50 years of air quality control in Northwestern Germany – how the blue skies over the Ruhr district were achieved

Part I

Dedicated to Dr. Manfred Buck on occasion of his 85th birthday

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Abstract The history of air quality control in the Rhine-Ruhr conurbation is discussed, starting with the foundations of a modern clean air legislation around 1960 on the federal and the state level. The aim of this series of three articles is to give a comprehensive picture from a technical point of view, bringing together the development of the legislation, the abatement measures based on this legislation and their impact on emissions and on air quality. Part I in hand covers the period from 1960 to 1975, the upcoming parts II and III will discuss the periods from 1975 to 2000 and from 2000 up to present, respectively. Each of these periods can be characterized by changes of the focus or the strategy of air pollution control. The first period described here concentrated on the systematic reduction of dust emissions from important industrial branches and on the control of small combustion facilities. Dust fall, emissions and concentrations of suspended particulates could be reduced significantly, whereas the emissions of sulfur dioxide were still slightly on the rise.

50 Jahre Luftreinhaltung in Nordwest-Deutschland – wie der blaue Himmel über der Ruhr zurückgewonnen wurde – Teil I

Zusammenfassung Die Geschichte der Luftreinhaltung im Rhein-Ruhr-Gebiet wird erläutert, beginnend mit der Schaffung der Grundlagen einer modernen Gesetzgebung zur Reinhaltung der Luft um 1960 sowohl auf Bundes- als auch auf Länderebene. Ziel dieser Serie von insgesamt drei Beiträgen ist es, vom technischen Standpunkt aus ein möglichst umfassendes Bild zu zeichnen, indem sowohl die Gesetzgebung, die sich darauf abstützenden Minderungsmaßnahmen als auch ihre Auswirkungen auf die Emissionen und Immissionen dargestellt werden. Der vorliegende Teil I betrachtet den Zeitraum von 1960 bis 1975, die folgenden Teile II und III werden die Zeiträume von 1975 bis 2000 und von 2000 bis heute zum Gegenstand haben. Jede dieser Perioden zeichnet sich durch einen geänderten Fokus oder eine andere Strategie der Luftreinhaltung aus. Die erste Periode konzentrierte sich auf die systematische Verminderung der Staubemissionen wichtiger Industriezweige und auf die Kontrolle von Kleinfeuerungen. Die Belastung durch Staubniederschlag, die Emissionen und die Immissionen an luftgetragenen Stäuben konnten deutlich vermindert werden, während die Emissionen von Schwefeldioxid weiter leicht anstiegen.

1 Introduction

When the later German chancellor *Willi Brandt* introduced air quality control as a political requirement with his famous vision of the „blue skies over the Ruhr district“ on April 28, 1961 in the course of a federal election campaign [1], the widespread reaction was disbelief or even sarcasm, taking into account a dust deposition up to 2 mg/(m²day) in parts of the Ruhr area [2]. A lively picture of the deplorable conditions at that time was presented by the magazin “Der Spiegel” in its issue from August 1961 [2]. Pollution levels were so high that it could be sensed by every citizen without any monitoring devices. Today, the vision of the “blue skies over the Ruhr district” has become true. Willi Brandt’s speech had touched an urgent political need. Already several years before, far-seeing parts of the administration on the federal and state levels had started to lay the foundations of a modern legislation for clean air (see section 2.2). Cleaning up the Ruhr district has turned out to be a tremendous success story.

Several authors [3; 4] have presented this success story from a political perspective or focussed on special aspects such as the development of an important environmental agency [5], the development of the environmental legislation [6] or trends of air quality [7; 8]. What is missing is a description of the development from a comprehensive technical point of view, discussing trends of emissions and air quality together with the development of environmental legislation on the federal and on the state level and the key abatement actions which finally brought pollution levels down.

In the following, we try to present such a comprehensive picture of air quality control during the last 50 years in order to make it understandable by which means the success could be achieved. Our paper is also intended to bring a wealth of data mostly buried in the “grey literature” to the awareness of a greater audience. The amount of material made it necessary to cut the whole story into three parts, presenting periods from 1960 to 1975, from 1975 to 2000 and from 2000 to present, which can be characterized by changes in strategy or new concepts of air pollution control.

2 Setting the legal basis and reducing dust levels (1960 to 1975)

2.1 The starting point: the severe pollution in the sixties

Taking current benchmarks, the air quality at the beginning of the sixties of the preceding century when systematic monitoring of sulfur dioxide (SO_2) [9], suspended particulate matter (TSP) [10] and dust deposition [11] started in the Rhine-Ruhr area was deplorable. **Figure 1** shows the average diurnal cycle of SO_2 measured in Duisburg from March 1961 to March 1962 [12] in comparison to a current diurnal cycle measured 2012 in the same area. Daily means around or above 200 µg/m³ were normal, and the annual average in the Western part of the Ruhr district amounted to 240 µg/m³ [11]. This is more than one magnitude higher than today.

Also the dust deposition in the densely industrialized parts of the Ruhr area was extremely high [13]. Up to 4 g dust per day (current limit value: 0.35 g/(m²d)) sedimented on one

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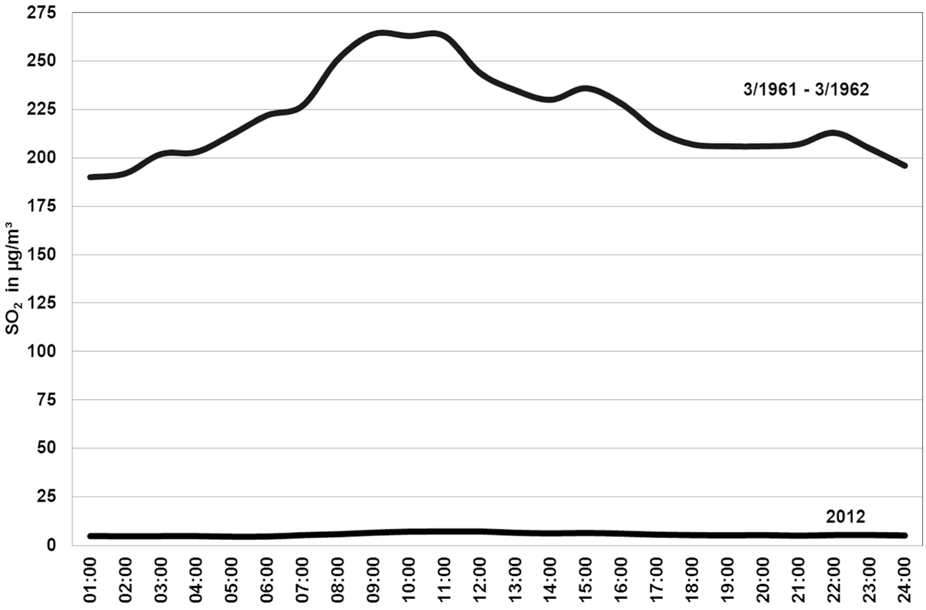

Figure 1. Averaged diurnal cycle of SO_2 in Duisburg in the years 1961/62 [12] compared with a current diurnal cycle from 2012 in the same area.

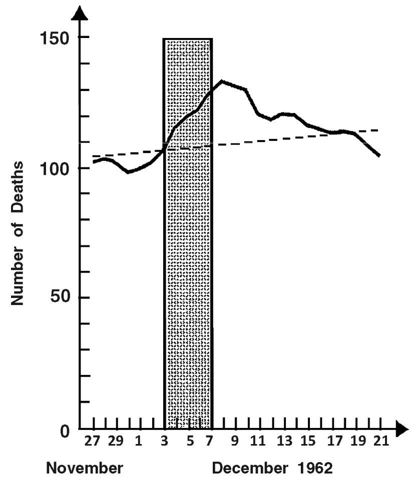

Figure 2. Number of deaths (sliding average over seven days) during the smog episode in the Ruhr area in December 1962 [14]. The grey column marks the duration of the smog period.

square meter in Duisburg in 1964/65, and the total amount of dust falling on the Ruhr area was estimated to 312,000 t per year [13].

The bad air quality reached its climax during a severe smog episode from December, 3rd to December, 7th 1962. Daily sulfur dioxide means peaked at 5,000 µg/m³ at Bochum on December 6th and TSP daily means reached 2,400 µg/m³ on December 5th [14]. These levels are comparable or even worse than the concentrations measured during recent smog episodes in Beijing, China [15]. In January 2013, $PM_{2.5}$ readings peaked at 755 µg/m³ by January 1 and 800 µg/m³ by January 12, according to data published by the US Embassy [15]. Official Chinese data showed readings up to 700 µg/m³ at individual recording stations [15]. Assuming a ratio of 0.5 between $PM_{2.5}$ and TSP concentrations, PM peak levels measured in Beijing would correspond with 1,400 to 1,600 µg/m³ TSP.

An evaluation of the smog episode performed in 1966 by *Steiger* and *Brockhaus* [14] revealed that mortality rose by 30% in the Ruhr district (**Figure 2**). Detrimental effects on human health by excessive air pollution could no longer be denied. This smog episode certainly gave further strong impetus to put air quality on the political agenda.

Also negative impacts on the vegetation were common. Already in 1956 experimental investigations at plants and forests in Biersdorf [16] had demonstrated that sulfur dioxide levels above 500 µg/m³ (averaged over the vegetation period) were noxious.

The pollution was mainly caused by the heavy industry, the Ruhr district being Germany's heart of steel and energy production, based on coal. According to [2], 82 blast furnaces, 56 Thomas-steel converters and 93 power plants burning coal were operating, mostly without dust filters, let alone flue gas cleaning. In addition, domestic heating was predominantly based on single coal burning stoves. Action to clean up the air was urgently needed.

2.2 Creating the legal instruments

Even before 1960, forrunners of air quality legislation existed such as the "Prussian Technical Instruction" from May 15, 1895 [17] which was updated several times. The "Technical Instruction" contained prescriptions for the authorization of industrial facilities according to Art. 16 and Art. 24 of the Prussian "trade regulations", which were amended in 1959 [18] to strengthen the legal instruments for air pollution control at industrial facilities. As authorization requirements, regulations to control certain emissions could be prescribed, and even orders to update facilities could be issued under certain conditions. This amendment can be regarded as the starting point of a modern legislation on clean air [6].

As air pollution control gained political momentum in the beginning of the sixties, the first "Act on Air Pollution Control, Noise and Vibration Abatement" [19] of the German state North Rhine-Westphalia from April 1962 was a big step forward. Article 2 – a general requirement to protect the neighbourhood and the general public against dangers or nuisances caused by air pollution – resembles already the general requirement of Art. 1 of the existing "Federal Immission protection law" [...] from 2013 [20]. This law also gave a legal basis for systematic air pollution monitoring (compare section 2.5).

However, the scope of this early law was limited to smaller facilities and small combustion units which were not covered by the Prussian "trade regulations". Detailed prescriptions for air quality control of certain types of facilities were contained in nine ordinances to the state law [19], for example in the 3rd ordinance on small combustion units burning oil or the 8th ordinance on small combustion units with solid fuels from 1970 [21; 22].

Triggered by the severe smog episode from December 1962 [14], the first smog ordinance was issued by the state of North Rhine-Westphalia in December 1964 [23]. In relation to current benchmarks, the alert criteria were very high, but were lowered by several revisions, particularly in 1974 [24] and 1985 [25]. **Table 1** gives an overview of the alert criteria, measures to be taken and their development over time. Due to the high alert criteria, the first smog alert was not issued before January 1979 [26]. The factual importance of the smog ordinances were thus limited, but they certainly helped to raise public awareness for air quality.

Table 1. Alert criteria (SO_2, µg/m³) and measures of the smog ordinances from 1965 to 1985. *VOC: volatile organic compounds*

Ordinance, year	Prealert	Alert 1	Alert 2
Criteria (1965)	1,000 (1 h)	2,500 (1 h) at several stations	5,000 (1 h) at several stations
Measures (1965)	–	Prepare for alert stage 2	Fuels with low S-content, traffic restrictions during rush hours
Criteria (1974)	800 (3 h) at more than half of the stations	1,600 (3 h) at more than half of the stations	2,400 (3 h) at more than half of the stations
(Additional criteria for CO, NO_2, VOC; for TSP since 1981 [27])			
Measures (1974)	Public information	Traffic reductions in rush hours in certain areas Fuels with low S-content	Traffic ban, fuels with low S-content Limited restrictions for certain facilities
Criteria (1985)	600 (3 h)	1,200 (3 h)	1,800 (3 h)
(Additional criteria for NO_2, CO and an index from TSP and SO_2)			
Measures (1985)	Public information	Traffic restrictions in rush hours in certain areas Fuels with low S-content	General traffic ban, fuels with low S-content Total shut down of certain facilities or reduction of production

Table 2. General emission standards for dust (TSP, mg/m³) from 1964 to 2002.

Instruction	TSP (general)
1964 [28]	150 (for installations emitting > 100 x 10³ m³/h)
1974 [29]	150 (for installations emitting > 70 x 10³ m³/h)
1986 [31]	150 (for installations emitting up to 0.5 kg/h)
	50 (for installations emitting > 0.5 kg/h)
2002 [32]	20 (for installations emitting > 0.2 kg/h)

On the federal level, the first "Technical instructions on air quality control" [28] was issued in September 1964. This "Technical instruction" – which was updated several times in 1974 [29], 1983 [30], 1986 [31] and 2002 [32] – gave detailed prescriptions for the authorization or the update of industrial facilities, flue gas cleaning, standards for air quality and the monitoring of air quality [28]. The **Tables 2** and **3** give examples for the development of emission standards (TSP) and air quality criteria from 1964 to 2002. This first instruction from 1964 already introduced the concept of "best available techniques" (Stand der Technik) which had to be applied to control the emissions. The "best available techniques" were expressed for most installations in terms of an emission limit of 150 mg/m³ for dust (1964). This general TSP limit remained in force for more than 20 years and was not lowered significantly before 1986. For certain types of facilities with high emission fluxes such as blast furnaces an ambituous emission limit of 20 mg/m³ was already in force in 1964 [28]. The guidelines of the German federation of engineers (VDI) [33] played a decisive role by the definition and the upgrading of the "best available techniques".

The general tightening of the ambient air quality standards over time is presented in **Table 3**. The lowering reflects not only the better practicability of lower standards with decreasing pollution levels (compare section 2.4), but also a growing sensitivity of the research on the impact of air pollutants. A standard for fine particles (PM_{10}) already existed in 1974 with a ratio of 0.5 to total suspended particulates (TSP).

A Federal Immission Control Act (on Air Pollution Control and Abatement of Noise and Vibrations) [34] could not be established before 1974, because the constitution governing the balance between the Federal level and the German states had to be changed first (in 1972, [35]). The Federal Immission Control Act [34] enabled the government to establish ordinances such as the 1st ordinance on small combustion units [36], which replaced the corresponding and preceding ordinances of the German states in 1974.

2.3 Abatement measures

Parallel to air quality control becoming a political issue in 1961, it also gained more importance in the administration. For the first time, air quality control or the protection of the neighbourhood against air pollutants based on Art. 16 of the amended Prussian trade regulations [18] got a special section in the report of the factory inspectorates [37] from 1961.

At that time, the techniques to remove dust from the flue gases such as electric or mechanical precipitators were already available. However, many industrial facilities such as cupola furnaces or Thomas converters were operated without any dust filters. In 1960, only 1 of the 54 Thomas converters operating met an emission value of 150 mg/m³, three others emitted less than 2,000 mg/m³. Consequently, the visible brown smoke arising from these converters was a big issue.

The first systematic programs to abate air pollution thus concentrated on eight branches: Thomas converters, potteries, cement works, power plants, sintering facilities, cupola furnaces, cokeries and briquette production. Aim of the program was to meet an emission standard of 150 mg/m³ TSP of the upcoming first "technical instruction" [28] as far as possible. The report of the factory inspectorates from 1967 [38] gives a nice overview of the successes of these first systematic improvement programs. For example, only 27 of the 47 cement rotary kilns were equipped with electric precipitors in 1962, and 100 operating shaft furnaces had no dust filters at all. In 1968, all of the 54 operating cement rotary kilns had

Table 3. Ambient air quality standards in the technical instructions from 1964 to 2002*).

Instruction	Dustfall in g/m²d (annual mean)	TSP/PM_{10} in µg/m³ (annual mean)	NO_2 in µg/m³	SO_2 in µg/m³
1964 [28]	0.42 0.85 (industrialized conurbations)	–	1,000 (1/2 h)	400 (1/2 h)
1974 [29]	0.35	100 (PM_{10}) 200 (TSP)	100 (annual mean) 300 (95%)	140 (annual mean) 400 (95%)
1983/1986 [31]	0.35	150 (TSP)	80 (annual mean) 200 (98%)	140 (annual mean) 400 (98%)
2002 [32]	0.35	40 (PM_{10})	40 (annual mean) 200 (1 h)	50 (annual mean) 350 (1 h)

* Please note: Due to different monitoring requirements (area versus point) and different definitions of the standards for the short term (e.g. percentiles) not directly comparable

Table 4. Emissions (in 10^6 tons per year) for Western Germany before the reunification.

Year	SO_2	TSP	NO_x (as NO_2)	Ref.
1960	3.1		about 1.3	[45; 47]
1962	3.9	2		[43]
1965	about 4 a)	2.57	about 1.3	[48; 49]
1966		1.8	2	[50]
1967	3.7 a)			[48]
1970	3.6	1.57	2	[45; 47 to 49]
1973	4.2 a)	1.17		[48; 49]
1980			2.7	[47]
1982	3.2	0.72	3	[50]

a) from combustion sources

electric precipitators. 45 shaft furnaces had been closed (structural change). From the remaining 55 facilities, 31 had satisfactory dust filters, and 15 further furnaces were upgraded in the years 1968 and 1969. The efforts to reduce the high dust emissions were also supported by new technical developments and the structural change, for example replacing the Thomas converters by oxygen converters or electric steel works with lower emissions.

All in all, the annual dust emissions from the iron and steel production in North Rhine-Westphalia could be reduced from 200,000 t (1965) to 50,000 t (1975) [39].

In contrast to the success in lowering the dust emissions, efforts to abate SO_2 emissions were limited and concentrated on the reduction of the sulfur content in fuels and materials, for example removing pyrite from ores as far as practicable. To protect the neighbourhood from very high SO_2 concentrations, high chimneys up to 200 m for several power plants and sintering facilities were constructed [37]. Flue gas desulfurization was not yet "state of the art", the first pilot facility operating in the chemical industry in 1962 [40]. Nevertheless, new power plants had to reserve sufficient space for the construction of a desulfurization unit at a later date since 1962 [40].

Other pollutants such as heavy metals or organic pollutants were not in the focus of the reduction programs, the reasons being the limited analytical methods to monitor those compounds, the missing emission limits and the state of the flue gas cleaning.

Another focus of air qualiy control in this pioneer period were programs to control and reduce the emissions of small combustion units [41]. Since 1966, all units burning oil (residential and industrial) were controlled annually. The soot content of the flue gas was estimated by the Bacharach method [42]. The number of exceedances of a soot index 3 in combination with oil derivates in the flue gases could be reduced from 60% (in 1964/65) to 10% in 1973/74 [41]. This success was supported by the 3rd ordinance (1965, [21]) to the state law on air pollution control [19], compare section 2.2.

Even more important was the control of small combustion units burning solid fuels, predominantly coal. In 1964, 81,5% of residential heating in Western Germany consisted of small ovens, 83% of them using solid fuels [43]. In 1962, 18% of total SO_2 emissions and 20% of total dust emissions in Western Germany (706 x 10^3 t SO_2 and 411 x 10^3 t dust per year, respectively) were caused by residential heating [44]. Fortunately, structural change helped a lot to improve the situation, gradually replacing coal ovens by central heating burning oil or gas. For example, sales for ovens with solid fuel fell from 1,500 x 10^3 in 1956 to 800 x 10^3 in 1962 [43], and the share of solid fuels in residential heating was reduced from 75% in 1960 to 27% in 1970 [45]. Again, the 1st ordinance (1963, [46]) and the 8th ordinance (1970, [22]) to the state law on air pollution control [19] formed the legal basis for the improvement of small combustion units burning fossil fuels. The visual inspection of the opacity of the plume according to the Ringelmann scale [46] was a simple means to control the soot and dust emissions.

2.4 Development of emissions

Emission data on the first decade of systematic air pollution control are sparse and sometimes uncertain. The magazine "Der Spiegel" [2] quotes annual emissions of 1.5 x 10^6 t dust and 4 x 10^6 t SO_2 for the Ruhr district in 1960 unfortunately without citation, but these figures seem somewhat high in comparison with other data (**Table 4**).

Emission data quoted from several authors for Western Germany (without the former GDR) are compiled in Table 4. Without going into details, it can be stated that

– TSP emissions decreased by about 60% from 1960 to 1980.
– SO_2 emissions were more or less constant between 3 and 4 x 10^6 tons per year with peak emissions around 1970.
– NO_x emissions increased strongly and were in the same range as the SO_2 emissions by 1982.

In North Rhine-Westphalia, TSP emissions decreased from 1.3 x 10^6 tons per year (1960) to 0.94 x 10^6 tons per year (1974) [49].
Several authors present data on the contribution of important source categories to total emissions.
Power plants and industrial sources emitted about 82% of total dust emissions in 1965 [49]. Residential small combustion units were second with 12.7%, whereas traffic caused only 4.8% of the TSP emissions [49].
According to *Bröker* [47], traffic (49.2%) and power plants (36.7%) had the lion's share of overall NO_x emissions in 1980, with the residential sector (4.7%) and industrial combustion units (9.4%) having minor amounts. The distinct increase of NO_x emissions from 1970 to 1980 is predominantly caused by traffic.
In [45], a detailed analysis of SO_2 emissions is presented for the years 1960 and 1970. In 1970, 76% of the emissions were due to large combustion plants and industrial installations. 20.4% of the emissions originated from residential heating, whereas the share due to traffic (3.5%) was rather small. Compared with 1960, the share of residential heating (24.9% in 1960) had diminished, whereas the emissions of large combustion plants were on the rise.

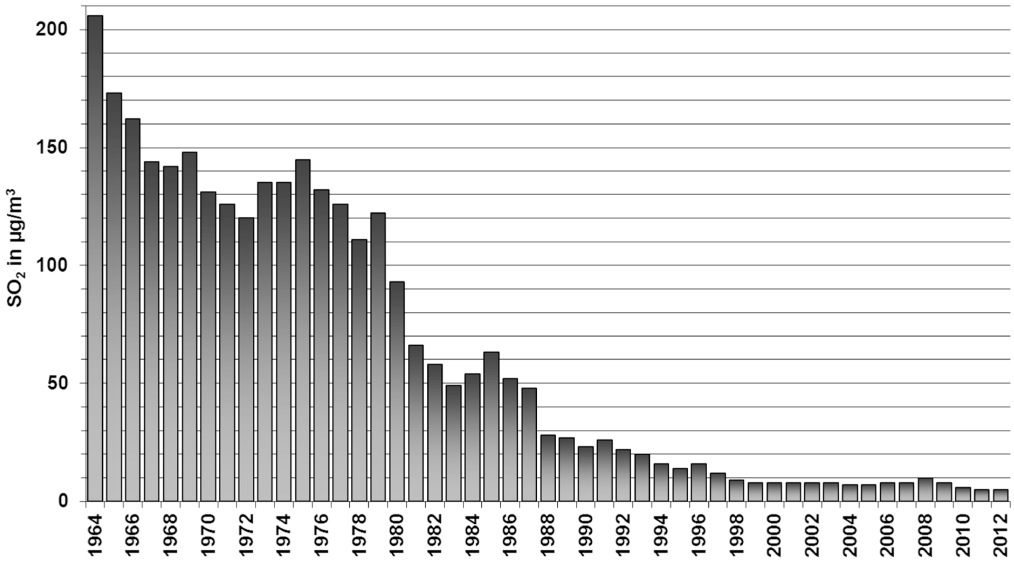

Figure 3. Trend of the average SO_2 burden in the Rhine-Ruhr area (annual means, µg/m³) [54].

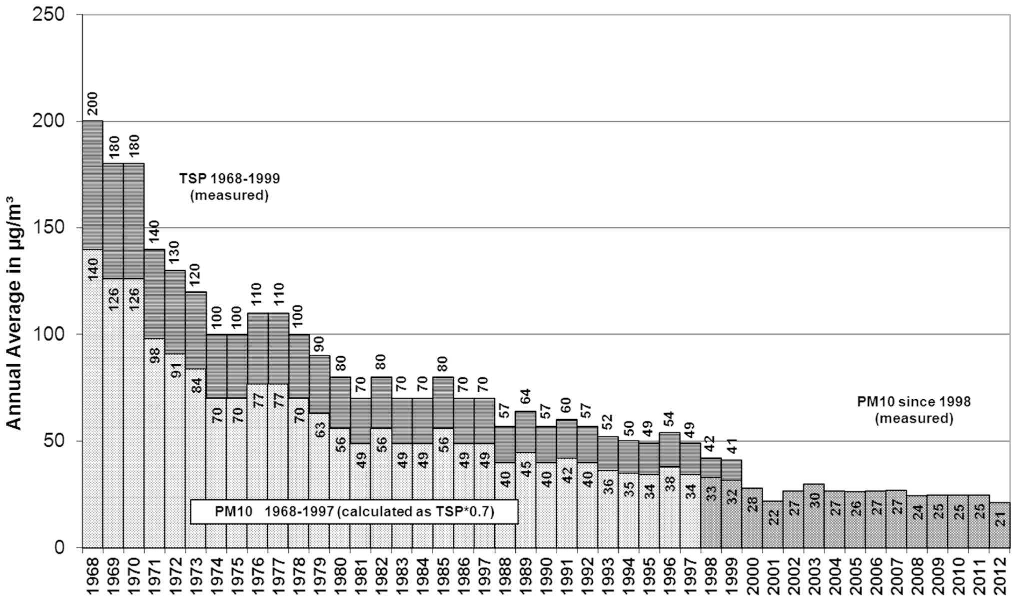

Figure 4. Trend of the average TSP and PM_{10} burden in the Rhine-Ruhr area (annual means, µg/m³). The PM_{10} concentrations before 1998 are estimated from the TSP to PM_{10} ratio, measured simultaneously in the years 1998 and 1999 [54].

The increase of overall SO_2 emissions from 1960 to 1970 by 16% is compared in [45] with the increase in the industrial production (74%) and with the increase in fuel consumption (61%). It can be stated that abatement measures – predominantly the use of fuels and raw materials with lower sulfur content – and structural changes have prevented a stronger increase in SO_2 emissions.

2.5 Trend of the air quality

As already mentioned in section 2.1, systematic monitoring of the air quality in the Ruhr district started at the beginning of the sixties of the last century. Based on Art. 7 of the state act on Air Pollution Control, Noise and Vibration [19], three monitoring programs were implemented. The first program measured dust fall at 2,715 sites, covering an area of 6,100 km², since October 1963 [13]. The second program starting in November 1964 comprised already continuous monitoring of SO_2, since 1968 also TSP, at eleven stations in the Ruhr district and one station in the conurbation Düsseldorf [10]. Continuous monitoring was necessary to implement the smog alert ordinance from 1965 [23]. A third program starting in November 1964 comprised discontinuous spot check measurements of SO_2 in a grid of 1 km² covering an area of 5,000 km² [9]. From 1970 onwards, also discontinuous TSP measurements were performed at 71 sites in the Rhine-Ruhr area [51] with high volume samplers, and further compounds such as fluoride, chloride and total organic carbon (TOC) were included in the spot check measurements [52].
First sporadic NO_2 spot check measurements started in 1965 in 15 circular areas in North Rhine-Westphalia [53], covering an area of 28 km² in each cycle, but these measurements were not pursued further.
It should be borne in mind that the monitoring strategy was aimed at collecting data which were representative for the average burden of an area. This strategy differs from current monitoring planning following an exposure oriented approach and aiming at measurements in different micro-

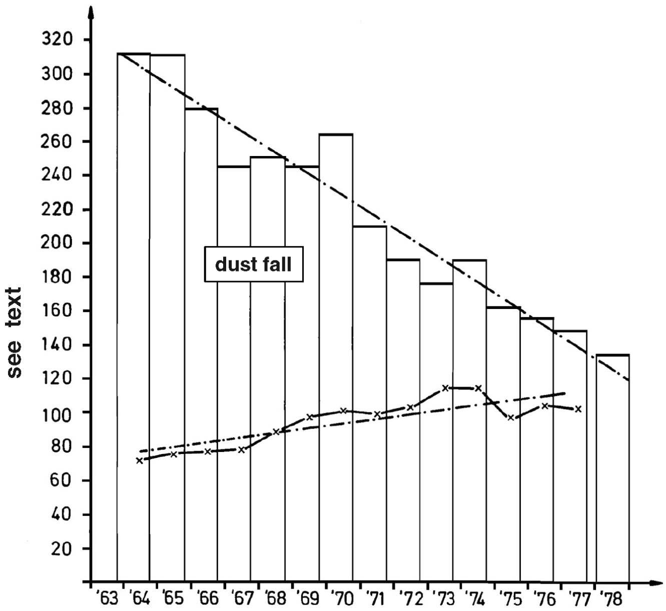

Figure 5. Trend of the average annual dust fall in the Ruhr area in 10^3 tons dust per year [55] compared to the index of the industrial production (1970 = 100) in the state of North Rhine-Westphalia.

environments, including hot-spots (see Part 3). For example, monitoring in street canyons was not an issue at that time.

The strategy gathering data representative for a whole area has the advantage that long time series can be studied even though the number and the locations of individual stations varied over time. **Figures 3** and **4** present such long time series for SO_2 and suspended particulates (TSP, later PM_{10}), representing the average burden in the Rhine-Ruhr conurbation (about 3,500 km² with about 6.5 Million inhabitants). In this part, only the period from the start of the measurements until 1975 will be discussed.

It can be seen from Figure 3 that there was a distinct decrease of average SO_2 levels in the first three years, with a stagnation afterwards. The decrease in the first years was not due to a decrease in overall emissions (compare section 2.4). It can be assumed that better dispersion conditions (higher chimneys), the control of small scale combustion units and the structural change in residential heating away from coal burning was responsible for this first improvement. Ovens and other small scale combustion units emitting at low altitudes near the breathing zone influence air quality at the ground more strongly than is reflected by their share in emissions. The stagnation after 1967 corresponds to the constant or slightly rising emissions. Interannual fluctuations are mainly due to different meteorological dispersion conditions.

The TSP trend in Figure 4 shows a stronger decrease in the first decade than the SO_2 concentrations. In addition to the factors discussed above (higher chimneys, residential heating), there was also a net decrease of dust emissions by control of the industrial sources (see sections 2.3 and 2.4) which compares nicely to the stronger trend in TSP levels. However, the very distinct decrease from 1970 to 1971 may partly be a monitoring artefact, as the number of the monitoring stations in the Rhine-Ruhr conurbation increased steeply from 13 stations in 1970 to 68 stations in 1971 [51].

PM_{10} levels that are also given in Figure 4 were not measured but estimated (see Part III).

The net decrease in dust emissions also corresponds to the amount of dust deposited in the Ruhr area, calculated from dust fall measurements ([55], see **Figure 5**). From 1964 to 1975, the deposited dust was nearly halved from about 310 x 10^3 tons per year to about 160 x 10^3 tons per year, in contrast to the rising industrial production [55]. Dust fall reacts particularly sensitive to control measures at industrial sources, because coarse particles sediment near the sources without much transport.

The first systematic NO_2 measurements in 1966 [53] yielded annual means between 24.8 µg/m³ in a rural area near Rees up to levels between 57 and 59 µg/m³ in cities (Essen, Düsseldorf, Wanne-Eickel). Time trends for NO_2 will be discussed in parts II and III.

2.6 Conclusions

The first period of air pollution control in Northwestern Germany brought a distinct decrease of pollution levels particularly for dust fall and suspended particles (TSP), to a lesser extent for SO_2. The factors responsible for this first success can be summarized as follows:

Becoming a political issue, air quality control was regulated in important laws, technical instructions and ordinances on the state and the federal level. First emission limits for TSP (ambitious at the time) were laid down.

The emission limits for TSP were implemented by systematic programs by the state authorities, covering the most important industrial branches. This led to a net decrease in dust emissions.

Small combustion units were controlled in systematic programs. Structural changes in residential heating from solid fuels to oil and to gas (to a minor extent) helped to clean up this sector.

Sulfur dioxide emissions increased slightly in this period. Abatement measures such as lower sulfur contents in fuels and raw materials only prevented a steeper increase in emissions.

Sulfur dioxide concentrations decreased at the beginning and stagnated afterwards. The first decrease was probably due to better dispersion conditions (higher chimneys) and control of small combustion units emitting in the breathing zone.

Systematic monitoring of air quality revealed the magnitude of the problem, detected areas with a particular high pollution burden and could be used as a benchmark for the success of abatement measures.

The first smog ordinance, having little effect as such, helped to raise public awareness that action to reduce the high air pollution was needed.

Notwithstanding these first successes, there was still a long way to go to current pollution levels. This way is described in the upcoming parts II and III.

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