NILU
OR 17/81

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NORWEGIAN INSTITUTE FOR AIR RESEARCH

ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

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The Norwegian Institute of Air Research (NILU)
P.O.Box 130 - 2001 Lillestrøm

SUMMARY

The Ministry of Environment is considering imposing a requirement to use fuel oils with a maximum sulphur content of 1.0% in the nine coastal counties from Østfold to Rogaland. The present report deals with calculations of the total costs of atmospheric corrosion and the possible savings as a result of the estimated reduction in SO_2 if the requirement is imposed. The reduced concentrations of SO_2 are calculated by the Norwegian Institute of Air Research (NILU) in an earlier report.

As a basis for the calculations we have used the same model as employed by the Swedish Corrosion Institute in a study conducted for OECD, with adjustments to the basic data to suit Norwegian conditions. The calculations refer to 1979, and are limited to painted steel and galvanized steel in the form of sheeting, wire and profiles. The period 1960-79 is used as a basis for the accumulation of quantities of material.

The total yearly costs of corrosion in the nine counties are estimated at 644 million kroner in built-up areas and 345 million kroner in rural areas, totalling 989 million kroner. Corresponding yearly savings given a requirement for a sulphur content of maximum 1.0% are 14.7 million kroner and 1.0 million kroner respectively, totalling 15.7 million kroner.

These are relatively rough calcuations and are made on the basis of data that are fairly easily accessible. Emphasis has been placed on cautious assessments. Calculations of uncertainties show that the total saving of 15.7 million kroner may lie between 12 and 49 million kroner.

Table 1. SO_2 concentrations and corrosion costs for Norway (2). (x 1000 Nkr).

Area	Population	SO_2(1974) ($\mu g/m^3$)	SO_2(1985) ($\mu g/m^3$)	Tot.costs 1974	Tot.costs 1985	Saving
Oslo/Drammen	606 551	26.03	18.06	277 350	265 595	11 755
Rural areas south round Oslo	1 058 599	2.80	2.67	435 540	435 540	190
Rural areas round Bergen and Stavanger	316 017	1.67	1.69	129 540	129 535	- 10
Rural areas north Oslo	278 391	1.49	1.49	114 035	129 535	0
Rural areas north of Sandefjord	101 076	0.91	0.92	41 323	41 325	- 2
North Norway	952 422	0.68	0.70	378 055	378 080	- 25
Stavanger	124 254	9.17	6.62	52 210	51 780	430
Trondheim	129 229	11.21	8.34	54 665	54 160	505
Bergen	212 120	8.61	6.11	88 970	88 235	735
Sum	3 875 913			1 571 673	1 558 285	≃13 388

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The most important properties of the moisture film are chemical composition, thickness, and distribution over the surface either as a continous layer or in the form of droplets. The chemical composition of the moisture film depends on the type and quantity of soluble components in air and precipitation, especially sulphur components and chlorides, as well as the type and quantity of insoluble components on the surface, such as solid particles, salts, dust and the reaction/corrosion products that are formed.

The OECD calculations assume that for Europe, the corrosion caused by naturally occurring factors such as moisture, temperature etc., is more or less constant for the entire European temperate climate zone, except in coastal areas where chlorides play and important part. Since it was beyond the intention of the report to estimate the contribution made by sea-salt, and since no synergistic corrosion effect of chlorides and sulphur pollutants could be demonstrated, the OECD report has ignored the effect of chlorides in the atmosphere.

In Norway there are substantial local and regional variations in the amount of precipitation (3). In the nine counties to which the calculations refer, the amount of precipitation varies with a factor 3, and the amounts in the areas of Rogaland with most precipitation (2400 mm per year) will be very much greater than in most areas of Europe. From the corrosion point of view, this may lead to fairly large differences both in washing effect (4) and wet time, both in relation to Europe and locally between the different areas in question.

Our data on the relation between corrosion and precipitation /wet time are not good enough to correct the assumptions from the OECD calculations directly. However, NILU's corrosion data from Norway show higher values than used in the OECD calculations, and a possible reason could in fact be the longer wet times (see section 2.3)

Near the coast, sea-salt in air and precipitation will have a very strong influence from the corrosion point of view, and in Norway, acidity/precipitation frequency, and between corrosion and the concentration of sulphur pollutants, are not good enought to be able to make sound calculations for practical conditions. This of course represents a certain simplification and underestimation of the true corrosion costs of sulphur pollutants, but is nevertheless the best that can be achieved at the present time.

2.3 The included materials

2.3.1 Zinc and galvanized steel

The results of four different investigations are shown in Annex A, figure A.1+ (2). KI employed in its calculations the relation found by Hudson & Stanners (relation B), because this applied for areas in the temperate climate zone of Europe, and also covered a wide range of SO_2 concentrations.

For Norway we have data for up to 5 years from rural, town and industrial atmosphers in southern and western Norway (11,12). These data are shown in Figure 1, where relations A and B from Figure A.1 are also drawn in. It can be seen that the relation conforming with the Norwegian data shows a stronger corrosion as a function of SO_2 than does Hudson & Stanners data. A possible reason may be precisely that there are longer wet times in Norway than in most other European countries. The Norwegian data are considered the most relevant for Norwegian conditions, and the relation shown has been chosen for the present study (see 5.2). Furthermore, the Norwegian data conform very well with the Swedish data.

2.3.2 Painted steel

Several investigations have shown that the lifetime of the paint is related to the SO_2 concentrations (13-17). In the OECD study, KI has used data from USA (13) for the lifetime of paint on steel

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+ Figures and tables in Annexes are numbered consecutively for each Annex, and are referred to by a letter and number, e.g. figure A.1.

and on galvanized steel. It is assumed that there is a linear relation between lifetime and SO_2 level, and Figure 2 shows the relation calculated on the basis of the American data. The quantity of the data in the investigation is small, however, and the angle coefficient of the equation is strongly dependent on a small number of values with high SO_2 concentration.

There is little systematic data from Norwegian conditions. Both users and manufacturers in Norway agree, however, that a fundamental weakness in the data from USA is that they do not demonstrate any advantage from using paint on galvanized materials when there are high SO_2 concentrations (figure 2). This weakness is also recognized by KI, which plans to adjust the relations if another study is conducted later.

NILU has therefore tried to adjust the relations from the OECD study using own data and by charting user experience from various large companies in Norway and from industrial areas in Czechoslovakia (16) where charting of the lifetime is also based on user experience.

A NILU project in cooperation with manufacturers and users, for testing matallized and painted coatings, seems to show clear damage on most paint systems, both on bare steel and on hot-dip galvanized steel after about 3 1/2 years exposure at Borregaard (18,19).

The Norwegian State Railways (NSB) state that the average lifetime of their alkyd system is 12-15 years in southern Norway and 8-10 years in the Drammen district. In the coastal climate of Jæren, the lifetime is 7-8 years (20). (The data from Jæren are not included). In the NILU investigation referred to above, NSB's alkyd system was the best of the paint systems tested.

The Jotun Group has informed us that they normally operate with a 4-yearly maintenance cycle for paint in an industrial atmosphere. The industrial atmosphere is not quantitatively defined, however, Carbon_steel is so strongly affected by SO_2 that it is usually protected, for example by paint etc. When it is used unprotected, as in railway tracks and wheels for example, the lifetime is determined by factors other than corrosion.

Copper_and_copper_alloys corrode very much more quickly in a SO_2-polluted atmosphere than in clean air, but not so rapidly that this is considered a limiting factor for the lifetime of constructions in which these are used.

Aluminium_alloys are highly resistant to SO_2.

Nickel_and_nickel-plated_steel corrodes much more quickly with high levels of SO_2, but these materials have very limited distribution.

Stainless_steel is resistant to atmospheric corrosion in most applications.

The_precious_metals in electric switches, for example gold, silver, copper and nickel, deteriorate in the presence of reduced sulphur compounds. This is a major problem which is being awarded increasing attention by research groups the world over. Recent studies have gradually shown quite good correlations between the sulphur concentration and several of the metals (9,10). For Norwegian conditions, we do not yet know enough about the actual levels of pollution and corresponding corrosion data. However, NILU is at present carrying out extensive investigations for the Telecommunications Administration, where this is considered a serious problem (24,25).

Other_materials are also excluded. This applies to deterioration of buildings and monuments of sandstone and limestone as a result of SO_2. This is an international problem, and some of the costs can undoubtedly be put down to the maintenance aspect. However, we do not know the quantitative relation between SO_2 and the deterioration of different kinds of stone, and furthermore it is difficult to determine costs for loss of artistic values. A larger project administered by the NATO Committee on the Challenge of

Table A.1. lists the built-up areas included in the calculation, the population in the built-up areas, and the annual mean concentrations of SO_2 (1). More than one SO_2 concentration is given for some of the built-up areas, in which case is also given the percentage material to which each concentration area refers. By "percentage material" is meant the percentage found in a given area of the total mass of material in the built-up area.

3.2. Galvanized steel

The galvanized materials included in the calculations are first exposed unpainted. For the OECD study the following assumptions apply:

a. Galvanized sheeting is coated with 30 µm zinc and will be covered with paint when 20 µm of the coating has corroded.

b. Galvanized profiles are coated with 80 µm zinc and will be covered with paint when 60 um has corroded.

c. Galvanized wire has a diameter of 3 mm and is covered with 30 µm zinc. The wire will be replaced with new wire when all the zinc has corroded.

d. All these materials are used in the different regions in proportion to the density of the population.

As for painted steel, we also in this case make use of a distribution according to the percentage material in the different built-up areas. Furthermore, as in the case of paint, we have found it more realistic to calculate an average lifetime for galvanized sheets and wire (see paragraph 5.3).

4 CALCULATION OF LIFETIMES

4.1 Painted carbon steel and painted galvanized steel

As mentioned above, in the OECD study the lifetime for paint on steel and galvanized steel is calculated out from American data (figure 2) in accordance with the following equations:

(1) $L_1 = 11.6 - 0.016 \times (SO_2)$

(2) $L_2 = 15.3 - 0.031 \times (SO_2)$

5 CALCULATION OF COSTS AND PROTECTION AGAINST CORROSION

5.1 Prices

In the OECD study the total costs comprise the sum of the costs of painting carbon steel, corrosion of galvanized sheets and profiles and wire, and painting of galvanized sheets and profiles. The calculations take into account the costs of materials only in the case of galvanized wire, which has to be replaced. For the other materials the calculations include the costs of protection only, i.e. galvanizing and painting.

The calculations of the costs of protection against corrosion are based on Swedish 1979 prices. These prices, shown below in Table 2, are exclusive VAT, but include social expenses, which amount to about one third of the total labour costs.

Table 2: Costs of protection against corrosion

Material	OECD calc. (2) US doll./m^2	These calc. (Nkr/m^2)
Galv. sheet (30 µm)	0.57	2.85
profile (80 µm)	5	32
wire (30 µm)	4	40
Painting of steel and galvanized materials+	11.40	57

\+ Cost of paint approx. 50%

Eijnsbergen (23) has compared the costs of hot dip galvanizing with the costs of painting for 9 practical constructions consisting of from 50 to 500 tons of steel. The costs of hot dip galvanizing vary from 21.30 to 46.90 Kr/m^2 with a mean value of 32.85 Skr/m^2. In the light of this we have chosen to increase the price for profiles to Nkr. 32.00.

For the same constructions the costs of painting are from 29.20 to 79.90 Skr/m^2, with a mean of 53.75 Skr/m^2. Haug of Protectors A/S (28) informs us that the painting costs vary from 30 to 200 Nkr/m^2, quite independent of the kind of pretreatment, building design (scaffolding , wastage of paint etc). A price

The costs of painting carbon steel in a particular area are therefore calculated from the following expression:

$$\text{Cost ptd.steel} = \frac{\text{Amt.ptd.steel } (m^2/\text{inhab. x cost paint } (kr/m^2)}{\text{lifetime paint (years)}}$$

In the present calculations we have used the same assumptions but with a revised lifetime function for paint on steel (equation (3) p. 16). Data on production and consumption of paint in Norway are given in table B.1, and are taken from the OECD statistics (29). As also shown in Annex B, we thus get the following expression for the annual corrosion costs per inhabitant:

$$\text{Cost painted steel} = \frac{75(m^2/\text{inhabitant x } 57(kr/m^2)}{(11.7-0.042 \text{ x } SO_2) \text{ (yrs)}}$$

5.3 Galvanized steel

Only galvanized steel exposed in 1960 or later is included in the calculations. In the OECD study the total amount of galvanized steel is estimated from the OECD statistics on zinc consumption. These statistics give no information, however, on where the zinc is used. Smaller countries which export a lot of zinc for the galvanizing industry, will have too large amounts of galvanized materials. For this reason the mean values for Great Britain, France and West Germany are used as a basis for the calculations relating to the smaller countries, such as Norway (2).

For the purpose of this report we have collected figures for the consumption of zinc for galvanizing from the Scandinavian Galvanisers Association (30). These figures for wire and profiles are shown in Table C.1. Norway imports nearly all of its thin sheets, and the statistics therefore tell nothing concerning the amount of thin sheeting found in Norway. As an approximation we have therefore assumed the same amount of zinc for thin sheets as for wire.

Certain galvanized products are either covered with paint or are exposed indoors. To arrive at an estimate of the actual amount

5.3.1 Galvanized wire

The following steps are used when calculating the costs for wire in each area:

- The actual lifetime of the wire is calculated as 3 x t, that is to say, three times the time it takes to corrode 10 um (equation 6, page 16).
- The amount of galvanized wire is calculated from the mean lifetime, the population and Table C.1.

For wire, the calculated lifetime is shorter than the accumulation period (1960-79) for which we are calculating for, only in areas with more than 36 $\mu g\ SO_2/m^3$. We have therefore calculated the total amount of material out from a mean lifetime of 20 years. We believe this to be a realistic figure even for the polluted areas, because wire will often be exposed for a longer time than it takes the zinc coating to wear away. The annual costs for corrosion of wire in each area are calculated from the expression:

$$\text{Costs wire} = \frac{\text{Amount wire } (m^2/\text{inhab.}) \times \text{costs for wire } (kr/m^2)}{\text{Calculated lifetime (yrs)}}$$

As also shown in Annex C, we thus get the following expression for the annual corrosion costs per inhabitant:

$$\text{Costs wire} = \frac{30 (m^2/\text{inhab}) \times 40\ (kr/m^2)}{(71 \times 3/0.45\ (SO_2) + 0.7)\ (yr)}$$

5.3.2 Galvanized thin sheets and profiles

The calculations for thin sheets and profiles are carried out separately, but by the same procedure and in the following stages:

- The lifetime for material which has been galvanized is calculated as 2 x t for thin sheets and 6 x t for profiles using equation (6)
- The total amount of thin sheets and profiles for the area are calculated out from the mean lifetime, the population and Table C.1.

For Norway we have considered it more realistic to assume that no painting of the zinc is carried out during the period. As will be seen from the results, the calculated lifetime is less than

Table 3: Annual corrosion costs and possible savings for painted and galvanized steel with a reduction of the SO_2 level and when $SO_2 = 0$.

MATERIAL	BUILT-UP AREAS			RURAL AREAS		
	Costs	Savings		Costs	Savings	
		With oil with low sulphur content	Theoretical when $SO_2=0$		With oil with low sulphur content	Theoretical when $SO_2= 0$
Painted steel						
Costs before	508.7			280.2		
Costs after	501.5	7.2	45.8	279.2	1.0	5.2
Costs.$SO_2=0$	462.9			275.0		
Galvanized sheets						
Costs before	4.3			1.9		
Costs after	4.0	0.3		1.9	0	0
Costs.$SO_2=0$	3.2			1.9		
Galvanized wire						
Costs before	75.8			36.1		
Costs after	71.6	4.2	14.8	36.1	0	0
Costs.$SO_2=0$	61.0			36.1		
Galvanized profiles						
Costs before	55.5			26.5		
Costs after	52.5	3.0	10.8	26.5	0	0
Costs.$SO_2=0$	44.7			26.5		
Sum						
Costs before	644.3			344.7		
Costs after	629.6	14.7	72.5	343.7	1.0	5.2
Cost.$SO_2=0$	571.8			339.5		
Sum total built-up areas plus rural areas						
Costs before	989.0					
Costs after	973.3	15.7	77.7			
Cost. $SO_2=0$	911.3					

for example, from 42 to 48 years (coast Østfold/Telemark), this is of no economic importance. As can be seen from Table 6, this is also the case for a number of built-up areas. Only parts of Halden, Moss, Oslo, Drammen, Skien and Sarpsborg, Fredrikstad, Porsgrunn and Kristiansand achieve a saving for galvanized steel as a result of the requirement for oils with low sulphur content.

Of the savings of 7.5 mill.kr, Oslo accounts for 3.65 mill.kr. (48.7%) and Sarpsborg for 1.59 mill.kr. (21.2%).

6.3 In total

The total corrosion costs are 644.3 mill.kr. for the built-up areas and 344.7 mill.kr. for the rural areas, giving a sum of 989 mill.kr. With a requirement for oils with low sulphur content the total savings are calculated to 15.7 mill.kr. This gives corrosion costs of approx. 490 kr/inhab. per year and savings of 7.30 kr/inhab. per year with a 1% S initiative.

6.4 Discussion

6.4.1 General evaluation of the basis for the calculations

Just as for the calculations of changes in SO_2 concentrations (1) it must be emphasized that the calculations are carried out in a limited time and within a limited cost bracket. We have based on our calculations on a model used before (2) and existing, fairly easily accessible data material, and have not made the calculations more detailed than justified by the data.

We have tried to exercise a certain caution when making our assumptions so as not to overestimate the corrosion damages and the savings as a function of SO_2. This is demonstrated in the estimate of uncertainties in the calculations (para.6.4.2 and Table D.3).

The OECD model is modified on certain points. Based on a larger data material we have made the deterioration of paint more depdendent on SO_2. This leads to greater savings.

Based on Norwegian data we have modified the relation for corrosion of zinc as a function of SO_2. It must be emphasized that the by means of the consumption of paint, because most of these sheets are imported ready painted, especially from Sweden. That we are dealing with substantial quantities is illustrated by the fact that in 1978 a total of 617 000 m^2 roof and wall sheets and flashing/flat sheets were exposed for outdo r use. The average quantity per year in the last ten years has been of about the same order (31).

The prices are also very uncertain, especially for painted steel, and can easily be very much greater. Considering the heavy burden of savings associated with this aspect, this will have considerable importance (see para. 6.4.2 and Table D.3).

In this connection the specification of prices for sheets is also of consequence. In this case we have only calculated the price of the zinc coating. On the basis of our assumption concerning the replacement of the sheets as a result of corrosion, it would have been more correct, as in the case of wire, to include the price of the material. This applies to factory-lacquered sheets of the above type between 30-50 kr/m^2 (31).

The total costs of 989 mill.kr. are equivalent to a cost of 1957 mill.kroner for the whole country, as against 1571 mill.kroner in the OECD study (Table 1). Correspondingly, the savings for the whole country will be about 31 mill.kroner.

6.4.2 Estimate of uncertainties

It would be to go too far to calculate all the uncertainties connected with all the conditions discussed above. Nevertheless, to give some idea, we have chosen to calculate the uncertainties for the two alternatives:

a) the uncertainty in the price for maintenance painting of steel. A price of kr.57/m^2 is used in the main calculation, while we have calculated for a minimum price of kr.30/m^2, a maximum price of kr.200/m^2 and a middle price of kr.100/m^2 (see 5.1).

Total savings given the introduction of a requirement for oils with low sulphur content are calculated as 15.7 mill.kr. An estimate of uncertainty as a result of uncertainty regarding maintenance prices and the introduction of economic lifetimes for galvanized coating show that the total savings may lie between 12 mill.kr/yr and 49 mill.kr/yr.

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ANNEX A

Table A.1. Material percent and annual mean concentration of SO_2. Basis year 1979.

County	Location	Material-percent	concentration of SO_2 ($\mu g/m^3$)
Østfold	Halden	70	35
		30	15
	Sarpsborg	60	50
		40	25
	Fredrikstad		25
	Moss	70	20
		30	10
	Askim		7
Akershus/ Oslo	Ski		10
	Oslo	40	40
		40	25
		20	10
Buskerud	Drammen	70	40
		30	20
	Hønefoss	40	20
		60	15
	Kongsberg		15
Vestfold	Horten		10
	Tønsberg		15
	Sandefjord		15
	Larvik	40	15
		60	10
Telemark	Porsgrunn		20
	Skien	60	35
		40	20
	Notodden		10
Aust-Agder	Arendal		10
Vest-Agder	Kristiansand	40	20
		60	15
	Vennesla		15
	Mandal		10
Rogaland	Egersund		10
	Sandnes		10
	Stavanger		15
	Haugesund		10

Table B.1. Production/Consumption of paint in Norway (25)

Year	x 1000 tons			Consumption
	Production	Import	Export	kg/head
1979				
1978				
1977	60.8			15.2
1976				
1975	72.3	9.4	12.4	15.1
1974				17.3
1973	66.2	8.4	11.4	16.4
1972	63.0	7.6	10.1	16.1
1971	59.1	6.3	10.7	15.0
1970	56.2	6.1	9.8	14.3
1969	53.1	5.4	8.6	13.8

Corrosion costs painted steel

On the basis of the above table is estimated:

1. Middle annual production (-69-79) = 60.2×10^3 tons/yr

Assuming 15% is used for outdoor protection against corrosion we get:

2. Outdoor anti-corrosion paint $60.2 \times 0.15 \times 10^3 = 9 \times 10^3$ tons

Assuming 100 um coat thickness and a specific weight of 2 kg/dm^3 we get:

3. The weight of 1 m^2 coat of paint $2 \times 100 \times 100 \times 10^{-5} = 0.2$ kg

With a dry matter content in the paint of 67% we get:

4. Painted surface per yr: $\frac{10^3 \times 9 \times 10^3 \times 0.67}{0.2} = 3 \times 10^7 \frac{m^2}{yr}$

5. With a middle lifetime change of 10 years and 4 mill.inhabitants we get:

$$\frac{3 \times 10^7 \times 10}{4 \times 10^6} = 75 \text{ m}^2 \text{ painted surface/inhabitant}$$

6. Paintcosts:

$$\frac{75 \times 57}{11.7-0.042\ SO_2} \text{kr/inhab/yr} = \frac{4275}{11.7-0.042\ SO_2}$$

Table C.1 Annual consumption of zinc for galvanization (1000 tons) (30)

Yr	[2] Thin sheet (30 µm)			Wire (30 µm)			Profile(pc,gds)(80µm)		
	yearly	reduced 50%	area inh/yr	yearly	reduced 67%	area inh/yr	Yearly	reduced 75%	area inh/yr
		[2] Assumed the same as for wire							
1979		0.84		1.68	1.1		6.10	4.6	
78		0.68	0.88	1.35	0.9	1.2	6.32	4.7	2.2
77		0.77	1.76	1.54	1.1	2.4	6.46	4.9	4.4
76		0.73	2.64	1.45	1.0	3.6	6.05	4.6	6.6
75		0.76	3.52	1.52	1.0	4.8	6.93	5.2	8.8
74		0.79	4.4	1.57	1.1	6.0	7.23	5.4	11.0
73		0.77	5.28	1.53	1.0	7.2	6.87	5.2	13.2
72		0.73	6.16	1.45	1.0	8.4	7.30	5.5	15.4
71		0.68	7.04	1.35	0.9	9.6	6.25	4.7	17.6
70		0.68	7.92	1.35	0.9	10.8	6.88	5.2	19.8
69 [1]		0.75	8.8	1.48	1.0	12.0	6.63	5.0	22.0
68		0.75	9.68	1.48	1.0	13.2	6.63	5.0	24.2
67		0.75	10.56	1.48	1.0	14.4	6.63	5.0	26.4
66		0.75	11.44	1.48	1.0	15.6	6.63	5.0	28.6
65		0.75	12.32	1.48	1.0	16.8	6.63	5.0	30.8
64		0.75	13.2	1.48	1.0	18.0	6.63	5.0	33.0
63		0.75	14.08	1.48	1.0	19.2	6.63	5.0	35.2
62		0.75	14.96	1.48	1.0	20.4	6.63	5.0	37.4
61		0.75	15.84	1.48	1.0	21.6	6.63	5.0	39.6

1 The quantities for 1960s are estimated as mean values of the 1970-79 quantities.

1 GALVANIZED PROFILE (80 µm)

1 Middle annual consumption: 5000 tons

2 Weight of 1 m^2 zinc coating (from thin sheet)

$$0.213 \text{ kg} \times \frac{80}{30} = \underline{0.568 \text{ kg}}$$

3 Galvanized "profile" surface per yr

$$\frac{5000 \times 10^3}{0.568} = 8803 \times 10^3 \text{ m}^2/\text{yr}$$

4 Galvanized "profile" surface per inhabitant

$$\frac{8803 \times 10^3}{4 \times 10^6} = 2.2 \text{ m}^2/\text{inhab.yr}$$

The middle lifetime is 40 yrs., but because we calculate only for the period 1960-79 we get:

5 Total quantity $= \underline{\dfrac{2.2 \times 20}{\text{lifetime}} \text{ m}^2/\text{inhab} = 44 \text{ m}^2/\text{inhab.}}$

Given a cost of kr 32/m^2 we get:

6. Cost $= \underline{\dfrac{44 \times 32}{\text{Estimated lifetime}} \text{ kr/inhab. yr.}}$

ANNEX D

Table D.1: Annual corrosion costs and possible savings for painted steel after reduction of the SO_2 level.

Table D.2: Annual corrosion costs and possible savings for galvanized steel after reduction of the SO_2 level.

Table D.3 Alternative corrosion costs and possible savings for painted steel and galvanized steel with reduction of the SO_2 level.

Table D.1 continued.

Location	Population	SO_2 Bef.	SO_2 Aft.	Annual cost paint-before	Annual cost paint - after	Saving	Annual cost paint $SO_2=0$	Theoretic: saving
Kyst Østfold - Telemark	262 400	6	5	97987	97629	358	95887	2110
Innland Østfold Telemark	235 500	5	4	87621	87302	319	86048	1573
Agder	124 000	4	3	45968	45801	167	45308	660
Rogaland	130 600	5	4	48591	48414	177	47719	872
	752 500			280167	279146	1021	274952	5215

Table D.2 continued

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	LEVETID FØR TRAD	LEVETID FØR PROFIL	LEVETID ETTER PLATE	LEVETID ETTER TRAD	LEVETID ETTER PROFIL	LEVETID SO2=0 PLATE	LEVETID SO2=0 TRAD	LEVETID SO2=0 PROFIL
MOSS	8220.	10.	8.	27.	41.	82.	33.	50.	99.	203.	304.	609.
ASKIM	8400.	7.	5.	37.	55.	111.	48.	72.	144.	203.	304.	609.
SKI	9300.	10.	8.	27.	41.	82.	33.	50.	99.	203.	304.	609.
OSLO	258160.	40.	39.	8.	11.	23.	8.	12.	23.	203.	304.	609.
OSLO	258160.	25.	22.	12.	18.	36.	13.	20.	40	203.	304.	609
OSLO	129030.	10.	8	27.	41.	82.	33.	50.	99.	203.	304.	609.

OMRADE		PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
MOSS	KOSTNADER FØR	20616.	394560.	289344.				
	KOSTNADER ETTER	20616.	394560.	289344.	BESPARELSE TILTAK	0.	0.	0.
	KOSTNADER SO2=0	20616.	394560.	289344.	BESPARELSE TEORETISK	0.	0.	0.
ASKIM	KOSTNADER FØR	21067.	403200.	295680.				
	KOSTNADER ETTER	21067.	403200.	295680.	BESPARELSE TILTAK	0.	0.	0.
	KOSTNADER SO2=0	21067.	403200.	295680.	BESPARELSE TEORETISK	0.	0.	0.
SKI	KOSTNADER FØR	24578.	470400.	344960.				
	KOSTNADER ETTER	24578.	470400.	344960.	BESPARELSE TILTAK	0.	0.	0.
	KOSTNADER SO2=0	24578.	470400.	344960.	BESPARELSE TEORETISK	0.	0.	0.
OSLO	KOSTNADER FØR	1278972.	21758161.	15955985.				
	KOSTNADER ETTER	1248195.	21234569.	15572017.	BESPARELSE TILTAK	30777.	523592.	383968.
	KOSTNADER SO2=0	647465.	12391680.	9087232.	BESPARELSE TEORETISK	631507.	9366481.	6868753.
OSLO	KOSTNADER FØR	817311.	13904279.	10196472.				
	KOSTNADER ETTER	724979.	12391680.	9087232.	BESPARELSE TILTAK	92332.	1512599.	1109240.
	KOSTNADER SO2=0	647465.	12391680.	9087232.	BESPARELSE TEORETISK	169846.	1512599.	1109240.
OSLO	KOSTNADER FØR	323733.	6195840.	4543616.				
	KOSTNADER ETTER	323733.	6195840.	4543616.	BESPARELSE TILTAK	0.	0.	0.
	KOSTNADER SO2=0	323733.	6195840.	4543616.	BESPARELSE TEORETISK	0	0.	0.

Table D.2 continued

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	TRAD	PROFIL	LEVETID ETTER PLATE	TRAD	PROFIL	LEVETID SO2=0 PLATE	TRAD	PROFIL
TØNSBERG	36400.	15.	10.	19.	29.	57.	27.	41.	82.	203.	304.	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	91291.	1747200.	1281280.				
KOSTNADER ETTER	91291.	1747200.	1281280.	BESPARELSE TILTAK	0.	0.	0.
KOSTNADER SO2=0	91291.	1747200.	1281280.	BESPARELSE TEORETISK	0.	0.	0.

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	TRAD	PROFIL	LEVETID ETTER PLATE	TRAD	PROFIL	LEVETID SO2=0 PLATE	TRAD	PROFIL
SANDEFJORD	28700.	15.	10.	19.	29.	57.	27.	41.	82.	203.	304.	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	71980.	1377600.	1010240.				
KOSTNADER ETTER	71930.	1377600.	1010240.	BESPARELSE TILTAK	0.	0.	0.
KOSTNADER SO2=0	71980.	1377600.	1010240.	BESPARELSE TEORETISK	0.	0.	0.

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	TRAD	PROFIL	LEVETID ETTER PLATE	TRAD	PROFIL	LEVETID SO2=0 PLATE	TRAD	PROFIL
LARVIK	7680.	15.	10.	19.	29.	57.	27.	41.	82.	203.	304.	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	19261.	368640.	270336.				
KOSTNADER ETTER	19261.	368640.	270336.	BESPARELSE TILTAK	0.	0.	0.
KOSTNADER SO2=0	19261.	368640.	270336.	BESPARELSE TEORETISK	0.	0.	0.

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	TRAD	PROFIL	LEVETID ETTER PLATE	TRAD	PROFIL	LEVETID SO2=0 PLATE	TRAD	PROFIL
LARVIK	11520.	10.	7.	27.	41.	83.	37.	55.	111.	203.	304.	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	28892.	552960.	405504.				
KOSTNADER ETTER	28892.	552960.	405504.	BESPARELSE TILTAK	0.	0.	0.
KOSTNADER SO2=0	28892.	552960.	405504.	BESPARELSE TEORETISK	0.	0.	0.

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	TRAD	PROFIL	LEVETID ETTER PLATE	TRAD	PROFIL	LEVETID SO2=0 PLATE	TRAD	PROFIL
PORSGRUNN	32600.	20.	14.	15.	22.	44.	30.	30.	61.	203.	304.	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	83776.	1564800.	1147520.				
KOSTNADER ETTER	81761	1564800.	1147520.	BESPARELSE TILTAK	2015.	0.	0.
KOSTNADER SO2=0	81761.	1564800.	1147520.	BESPARELSE TEORETISK	2015.	0.	0.

OMRADE	BEFOLKN	SO2FOR	SO2ETTER	LEVETID FOR PLATE	TRAD	PROFIL	LEVETID ETTER PLATE	TRAD	PROFIL	LEVETID SO2=0 PLATE	TRAD	PROFIL
SKIEN	17760.	35.	29.	9.	13	26	10.	15.	31	203.	304	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	77400.	1316741.	965610.				
KOSTNADER ETTER	64696.	1100620.	807121.	BESPARELSE TILTAK	12704	216122.	158489.
KOSTNADER SO2=0	44542.	852480.	625152.	BESPARELSE TEORETISK	32858.	464261.	340458.

Table D.2 continued

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	LEVETID FØR TRAD	LEVETID FØR PROFIL	LEVETID ETTER PLATE	LEVETID ETTER TRAD	LEVETID ETTER PROFIL	LEVETID SO2=0 PLATE	LEVETID SO2=0 TRAD	LEVETID SO2=0 PROFIL
MANDAL	7700.	10.	8.	27.	41.	82.	33.	50.	92.	203.	304.	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	19312.	369600.	271040.				
KOSTNADER ETTER	19312.	369600.	271040.	BESPARELSE TILTAK	0.	0.	0.
KOSTNADER SO2=0	19312.	369600.	271040.	BESPARELSE TEORETISK	0.	0.	0.

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	LEVETID FØR TRAD	LEVETID FØR PROFIL	LEVETID ETTER PLATE	LEVETID ETTER TRAD	LEVETID ETTER PROFIL	LEVETID SO2=0 PLATE	LEVETID SO2=0 TRAD	LEVETID SO2=0 PROFIL
EGERSUND	7000.	10.	7.	27.	41.	82.	37.	55.	111.	203.	304.	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	17556.	336000.	246400.				
KOSTNADER ETTER	17556.	336000.	246400.	BESPARELSE TILTAK	0.	0.	0.
KOSTNADER SO2=0	17556.	336000.	246400.	BESPARELSE TEORETISK	0.	0.	0.

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	LEVETID FØR TRAD	LEVETID FØR PROFIL	LEVETID ETTER PLATE	LEVETID ETTER TRAD	LEVETID ETTER PROFIL	LEVETID SO2=0 PLATE	LEVETID SO2=0 TRAD	LEVETID SO2=0 PROFIL
SANDNES	21800.	10.	7.	27.	41.	82	37.	55.	111.	203.	304.	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	54674.	1046400.	767360.				
KOSTNADER ETTER	54674.	1046400.	767360.	BESPARELSE TILTAK	0.	0.	0.
KOSTNADER SO2=0	54674.	1046400.	767360.	BESPARELSE TEORETISK	0.	0.	0.

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	LEVETID FØR TRAD	LEVETID FØR PROFIL	LEVETID ETTER PLATE	LEVETID ETTER TRAD	LEVETID ETTER PROFIL	LEVETID SO2=0 PLATE	LEVETID SO2=0 TRAD	LEVETID SO2=0 PROFIL
STAVANGER	79300.	15.	10.	19.	29.	57.	27.	41.	82.	203.	304.	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	198884.	3806400.	2791360.				
KOSTNADER ETTER	198884.	3806400.	2791360.	BESPARELSE TILTAK	0.	0.	0.
KOSTNADER SO2=0	198884.	3806400.	2791360.	BESPARELSE TEORETISK	0	0.	0.

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	LEVETID FØR TRAD	LEVETID FØR PROFIL	LEVETID ETTER PLATE	LEVETID ETTER TRAD	LEVETID ETTER PROFIL	LEVETID SO2=0 PLATE	LEVETID SO2=0 TRAD	LEVETID SO2=0 PROFIL
HAUGESUND	29300.	10.	7.	27.	41.	82.	37.	55.	111.	203.	304.	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	73484.	1406400.	1031360.				
KOSTNADER ETTER	73484.	1406400.	1031360.	BESPARELSE TILTAK	0.	0.	0
KOSTNADER SO2=0	73484.	1406400.	1031360.	BESPARELSE TEORETISK	0	0.	0.

OMRADE	BEFOLKN	SO2FØR	SO2ETTER	LEVETID FØR PLATE	LEVETID FØR TRAD	LEVETID FØR PROFIL	LEVETID ETTER PLATE	LEVETID ETTER TRAD	LEVETID ETTER PROFIL	LEVETID SO2=0 PLATE	LEVETID SO2=0 TRAD	LEVETID SO2=0 PROFIL
KYST ØSTFOLDTELEMARK	262400	6.	5.	42.	63.	125.	43.	72.	144	203.	304.	609.

	PLATE	TRAD	PROFIL		PLATE	TRAD	PROFIL
KOSTNADER FØR	658099.	12595200.	9236480.				
KOSTNADER ETTER	658099.	12595200.	9236480.	BESPARELSE TILTAK	0.	0.	0.
KOSTNADER SO2=0	658099.	12595200.	9236480.	BESPARELSE TEORETISK	0	0.	0.

Table D.3. Alternative corrosion damages and possible savings for painted and galvanized steel with a reduction of the SO_2 level (1) (mill.kr).

Materials	Built-up areas			Rural areas			Total savings
	Costs	Savings		Costs	Savings		
		Bef/aft.	Theoret:		Bef/aft.	Theoret.	
Painted steel							
Uncertainty in maintenance price paint							
Min.kr.30/-	268	4	24	145	0.05	3	4.5
Midd.kr 57/- (used in report)	501.5	7.2	45.8	280.2	1.0	5.2	8.2
Kr. 100/-	880	13	80	491	2.0	9	15
Max.kr 200/-	1760	26	160	982	3	18	29
Galvanized steel							
Economic lifetimes 15,20,40 yrs (cf.report)							
Gal.sheets	4.3	0.3	1.1	1.9	0	0	0.3
" wire	75.8	4.2	14.8	36.1	0	0	4.2
" profile	55.5	3.0	10.8	26.5	0	0	3.0
Sum		7.5			0		7.5
Without economic lifetimes							
Galv.sheets	3.4	0.5	3.4	0.6	0.1	0.5	0.6
" wire	66	9.5	61	10	1.5	7.9	11
" profile	48	7	45	7	1	5.8	8
Sum		17			3		20