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Rationalised Economic Appraisal of Cultural Heritage

Case Study of "Kristiania Kvadraturen" in Oslo

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NILU

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Summary

The REACH project , ENV4-CT98-0708, aims to bring together the relevant information on physical and economic factors which provide necessary data to managers concerned with the care of the built cultural heritage. This will be used to develop an integrated cost-benefit model incorparating the relevant factors, "The REACH management tool". The protected old part in the centre of Oslo, "Kristiania Kvadraturen" situated behind the Akershus castle was selected as one of the case studies in the REACH project. The main reasons for selecting this protected old part of Oslo were:

- Kristiania Kvadraturen is a part of Oslo where the whole area is protected as a national cultural monument, and it has also been one of the most polluted parts of the city for a long time.
- Several air pollution studies have been carried out in Oslo during the last 20 years. It is therefore possible to use Oslo as a case for calculation of the cost of maintenance and repair for building materials.
- The air pollution studies included modelling of the variation of the pollutants inside an area. The effect to buildings could therefore differ within the selected area.
- This can be achieved by use of the CorrCost module, a GIS (geographic information system) based module for corrosion and cost assessment that has been introduced as a part of the REACH management tool.
- By linking the CorrCost module to the air pollution situations in Oslo, it will be possible to demonstrate the benefits obtained from the emission reduction strategies that have been carried out during the last decades in Norway.

For studying the air pollution effect in the area, 16 protected buildings were selected for inspection, and the façade materials exposed to the street canyon were measured. The time intervals between maintenance and repair for different materials were calculated for the pollution situation in 1979 and 1995. The cost for the maintenance and repair for the amount of façade materials found for the 16 buildings was calculated for the two pollution scenarios.

The scenarios have shown that while the pollution in 1979 covered for 20.6% of the maintenance costs for the 16 buildings, the pollution in 1995 only covered for 4.8% of the costs.

The total cost for maintenance and repair has been reduced with 20% during the period 1979 to 1995. The main part of benefits, 15.9%, has come from reduction of the local pollution. However even without air pollution, building materials will need maintenance and repair. The rain, the relative humidity and temperature alone will cause material damage. In these scenarios this is calculated as cost when only background pollution is taken into account. A difference in the background pollution costs between 1979 and 1995 of 4.1% is observed caused by the change in the rain acidity. In 1979 the average pH in rain in the Oslo area was 4.3 while pH of 4.6 was observed in 1995. The local emission reduction strategies for Oslo have reduced the pollution impact on material cost considerably. The part linked to the local air pollution has been reduced by 81.4%.

The highest percentage cost reduction during the period 1979 to 1995 can be observed for copper roofing, while the lowest reduction is found for painted Al. The highest cost per square meter for maintenance is observed for painted steel. This is because the low lifetime calculated and the high maintenance price for the work. It is obvious that material with low lifetime and high price for maintenance gets high cost in the calculations. This is true for all painted materials. Copper roofing gave the lowest costs per square meter even if the material is expensive. This is because the lifetime obtained in our calculations is very long, 165-282 years in 1979 and 400-512 in 1995.

The case study has shown that the CorrCost module can be a useful part of an economic management tool for authorities dealing with air pollution control and cultural heritage.

Case Study of "Kristiania Kvadraturen" in Oslo

1 Introduction

The REACH project , ENV4-CT98-0708, aims to bring together the relevant information on physical and economic factors which provide necessary data to managers concerned with the care of the built cultural heritage. This will be used to develop an intergrated cost-benefit model incorparating the relevant factors, "The REACH management tool". It will seek to provide a basis for the tool by:

- collating available information on pollution and dispersion modelling,
- devising a cost model for material degradation,
- devising data collation and a cost model for the direct costs,
- devising data collation and a cost model for indirect costs,
- devising data collation and a cost model for environmental policy issues.

Inside the project specific case studies were selected. Some of the case studies were selected to obtain parts of the necessary background information needed for the cost-benefit model while some are selected for demonstrating the use of the model.

The main reasons for selecting the protected old part of Oslo ("Kristiania Kvadraturen") situated behind the Akershus castle as a case study was:

- Kristiania Kvadraturen is a part of Oslo where the whole area is protected as a national cultural monument and it has also been one of the most polluted parts of the city for a long time.
- Several air pollution studies have been carried out in Oslo during the last 20 years. It is therefore possible to use Oslo as a case for calculation the cost of maintenance and repair for building materials.
- The air pollution studies included modelling of the variation of the pollutants inside an area. The effect to buildings could therefore differ inside the selected area.
- This can be achieved by use of the CorrCost module, a module for corrosion and cost assessment that has been introduced as a part of the REACH management tool.
- By linking the CorrCost module to the air pollution situations in Oslo, it will be possible to demonstrate the benefits obtained from the emission reduction strategies that have been carried out during the last decades in Norway.

2 Background

At Norwegian Institute for Air Research emission surveys for pollutants in Oslo have been carried out for different years. Based on these surveys, the average pollutant levels have been modelled in 500x500 m grid squares. For the REACH case study two different pollution scenarios have been selected 1979 and 1995. For the implementation and demonstration of CorrCost as a part of the management tool in REACH real material data for 16 historic buildings were used. The selected buildings had a geographical distribution wide enough to get different impact of pollutants to the buildings.

The CorrCost module used is a GIS (geographic information system) based system for modelling material damage either as dose-response functions or lifetime equations. By applying the lifetime equations to the building materials the cost for maintenance, repair and replacement can be calculated. The CorrCost module consists of the following parts:

Definition part: In this part the material types and all existing lifetime equations and dose-response functions will be defined. The environmental parameters are defined and must reflect the parameters observed in the equations used. Further, this part includes information of building types and the statistical amount of materials linked to the building types. Optionally it is possible to use building materials from real buildings. This option is applied in this case study. Standard prices for maintenance and replacement costs for each material are also input in this part.

The CorrCost model part: Based on a grid module for the important air pollutants, this part calculates the material degradation rate for material loss in g/m^3 or thickness reduction in μm in grids. The lifetime module for the materials gives the time between maintenance and repair in years in the same grids. The air pollution map used has been generated by use of a model for long-time average air pollutant concentrations "KILDER" developed at NILU (Gram, 1996).

The materials service life cost part: This part gives the corrosion costs for each grid point based on lifetime equation. It can also give the cost for single buildings or from different regions of the grid area.

3 History of "Kristiania Kvadraturen"

"Kristiania Kvadraturen" is the name of the rectangle blocks of buildings formed when the king Christian IV decided to move the city to the area behind the Akershus Castle after the big city fire in Oslo in 1624. Inside this area to day, 10 buildings from the years 16-1700, protected by law, still exist. Ministry of the Environment in 1979 ratified a plan for protection of 180 younger buildings in the area, and in 1992 a royal decree was given to protect the whole "Kvadraturen" as a national cultural monument specifically for protecting the buildings from the 1900-century. Even if some of these buildings still have been modified for other use, the external facades have generally been kept. Some of the buildings have been destroyed in fires during the past, but as a total the area is still one of the best-preserved areas in Europe concerning buildings representing from classic empire to baroque style.

In Norway the traditional building material have always been wood. However, inside "Kvadraturen" a law, mainly as a fire protection for the city, forbade wooden buildings. The dominating materials used for buildings in the area have been brick, brick with calcareous rendering, stone and half-timbered brick buildings with brick or brick rendered facing.

4 Selection of buildings for damage and maintenance cost evaluation.

The criteria for the selection of buildings to be studied have been as follows:

- The façade material should be a material with known lifetime equation for deterioration. Buildings with calcareous rendering as the main façade material were chosen.
- As many as possible of the buildings from the 1600 and 1700 should be included.
- The buildings should be exposed to different levels of pollutants.

The area "Kvadraturen" and the selected buildings are shown in Figure 1. In total 16 buildings were inspected. 8 of the buildings were built between 1626 and 1800, the remaining were from 1800 to 1914.

Figure 1: The preserve area "Kristiania Kvadraturen" with the inspected buildings marked. (Fortidsminneforeningen, 1996).

The buildings selected were situated in different exposure regions. Two streets have fairly high traffic intensity, Prinsens gate and Rådhusgata. The Rådhusgata was the street with the highest traffic intensity in Oslo up to 1990. The buildings along Dronningens gate are less influenced from the traffic. The Bankplassen square in front of the old Bank of Norway has the lowest traffic intensity of the area. This square belongs to Kvadraturen but belong to a special protected area around the old Bank of Norway. One building just outside the protected area Grensen 1 was included because it is the most original building downtown in Oslo.

5 Short history of the inspected buildings

The sources for the short history given for the buildings are two Norwegian books (Fortidsminneforeningen, 1996 and Bruun 1999), where a more complete description of the buildings and their history is given. The description given in the following chapters is following the numbering given in Figure 1.

5.1 Rådhusgata 19, the annex

Photo: Thor Ofstad

The building was built in the 1640-ies and is the oldest half-timbered house with calcareous rendering in Oslo. The house has one floor and an attic. It was originally a private home, but has had different owners and different use during the history. The house is to day used for exhibitions by Young Artist Society (UKD).

5.2 Nedre Slottsgate 1

Photo: Thor Ofstad

The building was built in 1641 as the city hall of Christiania (Oslo), and was used as city hall up to 1733. A wing was attached in 1850-ies as a restaurant. The house has two floors and an attic. The building was partly destroyed by a fire in 1996 and has been restored to its original construction. The owner of today is the City of Oslo and the building contains one museum and one restaurant.

5.3 Bankplassen 1A

Foto: Thor Ofstad

The building was built in 1895 as an apartment house in new baroque style. The house has nice décor and mixture of materials used in the façade. The building is private owned and is used mostly as offices today.

5.4 Bankplassen 1B

Photo: Thor Ofstad

The low part of the building is facing the square and was built in 1760 with one floor and an attic. The wing towards the street (Kirkegata) was built in 1814 with two floors and an attic. The building is private owned and contains the oldest existing restaurant in Oslo, Engebret Café from 1857. The building was restored in its old style after a fire in 1921.

5.5 Rådhusgata 7

Photo: Thor Ofstad

The building was originally built as a private home in 1647. The oldest part is facing Dronningens gate. The extension to Rådhusgata was built in 1750 when the building became the second city hall of Oslo. The building was the city hall from 1733-1843. It included the jail from 1745-1866 and became the police station from 1866-1963. The owner today is the City of Oslo.

5.6 Tollbugata 2

Photo: Thor Ofstad

The oldest part to the north was built in empire stile as the stock exchange of Oslo in 1826-28. An extension in the same style was built in 1909-10. The building still contains the stock exchange of Oslo.

5.7 Dronningens gate 11

Photo: Thor Ofstad

The building was built as a private home. The basement is from 1624 and the building was finished with two floors in 1647. It was private owned up to 1843, and a large private re-construction took place in 1758. The building was bought by the City of Oslo in 1843 and was used as offices up to now. For a short period it contained the National Library of Norway

5.8 Dronningens gate 13/13A

Photo: Thor Ofstad

The building has gone through a lot of re-constructions during the history. It was first built as a private home in 1643 and rebuilt in 1762. In 1828 it was again rebuilt and became Hotel du Nord. The hotel had a fire in 1859. The facade today is more or less the same as after the hotel was rebuilt in 1860. In 1899 the building was reconstructed to offices and one floor was added. The building is private owned and the user today is The Norwegian Directorate for Cultural Heritage.

5.9 Tollbugata 10

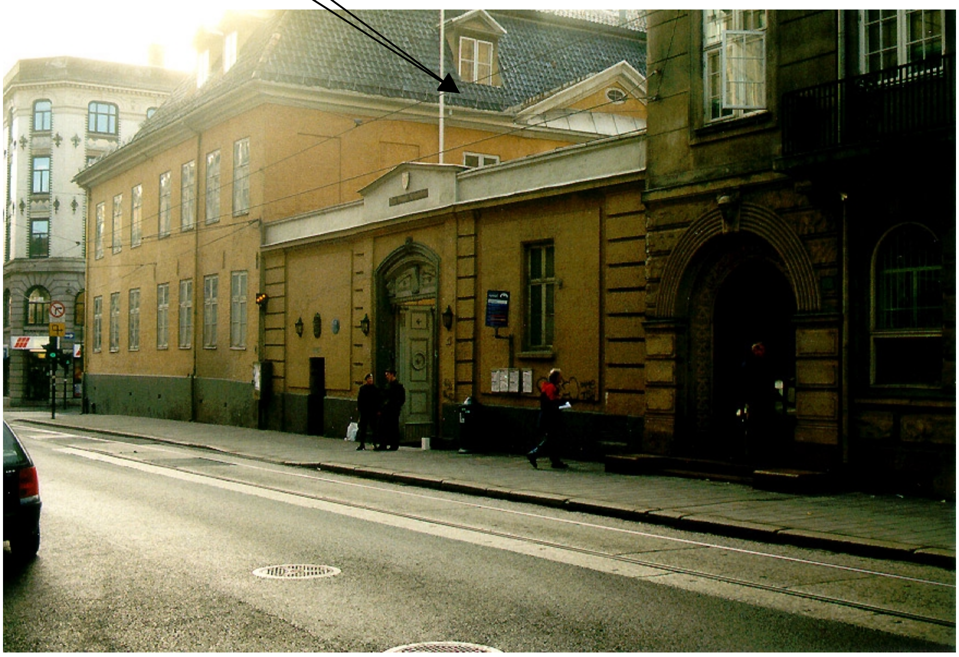

Photo: Thor Ofstad

The property has been used as private home from 1624 to 1802. The building, as it looks to day, is from 1765. From 1802 the building has belonged to the Norwegian Army, mainly as The Officers School. From 1979 it has been a representation house for the Army.

5.10 Dronningens gate 15

The building was built as The National Post Office in 1914-18 and 1921-24. The building is in a national baroque style. It was the main post distribution central up to 1995 and it is still one of the largest post offices in Norway (see the picture for Prinsens gate 5).

5.11 Prinsens gate 5

Photo: Thor Ofstad

A fire destroyed the whole block between Dronningens gate and Kirkegata in 1858. The building of today was built in 1860, but some re-constructions have been carried out. The fourth floor was re-constructed in 1876 with larger windows. The ground floor was changed both in 1891 and 1932, and modern windows were installed in 1980. The house is private owned and is used for shops and offices.

5.12 Prinsens gate 7

Photo: Thor Ofstad

The building was built in 1860 as a private house with a repair shop in the backyard. A big re-construction was made in 1985. Only the façade was kept more or less as original. This re-construction was one of the cases that started the process for the later protection act for the area. The building is private owned and is used for offices.

5.13 Prinsens gate 9

The building as it appears today was built as a bank in 1898 in a neo renaissance style and changed to offices in 1922. The building was a part of the big re-construction that took place in 1985 (see Prinsens gate 7, left part). The building is private owned and is used for offices.

5.14 Prinsens gate 11

The building was built in 1858 just after the big fire. The façade in the ground floor was changed in 1896 and again in 1930. The roof construction was changed in the big re-construction of the area in 1985. The building is private owned and used for offices and with shops in the ground floor.

5.15 Kirkegata 24

Photo: Thor Ofstad

The building was built as a bank in 1858-60 in neo renaissance style. The building also had offices for the Norwegian Telegraph. In 1926 the fourth and fifth floor were added. The building is private owned and contains shops and offices today.

5.16 Grensen 1

Photo: Thor Ofstad

The part of the building facing the street, Grensen, was built in 1700. The building is just outside the “Kristiania Kvadraturen”, but is facing one of the most important streets for the traffic between east and west in Oslo, even in that time of the history. Originally it was a private home, but was changed to a hostel in 1860-ies and two wings were added. The hostel has included some sort of restaurant from 1863. A restoration back to its original style was carried out between 1890 and 1920. The house is private owned today and is used as a restaurant.

6 Building materials

An inspection of the 16 buildings was carried out, and the amount of outer materials used in the buildings were defined and measured. The inspections were performed in October and November 1999. The inspection was only looking at materials facing the street. This restriction was made since the protection of buildings from the 1900 century only covers the façade and therefore the backyard in many of the houses was completely rebuilt. The wall and roof materials as well as windows, doors, gutters, ventilation pipes and chimneys were measured. The foundation wall was also inspected and measured. Table 1 includes all materials observed where either lifetime equations exist or where the amount of materials was substantial like glass. The total amount of materials reported in Table 1 was 19 261 m^2. In addition, small amount of other materials like reinforced plastic and lead was also observed, in total 203 m^2.

Table 1: Material types and amounts for the 16 inspected houses in m^2.

Number	Address	Tile	Tile glazed	Wood painted	Rende ring	Renderin g Painted	Stone mainly granite	Glass	Aluminium painted	Galv. steel	Galv. steel painted	Zinc	copper	Pain ted steel	St. Steel	Brick
1	Rådhusgt. 19 annex		139	21	2	80	3	20			3	12		1		
2	N. Slottsgt 1		242	35		366		72			26	16	2	1		
3	Bankpl. 1A			15	1	290 10 decor	16	85		9	79		6	42		15
4	Bankpl 1B	161		8		174		59		5	41		3	2		
5	Rådhusgt.7		175	30	2	318	1	63		6	48			1		
6	Tollbugt.2		866	31	28	1495	49	182	5	19		4	857	48		
7	Dronningensgt. 11	130		23	3	116		45			16			2		
8	Dronningensgt. 13			21		226	12	139	2	8	315		1	16		
9	Tollbugt. 10	340		101	21	742		123			53	18	15	12		
10	Dronningensgt 15		1055	88		1864	1062	745			39		424 12 brass	75		
11	Prinsensgt 5			14	38	370		118	24	4	242				20	
12	Prinsensgt 7			7		256	8	65		3			70			
13	Prinsensgt 9			5		225	4	51		3			145 4 brass	1		
14	Prinsensgt 11			5		186		58	3	1			38	1	2	
15	Kirkegt. 24		213	22		984	32	191	10		135		16	24		
16	Grensen 1	264	184	103	13	511		154	1	20	49		4	3		
	Total	895	2874	529	108	8203 10 decor	1187	2170	45	78	1046	50	1581 16 brass	229	22	15

7 Environmental data for Oslo area

Oslo is situated at the head of the narrow Oslo fjord. The city is surrounded by high hills (400-500 m) creating inversion periods during the winter where cold and polluted air in the lower part of the city is trapped by warmer air above.

The expansion of apartment houses heated with fuel oil and local industry using heavy fuel oil gave increased pollution problems and reached a top level in the 1960-ies. Particularly the winter situation could be very polluted. The main problem was SO_2 and soot. The environmental condition in Oslo has been drastically improved during the last part of the century. This is illustrated in Figure 2 where the winter pollutant levels for SO_2 measured from 1958 to 1965 and later from 1969 and up to these days is shown.

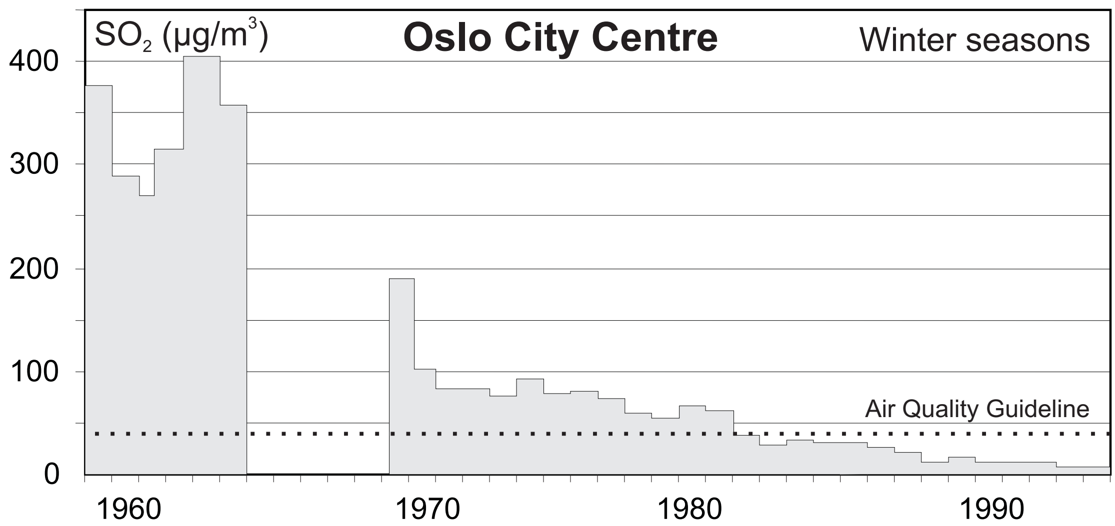

Figure 2: Winter concentration of SO_2 in Oslo city from 1958 to 1995. The Norwegian recommended Air Quality Guideline is given (Larssen, 1998).

As seen in Figure 2 a great improvement has been obtained for the SO_2 pollution during the last part of the 20^{th} century. The main pollution problem in Oslo today is linked to particles from traffic and heating with wood stoves during the winter and NO_2 mainly linked to the traffic. Before 1990 the main traffic between east and west went through Rådhusgata. In 1990 a tunnel was built to reduce the traffic impact in the old part of the city.

NILU has measured and modelled the air pollution situation in several studies the last 30 years. By combining these results with the CorrCost model for estimating corrosion rates and cost, scenarios for documentation of CorrCost as a part of the REACH management tool can be shown.

The first detailed emission study of the Oslo region was made in 1970 (Grønskei, 1973), and a more detailed study in 1979 (Grønskei, 1982). Later another study was carried out in 1989 and the latest was in 1995. To illustrate the damage costs for the inspected buildings today and the benefits caused by the reduced sulphur dioxide concentration in the air during this period, pollution levels, the resulting lifetime and the yearly costs are calculated for the years 1979 and 1995.

The concentration maps for Oslo are given in 500x500 m grid squares for SO_2 and NO_2. A modelling programme, KILDER, was used for creating the input parameters. KILDER is designed for calculation long time average values based on emission data from different emission sources and meteorological parameters (Gram, 1996). The results were imported into the CorrCost model for further calculation of lifetime and corrosion costs and for presentation of the pollution levels as maps. Figure 3 gives the SO_2 concentrations as iso-lines for 1979 and Figure 4 for 1995.

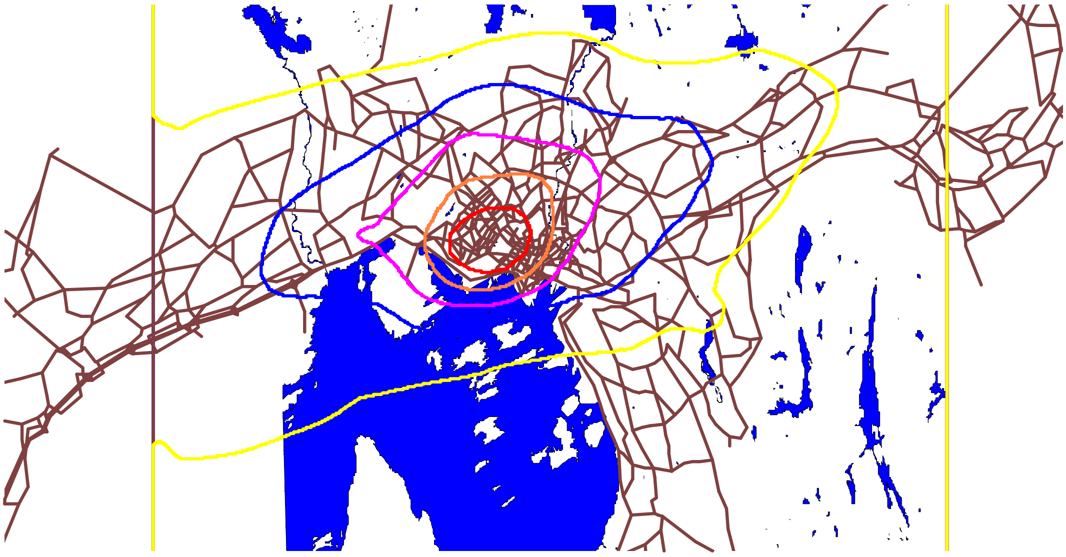

Figure 3: SO_2 concentrations for Oslo in 1979. Iso-lines for 5, 25, 35, 45, 55 $\mu g/m^3$.

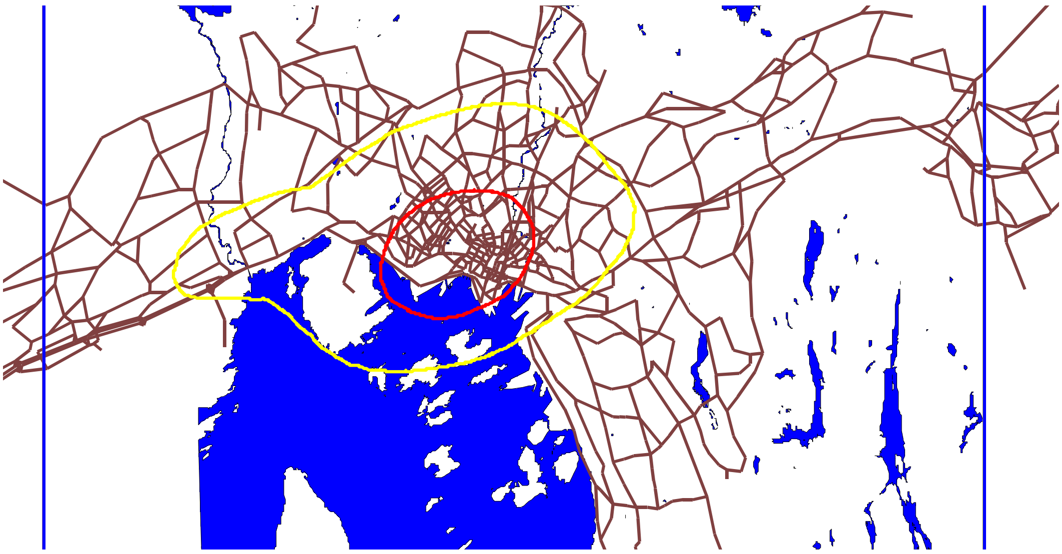

Figure 4: SO_2 concentrations for Oslo in 1995. Iso-lines for 3 and 5 $\mu g/m^3$.

For the corrosion rate and lifetime calculations the best available equations from the ECE/materials programme (Tidblad et al, 1998) and the MOBAK project (Andersson, 1994) were applied, see Table 2 and Table 3.

Table 2: Dose-response equations used for the CorrCost calculations.

Material	Dose-response function
Weathering steel	$\ln(ML) = 3.5 + 0.33\ln(t) + 0.13\ln[SO_2] + 0.020Rh + f(T)$ $f(T) = 0.059(T-10)$ when $T \le 10°C$, $-0.036(T-10)$ otherwise
Zinc and galvanised steel	$ML = 1.4[SO_2]^{0.22}e^{0.018Rh}e^{f(T)}t^{0.85} + 0.029Rain[H^+]t$ $f(T) = 0.062(T-10)$ when $T \le 10°C$, $-0.021(T-10)$ otherwise
Aluminium	$ML = 0.0021[SO_2]^{0.23}Rh \cdot e^{f(T)}t^{1.2} + 0.000023Rain[Cl^-]t$ $f(T) = 0.031(T-10)$ when $T \le 10°C$, $-0.061(T-10)$ otherwise
Copper	$ML = 0.0027[SO_2]^{0.32}[O_3]^{0.79}Rh \cdot e^{f(T)}t^{0.78} + 0.050Rain[H^+]t^{0.89}$ $f(T) = 0.083(T-10)$ when $T \le 10°C$, $-0.032(T-10)$ otherwise
Cast Bronze	$ML = 0.026[SO_2]^{0.44}Rh \cdot e^{f(T)}t^{0.86} + (0.029Rain[H^+] + 0.00043Rain[Cl^-])t^{0.76}$ $f(T) = 0.060(T-11)$ when $T \le 11°C$, $-0.067(T-11)$ otherwise
Limestone	$R = (2.7[SO_2]^{0.48}e^{-0.018T} + 0.019Rain[H^+])t^{0.96}$
Sandstone and spongilit	$R = (2.0[SO_2]^{0.52}e^{f(T)} + 0.028Rain[H^+])t^{0.91}$ $f(T) = 0$ when $T \le 10°C$, $-0.013(T-10)$ otherwise

Table 3: The lifetime equations used for the CorrCost calculations.

Material	Damage function
Zinc and galvanised steel[a]	$t = [\ 0.14[SO_2]^{0.26}e^{0.021Rh}e^{f(T)}/R^{1.18} + 0.0041Rain[H^+]/R\ ]^{-1}$ $f(T) = 0.073(T-10)$ when $T \le 10°C$, $-0.025(T-10)$ otherwise
Copper[b]	$t = [\ 0.00018[SO_2]^{0.34}[O_3]^{0.84}Rh^{1.06} \cdot e^{f(T)}/R^{1.06} + 0.0080(Rain[H^+]/R)^{0.93}\ ]^{-1/0.83}$ $f(T) = 0.028(T-10)$ when $T \le 10°C$, $-0.054(T-10)$ otherwise
Limestone[c]	$t = [\ R/(2.7[SO_2]^{0.48}e^{-0.018T} + 0.019Rain[H^+])\ ]^{1/0.96}$
Sandstone[c] and spongilit[c]	$t = [\ R/(2.0[SO_2]^{0.52}e^{f(T)} + 0.028Rain[H^+])\ ]^{1/0.91}$ $f(T) = 0$ when $T \le 10°C$, $-0.013(T-10)$ otherwise
Brick masonry	$t = 70 \pm 30$ ($SO_2 \le 10\ \mu g/m^3$), 65 ± 30 otherwise
Rendering	$t = 1000/(\ 15.5+0.124[SO_2]+0.013Rain[H^+]\ )$
Bitumen felt	$t = 1000/(\ 47.7+0.327[SO_2]+0.080Rain[H^+]\ )$
Concrete	$t = 50 \pm 30$ ($SO_2 \le 10\ \mu g/m^3$), 40 ± 30 otherwise
Paints on steel	$t = [\ 5/(0.033[SO_2] + 0.013Rh + f(T) + 0.0013Rain[H^+])\ ]^{1/0.41}$ $f(T) = 0.015(T-11)$ when $T \le 11°C$, $-0.15(T-11)$ otherwise
Paints on galvanised steel	$t = [\ 5/(0.0084[SO_2] + 0.015Rh + f(T) + 0.00082Rain)\ ]^{1/0.43}$ $f(T) = 0.040(T-10)$ when $T \le 10°C$, $-0.064(T-10)$ otherwise
Paints on aluminium	t = 1000/(32.2+0.107[SO2]+0.027Rain[H+])
Repainted aluminium	t = 1000/(62.9+0.37[SO2]+0.095Rain[H+])
Paints on rendering	$t = 1000/(\ 18.8+0.278[SO_2]+0.070Rain[H^+]\ )$

Paints on wood $t = 1000/(87.5+1.03[SO_2]+0.260Rain[H^+])$

[a]R is equal to 20 µm for maintenance of galvanised sheet, 30 µm for replacement of galvanised sheet and wire and 60 µm for maintenance of galvanised profile.
[b]R is equal to 100 µm for copper roofing of 800 µm total thickness.
[c]R is equal to 5000 µm for large constructions and 1000 µm for ornaments and inscriptions

In equations where O_3 is needed these values were generated from the NO_2 values using the equation:

$O_3= 60.5*\exp(-0.014* NO_2)$

The rest of the parameters in the equations were kept as constants in he calculations. The parameters used for Oslo are:
Yearly mean temperature: 7.7 C
Yearly mean relative humidity: 71%
Precipitation: 600 mm
H^+ concentration: 0.05 mg/l in 1979 and 0.025 mg/l in 1995
Cl^- concentration: 1.7 mg/l.

8 Corrosion data for Oslo area

The CorrCost module of the Reach management tool was used for calculating the corrosion rates in Oslo. The corrosion rates for materials where dose-response equations exist were calculated for both 1979 and 1995. The corrosion results and the % reduction during the period are given in Table 4, and an example of the corrosion variation of zinc through the city is given in Figure 5.

Table 4: The corrosion rates and percentage reduction for selected materials for 1979 and 1995.

Material	Min. and max. corrosion 1979 g/m^2	Min. and max. corrosion 1995 g/m^2	% max reduction corrosion
Galvanised steel / zinc	5.8-11.6	4.8-7.1	39
Copper	6.2-10.2	4.0-5.0	51
Bronze	3.3-10.6	2.4-4.4	58.5
Aluminium	0.18-0.38	0.16-0.24	36.8
Weathering steel	129-204	120-153	25
Limestone	3.7-17.5	2.6-6.2	64.6
Calcareous sandstone	3.6-17.8	2.4-5.8	67.4

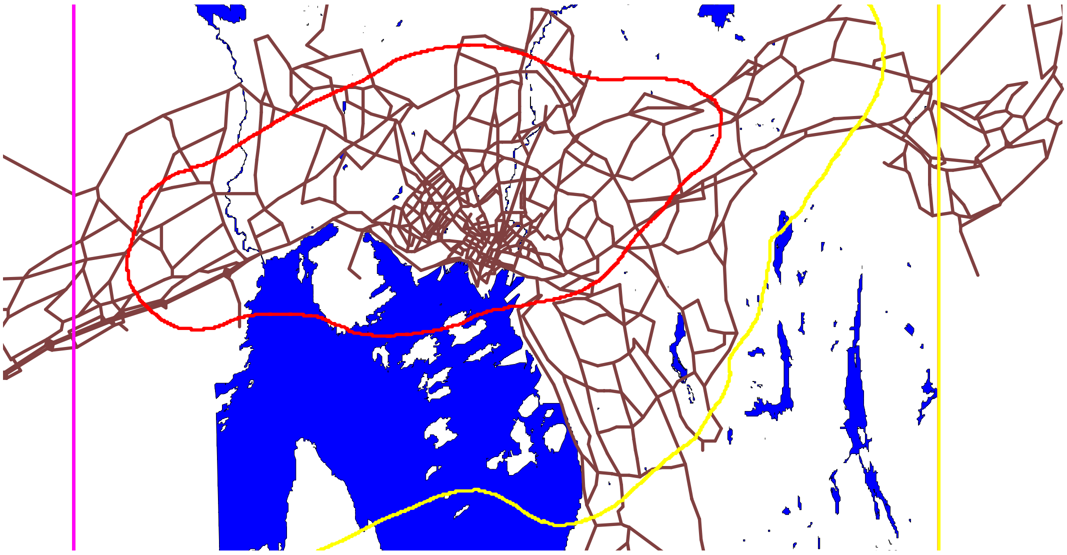

Figure 5: Zinc corrosion in Oslo in 1979. Iso-lines for 7 and 9 g/m^2.

9 Lifetime data for the Oslo region

The CorrCost module was also used for calculating the lifetime for materials in Oslo. The lifetimes for both 1979 and 1995 scenarios were calculated. The lifetime results and the % reduction during the period are given in Table 5, and an example of the corrosion variation for galvanised steel through the city is given in Figure 6.

Table 5: The lifetime for materials in years used in the cost calculations on the inspected buildings for the scenarios 1979 and 1995.

Material	Min. and max. lifetime 1979 in years	Min. and max. lifetime 1995 in years	% max increased lifetime
Painted wood	6.3-10.3	10.2-10.8	62
Copper	165-282	400-512	142
Painted rendering	26-42	46-50	77
Rendering	42-62	61-63	45
Painted galv. sheet	7.3-11.2	11.1-11.7	52
Galv. sheet	28-59	50-76	79
Painted steel	5.3-9.4	8.9-9.5	68
Painted Al	25.5-30.5	30.0-30.6	15
Tiles	65-70	70	8
Bricks	65-70	70	8

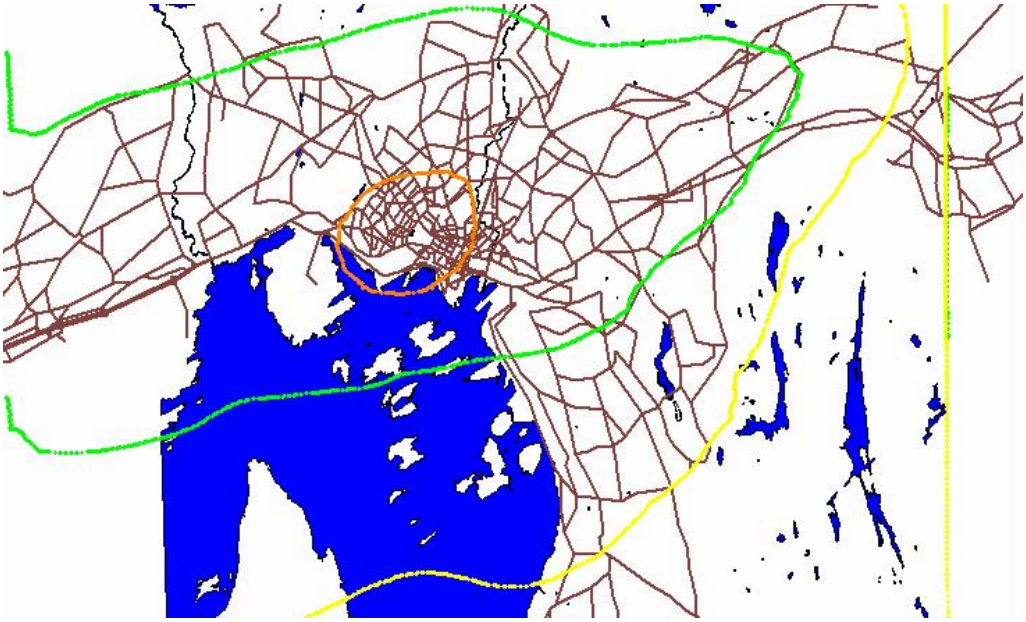

Figure 6: Lifetime for galvanised steel in 1979. The lifetime is defined as the time where the zinc coating was corroded away. The iso-lines are given for 30, 40 and 50 years. 30 years is in the centre of Oslo.

10 Cost calculations for the case study buildings

All calculations were carried out by using the CorrCost module of the REACH management tool. For all materials where lifetime equations exist the lifetime for the pollution situation in 1979 and 1995 and for non-polluted (background) situation were carried out. The amount of materials for the case study was taken from Table 1. Out of the total surface area of 19261 m^2, 3648 m^2 or 18.9% was not included in the cost calculation due to lack of lifetime equations. The most important materials without lifetime equations are glass with 11.3% of the total and granite with 6.2%.

The cost calculation in the Oslo study has been carried out by adapting the general maintenance prices used for contractors in Norway in 1994, see Table 6. The exchange rate used for EURO is 1 EURO= 8.2 NOK. For the comparison of the pollution effect and to show the benefits of the emission reduction strategies carried out in Oslo during the last 30 years, two scenarios have been selected. To compare the cost of the pollution impact, the 1994 prices in Table 6 have been used for both for the 1979- and the 1995-scenario.

Table 6: The mean maintenance prices in Norway from 1994 used in this case study (NOK).

Type of material	Treatment	Assumption	Price (kr/m²) Excl. VAT min	max	average	Incl. VAT[1] average
Galvanised steel sheet	maintenance	cleaning + 2 coats of paint	100	200	150	**183**
Galvanised steel sheet	replacement		250	300	275	**336**
Galvanised steel wire	replacement		90	120	105	**128**
Galvanised steel profile	maintenance	cleaning + 2 coats of paint	250	350	300	**366**
Limestone/Cement rendering	replacement	3-tiered new plaster incl. and scaffolding	300	400	350	**427**
Painted rendering	maintenance	repair + 2 coats of original paint	200	300	250	**305**
Copper roofing	replacement	incl. new felt	400	500	450	**549**
Strip-lacquered aluminium	maintenance	cleaning + 2 coats of paint	100	200	150	**183**
Strip-lacquered galvanised steel	maintenance	cleaning + 2 coats of paint	100	200	150	**183**
Painted galvanised steel	maintenance	sandblasting + 3 coats of paint	250	350	300	**366**
Roofing felt	replacement	new covering, two layers	120	200	160	**195**
Painted/stained wood	maintenance	cleaning + 2 coats of paint	60	100	80	**98**
Brick	maintenance	repair, resealing incl. scaffolding	200	400	300	**366**
Concrete	maintenance	repair and painting incl. scaffolding	350	700	525	**641**

[1] 22% in 1994. Our cost calculations are based on these prices.

The cost for each material in each building was calculated in accordance with the equations:

The total cost: $Ct = Q*f/t_t$
The background cost: $Cb = Q*f/t_b$
The pollution cost: $Cp = Q*f/(t_t-t_b)$

Q= the amount of one type of building material for the building in m^2
f= the price for maintenance or repair for the given material in NOK/m^2.
t_t= the lifetime for the given material in the grid square for the building in years.
t_b= the lifetime for the given material in natural ambient air in years.

The buildings in the case study were situated within three different grid squares. Building 1, 2, 3 and 4 are situated in a square where the calculated average of SO_2 concentration was 43.4 $\mu g/m^3$ in 1979. Building 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15 were in a square with SO_2 concentration 36.9 $\mu g/m^3$ and building 16 in a square with SO_2 concentration 43.0 $\mu g/m^3$. In 1979 the in Oslo H^+ concentration had a value of 0.05 mg/l (pH 4,3). The meteorological data was kept constant for the cost calculation in 1979 and 1995. The results for 1979 are given in Table 7-Table 9.

Table 7 gives the yearly cost for maintenance and repair work linked to the pollution situation in 1979. Table 8 gives the cost for 1979 in the city with only the background pollution levels present. The background pollution used for SO_2 is 1 µg/m^3 and for O_3 is 40 µg/m^3 used. This illustrates that cost for maintenance is needed even without pollution. By subtracting the values in Table 8 from the values in Table 7, the part of the costs that is linked to air pollution situation can be estimated. The costs caused by air pollution are shown in Table 9. All values are presented as calculated in the CorrCost module without any rounding off. Only the material facing the street is included. If the whole building should be maintained, substantial higher costs must be expected.

Table 7: Yearly maintenance and repair cost for the façade materials on 16 inspected houses in "Kristiania Kvadraturen" in Oslo based on the pollutant levels in 1979. The prices are given in NOK.

Building no	Paint wood	Paint rendering	Copper	Galv sheet	Paint galv sheet	Paint Al	Tile	Painted steel	Untr. rendering	Brick	Total for each house
1	255.16	681.11	0.00	0.00	23.77	0.00	782.68	59.84	16.60	0.00	1 819.15
2	425.26	3116.08	5.75	0.00	206.02	0.00	1 362.65	59.84	0.00	0.00	5 175.60
3	182.25	2554.17	17.25	44.10	626.00	0.00	0.00	2 513.26	8.30	84.46	6 029.79
5	355.92	2636.20	0.00	28.33	376.12	0.00	985.38	56.58	16.28	0.00	4 454.81
4	97.20	1481.42	8.63	24.50	324.89	0.00	906.55	119.68	0.00	0.00	2 962.86
6	367.78	12393.43	2 483.43	89.70	0.00	32.34	4 876.25	2 715.66	227.96	0.00	23 186.55
7	272.87	961.63	0.00	0.00	125.37	0.00	732.00	113.15	24.42	0.00	2 229.45
8	249.14	1873.52	2.90	37.77	2 468.30	12.94	0.00	905.22	0.00	0.00	5 549.79
9	1198.26	6151.12	43.47	0.00	415.30	0.00	1 914.46	678.91	170.97	0.00	10 572.49
10	1044.03	15452.42	1 263.45	0.00	305.60	0.00	5 940.46	4 243.21	0.00	0.00	28 249.17
11	166.10	3067.27	0.00	18.88	1 896.28	155.25	0.00	0.00	309.37	0.00	5 613.15
12	83.05	2122.22	202.85	14.16	0.00	0.00	0.00	0.00	0.00	0.00	2 422.28
13	59.32	1865.23	0.00	14.16	0.00	0.00	0.00	56.58	0.00	0.00	1 995.29
14	59.32	1541.93	110.12	0.00	7.84	19.41	0.00	56.58	0.00	0.00	1 795.18
15	261.01	8157.28	46.37	0.00	1057.84	64.69	1199.35	1 357.83	0.00	0.00	12 144.37
16	1246.84	4331.03	11.50	97.78	387.67	6.52	2522.59	178.85	107.57	0.00	8 890.34
Total	6323.51	68386.05	4 195.71	369.39	8 221.01	291.15	21 222.37	13 115.18	881.47	84.46	123 090.29

Table 8: Yearly maintenance and repair cost for the façade materials on 16 inspected houses in "Kristiania Kvadraturen" in Oslo by using background pollution levels. The prices are given in NOK.

Building no	Paint wood	Paint rendering	Copper	Galv sheet	Paint galv sheet	Paint Al	Tile	Painted steel	Untr. rendering	Brick	Total for each house
1	194.15	521.62	0.00	0.00	21.65	0.00	726.77	38.58	13.98	0.00	1 464.20
2	323.59	2 386.42	2.72	0.00	187.66	0.00	1 265.31	38.58	0.00	0.00	4 165.70
3	138.68	1 956.08	8.17	19.71	570.19	0.00	0.00	1 620.52	6.99	78.43	2 692.84
5	277.36	2 073.45	0.00	13.14	346.45	0.00	915.00	38.58	13.98	0.00	3 625.39
4	73.96	1 134.53	4.09	10.95	295.92	0.00	841.80	77.17	0.00	0.00	2 361.25
6	286.60	9 747.81	1 167.39	41.62	0.00	30.18	4 527.94	1 852.02	195.70	0.00	15 801.55
7	212.64	756.35	0.00	0.00	115.48	0.00	679.71	77.17	20.97	0.00	1 764.19
8	194.15	1 473.58	1.36	17.52	2 273.55	12.07	0.00	617.34	0.00	0.00	3 972.25
9	933.77	4 838.04	20.43	0.00	382.53	0.00	1 777.71	463.00	146.78	0.00	7 952.50
10	813.59	12 153.79	593.91	0.00	281.49	0.00	5 516.14	2 893.78	0.00	0.00	19 358.92
11	129.43	2 412.50	0.00	8.76	1 746.67	144.88	0.00	0.00	265.60	0.00	4 442.24
12	64.72	1 669.19	95.35	6.57	0.00	0.00	0.00	0.00	0.00	0.00	1 835.83
13	46.23	1 467.06	0.00	6.57	0.00	0.00	0.00	38.58	0.00	0.00	1 519.86
14	46.23	1 212.77	51.77	0.00	7.22	18.11	0.00	38.58	0.00	0.00	1 336.09
15	203.40	6 415.95	21.80	0.00	974.38	60.37	1 113.69	926.01	0.00	0.00	8 789.57
16	952.27	3 331.86	5.45	43.81	353.66	6.04	2 342.40	115.75	90.86	0.00	7 035.48
Total	4 890.76	53 551.01	1 972.45	168.65	7 556.86	271.65	19 706.49	8 835.67	754.85	78.43	97 786.81

Table 9: Yearly maintenance and repair cost for the façade materials on 16 inspected houses in "Kristiania Kvadraturen" in Oslo in1979 caused by air pollution. The prices are given in NOK.

Building no	Paint wood	Paint rendering	Copper	Galv sheet	Paint galv sheet	Paint Al	Tile	Painted steel	Untr. rendering	Brick	Total for each house
1	61.00	159.49	0.00	0.00	2.12	0.00	55.91	21.26	21.26	0.00	302.39
2	101.67	729.66	3.03	0.00	18.37	0.00	97.33	21.26	21.26	0.00	971.32
3	43.57	598.08	9.08	24.39	55.81	0.00	0.00	892.74	892.74	6.03	1 631.02
5	78.56	562.75	0.00	15.18	29.68	0.00	70.38	17.99	17.99	0.00	776.85
4	23.24	346.89	4.54	13.55	28.96	0.00	64.75	42.51	42.51	0.00	524.45
6	81.18	2 645.62	1 316.04	48.08	0.00	2.16	348.30	863.64	863.64	0.00	5 337.28
7	60.23	205.28	0.00	0.00	9.89	0.00	52.29	35.98	35.98	0.00	367.13
8	54.99	399.94	1.54	20.25	194.75	0.86	0.00	287.88	287.88	0.00	960.20
9	264.49	1 313.08	23.03	0.00	32.77	0.00	136.75	215.91	215.91	0.00	2 010.21
10	230.44	3 298.62	669.54	0.00	24.11	0.00	424.32	1 349.43	1 349.43	0.00	5 996.47
11	36.66	654.77	0.00	10.12	149.61	10.37	0.00	0.00	0.00	0.00	905.31
12	18.33	453.03	107.49	7.59	0.00	0.00	0.00	0.00	0.00	0.00	586.45
13	13.09	398.17	0.00	7.59	0.00	0.00	0.00	17.99	17.99	0.00	436.85
14	13.09	329.15	58.35	0.00	0.62	1.30	0.00	17.99	17.99	0.00	420.51
15	57.61	1741.33	24.57	0.00	83.46	4.32	85.67	431.82	431.82	0.00	2 428.79
16	294.57	999.17	6.05	53.97	34.00	0.49	180.18	63.10	63.10	0.00	1 648.25
Total	1 432.75	14 835.04	2223.26	200.73	664.15	19.50	1 515.88	4 279.51	4 279.51	6.03	25 303.47

The calculated yearly costs per square meter for the inspected materials in 1979 are shown in Table 10. The values derive from Table 7 by dividing the cost with area in Table 1.

Table 10: Calculated yearly maintenance cost per square meter based on the pollution situation in 1979.

Materials	Yearly maintenance prices (NOK/m^2)
Painted wood	11.95
Painted rendering	8.33
Rendering	8.16
Copper	2.65
Galv. steel	4.74
Painted galv. steel	7.86
Painted Al	6.47
Painted steel	57.27
Tile	5.63
Brick	5.63
All materials	6.39

The same cost calculation as for the 1979 scenario was carried out for the 1995 situation. In 1995 the SO_2 concentrations in the same grid squares as in 1979 were reduced by a factor of about 7 to 6.4 µg/m^3, 5.8 µg/m^3 and 6.2 µg/m^3 respectively. The H+ concentration was reduced to 0.025 mg/l while the other parameters were the same. The yearly cost of corrosion in 1995 is given in Table 11, the yearly cost in the background situation in Table 12 and the cost caused by the remaining air pollution in Table 13.

Table 11: Yearly maintenance and repair cost for the façade materials on 16 inspected houses in "Kristiania Kvadraturen" in Oslo based on the pollutant levels in1995. The prices are given in NOK.

Building no	Paint wood	Paint rendering	Copper	Galv sheet	Paint galv sheet	Paint Al	Tile	Painted steel	Untr. rendering	Brick	Total for each house
1	201.64	527.98	0.00	0.00	21.73	0.00	726.77	41.09	14.08	0.00	1 533.29
2	336.07	2415.49	2.26	0.00	188.30	0.00	1 265.31	41.09	0.00	0.00	4 248.52
3	144.03	1979.91	6.78	26.25	572.14	0.00	0.00	1 725.89	7.04	78.43	4 540.48
5	286.29	2082.87	0.00	17.11	346.83	0.00	915.00	40.80	14.02	0.00	3 702.93
4	76.82	1148.35	3.39	14.59	296.93	0.00	841.80	82.19	0.00	0.00	2 464.06
6	295.83	9792.12	950.76	54.20	0.00	30.40	4 527.94	1 958.42	196.25	0.00	17 805.92
7	219.49	759.79	0.00	0.00	115.61	0.00	679.71	81.60	21.03	0.00	1 877.23
8	200.40	1480.28	1.11	22.82	2 276.09	12.16	0.00	652.81	0.00	0.00	4 645.67
9	963.85	4860.04	16.64	0.00	382.96	0.00	1 777.71	489.60	147.19	0.00	8 638.00
10	839.79	12209.04	483.70	0.00	281.80	0.00	5 516.14	3 060.03	0.00	0.00	22 390.50
11	133.60	2423.47	0.00	11.41	1 748.62	145.93	0.00	0.00	266.34	0.00	4 729.37
12	66.80	1676.78	77.66	8.56	0.00	0.00	0.00	0.00	0.00	0.00	1 829.79
13	47.72	1473.73	0.00	8.56	0.00	0.00	0.00	40.80	0.00	0.00	1 570.80
14	47.72	1218.28	42.16	0.00	7.23	18.24	0.00	40.80	0.00	0.00	1 374.42
15	209.95	6445.11	17.75	0.00	975.47	60.80	1 113.69	979.21	0.00	0.00	9 801.98
16	986.67	3362.67	4.57	57.86	354.56	6.09	2 342.40	122.94	91.37	0.00	7 329.12
Total	5 056.66	53855.90	1 606.79	221.35	7 568.26	273.62	19 706.49	9 357.28	757.32	78.43	98 482.09

Table 12: Yearly maintenance and repair cost for the façade materials on 16 inspected houses in "Kristiania Kvadraturen" in Oslo by using background pollution levels. The prices are given in NOK.

Building no	paint wood	paint rendering	copper	galv sheet	paint galv sheet	paint Al	tile	Painted steel	Untr. rendering	brick	total for each house
1	190.22	491.17	0.00	0.00	21.27	0.00	726.77	38.39	13.51	0.00	1 481.33
2	317.03	2 247.11	1.94	0.00	184.32	0.00	1 265.31	38.39	0.00	0.00	4 054.12
3	135.87	1 841.90	5.83	17.18	560.06	0.00	0.00	1 612.45	6.75	78.43	4 258.47
5	271.74	1 952.41	0.00	11.45	340.29	0.00	915.00	38.39	13.51	0.00	3 542.80
4	72.47	1 068.30	2.91	9.54	290.67	0.00	841.80	76.78	0.00	0.00	2 362.47
6	280.80	9 178.78	832.36	36.27	0.00	29.93	4 527.94	1 842.80	189.13	0.00	16 918.01
7	208.34	712.20	0.00	0.00	113.43	0.00	679.71	76.78	20.26	0.00	1 810.73
8	190.22	1 387.56	0.97	15.27	2 233.17	11.97	0.00	614.27	0.00	0.00	4 453.43
9	914.87	4 555.62	14.57	0.00	375.74	0.00	1 777.71	460.70	141.85	0.00	8 241.06
10	797.12	11 444.31	423.47	0.00	276.49	0.00	5 516.14	2 879.37	0.00	0.00	21 336.89
11	126.81	2 271.67	0.00	7.64	1 715.64	143.67	0.00	0.00	256.68	0.00	4 522.11
12	63.41	1 571.75	67.99	5.73	0.00	0.00	0.00	0.00	0.00	0.00	1 708.87
13	45.29	1 381.42	0.00	5.73	0.00	0.00	0.00	38.39	0.00	0.00	1 470.83
14	45.29	1 141.98	36.91	0.00	7.09	17.96	0.00	38.39	0.00	0.00	1 287.61
15	199.28	6 041.42	15.54	0.00	957.07	59.86	1 113.69	921.40	0.00	0.00	9 308.25
16	932.99	3 137.36	3.89	38.18	347.38	5.99	2 342.40	115.17	87.81	0.00	7 011.17
total	4 791.76	50 424.95	1 406.37	146.99	7 422.62	269.38	19 706.49	8 791.67	729.51	78.43	93 768.16

Table 13: Yearly maintenance and repair cost for the façade materials on 16 inspected houses in "Kristiania Kvadraturen" in Oslo in 1995 caused by air pollution. The prices are given in NOK.

Building no	Paint wood	Paint rendering	Copper	Galv sheet	Paint galv sheet	Paint Al	Tile	Painted steel	Untr. rendering	Brick	Total for each house
1	11.42	36.80	0.00	0.00	0.46	0.00	0.00	2.70	0.57	0.00	51.95
2	19.03	168.38	0.32	0.00	3.97	0.00	0.00	2.70	0.00	0.00	194.40
3	8.16	138.02	0.96	9.07	12.07	0.00	0.00	113.45	0.29	0.00	282.00
5	14.55	130.46	0.00	5.66	6.54	0.00	0.00	2.41	0.51	0.00	160.13
4	4.35	80.05	0.48	5.04	6.26	0.00	0.00	5.40	0.00	0.00	101.58
6	15.03	613.34	118.40	17.93	0.00	0.47	0.00	115.62	7.12	0.00	887.92
7	11.15	47.59	0.00	0.00	2.18	0.00	0.00	4.82	0.76	0.00	66.50
8	10.18	92.72	0.14	7.55	42.92	0.19	0.00	38.54	0.00	0.00	192.24
9	48.98	304.41	2.07	0.00	7.22	0.00	0.00	28.91	5.34	0.00	396.93
10	42.67	764.73	60.23	0.00	5.31	0.00	0.00	180.66	0.00	0.00	1053.61
11	6.79	151.80	0.00	3.77	32.98	2.26	0.00	0.00	9.67	0.00	207.26
12	3.39	105.03	9.67	2.83	0.00	0.00	0.00	0.00	0.00	0.00	120.92
13	2.42	92.31	0.00	2.83	0.00	0.00	0.00	2.41	0.00	0.00	99.97
14	2.42	76.31	5.25	0.00	0.14	0.28	0.00	2.41	0.00	0.00	86.81
15	10.67	403.70	2.21	0.00	18.40	0.94	0.00	57.81	0.00	0.00	493.72
16	53.68	225.31	0.69	19.68	7.18	0.10	0.00	7.77	3.55	0.00	317.96
Total	264.90	3 430.96	200.42	74.36	145.63	4.24	0.00	565.61	27.81	0.00	4 713.93

Table 14: Calculated yearly maintenance costs per square meter based on the pollution situation in 1995.

Materials	Yearly maintenance prices (NOK/m^2)
Painted wood	9.56
Painted rendering	6.56
Rendering	7.01
Copper	1.01
Galv. steel	2.84
Painted galv. steel	7.24
Painted Al	6.08
Painted steel	40.86
Tile	5.23
Brick	5.23
All materials	5.11

11 Conclusions

By comparing the total cost for maintenance and repair work in Table 7 with the part that can be linked to the man-made pollutants in Table 9, we can see that in 1979 pollution covered 20.5% of the total costs. However, when we look at the same data for 1995 the pollution covered only 4.8% of the total costs, see Table 11 and Table 13.

In Table 15 we have compared some of the results from the two scenarios. The results are given both in EURO and NOK.

The yearly cost reduction for maintenance and repair can be achieved by comparing the results from Table 7 with the results from Table 11. The savings obtained during the period 1979 to 1995 are 20%. The main benefits, 15.9%, have come from reduction of the local pollution sources while the rest comes from the long-range pollution transport.

Even without local air pollution, building materials will need repair. This is illustrated by the background pollution calculations. The difference in the background pollution costs between 1979 and 1995, 4.1%, is caused by the change in the rain acidity. In 1979 the average pH in rain in the Oslo area was 4.3 while pH of 4.6 was observed in 1995.

The local emission reduction strategies for Oslo have reduced the pollution impact on material cost considerably. In Table 15 we can see that the part linked to the local air pollution has been reduced with 81.4%.

The highest cost reduction can be observed for copper roofing while the lowest percentage reduction is found for painted Al.

Table 15: Comparison of some important data for the 1979 and 1995 scenarios.

	Scenario 1979	Scenario 1995	Cost reduction in %
Total cost for inspected materials Table 7 and 11.	123 090 NOK/year 15 010 EURO/year	98 482 NOK/year 12 010 EURO/year	20
Total cost for inspected materials with background pollution. Table 8 and 12.	97 787 NOK /year 11 925 EURO/year	93 768 NOK/ year 11 435 EURO/year	4.1
Total cost caused by air pollution in Oslo. Table 9 and 12.	25 303 NOK/year 3 085 EURO/year	4 714 NOK/year 575 EURO/year	81.4
Average yearly cost per square meter for all materials. Table 10 and 14.	6.39 NOK/year 0,78 EURO/year	5.11 NOK/year 0.62 EURO/year	20
Highest yearly material cost per square meter, painted steel. Table 10 and 14.	57.27 NOK/year 6.98 EURO/year	40.86 NOK/year 4.98 EURO/year	28.7
Lowest yearly material cost per square meter, copper roofing. Table 10 and 14.	2.65 NOK/ year 0.32 EURO/year	1.01 NOK/year 0.12 EURO/year	61,9
Lowest yearly benefit for material cost per square meter, painted Al. Table 10 and 14.	6.47 NOK/ year 0.79 EURO/year	6.08 NOK/year 0.74 EURO/year	6

The highest cost for maintenance is by far calculated for painted steel. This is because of the low lifetime calculated and the high maintenance prices for the work. The equation used is based on experiences from inspection of buildings. Today it is possible to use paint systems for steel with much longer lifetime and this will reduce the cost per square meter drastically. However, it is obvious that material with low lifetime and high price for maintenance get high costs in the calculations. This is true for all painted materials. Copper roofing gave the lowest yearly costs even if the material is expensive. This is because the lifetime obtained in our calculations is very long, 165-282 years in 1979 and 400-512 in 1995.

The CorrCost module has been applied for corrosion cost calculation in the "Kristiania" case study for the REACH project. By the use of the module, the corrosion rates and lifetime for materials have been estimated for two different pollution scenarios. The variation in the results across the city of Oslo can be shown geographically since CorrCost is a GIS (Geographic Information System) based module. This is illustrated in the case study. Real amount of materials has been obtained for 16 buildings in the old part of Oslo. The materials used are limited to the building parts phasing the street canyons. Based on the amount of materials, the lifetime between maintenance and repair, the cost for the repair and the yearly cost for the maintenance and repair has been calculated. The use of CorrCost as a management tool has been demonstrated. By subtracting the background pollution scenario from the real values inside a city, the cost caused by the air pollution can be estimated. By comparing the results from different years, the benefits for the lifetimes and maintenance costs for buildings inside the city can be estimated and compared with the reduction strategies that have been carried out during that time.

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ABSTRACT
The old part of Oslo, "Kristiania Kvadraturen", has been used as a case study for the "REACH management tool". The study shows that the CorrCost module in the management tool is able to calculate the corrosion rate, lifetime and cost for building materials based on the impact of the environment. Two scenarios have been tested, and the benefit in the cost from the emission reduction strategies carried out during the time has been illustrated. The case study has shown that the CorrCost module can be a useful part of an ecomonic management tool for authorities dealing with air pollution control and cultural heritage.

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