, the plants concerned by technical directive for air 1986 were forced to apply the BAT[65].

It can be concluded at this point, that partly administrative efficiency was increased at the expense of environmental effectiveness and economic efficiency.

With the BImSchG 1974 requirements with respect to 'Immissionsschutz' became valid for all possible sources of emissions. Not only industrial plants had to meet demands but also the administration and private persons. This improved the plant operators' willingness to cooperate with leagal requirements (Jahresbericht 1975). With the BImSchG 1974 the State Trade Supervisory Offices took over responsibility for all possible sources of emissions, while they had previously only been responsible for industrial plants. This improved the authorities' overview of the complete requirements of 'Immissionsschutz'.

With respect to control of emissions, practicability and efficiency have been considerably increased over the last three decades. During the early 60s a regular control of air quality was not possible, due to a shortage of personnel within the supervisory offices. Involvement was mainly restricted to complaints from local residents (Nachbarschaftsbeschwerden) and posed severe problems with respect to proving non-compliance with standards (Jahresbericht 1964; Jahresbericht 1971). In later years registers of assessment for emissions were developed, covering all sources of emissions[66]. The data collected on industrial emission sources relied mostly on data

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[64] While compensating activities have been possible with respect to the authorization of new plants already since TA Luft 1964, compensation models for the refitting of existing plants were first mentioned in TA Luft 1986.

[65] Interview with Mr. Krüner, Umweltamt Hagen.

[66] Industry, traffic, households and small entreprises.

provided by the entreprises and in few cases on direct measurements (Jahresbericht 1996). In order to improve the supervisory offices' possibilties of controlling compliance with standards for individual plants, telemetric monitoring systems were developed and applied with public financial support. Side-effects of these measures were improved possibilties for self-control of emissions by the entreprises and, consequently, an increased willingness of the operators to invest in clean air measures. Furthermore, information on more and less favourable modes of operation of specific plants became obvious which allowed appropriate improvements. Finally, monitoring systems allow the control of installed filter technologies and therefore make timely repairs feasible (Jahresbericht 1971).

5.3. Assessment of Key-Elements of Clean Air Policies

A variety of factors were relevant to the reduction of heavy metal and dust emissions related to the iron and steel industry, as well as to other industrial sectors, in NRW. These include the development of a legal framework, sectoral amelioration programmes, regional planning, the establishment of institutions, cooperative means of standard setting and implementation as well as federal and state financial support. Further factors of influence can be seen in exogenous technological development and in entreprises' economic motivations. The interplay of all these factors seems to have been important in the considerable improvements of air quality achieved in NRW since the mid sixties.

Early Moves at the Regional Level

The state government of NRW has imposed clean air policies since the early 60s based on the federal 'Clean Air Law' of 1960 (Jahresbericht 1967). For the implementation of clean air legislation the government relied on existing administrations, the State Trade Supervisory Offices, which had previously been responsible for overseeing technical installations in industry in order to prevent accidents. Owing to severe environmental problems, related to its high density of heavy industry especially in the Ruhr Area, NRW took a lead in clean air policies during the early 60s with the adoption of its LImSchG in 1962. This law was designed to reduce pollution from plants not covered by the industrial code - i.e. the federal law determining standards for plants subject to authorization - requiring the application of BAT. Furthermore, this law allowed the imposition of stricter standards on plants situated in areas of particularly high pollution (LImSchG 1964). As a side-effect complaints from local residents about air pollution increased drastically after the adoption of the LImSchG: According to official statistics almost 18,400 orders and agreements aimed at the reduction of air pollution were issued in 1963 (Jahresbericht 1963). In the following years this number increased even further.

With the LIB - now called LIS - a special authority, responsible for measuring and monitoring of air pollution, especially of emissions and depositions, was founded in 1963. Further tasks of this institution were amongst others the investigation of possible effects of emissions, an evaluation of technologies for pollution control and the setting of standards. It also provided training for the administration. Within 5 years of its establishment, the institution had built up a network of measuring and monitoring stations for air pollution, covering the whole region (Petzold 1996).

NRW was also the first federal state to set up registers of assessment for emissions and to develop clean air plans. Registers of assessment for emissions in NRW were set up even before they were required by BImSchG 1974 (Institut für Stadtforschung 1980; Jahresbericht 1974). Northrhine-Westfalian experiences considerably influenced the BImSchG 1974, above all the state played an important role in the development of more regionally oriented concepts, such as the clean air plans (Institut für Stadtforschung 1980; RISP 1982).

Background of Refitting Measures

Characteristic of the clean air policies is the interlacing of federal and state law, federal and state promotion programmes, as well as of sectoral and regional oriented measure programmes at the state level. With the BImSchG and the technical directives for air federal law sets requirements and standards, closely linked to BAT as defined in the VDI-guide-lines, for plants subject to authorization. At the state level these laws were supplemented first - during the 60s - by sectoral amelioration programmes, since the mid 70s they are complemented by the more regionally oriented clean air planning.

Both investigate amongst other things emission sources and specify measures to be taken by individual industrial plants.

Investment in clean air measures was heavily subsidized (see chapter 4.4.). Between 1959 and 1990 depreciation allowances were granted for end-of-pipe measures in existing plants. Financial support from federal budget was granted a) for pilot projects within the 'Investment Programme Aimed at the Reduction of Pollution' and b) within the 'Economic Policy Programme of the Federation'. Further financial support was available from the European Recovery Programme. Since the early 60s financial support from the NRW budget was paid within the IFP, granting credits and soft loans, as well as in the APR. The latter granted financial support only for the years 1980 to 1986. The promotion programmes set up by NRW were primarily designed to implement measures which otherwise would have failed under the 'economically reasonable criterion'. In order to speed up the accomplishment of the technical directive for air 1986, NRW furthermore granted soft loans for refitting measures which were started before the lapse of time set by this law.

Cooperative Means

Cooperative institutions were set up on various institutional levels. On the governmental level the state government of NRW set up an 'interministerial committee for environmental protection' (Interministerieller Ausschuß für Umweltschutz) in 1971. This consisted of representatives of all ministries relevant to pollution control, such as the ministries for health, agriculture, inner affairs, economy and traffic. It was seen as a basis for cooperation between, and for coordination of, all relevant departments. It pursued various tasks, including the evaluation of laws with respect to their relevance to pollution, the development of the first Northrhine-Westfalian environmental report and the development of regulations for soil protection (Jahresbericht 1972; Jahresbericht 1984; Jahresbericht 1982).

In 1972 the Northrhine-Westfalian ministry responsible for the environment required the State Trade Supervisory Offices to set up 'environmental protection working groups' (Arbeitskreise Umweltschutz). This was designed to promote the exchange of information within the administration on regional and town level. In special cases representatives from industrial associations and other state authorities were to be taken into consultation. Amongst other topics this institution was concerned with questions of regional planning (Bauleitplanung) (Jahresbericht 1972; Jahresbericht 1975; Jahresbericht 1984).

In 1962 the NRW state government had already established a council on pollution control (Landesbeirat für Immissionsschutz) designed to promote the exchange of information between the administration, polluters and groups from society affected by pollution (Arbeits- und Sozialminister NRW 1969).

Various cooperative approaches exist between authorities and industry (see chapter 4.5.). In order to promote the exchange of information between the state offices and the industry, from 1975 on the BImSchG required the institution of a representative for 'Immissionsschutz' within entreprises subject to authorization. Further cooperative means can be found with respect to standard setting and implementation. Standards are set in cooperation between the government and private standard setting associations (see chapter 4.5.). This ensures an inclusion of different interests, as well as of expert knowledge in decisions on standards. The transformation of legally set emission and deposition standards into specific measures to be taken by the entreprises is also pursued in cooperation between the State Offices and the industry. The choice between various measures which meet the BAT criteria is left to the plant operators. For the accomplishment of clean air plans possible measures were also discussed between the industry and the State Offices.

Promotion Programmes

Financial support for investment in pollution control has been granted since the early 60s. Over time, subsidies have increasingly been applied to influence the direction of technological change by promoting the development and pilot application of environmental technologies (Blazejczak 1997). The 'Investment Programme Aimed at the Reduction of Pollution' was set up in 1979. By 1986 it supported 180 projects amounting to a total investment of DM 1,16 billion within the metal producing industries.

With respect to the Northrhine-Westfalian iron and steel industry about DM 205 million were granted within the APR for secondary dedusting, representing an expenditure of about DM 703 million. Further financial support was available from the IFP, the European Recovery Programme and from the NRW and federal 'Economic Policy Programmes'. Data on financial support from these programmes on the level of individual sectors was not available. Between 1977 and 1984, however, financial support from the NRW budget granted for 'Immissionsschutz' measures within the steel industry amounted to credits of DM 2.4 million and grants of DM 37 million, representing total expenditure of DM 581 million.

Depreciation allowances of about DM 650 million were granted to the NRW iron and steel industry between 1965 and 1980 and of about DM 1050 million to the metal producing and manufacturing industries between 1981 and 1990[67].

Different authors come to the conclusion that with the APR and the IFP various projects were carried out that would have otherwise failed because of the 'economically reasonable criterion' (RISP 1984; MAGS 1985; MURL 1987). Furthermore, the promotion supported a fast accomplishment of standards and measures, as set for example in clean air plans (Jahresbericht 1978). In this respect the promotion of projects contributed to the reduction of air pollution in NRW. The financial support granted for the accomplishment of technical directive for air 1986 led, in the first place, to a faster implementation of the required standards and increased the entreprises' willingness to cooperate. However several problems are, in general, connected to subsidies. 'Mitnahmeeffekte' (i.e. entreprises not really in need managing to be supported) cannot be completely eliminated. It is, therefore, not guaranteed that the 'economically reasonable criterion' was not met by all projects supported. Furthermore, subsidizing of primarily end-of-pipe technology leads to medial shifts in environmental problems

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[67] It should be noted, that the statistical basis of data on depreciation allowances published by the State Trade Supervisory Offices is not clear. Double counting may be involved.

(Institut für Stadtforschung 1980). For general schemes, such as depreciation allowances, there is no control of efficiency. If granted, as pursued in Germany, for end-of-pipe technologies only, more efficient integrated solutions are even discouraged (Blazejczak 1997).

In contrast to the APR and IFP, the 'Investment Programme Aimed at the Reduction of Pollution' rather - and increasingly over time - supported integrated technologies, putting an emphasis on the re-use of heat and waste in recent years. Furthermore, the development of legal framework such as, for example, the technical directives for air and the ordinance for large combustion plants, were influenced by the results of this programme (Horbach et al. 1995; Angrick 1993). It also contributed to the development of BAT and the application of promoted technologies contributed to the reduction of dust, SO_2 and NO_x emissions (Horbach et al. 1995).

Command and Control Type Policy - Was the Approach Efficient?

Clean air policy in NRW and also Germany as a whole, has so far relied almost exclusively upon a command and control type policy. This, together with financial support schemes, has led to an effective reduction of emissions within a rather short period of time. The problem of insufficient dynamic incentives caused by standards basing on BAT was partially alleviated by promotion programmes supporting progress of technologies (Blazejczak 1997). It has to be also noted, that emissions from the iron and steel industry were frequently reduced to values below the standards set by technical directive for air.

The formulation of standards was neither based on a sound procedure starting from a well founded notion of environmental quality nor solely on the criterion of technological feasibility. Standards were rather based on a balance of expected emission or deposition reductions against the costs involved[68]. Whether efficiency was increased by taking into account information provided by entreprises, is open to question.

[68] Interview with Mr. Kochskämper, Umweltamt Duisburg.

Additional programmes on state level, such as sectoral amelioration programmes and clean air plans, however, supplemented the standard oriented federal clean air policy. The latter, in particular, took into account the problem of stocks and flows by focussing on depositions, tracing them back to their sources and imposing specific measures.

6. Conclusions

The development of airborne heavy metal emissions related to the iron and steel industry has been influenced by both, intersectoral and intrasectoral changes. While intersectoral change was responsible for the increase in emissions up to the end 60s, intrasectoral changes were of major importance for the reduction in emissions since the early 70s.

For the increase in emissions the development of the iron and steel industry after the Second World War is important. Owing to developments in demand, and supported by the state, iron and steel production increased strongly during the 60s and up to the early 70s. With the world wide depression during the mid 70s the sector went into structural crisis. Since then the market is characterized by an enduring weakness in demand and distortions of competition due to subsidies.

Several factors supported the technological development within the iron and steel industry which contributed to the reduction in dust and heavy metal emissions. These include economic motivations, exogenous technological change, legal requirements and promotion programmes. Especially for the latter two the interlacing between federal and state law, sectoral and regionally oriented planning, as well as various promotion programmes at federal and state level is important.

Intrasectoral Change

With reference to the classification of determinants of intrasectoral change (see chapter 1.2.), process related technological changes, a substitution of inputs, as well as improvements in end-of-pipe technologies contributed to the reduction in emissions. The following technological developments are important for the decrease in emissions since the early 70s:

a) non-dedusted Thomas and Siemens-Martin converters were replaced by dedusted top blowing converters and electric arc furnaces
b) remaining Siemens-Martin furnaces were, additionally, dedusted,
c) plants were enlarged, thus the number of aggregates was reduced and emissions were concentrated,
d) blast furnaces have become widely sealed units,
e) facilities to reduce dust emissions were installed in further production steps,
f) since the mid-seventies increasing effort was put on reducing secondary and tertiary source emissions,
g) off-gas cleaning and dust arresting technologies were improved,
h) inputs, such as coke, were reduced with improving technologies,
i) increasing amounts of waste, water and energy are recycled.

Driving Forces Behind Intrasectoral Change

While developments given under c) and d) are, in the first place, due to economic interests of the enterprises or to technological requirements, the developments stated under a), h) and i) represent a mixture of exogenously induced technological developments, economic interests and concerns about pollution control. The conversion of steel converters was in particular supported by the NRW state government's amelioration programme. The remaining developments, given under b), e), f) and g), were induced by clean air policies.

a) Legislative

The interlacing of federal and state law, as well as of state planning is characteristic of the clean air policies. With the BImSchG and the technical directives for air federal law sets requirements and pollution standards closely linked to BAT. With the technical directive for air 1974 and its amendments the dedusting of increasingly more facilities, including the remaining Siemens-Martin plants, was enforced. Over time, growing concern was placed on heavy metal emissions and on dedusting of secondary and tertiary emission sources.

At the state level these laws were supplemented by a) sectoral amelioration programmes during the 60s and b) regionally oriented clean air plans since the mid 70s. Both investigated emission sources and set up additional measures to be taken by specific entreprises, aimed at improving the environmental situation. The clean air plans in particular take into account the problem of stocks and flows by focussing on depositions and tracing them back to their sources. This is of particular importance, as deposition standards in several regions of NRW were exceeded, despite most industrial sources meeting the set emission standards.

b) Promotion Programmes

Technological development with respect to pollution control (cleaner technologies and improved end-of-pipe technologies) was supported by promotion funds granted by the UBA on behalf of the German Ministries for the Environment and for Inner Affairs. Soft loans, investment grants and loans were granted for pilot research projects. For the refitting of existing plants further financial support for projects aimed at the reduction of emissions was granted by the APR and the IFP on state level, as well as by depreciation allowances. These programmes primarily supported end-of-pipe technologies. The APR, as well as the IFP were in the first place designed to support measures for which there would have otherwise been no legal basis, as measures required for existing plants have to be economically reasonable. The APR in particular supported the realization of measures recommended by the clean air plans. Further promotion programmes were the 'Economic Policy Programmes' of the federal and of the NRW state governments and the European Recovery Programme. Aimed at a rapid realization of technical directive for air 1986, NRW supported refitting measures which were begun before the time specified by law.

It can be concluded that the promotion of clean air measures contributed to the reduction of emissions in NRW. It contributed to a rapid accomplishment of standards and facilitated the realization of projects that would have otherwise failed because they were not economically reasonable. Problems can be seen in the tendency to support end-of-pipe technologies, discouraging more efficient integrated solutions. Furthermore, especially in the case of general schemes such as depreciation allowances, there is no control of efficiency. The only exception is the 'Investment Programme Aimed at the Reduction of Pollution', supporting integrated technologies and contributing to the development of BAT.

c) Cooperative Means

Several cooperative means are to be found ensuring that various interests and expert knowledge are taken into account with respect to standard setting, increasing the entreprises' willingness to contribute to clean air measures and allowing for flexibility.

At the NRW administrative level various cooperative institutions were set up, designed to promote an exchange of information within the administration and to allow for cooperation within the relevant departments. Further cooperative institutions were set up in order to promote the exchange of information between the administration, polluters and groups in society affected by pollution. In Germany, standards required by law are set in cooperation between the state and private (industrial) standard setting associations. The implementation of standards set by law, as well as of specific measures such as, for example, required by clean air plans, is pursued in cooperation between plant operators and state authorities. The latter in particular allows for improving efficiency of the command and control type oriented clean air policy, leaving the choice of measures, to a large extent, up to the operators.

d) Entreprise Policies

Even before the clean air legislation was set up, gas cleaning technologies were installed within the iron and steel industry, focussing on process off-gases from chimneys. From 1964 primary dedusting facilities were installed in various plants. The dedusting of primary sources had already been largely completed by the mid 70s. Since then the aim has been to fulfill the respective standards set by technical directive for air with respect to collection and dedusting of secondary emission sources.

In order to reduce costs, the steel industry has taken significant measures to reduce energy consumption. Energy consumption was reduced by means of process optimization, process changes and recycling. Recycling was also important for the reduction of water input and residues. Residues were further reduced with the introduction of new processes such as the continuous casting process.

Outlook

The significant reduction of dust and heavy metal emissions in NRW can be explained by various determinants. Characteristics of NRW are its early moves, as shown by the state taking lead in clean air policies during the early 60s. In 1962 the state implemented its LImSchG and in 1963 it set up a special authority (LIB/LIS) responsible for measuring and monitoring of air pollution, for the investigation of possible effects of emissions and for the evaluation of technologies for pollution control. Particularly the early establishment of a complete network of measuring and monitoring stations served as a basis for effective clean air measures and pollution control.

The early replenishment of federal law by sectorally and regionally oriented planning also contributed to the success in improving air quality. Furthermore, NRW's early experiences influenced the development of federal law as, for example, the development of the concept of clean air plans required by BImSchG 1974 for highly polluted areas. The various promotion programmes are important for the rapid realization of clean air standards.

Partly the reduction of emissions was brought about by exogenous technological developments. This holds particularly true for the conversion of crude steel production processes since the early 60s, contributing to economic and environmental improvements. Further measures allowing for policy integration, i.e. exploiting opportunities for achieving environmental and economic objectives simultaneously, were important in the first place with respect to energy and water saving, as well as to waste reducing policies. These were initially brought about by the entreprises' wish to reduce costs. Furthermore clean air policies, especially since the amendment of the technical directive for air in 1986, put increasing emphasis on recycling.

Whereas primary dedusting seems to have been highly efficient, the efficiency of secondary dedusting is less clear: While some authors argue that secondary dedusting is not justified when taking into account the low effects in relation to the high costs and energy consumption involved, others point out at the importance of secondary dedusting. According to them still considerable amounts of dust are collected, serving environmental and health protection at the same time. Emphasis is also put on the fact that substances with high toxic effects are collected.

The efficiency of policy instruments, however, could be improved if the command and control type policy would be complemented by economic instruments and, thus, increase dynamic incentives. Furthermore, standards should be based on a sound procedure starting from a well founded notion of environmental quality. Specific standards for individual plants, instead of general schemes, would increase ecological as well as economic efficiency, but complicate the administrative practicability.

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