ENVIRONMENTAL IMPACT OF WINTER MAINTENANCE WITH SALT

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EXECUTIVE SUMMARY

The scope of this study involved a comprehensive search to assemble information about snow and ice control materials. The review included published information and current practices. The following topics were covered:

- Mobility and safety through winter road maintenance
- Production routes for salt
- Quality of salt
- Storage and logistics of salt
- Consumption of salt
- Performance of salt compared with other inorganic and organic de-icers as well as abrasives
- Environmental impacts of de-icers and abrasives
- Winter service and circular economy,
- Strategies and technologies to optimize the use of salt.

The major objective of this study was to determine the environmental impact of winter maintenance with salt and its alternatives.

It is necessary to maintain mobility and road safety in winter. Therefore, winter maintenance is a systemically important activity. The objective of achieving the same mobility in winter as in the rest of the year can only be achieved through efficient winter service. The total number of accidents on ice and snow has decreased, offering a clear indication of good winter service practices in Europe of which the use of sodium chloride (NaCl, salt) is an essential part.

Europe has an excellent raw material situation. The salt can be obtained from rock salt deposits, sea water and salt lakes. Salt production techniques prevent or minimize any contribution to the contamination of environment, contribute to biodiversity preservation and sustainable use of resources offering the lowest possible ecological footprint. All produced salt types are suitable for application as de-icing salt: Rock salt, evaporated salt, solar salt. The salt industry supplies high quality de-icing salt according to the European standard EN 16811-1.

All products spread on roads have an environmental impact on water, biodiversity, vegetation andsoil, depending on their inorganic or organic nature. The effects of salt are among the best studied because it is the most widely used. It has effects on soils: increase in concentration of sodium in soil tends to leach out K, Ca, and Mg cations, which can result in nutrient deficiencies in certain soil types. Sodium can also enhance the release

of heavy metals from roadside soils, if present. Also surface waters (standing and flowing waters) are affected by winter maintenance activities. This saline pressure can therefore lead to a loss of biodiversity in aquatic ecosystems, depending on the duration, frequency of exposure and sensitivity of the receiving ecosystems or cause significant symptoms on roadside trees (photosynthesis reduction etc.).

In contrast, major groundwater reservoirs remain insensitive to possible salt intake because of their volume and flow rate. The anti-caking agent ferrocyanide in salt is not persistent in the environment and is removed by precipitation, photolysis, volatilization, and biological degradation.

De-icers with high conductivity, like salt, may affect metals such as steel, zinc etc. Correct material selection and corrosion protection means that corrosion damage in vehicles and road infrastructure is no longer a big issue today. With salt, only an extremely small attack on road infrastructures built with concrete is to be expected if it complies with the current concrete and construction standards.

Calcium and magnesium chlorides have the advantage that they are still effective even at very low temperatures. However, with these products, more chloride is released into the environment. There is also the risk of chemical slipperiness as a result of the formation of hydrates on the road surface. These products are more expensive than salt.

There's a variety of other de-icers, some of them organic. Although they are mentioned as biodegradable, the quantity of oxygen required for their biodegradation must nevertheless be considered. This oxygen consumed can stress the environment and lead to a loss of biodiversity. Their impacts on waters, soils and vegetation still need to be studied further.

With the abrasives, formation of fine dust (PM10) due to the effects of traffic must be taken into account. The crushing of abrasives on the street can increase PM10 pollution during the winter months. In comparison, fine dust originating from salt dissolves in the mucous membranes and does not pose a health risk.

The issue of elimination or treatment of road drainage containing de-icers depends on the nature of them. For products with chloride ($NaCl$, $CaCl_2$, $MgCl_2$), a large part is collected in retention basins. To regulate the quality of runoff water discharged into the environment the water yield of the retention ponds can be optimised. Research is currently underway to test halophytic plants for desalination of road runoff.

For organic de-icers, such as formate or acetate, the main environmental impact is the oxygen consumption. Their degradation needs treatment in wastewater facilities. For abrasive materials in urban areas, sweeping is necessary to prevent clogging of sewerage networks, the production of fine particles and slippage due to residual materials.

The issue of environmental impact has to take into account the product life cycle. The fossil energy consumption to manufacture $NaCl$ is lower than for other de-icers (with the exception of abrasives that are of natural origin from quarries). The energy consumption for spreading is linked to the dosages, therefore predominant for abrasives and more important for organic liquid de-icers. Emission of greenhouse gases can be minimized by a domestic production of salt, and the right choice of means of transport.

There are many products on the market that are alternatives to salt. But there are no alternative de-icers that better satisfy all the requirements with regard to usability and , environmental impact, set forth by the European technical specification CEN/TS 16811-3. Some advantages like lower corrosiveness or higher biodegradability are often counterbalanced by other disadvantages like higher dosages or lower adhesion level. Usually, alternatives are much more expensive than salt and therefore used for specific needs only.

Abrasive products have a different objective than salt. They are only used in curative treatment to restore grip to a pavement that will remain snowy or icy. Spreading rates are much higher than for salt. Furthermore, they create fine dust and must be swept away at the end of winter. They are used only for networks located in areas with strong winter conditions and low traffic flows.

Salt is used in the manufacture of many products. At the end of the manufacturing process, salt, rather than being considered as waste, can be revalorised as a de-icing salt. Different examples in Europe show that the use of by-product salts and used salts in winter service contributes to resource efficiency and the circular economy.

In the event of a crisis, road-managers have to be sure of a sufficient stock of de-icer to respond to intense weather phenomena. Salt is a commonly available product and its European resources and production capacities are sufficient to cover these events.

The storage of the salt required for the winter months is usually based on a three-stage model. Small local silos and warehouses, medium sized regional warehouses and-warehouses of the salt industry. In some countries road authorities have build up emergency salt reserves to ensure national resilience. Salt industry uses all possible means of transport to fill the stocks: Trucks, trains, ships.

Protection of salt and the surrounding environment and ease of handling salt are necessary and can be ensured through proper storage of salt either under roof or by covering outside stockpiles. Web-based automated stock management schemes enable users to have full control over their stock levels and budget.

When choosing chemicals for de-icing, it is important to consider the availability, performance and cost under various weather conditions and to evaluate the relative environmental impact.

Sodium chloride has the best eco-efficiency for its lowest costs, applicability for normal winter weather and relatively low environmental impact. Combined with its highest-in-class availability it is therefore the de-icer no. 1 for roads.

The dynamics of salt consumption is driven by varying winter temperature and precipitation. The extremely volatile annual European salt consumption for de-icing is estimated with 5 to 17.5 million tons. The available national statistics mostly show a falling or constant trend in salt consumption and the decoupling of the salt consumption from the increase in road lengths or areas maintained. The reasons for this success are improved service strategies (ploughing first, preventive spreading, dosage recommendations), improved spreading quality (pre-wetted salt, direct brine application) and the use of road weather information systems (RWIS). In a long-term view, a decrease in salt consumption is to be expected due to climate change.

The study recommends further efforts to minimize and optimize salt consumption. This is welcomed and supported by the salt industry. There are several ways to optimize the amount of salt spread. The first is to spread the amount necessary and no more: Calibrating spreaders, adapting to weather phenomena etc. One trend in Europe is the use of brine (pre-wetted salt, over-saturated brine, brine alone). Other measures are possible, such as developing management strategies based on environmental sensitivity, or encouraging the use of winter tires.

The aim is to continue to decouple the consumption of salt from the increasing development of passenger and freight traffic as well as from the increasing road lengths and paved road areas in Europe. At the same time, traffic accidents caused by slippery roads are to be further reduced.

KEY FINDINGS AND MAJOR TRENDS

Key findings and major trends in snow and ice control material application found during the review include:

- To maintain mobility and safety on European roads efficient winter maintenance is necessary. The use of sodium chloride (NaCl, salt) is an essential part of this systemically important activity.
- De-icing salt is obtained from rock salt deposits, sea water and salt lakes and complies with the requirements of the European standard EN 16811-1.
- Salt and all alternative de-icing products as well as abrasives spread on roads have an impact on different environmental areas like water, biodiversity, vegetation and soil.
- The effects of salt are among the best studied because it is the most widely used snow and ice control material. Concerning the other de-icers, the environmental impact of many of them still has to be studied.
- Salt impacts the quality of soils and can cause harm to roadside trees. Surface waters are also affected by winter maintenance activities.
- Some advantages like lower corrosiveness or higher biodegradability of alternative de-icers are often counterbalanced by disadvantages like higher dosages, lower adhesion levels or high oxygen consumption. Usually, alternatives are much more expensive than salt and therefore used for specific needs only.
- Spreading rates for abrasives are much higher than for salt. They are only used in curative treatments to restore grip to a pavement that will remain snowy or icy. With abrasives, the formation of fine dust (PM10) must be taken into account. Also, abrasives need to be swept away at the end of winter.
- The issue of environmental impact has to take into account the product life cycle. The fossil energy consumption to manufacture salt is lower than for other de-icers. The energy consumption is linked to the dosages, therefore predominant for abrasives and higher for organic liquid de-icers.

- Salt is the de-icer with the best eco-efficiency for winter road maintenance: Suitable for preventive and curative treatment, effective up to temperature -15° with the possibility of low dosages, relatively low environmental impact and lowest costs compared to all other de-icers. Natural resources, production capacities of the local industry and logistics concepts guarantee a high availability of salt in Europe.
- Examples show that the increasing use of by-product salts and used salts from different industries as salt or brine for de-icing and anti-icing in winter service contributes to resource efficiency and the circular economy.
- The dynamics of salt consumption is driven by varying winter temperatures and precipitation. The extremely volatile annual European salt consumption for de-icing is estimated with 5 to 17.5 million tons.
- Available national statistics mostly show a falling or constant trend in salt consumption and the decoupling of the consumption from the increase in road lengths or areas maintained.
- Climate change with increasing temperature during winter has an impact on winter maintenance. Main effects are the change of intensity and type of the phenomena: Less snow, more ice, more recurrent freeze and defrost cycles, increasingly unfrequent but more intensive events. Winter service is then obliged to adapt itself. In a long-term view, a decrease in salt consumption is to be expected due to climate change.
- The study recommends further efforts to minimize and optimize salt consumption. This is welcomed and supported by the salt industry. There are several ways to optimize the amount of salt spread. The first is to spread the amount necessary and no more: Calibration spreaders, adaptation to weather phenomena etc. An important trend in Europe is the use of salt brine as pre-wetted salt, over-saturated brine, or brine alone.
- The aim is to continue to decouple the consumption of salt from the increasing development of passenger and freight traffic as well as from the increasing road lengths and paved road areas in Europe. At the same time, traffic accidents caused by slippery roads are to be further reduced.

Table 9: Comparison of different de-icers on some known environmental impacts

De-icer	Environmentally friendly characteristics	Negative impacts on the environment	Comments
Sodium chloride NaCl (solid)		Toxicity of chloride ions (contamination of the water table). Sodium Na^+ dispersant effect on soil.	Best eco-efficiency: for preventive and curative treatment; effective up to temperature -15° C; low dosage necessary; lowest cost compared to all other de-icers.

		Significant symptoms on roadside trees.	High availability (natural resources: rock salt deposits, seawater, salt lakes).
Brine of sodium chloride (liquid)	Less salt entry into the environment than with solid NaCl.	Same impacts as solid NaCl.	More efficient than solid NaCl in preventive treatment, but not suitable for all weather conditions.
Calcium chloride $CaCl_2$	Calcium Ca^{2+} has not dispersant effect on soil as sodium Na^{+}.	Toxicity of chloride ions (contamination of the water table). Double the amount of chloride compared to NaCl. Significant symptoms on roadside trees.	High cost compared to NaCl. Effective at temperatures lower than NaCl. Risk of chemical slipperiness. Its toxicity would be more important than NaCl for plankton and invertebrates, and less important for fish. GHS classification as hazardous substance ("eye irritating").
Magnesium chloride $MgCl_2$	Magnesium Mg^{2+} has not dispersant effect on soil as sodium Na^{+}.	Toxicity of chloride ions (contamination of the water table). Double the amount of chloride compared to NaCl. Significant symptoms on roadside trees.	Risk of chemical slipperiness. Magnesium chloride is more toxic than NaCl for some aquatic's species tested fish.
Potassium chloride KCl		Damages noted on some plants.	Ineffective at temperatures below -4° C / -7° C. Potassium chloride is more toxic than NaCl for some aquatic's species tested fish.
Acetate based de-icers (CMA, potassium acetate, sodium acetate) $C_2H_3O_2$-	Biodegradable. Less damage to flora and fauna than NaCl.	A priori more harmful effects on phytoplankton, invertebrates, and fishes than NaCl. Oxygen consuming biodegradation for sodium acetate. Impact of sodium ion Na^{+} (similar to NaCl).	Its cost is about 20 times higher than NaCl cost [28]
Formate based de-icers	Biodegradable.	Similar impacts than acetate. More difficult to biodegrade than acetate [28].	Its cost is about 20 times higher than NaCl cost [28]

		Oxygen consuming biodegradation.	
Urea	Low corrosivity.	Damage to vegetation promotes the growth of algae and the eutrophication of watercourses.	Effective up to temperatures -3° C / -4° C. High cost. Need to take precautions to limit runoff to ground water.
Sulphate / nitrate based de-icers		Harmful for concrete and porous stones. Significant pollution risks for surface waters (inorganic nitrogen). Very corrosive.	
Alcohol and glycol		Non-corrosive. Unauthorized substances in lakes and rivers. High oxygen consuming biodegradation.	GHS classification of ethylene glycol as hazardous substance.