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Conservation-restoration costs for limestone façades due to air pollution in Krakow, Poland, meeting European target values and expected climate change

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ABSTRACT

Conservation-restoration costs due to air pollution weathering of limestone façades in the city of Krakow, Poland, were assessed. For the air pollution situation in 2013-15, and for suggested weathering rate targets for 2020 and 2050, representing two and two point five times the rural background corrosion, the costs due to air pollution were found to be 67%, 49% and 33% of the total cost due to atmospheric chemical weathering. Savings of 27% and 51%, of the total weathering costs, could be obtained by meeting the two targets, representing simultaneous reduction of the SO_2, NO_2 and PM10 concentrations, by 36% and 67% from the 2013–15 level. Six percent reduction would compensate for the expected effect of climate change until the period 2081–2100. The cost increase due to this climate change was found to be three percent of the weathering costs, and four, nine and 16% of the cost due to the air pollution, at the present situation (2013–15), the 2050 and 2020 targets, respectively. Meeting the EU 2008 Air Quality Directive, would give similar savings, as meeting the 2020 target. Absolute costs estimates should be adjusted with the fraction importance of atmospheric chemical weathering for the implementation of conservation-restoration.

1. Introduction

Air pollution is still higher in European urban and industrial areas, than in the rural background. One undesirable effect of air pollution is, that it increases the degradation rate of building façades, and thus the need and costs for conservation-restoration actions. This paper presents estimated results for the excess atmospheric chemical weathering due to air pollution and expected climate change, and the respective increases in the conservation-restoration costs for limestone building façades, in Krakow and the nearby Pieskowa Skała area, 25 km northwest of Krakow, in southern Poland. A "first year of exposure" approach was applied to the calculation of the relative façade weathering rates and cost, assuming that the relative values for the first year weathering in different air quality scenarios represent the weathering rates and costs due to the air pollution over the lifetime between maintenance interventions.

Target values for atmospheric corrosion of materials in Europe has been suggested (ICP 2014; Kucera, 2005). The atmospheric corrosion depends on air pollution and climate factors, and is generally higher in more polluted industrial and urban, than in rural sites. The corrosion can also be enhanced along coasts, due to chloride deposition from the air, and in other natural locations with particular, e.g. volcanic, emission sources. Such non-anthropogenic causes for excessively corrosive atmospheres, will not be considered in this paper. The air pollution in Europe, especially of SO_2, has decreased considerably over the last decennia, with large benefits for built structures, as well as for health and ecosystems (Tidblad et al., 2012). Still, the more populated and, or industrialized areas of Europe have more air pollution than rural areas, often above target values (Guerreiro, de Leeuw, & Foltescu, 2013). Even as the atmospheric corrosion, and the excess conservation-restoration costs due to air pollution, has decreased very much nearly everywhere in Europe, it is still higher in the industrial and urban areas. The city of Krakow in southern Poland is located just southeast of the Silesia area of southwestern Poland. Silesia was an early industrialized area, and has historically experienced very high air pollution. About 25 years ago a sharp decline in the SO_2 air pollution, towards the present quite low values, occurred in Poland and the Czech Republic (EEA, 2013). Krakow is the second largest city in Poland, and the main administrative and cultural centre in southern Poland. The buildings in the old part of the city dates back to the 14th century, and, as the city was spared from damage during the Second

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Fig. 1. Left: The city of Krakow with the Wawel castle (Photo by author). Right: The Pieskowa Skała castle (Photo: Wikimedia commons).

World War, its important architectural history is present nearly everywhere in the city centre. The main wind directions in Krakow are from the southwest and northeast, with domination of winds from the southwest, in the direction from the Czech industrial city and area of Ostrava. Krakow has also had major industrial emission sources close nearby, such as the Nowa Huta iron works and the Solvay soda works, which were however closed or changed to release much less air pollution in the 1980s and 90s. Reductions in emissions, from industry and coal fired power plants, are the main causes for the improved air quality (Miller, 2010). Since approximately 2008, the level of air pollution has however not changed significantly, reflecting emission from sources more generally related to traffic and apartment heating, for which coal is still partly used, in an urban area with high population density (AirBase 2015-1). The Pieskowa Skała renaissance castle is located in a rural setting, in the Ojców national park, 25 km northwest of Krakow (Fig. 1).

2. Methods

Maintenance of buildings includes all building elements, in addition to façades, and is usually understood as immediate repair of protecting elements, such as roofs, gutters, joints etc., if something is broken. The more basic intervention of conservation-restoration, is undertaken after a study of the object, which will consider the effect of air pollution, but also factors such as humidity (which can have different sources than direct atmospheric impact), soluble salts, structural problems, historical and artistic analysis, and so on. An intervention can include different treatments, with very different costs for different objects. The atmospheric impact of humidity and air pollution results in weathering and formation of corrosion crusts on stone façades or other surfaces. Corrosion crusts can work as a protective layer in the first stage of development, when evaporation of water vapor from the stone is still possible. When the crust becomes thick and dense, and dust particles are bonded in the chemical corrosion products, such as, basically, gypsum on limestone, evaporation is reduced, and soluble salts crystallize under the crust. After some time, the outer layer of the stone is detached, and deep damage occurs. Because of this, the removal of crusts is often recommended and implemented during conservation-restoration.

The real long time corrosion on façades is irregular and includes different interacting processes, such as chemical weathering, macroscopic physical delamination caused by salt crystallization, frost or solar heating and the action of biofilms. The result is different kinds of loss and damage that will ultimately determine the reduced state of the façade, before conservation-restoration action (Inkpen, 2004; Brimblecombe, 2004; Smith & Warke, 2004; Prikryl & Viles, 2002; Schaffer, 1985). The actual decision to carry out conservation-restoration action is usually not based on values for the average corrosion depth, but rather on often irregular degradation patterns, a total evaluation of the conservation state of the façade, and the funding opportunities. If funding for the action cannot be found, a reduced condition may have to be accepted, maybe risking the integrity of the façade or increasing future conservation-restoration costs.

A part of the cost of a conservation-restoration intervention on an outdoor limestone façade, monument or structural surface can be attributed to atmospheric chemical weathering and air pollution in excess of the natural background level (B), or in excess of some target value for the corrosion rate or pollution level. In this work, costs due to air pollution are calculated, based on the assumption that a relative (percentage) increase in this intervention cost will be similar to the relative increase in the weathering rate of the facade as simulated by limestone experimental samples, due to an increase in air pollution.

The present conservation-restoration costs due to air pollution, exceeding background or target levels, were calculated, based on values for the air pollutants and climate in 2013-15. Integration of costs over past periods were not performed in this work. European continental atmospheric background levels for air pollutants and climate were used in the calculations, excluding values from high precipitation, e.g. coastal, locations. Conservation-restoration cost savings that could be obtained by reduction of the air pollutants, and the likely changes in costs due to expected future climate change, are presented.

The presented cost estimates (Euro) assume that conservation-renovation cost are fully explained by atmospheric chemical weathering. The cost estimates could therefore, in addition, be adjusted with a factor describing the fraction of the atmospheric chemical weathering rate to the total (actual or perceived) degradation rate, which would determine the timing for the conservation-restoration intervention. The total (actual or perceived) degradation rate would include additional (to chemical weathering) physical and human factors such as e.g. structural damage, aesthetical aspects and funding opportunities.

2.1. Corrosion equations relevant for building façades

The expected atmospheric corrosion of materials due to air pollution can be calculated from dose-response functions, derived from correlation of observed corrosion loss with values for the air pollution and climate.

Watt, Tidblad, Kucera, and Hamilton (2008) reports a dose response equation for the first year weathering of a fresh Portland