# ENVIRONMENTAL IMPACT OF WINTER MAINTENANCE WITH SALT

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## Contents

# 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; and
- 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 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. The use of sodium chloride (NaCl, salt) is an essential part of this.

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, contributes to biodiversity preservation and sustainable use of resources, as well as have 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 the European standard EN 16811-1.

All products spread on roads have an impact on different environmental compartments (water, biodiversity, vegetation, soil) and depends on their nature (inorganic, organic). 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 tend 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. Surface waters (standing and flowing waters) are more affected by winter maintenance activities. This saline polluting 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 contamination 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 a road infrastructure 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.

Concerning the other de-icers, their environmental impact can still be studied, due to their great variety. De-icers used in airport areas (formate, acetate, urea) are derived from organic chemistry. Although they are mentioned as biodegradable, the quantity of oxygen required for their biodegradation must nevertheless be considered. This oxygen consumed can asphyxiate the environment and lead to a loss of biodiversity. Their impacts on waters, soils, vegetation have to be still studied in function of their composition.

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. Fine salt dust dissolves in the mucous membranes and does not pose a health risk.

The issue of elimination or treatment of road effluent with 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 need 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 because it is natural and not require an industrial process for its elaboration (with the exception of abrasives that are 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 satisfy all the requirements (usability, environmental impact) of the European technical specification CEN/TS 16811-3. Some advantages (like less corrosive, biodegradable) are often counterbalanced by other disadvantages (like higher dosages, 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 / 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 rigorous winter (mountains, 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 common product whose production can be sufficient to cover these intense 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, - warehouses of the salt industry. In some countries road authorities 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 (lowest costs, applicable for normal winter weather, acceptable environmental impact) and highest availability and 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/use. 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. The 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.

# 1. INTRODUCTION

Roads are of outmost importance for mobility of people and transport of goods throughout Europe. Experts believe that up to 50% of the total maintenance budget is spent on winter maintenance in many European countries. It therefore has a high significance not only in keeping roads, cycle tracks and footways free from ice and snow but also in matters of pedestrian, cyclist, and driver safety.

Winter maintenance is a systemically important activity. Winter maintenance is necessary to maintain mobility and road safety in winter. The road administrations put a lot of resources to winter maintenance each year to be able to maintain a high level of service at the road networks. Winter maintenance needs personal, equipment, road weather information and spreading agents. In Europe, salt was first used in winter maintenance in Paris in the winter of 1879/80. Since the 1950s, sodium chloride (salt) has played an increasing role as a thawing spreading agent.

In addition to evaluating the benefits and costs of winter road clearance, it is also necessary to consider the effects of the use of salt and alternative spreading materials on the environment.

# 2. MOBILITY AND SAFETY THROUGH WINTER MAINTENANCE

Snow- and ice-covered roads can paralyze the functioning of the community and pose a considerable threat to the public safety. They produce hazardous driving conditions which increase traffic deaths, injuries, and property damage. The general assumption has always been that snow and ice on highways cause accidents. There are several reasons for this assumption. Snow and ice reduce the coefficient of friction between the pavement and vehicle tires, making maneuvering of the vehicle difficult and occasionally impossible. Ice is not always apparent to the motorist and is not uniform, so that the driver is not always prepared when he encounters an icy section on the roadway. Vehicle mobility is reduced, causing services such as fire, police, and ambulance operations.

During the late 1980’s, the Technical University of Darmstadt in Germany completed already an extensive research project documenting the accident experience before and after winter road maintenance operations and following a bare road pavement policy [1]. The analysis covered over 4.700 accidents, approximately 1.900 casualties, on about 650 kilometres of roads outside built-up areas in four representative highway maintenance centers. Salt was the only de-icing material used on these roads. The time was determined at which salt spreading took place, then an hourly accident analysis was conducted for 12 hours before and 12 hours after. The results of the accident analysis are shown in Figure 1. Similar results were found in a study of the Marquette University of Milwaukee in USA, utilizing the same methodology of the German study [2].

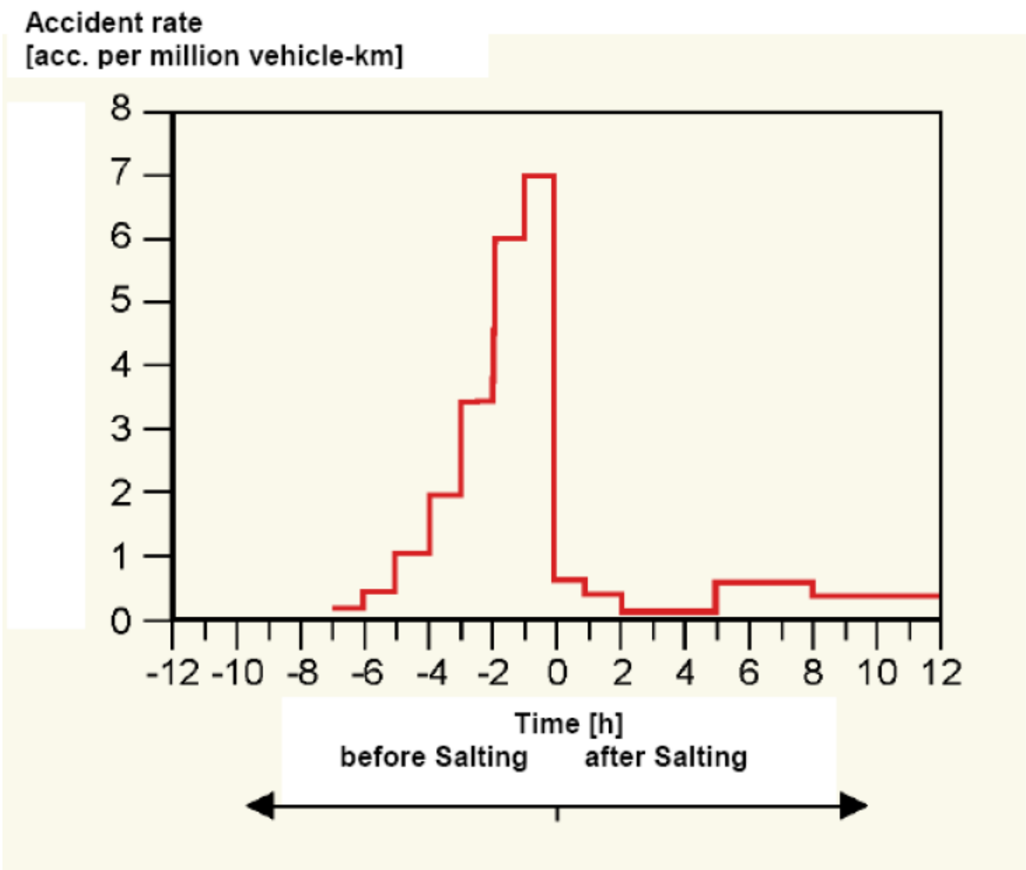



Figure 1: Accident rate with respect of time of road salting

In France, sodium chloride is the most used de-icer, upon 99%. No study demonstrates that salt (and only salt) has an impact on the mobility and safety.

However, the topic of the influence of salt use on safety could be approached by studies of the seasonal accidentology. Different factors affect the impact weather conditions have on road safety: regions and climate, driving habits (mountains drivers are more prepared for snow driving), road authorities, modes of transport [3].

In France, road fatalities vary over the year and the 1st quarter is usually the least lethal (21% of the mortality 2009-2018). This statistic includes all modes: motorcyclists, pedestrians, and vehicles (Figure 2). Pedestrian fatality is on its maximum in autumn / winter (43% of the annual total on the four months from October to January): night period is longer, and pedestrians are less visible at night for other users (Figure 3).

Specific weather conditions can influence road deaths through a combination of several, sometimes contradictory, effects. Difficult conditions lead to a decrease in travel, particularly for leisure travel and vulnerable modes (motorbikes, bicycles). and an increase individual risk of accidents for each user (poor visibility, loss of adhesion in case of rain, ice, etc.) [4].

One study shows, that accidentology on snowy or icy pavement is around 1% and that half of these occur in urban areas (Figure 4) [5]. The number of accidents outside urban areas is three times higher than on motorway. Although routes are different, the used speed is significantly higher on motorways. All these data show that winter maintenance is an important factor in increasing road safety.

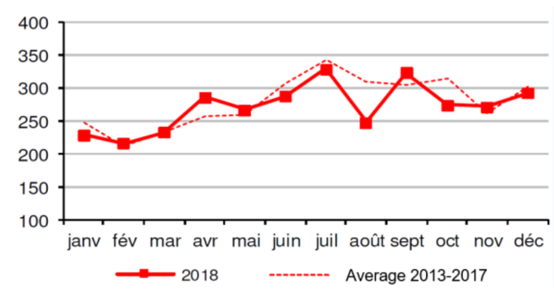



Figure 2: Monthly mortality: all users

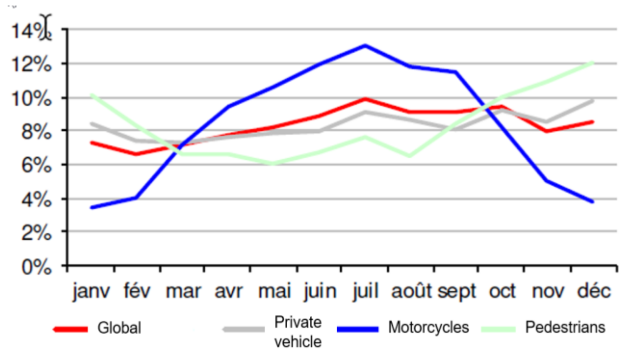



Figure 3: Annual mortality of the category of users, by months (average 2009-2018)

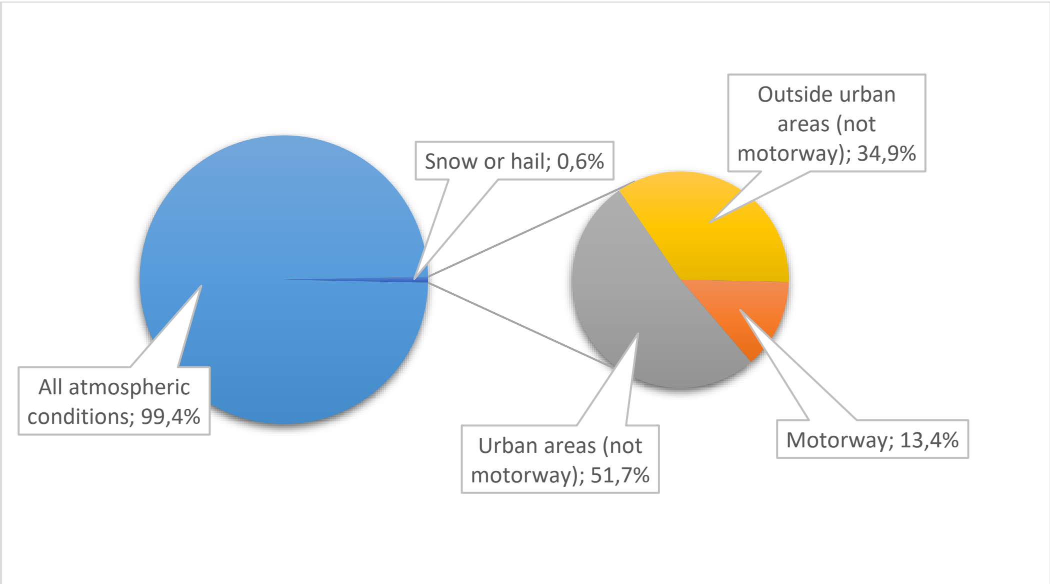



Figure 4: Accidentology statistic and atmospheric conditions in France (all users) 2018

The COST Action 353 "Winter service strategies for increased European road safety", developed between 2004 and 2008 a framework for the management of winter traffic for maximized road safety [6]. Models can be used to calculate the socio-economic costs for winter service, and these can be used as a tool in choosing the best winter service regime. Although the total number of vehicles on European roads has increased over the years, the total number of accidents on ice and snow has decreased, offering a clear indication of good winter service practices in Europe.

The capacity of a snow-covered or icy roadway is clearly lower than the capacity of a dry or a wet surface. Reduced grip implies lower speeds and larger safety distances between vehicles, which in turn lead to a decreased capacity of the road network. Resent research projects show that the capacity is reduced by winter conditions to approximately only 50 percent of the normal value, so that roads with high traffic volumes are overloaded und the traffic can come to a complete standstill. If the traffic breaks down on the motorways it takes a lot of time until the traffic flow is normal again, on average 6 hours. The economic costs are very high, up to estimated 1 million Euro for one traffic jam in Germany.

In geographical Europe, there are three strategic trunk road networks: International 'E' Roads, Trans-European Transport Roads and Pan-European Transport Roads. In order to maintain mobility and traffic safety throughout this route network in winter weather, a form of highway construction is necessary to coordinate with the winter highway maintenance services, a suitable situation-specific winter equipping of the motor vehicle of road users (winter tires, studded tires, snow-chains) as well as efficient winter road services.

**Conclusions:**

- **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.**
- **The use of salt is an essential part of the winter road maintenance in Europe.**

## 3. PRODUCTION ROUTES FOR SALT

Sodium chloride for de-icing is obtained from different natural resources:

- seawater,
- rock salt deposits,
- salt lakes.

Seawater is used for production of sea salt. Other salt types are made from rock salt deposits or from salt lakes. The other salt types produced are:

- rock salt
- evaporated salt, and
- solar salt.

Synonym to evaporated salt is vacuum salt. Figure 5 shows a schematic drawing of the different production routes for de-icing salt.

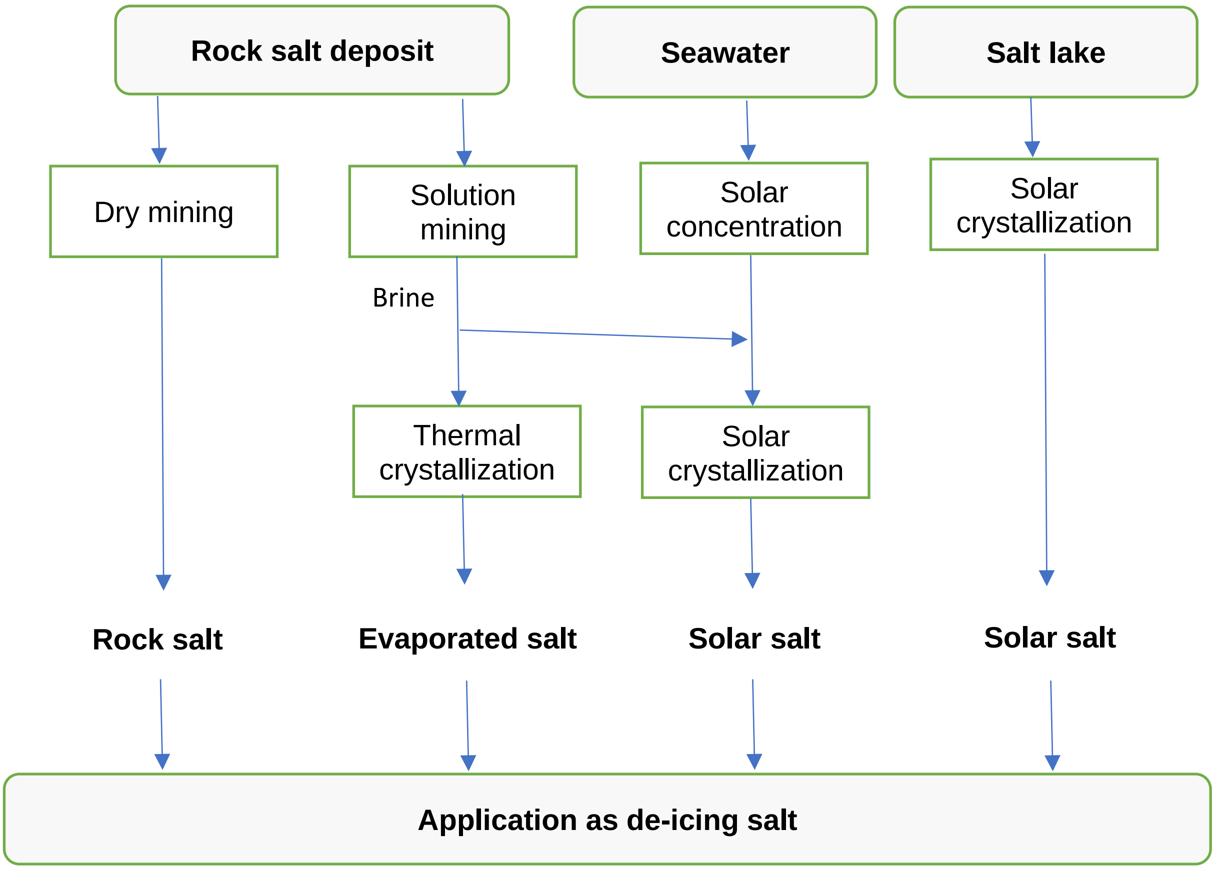



Figure 5: Production routes for de-icing salt

## Extracting salt from mines

Rock salt (halite) is the salt left behind by primordial oceans millions of years ago when lagoons dried out. These layers of salt were covered by rock formations and they are now located underground or inside mountains. Rock salt refers to the dry salt extracted from saliferous rock layers with the help of mining methods. Most salt mines operate underground but in salt deserts the rock salt is also mined at the surface (Figure 6).

Two main methods of extracting rock salt are used in underground mining:

- In drilling and blast mining a series of carefully sited holes are drilled and then charged with explosives to blast the rock. The resulting salt rocks are then repeatedly crushed into pieces.
- Continuous mining produces smaller lumps of rock using a machine similar to the one used for building tunnels. It bores into the salt extracting lumps that are then crushed into smaller pieces.

Both methods ensure that the mine is stable and safe by leaving substantial pillars of salt to support the mine roof.

After extraction, the empty salt chambers can be used as safe storage for various purpose (archives, waste).

Rock salt represents 45% of the salt produced in Europe and the main producers are in France, Germany, Italy, Poland, Spain, and the United Kingdom.

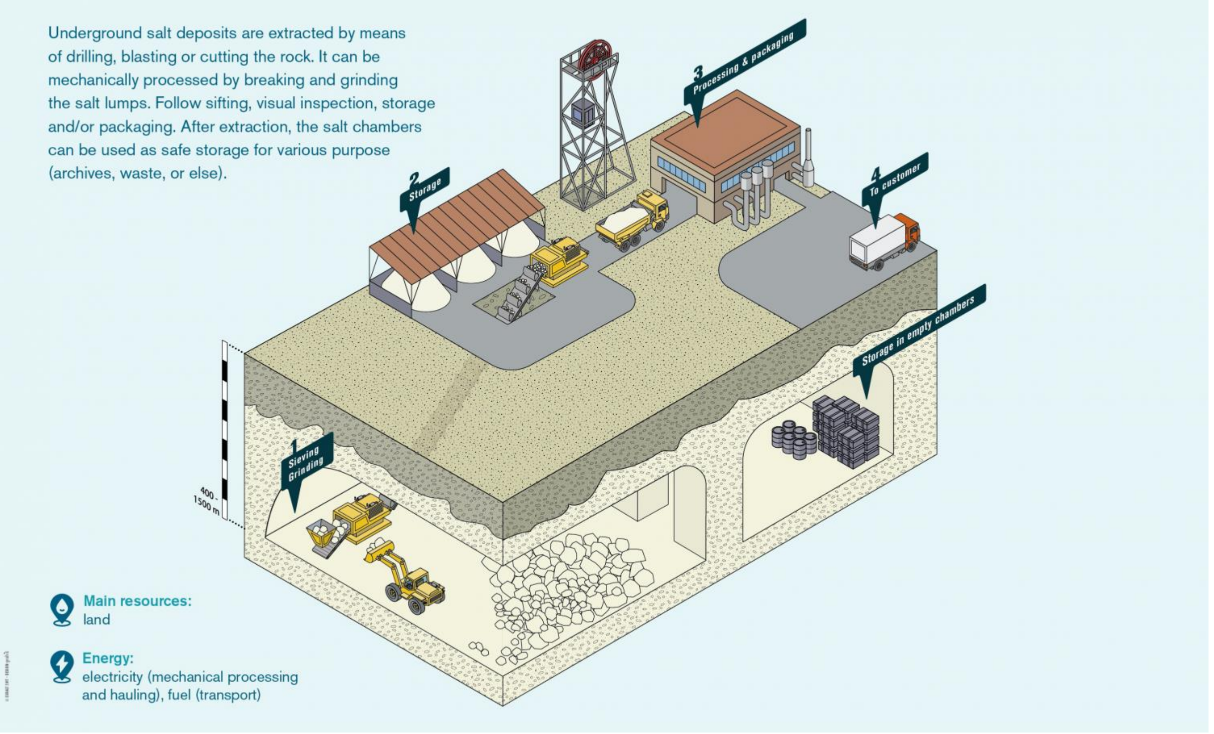



Figure 6: Process steps of rock salt mining

### Dissolving underground salt and pumping the brine to the surface

The salt used in this process is extracted from the rock salt layer at depths of as much as 3.000 meters by pumping down water and forcing out the resulting brine. This concentrated salt solution (brine) is piped to the collection tank and from here it is transported to the saltworks for softening and for undergoing the crystallisation process in the evaporator plant. This method yields a very high purity of salt (Figure 7).

In the caverns remaining after the extraction, for example gas, mineral oil, hydrocarbons or hydrogen, which is generated with renewable energy, can be stored.

Solution mined salt represents 45% of the salt produced in Europe and the main producers are in Austria, France, Denmark, Germany, the Netherlands, the United Kingdom, Poland, and Switzerland.

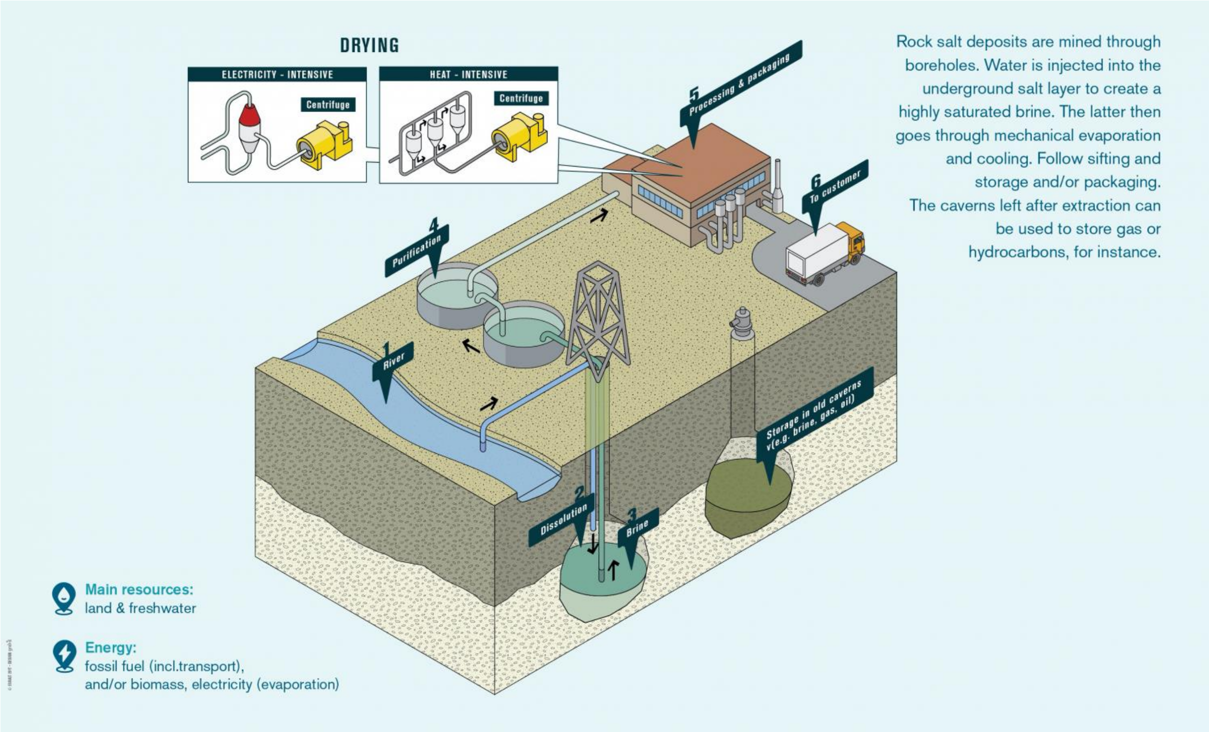



Figure 7: Process steps of evaporated salt production

## Harvesting salt by solar evaporation

Capturing salt by evaporating seawater in natural lagoons or artificially created ponds, salt marshes or marine salt flats is one of the oldest processes. Salt marshes were mainly created near areas inhabited by ancient civilisations and on flat stretches of coastline.

The principle has remained the same over centuries: sea water or natural brine evaporates up to the saturation point in open basins due to the action of sun and wind. Crystallisation occurs in dedicated open basins where the saturated brine is poured. Over time, the system of evaporation and crystallisation ponds and the method of operating them have gradually been improved. Once the salt crust has been formed, the exceeding concentrated seawater is eliminated before harvest. If necessary and depending upon requirements, the raw salt can be further processed, including washing, drying, and sieving. Harvesting salt from salt lakes does not need large concentration ponds as with salt production from sea water (Figure 8).

Solar salt represents 10% of the salt produced in Europe and the main producers are in France, Greece, Italy, Spain, and Turkey.

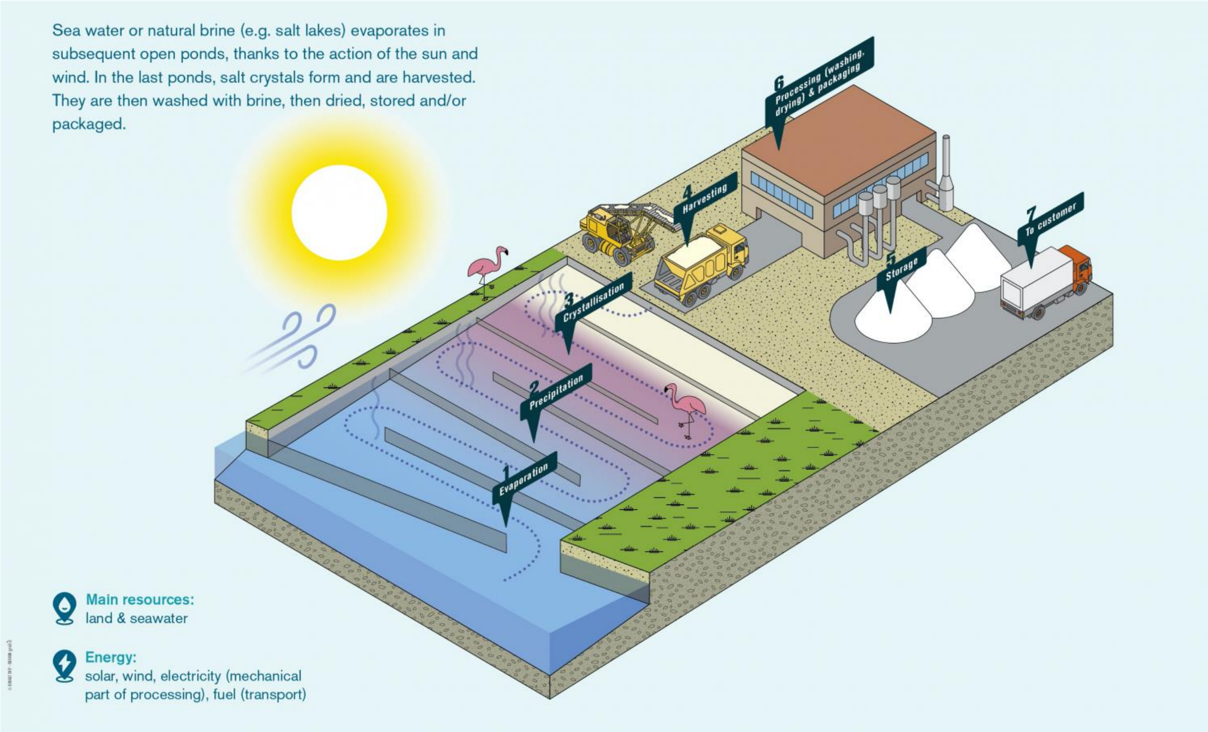



Figure 8: Process steps of sea salt production

## Biodiversity with sea salt production

Solar salt works are integrated constructed coastal ecosystems with a unique architecture. They consist of a system of shallow ponds connected mainly in series through which seawater flows, evaporates by the power of sun and wind, and deposits sodium chloride in crystallising ponds. The exploitation of sea salt contributes to the development of biodiversity with fauna and flora specific to wetlands. The spatial organisation of the ponds and their different depths and salinity levels favour the development of a variety of micro-environments and microorganisms (algae, bacteria, molluscs, worms etc.) which are attractive to a wide range of bird and fish species. This kind of habitats for communities of salt-tolerant vegetation and aquatic invertebrates are rarely found in other types of environments.

The microscopic pond life supplies food for a large number of waterbirds, some of which are endangered and protected. Certain species of birds, such as the Avocet, the Black-necked Grebe, or the Kentish Plover, depend directly on the productivity of salt works, since their diet is exclusively based on brine shrimps. These shrimps are also part of the diet of the beautiful flamingos. Salt works do not only provide key food resources for a wide variety of resident and migratory birds, but by their design, they also provide protection from predators and human disturbances. Vegetated dikes and islands within large ponds furnish birds with safe nesting and resting areas. Salt works with beaches closed for people provide undisturbed sites for sea turtles, seaside plants, fish nurseries and sea grasses.

Solar salt works are ecosystems with an important economic value. Apart from salt production, solar salt works spur other types of economic activities. The rich avifauna present here attracts birdwatchers developing eco-tourism and supporting local economies. The brine and mud of the evaporating ponds are widely used for therapeutic and cosmetic purposes. Furthermore, solar salt works improve water quality and prevent flooding.

The added value of solar salt works to biodiversity conservation and creation deserves broader public attention. While urbanisation and industrialisation have unfortunately severely altered the coastlines, salt works represent an important capital for the conservation of biodiversity. More supportive actions directed to this multifunctional activity are needed.

### Environmental impact of salt production

Salt production techniques prevent or minimize any contribution to the contamination of environment, contributes to biodiversity preservation and sustainable use of resources, as well as have the lowest possible ecological footprint. The energy and water consumption for rock salt and solar salt production is very low. For evaporated salt production the energy consumption is minimized by the best available techniques (MVR, MEE) and process water is re-used. Where possible, the use of energy is limited to energy from renewable sources. The $CO_2$-eq emissions depend on the share of renewable energies in the total energy consumption for salt production. Operators have established environmental and energy management systems.

$NO_x$ from explosives detonation in rock salt extraction creates due to the low specific explosive's consumption no environmental problem. Miners' health is not negatively affected, authorized $NO_x$ limits are respected by ventilation, organizational measures, and use of e-vehicles.

No toxic wastes result from salt production and tailings from processing are disposed in empty chambers of mines or brine caverns.

Salt production does not significantly affect the stability of the natural ecosystem or the maintenance of the species in the production area. Preservation of natural landscape elements, such as natural heritage sites is guaranteed.

### Brine supply

The winter services can be supplied with the required quantities of brine either by buying them on the market or by making them from de-icing salt (Figure 9). Brine is usually produced directly in operational centers, with a dedicated salt stock.  The transport of brine by tankers is ecologically harmful, which means that about 75% of water is transported. The quality requirements for the winter service brine are specified in the EN 16811-1 standard [7]. Basic specifications for brine production systems are in the EN 17443 standard [8].

Figure 9: Brine production system with salt silo and brine storage tanks at the highways maintenance center Erlangen on the A3 (Die Autobahn GmbH, Germany)

**Conclusions:**

- **Europe has an excellent raw material situation.**
- **The salt can be obtained from rock salt deposits, sea water and salt lakes.**
- **All produced salt types are suitable for application as de-icing salt: rock salt, evaporated salt, solar salt.**
- **Salt production techniques prevent or minimize any contribution to the contamination of environment, contributes to biodiversity preservation and sustainable use of resources, as well as have the lowest possible ecological footprint.**

## 4. QUALITY OF SALT

The European standard EN 16811-1 for de-icing salt has existed since 2016. The standard regulates the quality requirements for the salt and describes the methods for examining the salt.

Requirements are placed on the chemical composition, the water content, and the grain size. A minimum salt content shall guarantee a high de-icing effect. In view of the aggressiveness towards concrete structures, the content of water-soluble sulfates has been limited. There are three classes defined for the water content: dry salt, semi-dry salt, wet salt. The grain requirements are divided into four classes: extra-fine, fine, medium-coarse, and coarse salt. In addition, there are requirements for the pH value and the permissible heavy metal content for salts with natural and non-natural origin. The very low heavy metal content in de-icing salts does not result in any pollution of water or soil. The salt must be delivered to the user in a free flowing and usable condition. Ferrocyanide can be added to the salt as anti-caking agent in a dosage of 5 mg / kg to a maximum of 125 mg / kg to maintain its flowability. The detailed requirements are shown in Table 1.

Table 1: Requirements of EN 16811-1 standard for de-icing salt

<table>
<tr><th colspan="4">Composition</th></tr>
<tr><td>Sodium chloride</td><td colspan="3">Min. 90%</td></tr>
<tr><td>Sulfate</td><td colspan="3">Max. 3%</td></tr>
<tr><th colspan="4">Moisture</th></tr>
<tr><td>Dry salt</td><td colspan="2">Semi-dry salt</td><td>Wet salt</td></tr>
<tr><td>Max. 0,6%</td><td colspan="2">Max. 2,0%</td><td>Max. 6,0%</td></tr>
<tr><th colspan="4">Sieve analysis (weight % passing test sieve)</th></tr>
<tr><td>Extra fine</td><td>Fine</td><td>Medium</td><td>Coarse</td></tr>
<tr><td>0,125 mm max. 5<br>0,8 mm 25 to 100<br>2,0 mm 100</td><td>0,125 mm max. 5<br>0,8 mm 10 to 40<br>1,6 mm 30 to 80<br>3,15 mm 90 to 100<br>5,0 mm 100</td><td>0,125 mm max. 7<br>0,8 mm 5 to 35<br>1,6 mm 10 to 60<br>3,15 mm 45 to 90<br>6,3 mm 100</td><td>0,8 mm max. 35<br>3,15 mm 30 to 80<br>6,3 mm 75 to 95<br>10 mm 100</td></tr>
<tr><th colspan="4">General requirements</th></tr>
<tr><td>Anti-caking agent</td><td colspan="3">3 – 125 mg/kg</td></tr>
<tr><td>pH</td><td colspan="3">5 - 10</td></tr>
<tr><td>Aluminium<br>Arsenic<br>Cadmium<br>Cobalt<br>Chromium<br>Copper<br>Mercury<br>Nickel<br>Lead<br>Zinc<br>Hydrocarbons</td><td colspan="3">≤ 50 mg/kg<br>≤ 2,5 mg/kg<br>≤ 2 mg/kg<br>≤ 2 mg/kg<br>≤ 5 mg/kg<br>≤ 5 mg/kg<br>≤ 0,5 mg/kg<br>≤ 5 mg/kg<br>≤ 5 mg/kg<br>≤ 20 mg/kg<br>≤ 100 mg/kg</td></tr>
<tr><td colspan="4">The de-icing salt shall arrive at the user’s delivery point in a free-flowing and usable condition.</td></tr>
</table>

A recent study from Norway investigated if de-icing salt could be an additional source of microplastics to the environment. The identified and quantified polymer content in four types of de-icing salt, three sea salts and one rock salt, showed that microplastics in de-icing salt are a negligible source of microplastics from roads compared to other sources [9].

Some European countries have even higher requirements for de-icing salt. This considers the available national salt resources and user requirements. In some national annexes to EN 16811 standard, minimum salt contents of up to 98% and sulphate contents of a maximum of 1.0% are required. There are national annexes to the European standard EN 16811-1 in Austria, France, Germany, and Switzerland (Table 2).

Table 2: National requirements for de-icing salt that differ from the EN 16811-1 standard

| | Austria<br>ÖNORM EN 16811-1 | France<br>NF EN 16811-1 | Germany<br>DIN EN 16811-1 | Switzerland<br>SN EN 16811-1 |
|---|---|---|---|---|
| Sodium chloride | Min. 97,5% | Min. 98% (class A)<br>Min. 91% (class B) | Min. 97% | Min. 97% |
| Sulfate | Max. 1,0% | | Max. 1,5% | Max. 1,5% |

Additives in de-icings salts are always anti-caking agents. Salt premixed with agricultural by-products (molasses) can improve spreading efficiency, increase resilience, and helps reduce corrosion to both vehicles and infrastructure.

For salt in solution (brine), which is used in winter service, the quality requirements are also specified in the EN 16811-1 standard.

There is no European standard for abrasives. But individual countries such as Austria and Germany have defined quality requirements that were notified to the European Commission [10][11].

**Conclusions:**

- **The salt industry supplies high quality de-icing salt according the European standard EN 16811-1.**
- **Some European countries have even higher requirements. This considers the available national salt resources and user requirements.**
- **The very low heavy metal content in de-icing salts does not result in any pollution of water or soil. Compared to other sources of microplastics particles from roads, contribution from de-icing salt is negligible.**
- **Calcium chloride and magnesium chloride are regulated in EN 16811-2 standard.**
- **Other inorganic and organic de-icers are regulated in technical specification CEN/TS 16811-3. This specification specifies some requirements to prove that other de-icers are effective, non-corrosive, not slippery, etc. But there are no alternative de-icers that satisfy all the requirements of this technical specification.**

## 5. STORAGE AND LOGISTICS OF SALT

The salt industry guarantees the safe supply of salt throughout Europe. The security of supply with de-icing salt is guaranteed by the existing production capacities, a storage concept, and the economical use of the available transport options. The production capacities alone do not guarantee security of supply. This also requires nationwide storage concepts. The storage of the salt required for the winter months is usually based on a three-stage model:

- Small, local silos and warehouses

  They are guided by all winter services and hold salt reserves for several days or weeks, which are immediately ready for use.

- Medium-sized, regional warehouses

  Some road administrations and large cities have strategic stocks with reserves for several months.

- The warehouses of the salt industry

  Salt producers have storage capacities at their production units, this can be underground in mines or on surface, and storage capacities that are regionally distributed outside the production facilities. The winter services are also supplied from these regional warehouses.

In some countries road authorities build up an emergency salt reserve to ensure national resilience. These reserves are only for use as a last resort in the event of normal domestic salt supply channels being unable to meet the demands of local highways authorities.

On the one hand, the storage concept enables users and salt producers to react quickly to heavy snowfall. On the other hand, they are also equipped for the long term if, for example, several cold and snowy winters follow one another. In the event of a crisis, salt has the advantage that, due to its widespread use, it can be shared among the road managers, thereby maintaining the continuity of mobility.

The salt industry uses all possible means of transport to fill the stores: trucks, trains, ships. The transport of salt is mainly by road, especially to operation centres. The type of packaging depends on the quantities required. In the case of larger stocks, delivery is usually made in bulk. If the consumption is low, the salt is also supplied in large or smaller bags. The warehouses are already filled during the summer months. Subsequent deliveries are made in winter as required.

### Appropriate salt storage

The proper storage of salt by producers and users is extremely important. 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. Covered storage protects the salt from rain and snow and keeps the salt dry. Leaving salt uncovered can negatively affect quality, damage the environment and lead to stock losses.

Stockpiles, whether large or small, is never be left exposed to the elements - rain or snow. Storage is always be done on impermeable pads, either in a building or covered with one of the many types of temporary covering materials. Proper storage inside a building or under cover will also prevent possible detrimental effects on the environment. When salt is stored outside, runoff is properly controlled.

Properly stored salt will:

- Prevent formation of lumpy salt that is difficult to handle with loaders and to move through spreaders.
- Eliminate the possibility of contaminating streams, wells, or groundwater with salt runoff.
- Eliminate the loss of salt by runoff and dissolving by precipitation.
- Allows quick, easy access to the salt stocks.

The best way to prevent or minimize caking is to store salt under cover. Most salt producers add anticaking agents. However, if left exposed to weather, anticaking agents can be washed from the outer layer of salt.

Salt producers and street and highway maintenance agencies make a continuous effort to provide good salt storage. Good storage also includes proper maintenance of facilities and good housekeeping practices.

Web-based automated stock management schemes enable users to have full control over their stock levels und budget. Triggered by reports of salt usage via the web, the salt supplier can maintain the salt stocks at agreed levels.

Examples of appropriate salt storage are shown in Figures 10 to 15:

Figure 10:  Strategic salt stock under lightweight plastic sheeting (Compass Minerals, England)


Figure 11:  Salt and brine storage at the Newport Pagnell depot on the M1 (Highways England)

Figure 12: Covered storage of different salt qualities at the highway road maintenance center Le Touvet on the A41 (APRR/AREA, Autoroutes Rhone Alpes, France)

Figure 13: Salt storage in silos at the highway maintenance center Salzburg-Liefering on the A1 (ASFINAG, Austria)

Figure 14: Salt storage in a warehouse at the highway maintenance center Kaisersesch on the A48 (Die Autobahn GmbH, Germany)


Figure 15: Strategic salt storage in warehouses and domes in Riburg, Switzerland (Swiss Saltworks)

Example France:

In France, all road managers have their own warehouses. There are only a few strategic stocks that have been set up by those responsible for winter maintenance.

Covered storage is recommended, but in 2003, 45% could be considered as not covered (open air + tarp) (Figure 16) [12]. However, the trend is changing with environmental and salt-conservation quality considerations. A more recent study indicates that 75% of stocks are sheltered in a rural area (Figure 17) [13].

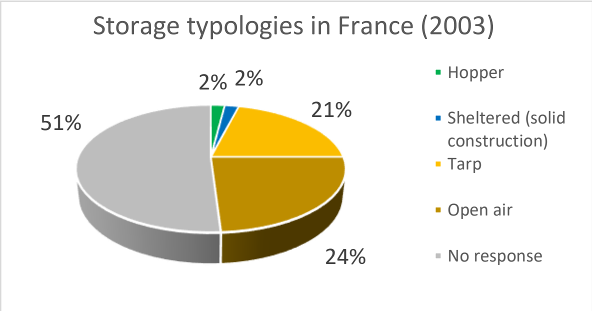



Figure 16: Storage typologies in France (2003)

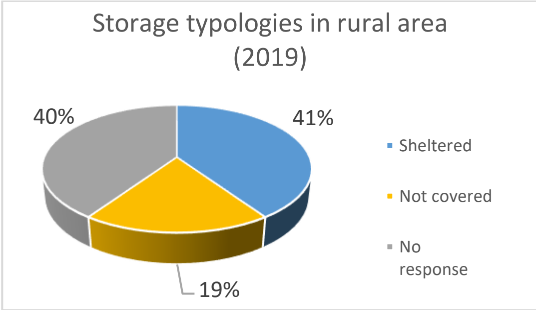



Figure 17: Storage typologies in a French rural region (2019)

**Conclusions:**

- **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 common product whose production can be sufficient to cover these intense 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, - warehouses of the salt industry.**
- **In some countries road authorities 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.**
- **Storage has to be adapted to the type of de-icers (liquids in tanks, $CaCl_2$ in specific silo or big-bags because they have not the same properties as salt).**

## 6. CONSUMPTION OF SALT

The demand for salt in the individual countries in winter depends on the type, extent and development of the road network and other areas in need of winter service, the traffic, the users demand, the strategy for winter service and the winter weather. In the long term, demand will be influenced by climate change.

Generally, more salt is used in a colder winter with a lot of snow fall. However, temperatures and snow fall vary across Europe and in the countries. A winter is seldom mild/severe in the whole country and an average temperature for the whole country does not describe the whole truth about the winter has been because it is salted differently depending on standards and the number of roads. For example, a winter with little traffic and a lot of precipitation is salted much more than a winter where it is cold for a long period while there is no precipitation and no salting.

There is no official European statistics on the consumption of de-icing salt and annual consumption quantities are only given for some countries. The estimated annual de-icing salt consumption in Europe varies between 5 to 17.5 million tons. Most of it is rock salt, followed by solar salt and evaporated salt. The following examples from European countries show the high volatility and trends in salt demand:

<u>France</u>

Salt consumption obviously varies according to the severity of the winter and could be correlated with the winter road maintenance index (*Index de Viabilité Hivernale - IVH)* which is an indicator of winter road network difficulties [14] (Figure 18). Last years, consumptions tend to decrease due to less rigorous winters and practical's as prewetted-salt and brine use. Salt sales in Figure 18 represent only sales for road managers and not for households. Consumption numbers come from Asselvia, a French association of salt producers.

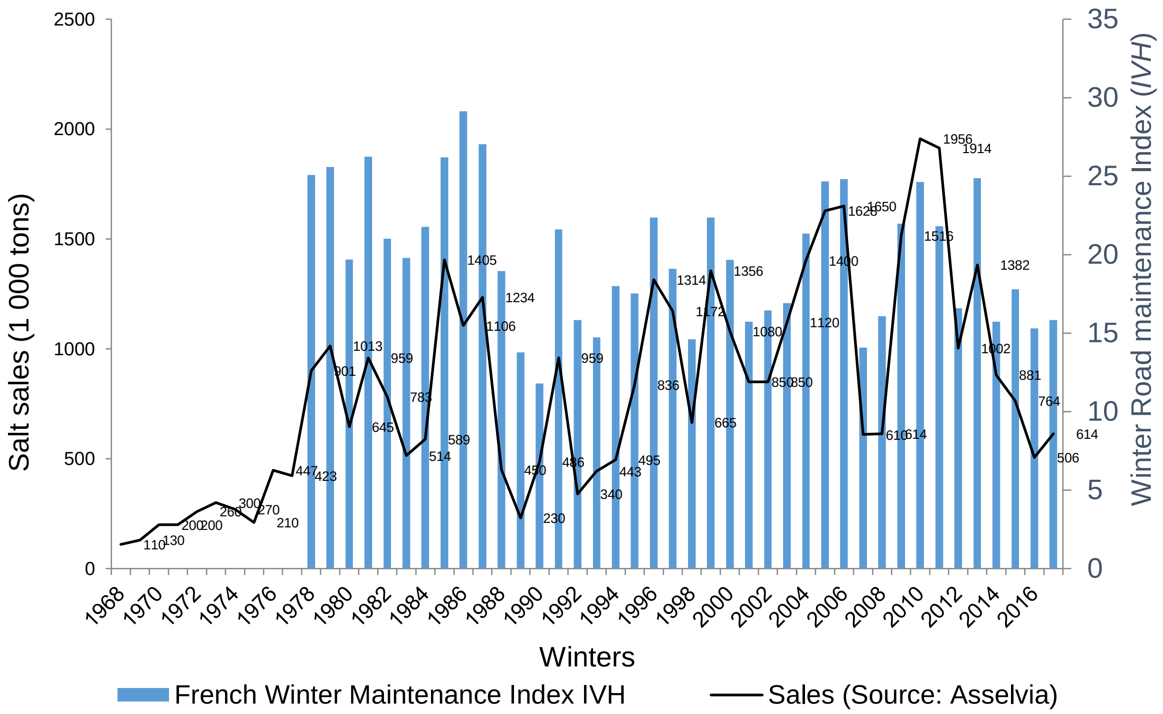



Figure 18: Salt sales and Winter Road Maintenance Index (IVH) in France – 1968-2017

<u>Switzerland</u>

Switzerland is a region that is close to or in the Alps. The consumption statistics show a clear upward trend for the years 1993 to 2019 (Figure 19) [15]. The main reasons for this increase are the strong expansion of national roads and the extended winter service times that are expected by the population. In addition, there is no obligation to use winter tires in Switzerland.

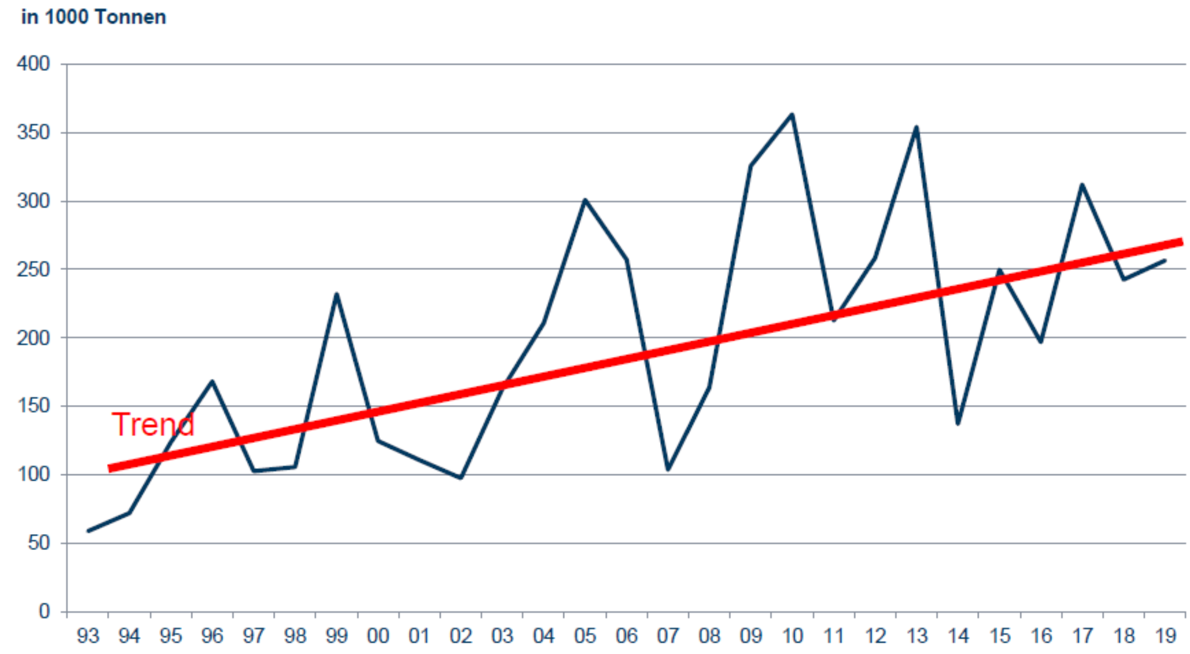



Figure 19: Total salt sales for de-icing in Switzerland (Source: Swiss Saltworks)

Austria

As a result of heavy snowfall and long winter periods, salt consumption reached maximum values on the Austrian motorways in the years 2008-2011, 2017 and 2018. (Figure 20) [16].

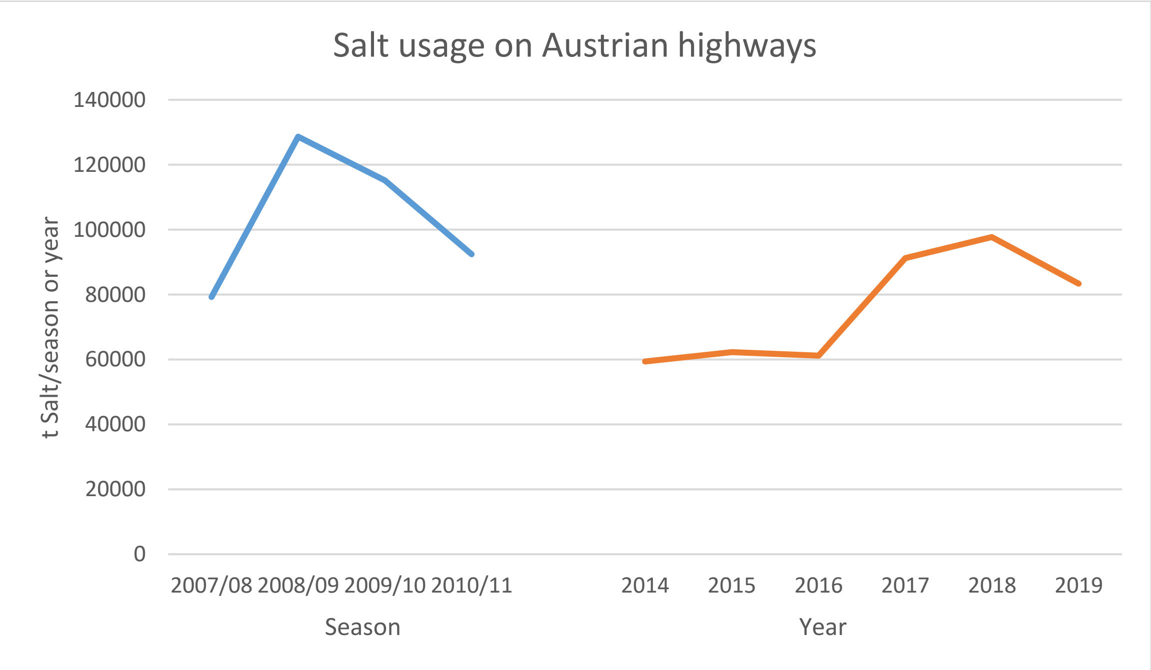



Figure 20: Salt usage on Austrian highways (Source: ASFINAG)

## Scandinavia

In Scandinavia, with the exception of Denmark, sand is also spread in addition to salt. The amount of de-icing salt used in the Nordic countries is shown in Figure 21 [17]. The figures are not directly comparable between countries due to different assumptions. In Denmark, salt consumption until the winter of 2007/08 applies to State Roads and County Roads, after this only States Roads. The picture is different for the individual countries. In Norway salt consumption can vary slightly from season to season, but the trend is that salt consumption has increased over time. The Norwegian Public Roads Administration explains the increase with several factors:

- Expansion of the road network being salted. On roads that are normally run with sand as a friction improvement salt is used to a greater extent because they have conditions where sand has little or poor effect.
- Several roads that are not usually salted are salted during a transition period.
- Increased road network in the form of multi-lane road.
- There are longer winter periods that have weather conditions with exchange around 0° C. This means that there are several periods when salts are needed.

In Sweden there has been a lower consumption of salt in recent years, while sand consumption has increased at the same time.

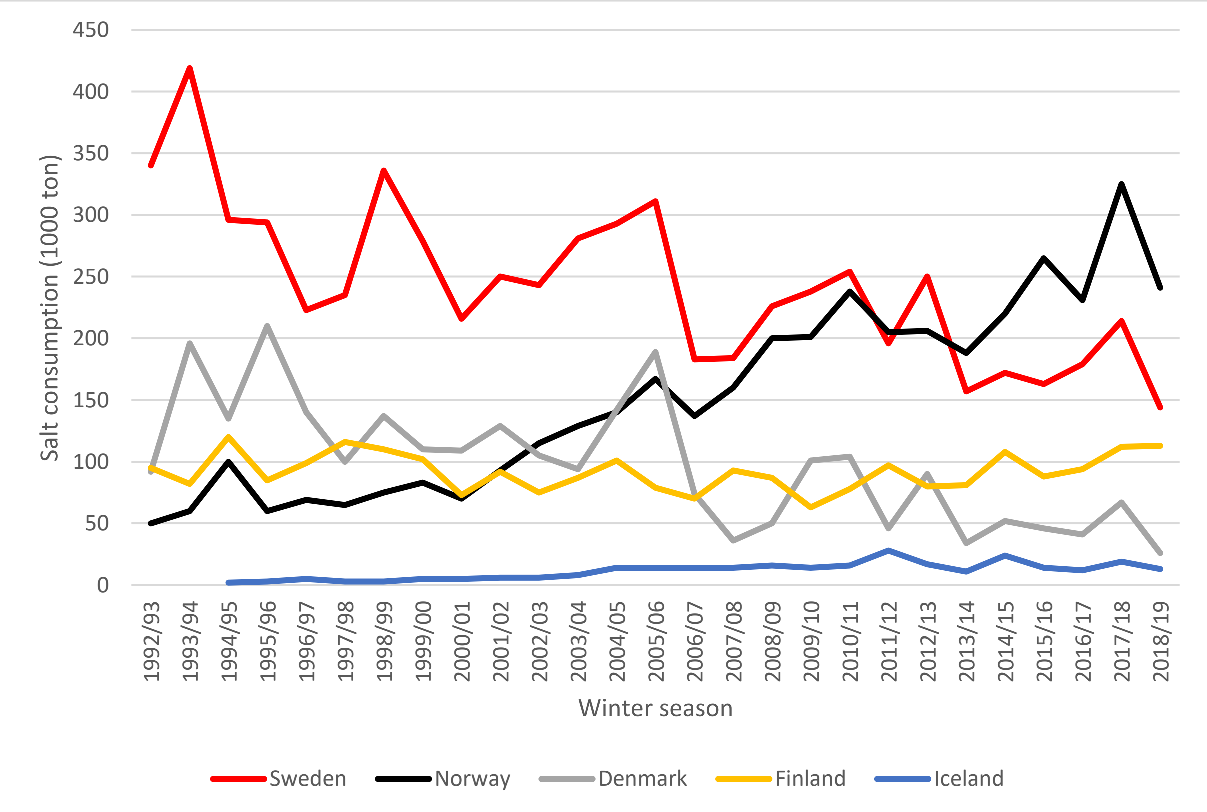



Figure 21: Salt consumption in Scandinavian countries

## England

The amount of de-icing salt used for the highways network in England is shown in Figure 22 [18].

As a result of heavy snowfalls and long winters, there was peak consumption in the winters 2009/10 and 2012/13. Since then, consumption has been significantly lower.

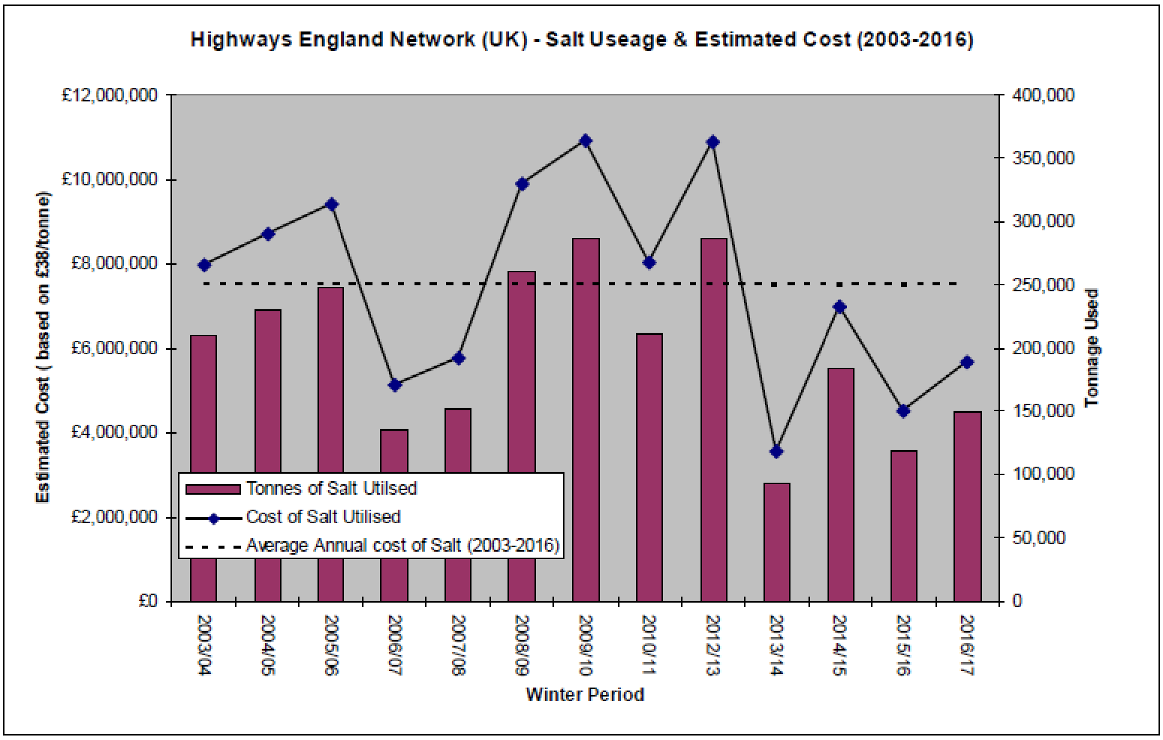



Figure 22: Highways England (UK) Annual salt usage and estimated cost of salt used

<u>Germany</u>

The Figure 23 shows the specific consumption of dry salt for spreading and brine production only. Similar to England, the diagram shows peak consumption for highways. Additionally, brines (NaCl, $CaCl_2$, $MgCl_2$) are purchased [19].

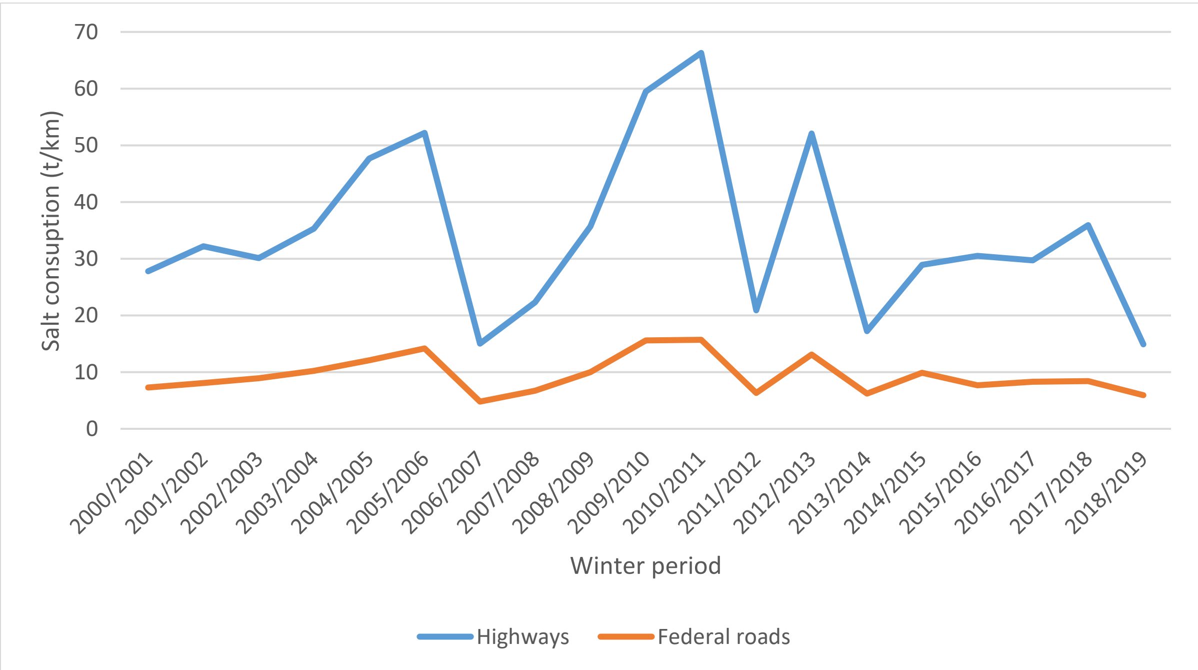



Figure 23: Specific salt consumption on highways and federal roads in Germany

### Influence of climate change on winter road maintenance

Climate change with increasing temperature during winter has an impact on winter maintenance (Figure 24). Climate change models predict (in the more or less short term):

- An increase in average winter temperatures, and therefore a change in winter phenomena (for example: temperatures close to 0° C and therefore more ice). For southern Europe, winter phenomena are likely to become less frequent, and therefore salt consumption will be reduced.
  For Europe at the central level (France type), practices show us that salt consumption increases in this temperature range (higher frequency of icy conditions, more "cautious" road managers).
  At the same time, the practices adapt with, as we have seen, an increased use of brine (more efficient against these phenomena and in this temperature range), thus a less important consumption of "solid" salt.
- More frequent intense phenomena. In terms of impact on salt consumption, it will probably be necessary to expect consumption peaks.

Climate change will also and certainly change the behaviour of road users (for example: more soft mobility). In the municipal sector, winter service will adapt its practices and use brine or alternative materials on cycle paths, for example.

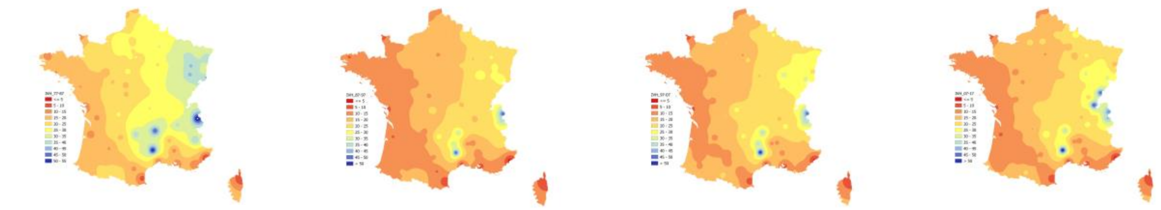



Figure 24: Evolution of Winter Road Maintenance Index (IVH) in France in four periods (Source: Cerema)

<u>Swiss study</u>

On behalf of the Swiss Saltworks, MeteoSchweiz carried out a study in 2015 on the consumption of de-icing salt in Switzerland considering climate change [20].

Due to the expected increase in temperature over the course of the century, the number of days with fresh snow will decrease. It is therefore obvious that less de-icing salt will be needed in the future. Indeed, the results of the study showed a decrease in the average salt demand, especially for emission scenarios without significant international one's measures to reduce greenhouse gas emissions.

According to these scenarios, the average nationwide salt turnover for the period 2045-2074 will be around half of today's expected value estimated. At the end of the 21st century, the average salt turnover is assumed over a 30-year period most pessimistic emissions scenario at around 70,000 Tons, which is slightly lower than the annual minimum of 1997. Salt consumption is currently highest in cantons with a large population and a dense road network, such as for example the canton of Zurich. Especially for cantons with a lower road network will result in a strong reduction the number of days with fresh snow and a correspondingly disproportionate decrease in salt consumption is expected, while for alpine cantons with higher road networks such as in relative terms, Graubünden has become weaker over time decrease is expected.

The estimates made in the report highlight average changes in 30-year periods. So, they do not provide any information on how much salt will be in demand in individual future years. Due to the currently available climate scenarios, the future of an equally strong year-to-year fluctuation of the winter temperature and the number of fresh snow days in the Switzerland can be assumed. So are also in the future still snowy winters possible.

## Dosage

Basically, from an ecological point of view as little as possible, from a traffic point of view as much as necessary of salt should be applied.

The dosage of the salt depends on the forecasted temperatures of roads, precipitation, and the technology for salt application. In Europe there are no standardized dosage recommendations for the various situations; a standard does not exist. Dosage recommendations are made individually at national level. However, they do not differ much from country to country. They depend on:

### Spreading strategies

- **Curative treatments** which consist in intervening once event has occurred. One international study [21] shows that nearly 90% of countries interviewed on the world spread salt during ongoing snowfall (Figure 25).
- **Preventive treatments** which consist in intervening before the winter event is occurred. In the past, there were great discussions about sense and success of preventive spreading. But the development of better spreading techniques (pre-wetted and brine), better road weather information and better experiences in choice of best method and time for application preventive actions are more and more used in winter maintenance. Accident, congestion risks on icy roads can be avoided with preventive spreading. Today more than 80 % of the countries practice preventive spreading regularly (see Figure 26). In half of the cases preventive spreading is only used in the main network, the other 50 % use it on all road types. Preventive actions are planned with the support of a good and detailed road weather information. Executed is preventive spreading before hoarfrost, black ice and freezing wetness. In 9 cases it is also used before snowfall.

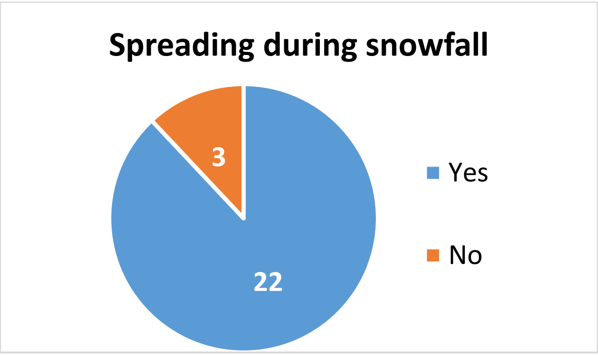



Figure 25: Spreading during Snowfall (Results of an international survey)

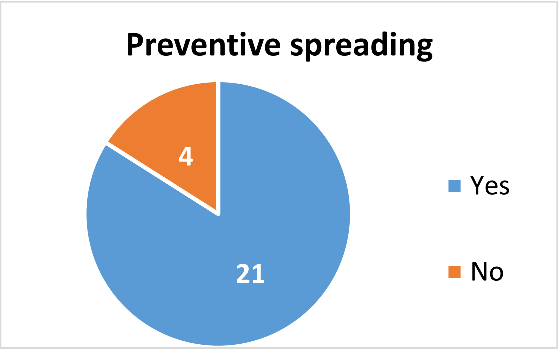



Figure 26: Preventive Spreading (Results of an international survey)

### The type of de-icers (dry salt, brine, pre-wetted)

- **Dry salt spreading:** Dry salt spreading is the result of historical applications. This technical is always used, especially for lowest service levels.
- **Pre-Wetted spreading:** Pre-wetted spreading today is the standard method for salt application in the main road network all over the world and Europe. Nearly all countries use this method in all types of roads. There are different types of brine used for the pre-wetted spreading, around 80 % use NaCl, sometimes $CaCl_2$ or $MgCl_2$ are used.
  In nearly all cases, in Germany or Austria, “FS 30” is used, that means 30 % brine with 70 % dry salt. The dosage amounts vary depending on the specific road and weather situation (between 5 and 40 g/m²); in most cases there exists differentiated guidelines for the spreading amounts.
- **Brine spreading:** Brine Spreading has increased in the use in the last years. Actually around 60% of countries in the world use it regularly (Figure 27).

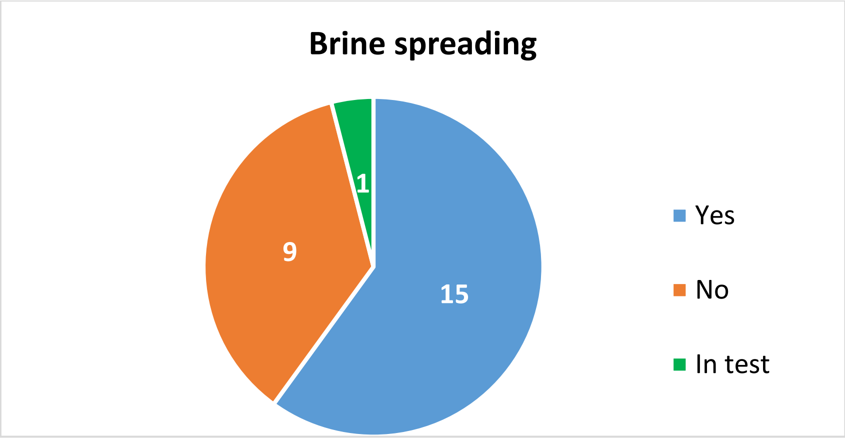



Figure 27: Use of Brine Spreading (Results of an international survey)

  95 % of countries use NaCl for brine spreading, others can use $CaCl_2$ and/or $MgCl_2$ in some cases.
  Some countries have fixed temperature limits for the use of brine spreading, different beginning from -4° C down to -12° C. The experiences with brine spreading are without exception very positive, especially for preventive spreading where it is normally used.
- **Over-satured brine spreading**, which distributes more brine than dry salt. This technique could be used only with specific spreaders. Proportion between brine and dry salt can be adjusted to weather and surface conditions. This technique needs good details road weather information.

### Weather and surface condition

Table 3 shows the comparison of the guidelines from 15 countries in the world for the most important surface and weather conditions. It shows the range for the recommended spreading dosage from lowest to highest value. In (brackets) is always the absolute lowest and the absolute highest value shown, the values without brackets are the most recommended from all countries.

Table 3: Comparison of recommended spreading dosages in the Guidelines [21]

| Weather/Surface Condition | Recommended Range of Spreading Dosage in the Guidelines [g/m²] | | | |
|---|---|---|---|---|
| | Absolute lowest recommendation | Most recommended lowest value | Most recommended highest value | Absolute highest recommendation |
| Hoarfrost | (5) | 10 | 15 | (30) |
| Freezing moist road | (5) | 10 | 20 | (40) |
| Freezing Rain | (10) | 25 | 30 | (50) |
| Spreading during snowfall | (5) | 10 | 30 | (50) |

It can be seen that in most cases the ranges of most countries are very similar and dense. The biggest differences and ranges appear when spreading during snowfall. Some countries spread big amounts, some very low amounts in these cases.

<u>Germany</u>

In the German Winter Maintenance Guidelines, the use of brine is recommended and detailed specifications for the spreading dosages are given (Table 4).

Table 4: German guidelines for spreading techniques and salt spreading amounts depending on the road and weather situation

| Expected Surface Condition | Recommended Winter Maintenance Action | Recommended Spreading Density*** |
|---|---|---|
| **Hoarfrost** | **Preventive Spreading****<br>- **preferential Liquid Spreading***<br>- **otherwise Pre-Wetted Salt**<br>- | **10 – 15 ml/m²**<br>**5 – 15 g/m²** |
| **Light Black Ice (freezing moisture)** | **Preventive Spreading****<br>- **preferential Liquid Spreading***<br>- **otherwise Pre-Wetted Salt**<br>- | **10 – 25 ml/m²**<br>**5 – 30 g/m²** |
| **Black Ice (freezing wetness)** | **Preventive Spreading****<br>- **Pre-Wetted Salt or Liquid Spreading***<br>- | **15 – 40 g/m² (20 – 50 ml/m²)** |
| **Freezing Rain (black ice)** | **If possible Preventive Spreading****<br>- **preferential Liquid Spreading***<br>- **otherwise Pre-Wetted Salt**<br>- | **40 – 60 ml/m²**<br>**30 – 40 g/m²** |
| **Snow Fall (packed snow)** | **1. Where possible Preventive Spreading with Liquid Spreading* or Pre-Wetted Salt**<br>**2. During Snow Fall Snow Removal and Spreading of Pre-Wetted Salt with low spreading density**<br>**3. After Snow Fall aggressive Removal of Snow and Spreading with Pre-Wetted Salt** | **15 – 30 ml/m² (10 – 20 g/m²)**<br>**10 – 15 g/m²**<br>**20 – 40 g/m²** |
| | ***Liquid Spreading only at temperatures above -6° C, at lower temperatures only Pre-Wetted Salt**<br>****if preventive salting was not possible, existing slipperiness must be eliminated with Pre-Wetted Salt with double spreading density** | *****low values for temperatures tight below 0° C, higher values for lower temperatures** |

## France

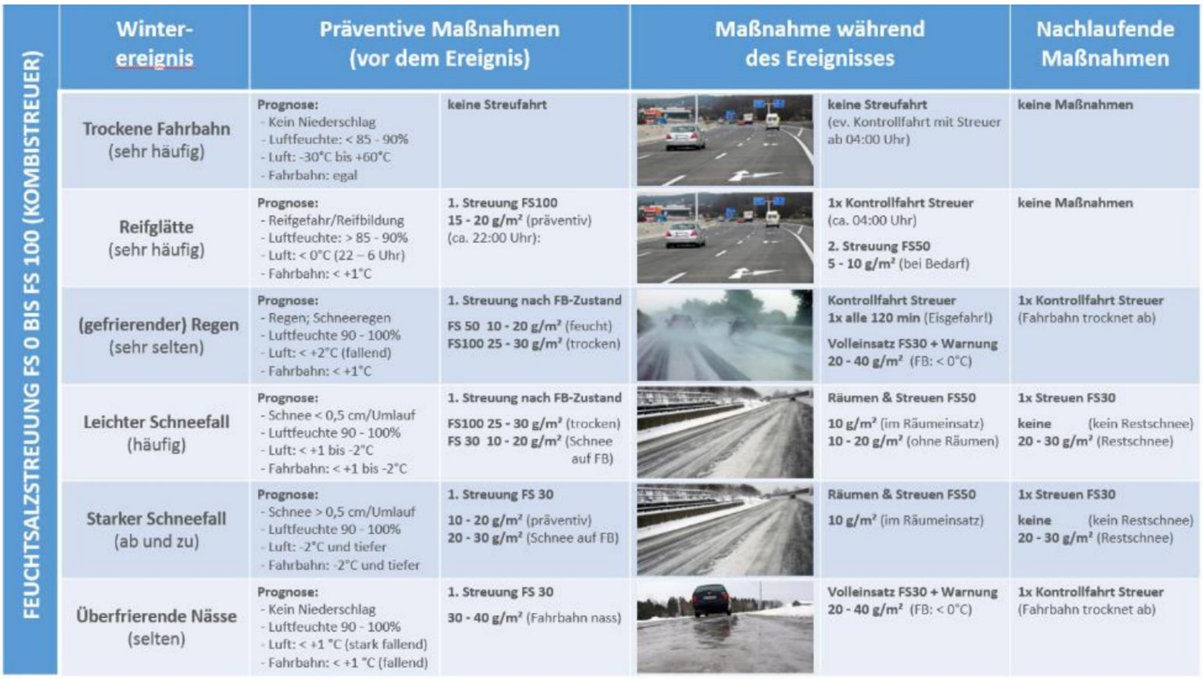
A new technical guide has published by Cerema to describe dosage recommendations for dry salt, prewetted-salt, over-saturated brine, and brine [14]. This guide suggests dosages for preventive and curative strategies. Ranges are described in Table 5.

Table 5: Range of salt dosages in France advised by Cerema

| | Brine | Over-saturated brine | Pre-wetted salt | Dry salt |
|---|---|---|---|---|
| **Ice** | | | | |
| Preventive treatment | 15 g/m² to 50 g/m² | 15 g/m² brine<br>to<br>40 g/m² brine + 10 g/m² salt | 10 g/m² salt + 30% brine<br>to<br>20 g/m² salt + 20% brine | 10 to 20 g/m² salt |
| Curative treatment | 40 g/m² to 50 g/m² | 30 g/m² brine + 5 g/m² salt<br>to<br>40 g/m² brine + 10 g/m² salt | 10 g/m² salt + 30% brine<br>to<br>30 g/m² salt + 20% brine | 10 to 30 g/m² salt |
| **Snow** | | | | |
| Preventive treatment | 0 to 50 g/m² | 0<br>to<br>20 g/m² brine + 15 g/m² salt | 0<br>to<br>15 g/m² salt + 20% brine | 0<br>to<br>15 g/m² salt |
| Curative treatment | 30 to 50 g/m² | 15 g/m² brine + 15 g/m² salt<br>to<br>24 g/m² brine + 10 g/m² salt | 10 g/m² salt + 20% brine<br>to<br>15 g/m² salt + 20% brine | 10 g/m² |

## Austria

Recommendations for preventive measures with salt on motorways in Austria are given in Figure 28.


FEUCHTSALZSTREUUNG FS 0 BIS FS 100 (KOMBISTREUER)

| Winter-ereignis | Präventive Maßnahmen (vor dem Ereignis) | | Maßnahme während des Ereignisses | Nachlaufende Maßnahmen |
|---|---|---|---|---|
| Trockene Fahrbahn (sehr häufig) | **Prognose:**<br>- Kein Niederschlag<br>- Luftfeuchte: < 85 - 90%<br>- Luft: -30°C bis +60°C<br>- Fahrbahn: egal | **keine Streufahrt** | **keine Streufahrt**<br>(ev. Kontrollfahrt mit Streuer ab 04:00 Uhr) | **keine Maßnahmen** |
| Reifglätte (sehr häufig) | **Prognose:**<br>- Reifgefahr/Reifbildung<br>- Luftfeuchte: > 85 - 90%<br>- Luft: < 0°C (22 – 6 Uhr)<br>- Fahrbahn: < +1°C | **1. Streuung FS100**<br>**15 - 20 g/m²** (präventiv)<br>(ca. 22:00 Uhr): | **1x Kontrollfahrt Streuer**<br>(ca. 04:00 Uhr)<br>**2. Streuung FS50**<br>**5 - 10 g/m²** (bei Bedarf) | **keine Maßnahmen** |
| (gefrierender) Regen (sehr selten) | **Prognose:**<br>- Regen; Schneeregen<br>- Luftfeuchte 90 - 100%<br>- Luft: < +2°C (fallend)<br>- Fahrbahn: < +1°C | **1. Streuung nach FB-Zustand**<br>**FS 50 10 - 20 g/m²** (feucht)<br>**FS100 25 - 30 g/m²** (trocken) | **Kontrollfahrt Streuer**<br>**1x alle 120 min** (Eisgefahr!)<br>**Volleinsatz FS30 + Warnung**<br>**20 - 40 g/m²** (FB: < 0°C) | **1x Kontrollfahrt Streuer**<br>(Fahrbahn trocknet ab) |
| Leichter Schneefall (häufig) | **Prognose:**<br>- Schnee < 0,5 cm/Umlauf<br>- Luftfeuchte 90 - 100%<br>- Luft: < +1 bis -2°C<br>- Fahrbahn: < +1 bis -2°C | **1. Streuung nach FB-Zustand**<br>**FS100 25 - 30 g/m²** (trocken)<br>**FS 30 10 - 20 g/m²** (Schnee auf FB) | **Räumen & Streuen FS50**<br>**10 g/m²** (im Räumeinsatz)<br>**10 - 20 g/m²** (ohne Räumen) | **1x Streuen FS30**<br>**keine** (kein Restschnee)<br>**20 - 30 g/m²** (Restschnee) |
| Starker Schneefall (ab und zu) | **Prognose:**<br>- Schnee > 0,5 cm/Umlauf<br>- Luftfeuchte 90 - 100%<br>- Luft: -2°C und tiefer<br>- Fahrbahn: -2°C und tiefer | **1. Streuung FS 30**<br>**10 - 20 g/m²** (präventiv)<br>**20 - 30 g/m²** (Schnee auf FB) | **Räumen & Streuen FS50**<br>**10 g/m²** (im Räumeinsatz) | **1x Streuen FS30**<br>**keine** (kein Restschnee)<br>**20 - 30 g/m²** (Restschnee) |
| Überfrierende Nässe (selten) | **Prognose:**<br>- Kein Niederschlag<br>- Luftfeuchte 90 - 100%<br>- Luft: < +1 °C (stark fallend)<br>- Fahrbahn: < +1 °C (fallend) | **1. Streuung FS 30**<br>**30 - 40 g/m²** (Fahrbahn nass) | **Volleinsatz FS30 + Warnung**<br>**20 - 40 g/m²** (FB: < 0°C) | **1x Kontrollfahrt Streuer**<br>(Fahrbahn trocknet ab) |

Figure 28: Recommendations for preventive salting and brine treatment for standardised scenarios on motorways in Austria

**Conclusions:**

- **Salt consumption dynamics is driven by varying winter temperature and precipitation.**
- **Estimated annual European salt consumption for de-icing: 5 to 17.5 million tons.**
- **Available national statistics show falling or constant trend (exceptions CH, NO).**
- **Decoupling the salt consumption from the increase in road lengths or areas maintained.**
- **Reasons for this: improved service strategies (ploughing first, preventive spreading, dosage recommendations), improved spreading quality (pre-wetted salt, direct brine application), road weather information systems (RWIS).**
- **Long-term influence of climate change is relevant.**

# 7. PERFORMANCE OF SALT COMPARED WITH OTHER INORGANIC AND ORGANIC DE-ICERS AS WELL AS ABRASIVES

## Alternative de-icers to salt / abrasives

De-icers are products designated to prevent ice formation and/or to ensure the melting of ice or snow. They must be soluble in order to be effective. They can be in solid or liquid form. The most common are listed in Table 6.

Table 6: Inorganic and organic de-icers

| Solid form: | Liquid form |
|---|---|
| Inorganic de-icers<br>- Sodium chloride<br>- Calcium chloride<br>- Magnesium chloride<br>Organic de-icers<br>- Sodium acetate<br>- Sodium formate<br>- Urea<br>- Calcium magnesium acetate | Inorganic de-icers<br>- Sodium chloride brine<br>- Calcium chloride solution<br>- Magnesium chloride solution<br>Organic de-icers<br>- Potassium acetate<br>- Potassium formate<br>- Glycerol based products<br>- Calcium magnesium acetate |

Most of road managers find a satisfactory and sufficient answer to their needs with sodium chloride. Other de-icer can be used for specific needs: corrosion, areas which are sensible to chloride. The wide range of products that can be used and the considerable spectrum of their specifications make the choice of the type and form more complex. Road managers must carefully review the markets offers and choose de-icer(s) adapted to his needs and his constraints [22].

All de-icers have to be conform to EN 16811-1 to 16811-3 to be used by road managers. [7-[23]-[24]].

Abrasive is not a de-icer. It is a winter maintenance material with no melting power. It is designated to be embed itself on the surface of a layer of snow or ice in order to recreate a texture that promote adhesion. They are used only for networks located in areas with rigorous winter (mountains, low traffic flows) [25]. After contaminant (ice or snow) has melted, they must be swept away to prevent clogging of sewer network, the production of fine particles and slippage (pavements, cycle paths) due to residual materials [26]-[30]. Abrasives are suitable only for curative treatments.

The market also offers <u>blends of abrasives and de-icers</u>. Their action is particular because they target two contradictory objectives: melting and restoring adhesion by embedding themselves in the contaminant layer. As well as abrasives, they must be swept away at the end of winter event.

### Eutectic temperatures

The eutectic point (the lowest freezing temperature) seems to be the main performance criteria of de-icers. Freezing-curves of solid formulations are similar with eutectic points slightly below -20° C. The off-the-shelf liquid formulations (potassium acetate, potassium formate and glycerol-based product) have their eutectic point around - 60° C / -70° C. Only calcium chloride has a specific behavior with a eutectic temperature approximately at - 50° C (Figure 29) [29].

This approach should be put in perspective, given that these products are only effective when in solution and that surface temperatures decrease rarely below -20° C in France. To protect a pavement from ice within a temperature range from -20° C to 0° C and for a given water quantity, de-icers amount to be applied are similar for solid product. To protect at same temperature, amounts have to be more than doubled for liquids compared to solids.

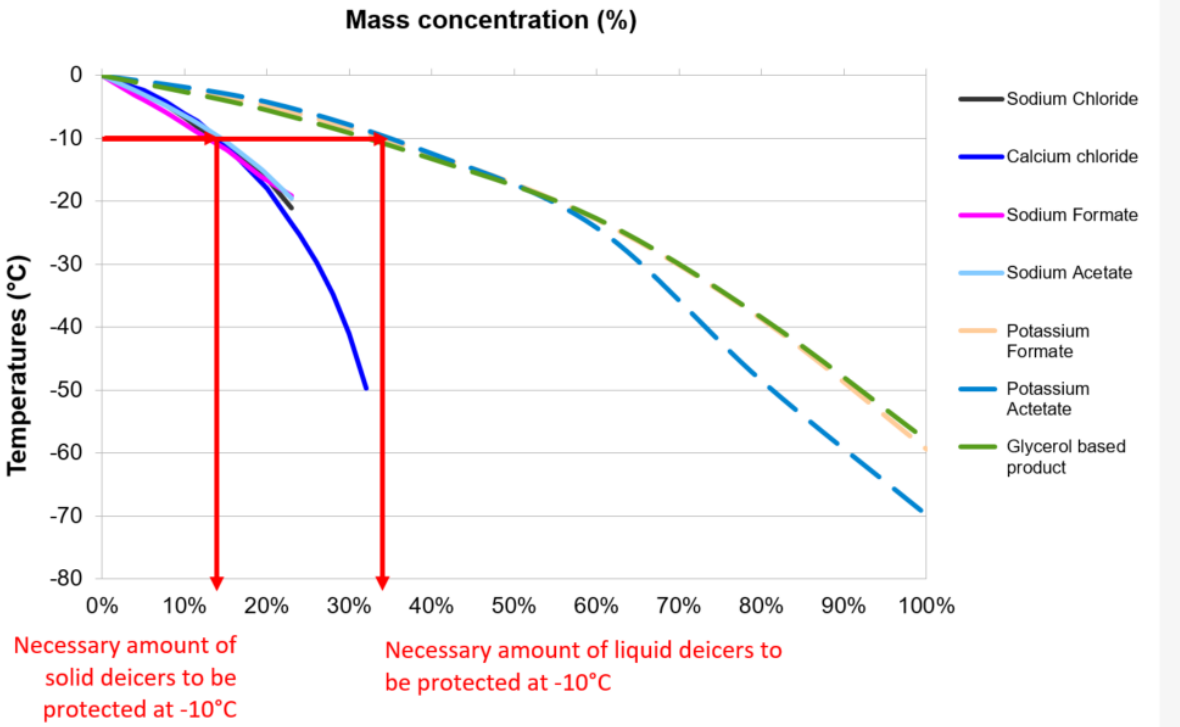



Figure 29: Phase diagrams of de-icers and necessary amounts to protect a pavement at -10° C

### Abrasives

In order to be effective, much larger quantities of abrasives must be spread compared to salt. For abrasives, dosage recommendations are given by Cerema (Table 7) [25]:

Table 7: Range of abrasive dosages in France advised by Cerema

| | Ice | Frozen snow | Ice snow |
|---|---|---|---|
| **Only curative treatment** | 20 to 50 g/m² of sand | 50 to 100 g/m² sand or mixture of sand (40%) + aggregate (60%) | 50 to 200 g/m² aggregate |

In Germany, a standard dosage of approx. 150 g/$m^2$ is recommended for abrasives [31].

A study with test routes in Zürich and Chur in Switzerland clearly showed that salt spreading has a high economic benefit. In contrast, the economic benefit of the abrasive's distribution is rather small. The application costs for the spreading in a normal winter are approx. 6 times higher for the abrasives spreading than for the salt spreading. In a severe winter, the factor is even around 10 [32].

With regard to the environmental impact, the study concludes that both salt spreading (damage to vegetation) and abrasives spreading (disposal, dust pollution, ecological balance) are to be classified as significant pollution. Measures to reduce the spreading of both materials are still necessary.

The study comes to the conclusion that the salt spreading ensures road safety in winter and can be described as a very good solution in terms of safety. In contrast, the effects of abrasives rarely last for a long time. In addition, traction measurements (adhesion of the vehicle wheel on the road; decisive for the braking distance and driving stability) showed that the effect of abrasives is only slight. Abrasives spreading suggests to the driver a greater increase in grip than is actually achieved, which results in excessive speeds. With abrasives spreading, the risk factor is exceeded more than with salt spreading.

It should also be noted that some slag-type abrasives can contain pollutants. That is why natural stone gravel or sand is preferred.

### Dissolution thermodynamic

De-icers, during their dissolution in water, can be exothermic, i.e., they provide heat to the road, as in case of calcium chloride, or endothermic, i.e., they capture heat from the road, as in case of sodium chloride. The same mechanism comes into play for the ice melting.

For each reaction, involved energies are estimated by enthalpy of fusion of ice (334 kJ/kg) and enthalpy of de-icers which can be exothermic or endothermic. Figure 30 shows the total energy for a treatment of 0,5 mm of ice by 20 g/m² of solid product. In the end, the global reaction is endothermic, with the ice melting reaction being the most important. Thus, a treatment with any solid product takes heat from the pavement, whose surface temperature decreases.

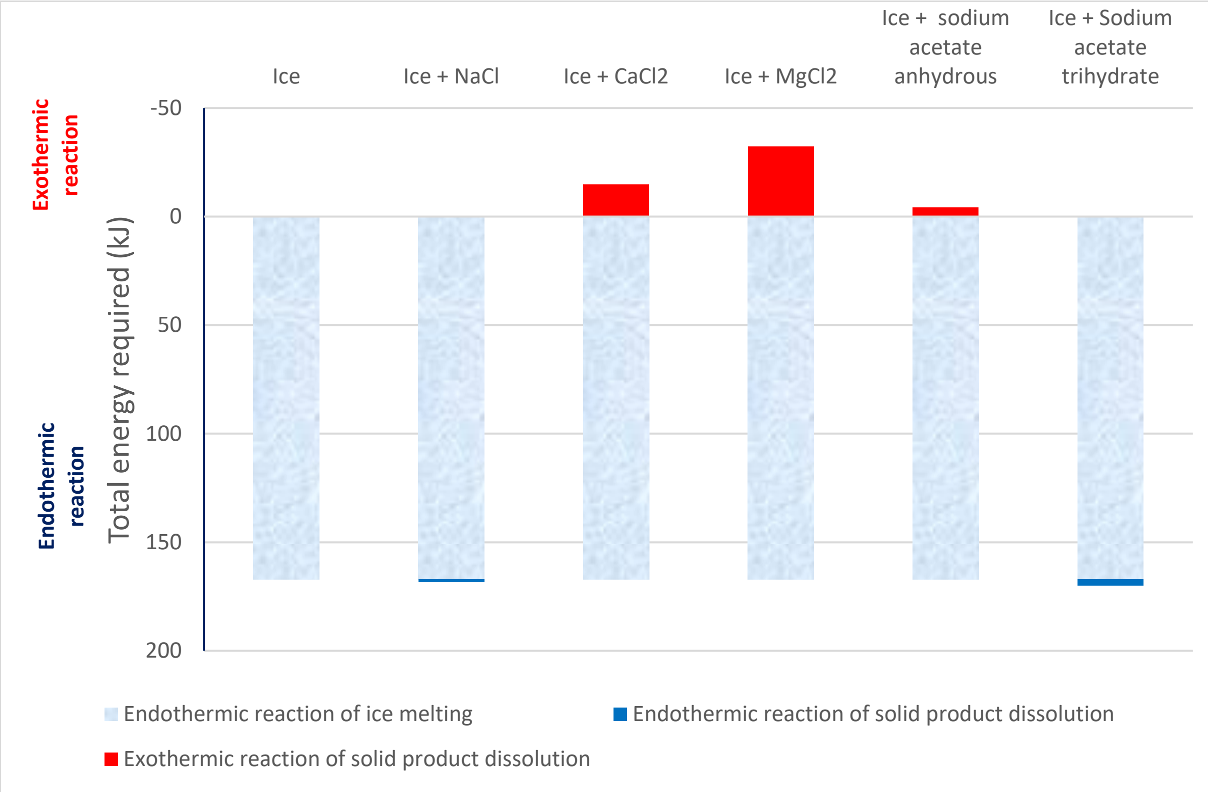



Figure 30: Total energy required (in kJ) to melt 0.5 mm of ice with 20 g/m² of solid material

## Slipperiness

To spread de-icers on pavement, especially in preventive practices or when they are in liquid form, could induce a risk of grip decreasing. This grip decreasing is linked to the viscosity of de-icers solutions on pavement. A study compares kinematic viscosity on liquid de-icers at maximum concentration and on solid de-icers in solution at 30%w/w. For all products, viscosity increases as temperature drops (Figure 31) [29]. Some of them may induce a grip decrease on pavement when they are spread in preventive treatment at negative surface temperature.

Measurements of the coefficient of friction with the SRT pendulum showed higher values for brine (sodium chloride solution) than for other solutions of chlorides (calcium chloride, magnesium chloride) (Figure 32) [24].

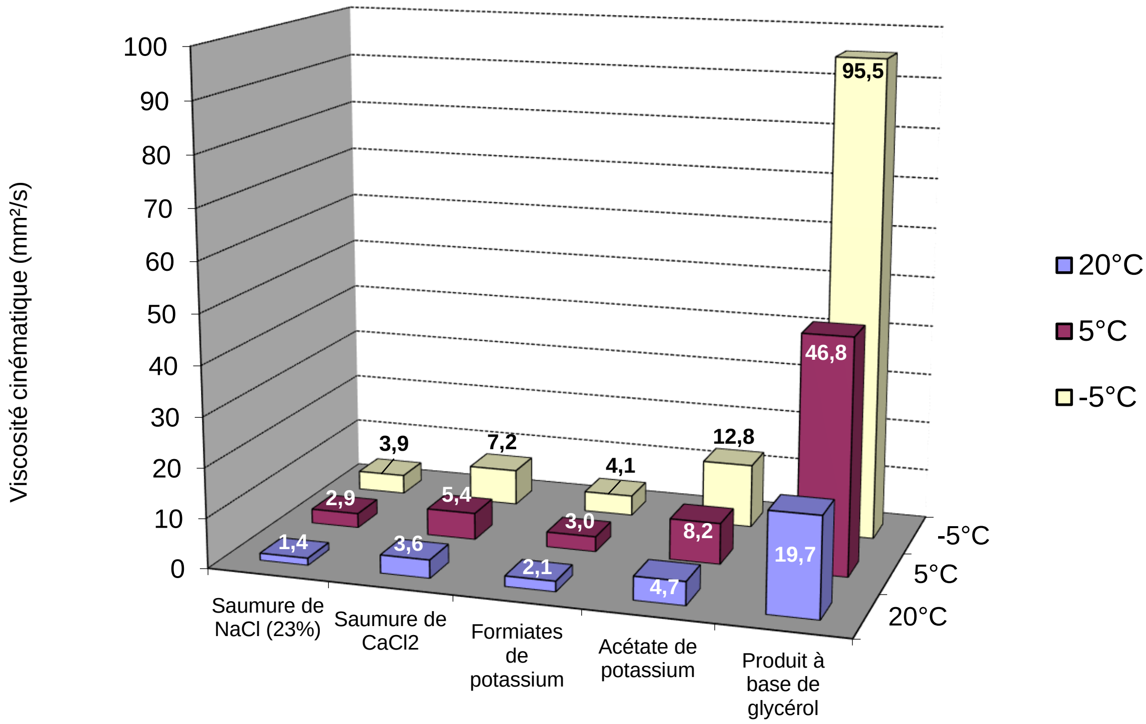



Figure 31: Kinematic viscosity of different de-icers in liquid form

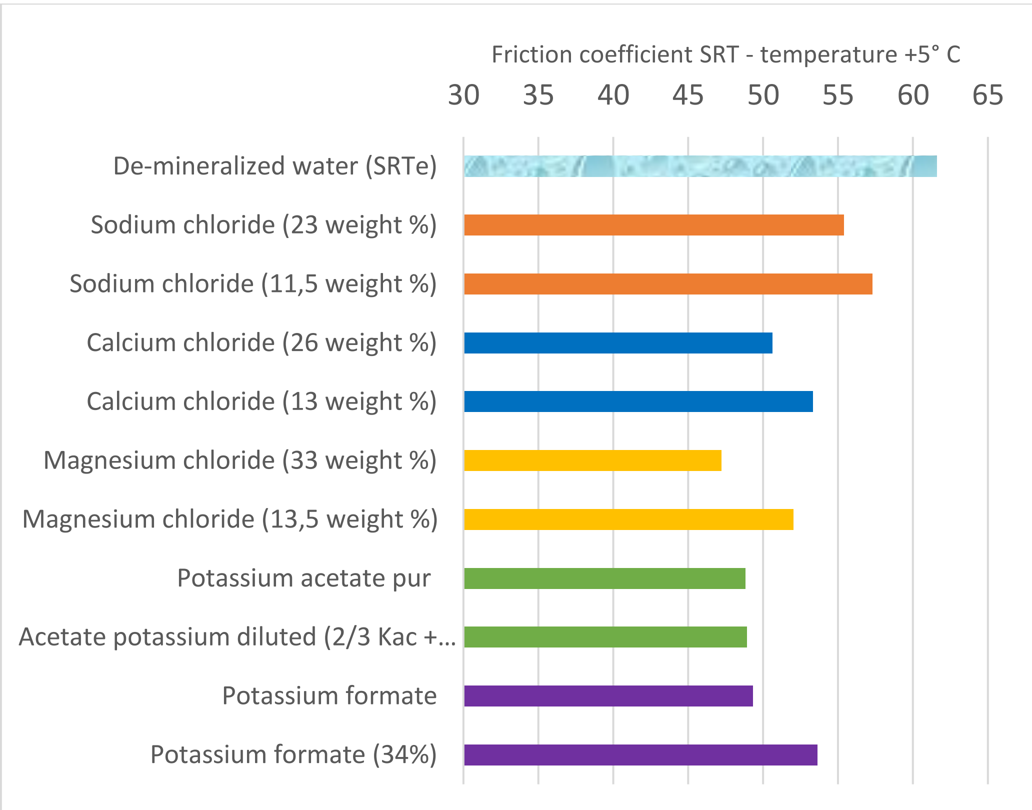



Figure 32: Slip resistance (friction coefficient SRT pendulum) of de-icers – Temperature + 5° C

**In conclusion, there are many products on the market that are alternatives to salt.**

- **Abrasive products with a different objective than salt: they are only used in curative treatment to restore grip to a pavement that will remain snowy / icy. Quantities needed are more important. 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 rigorous winter (mountains, low traffic flows).**
- **Melting products, i.e., they are intended to prevent ice formation and/or to ensure the melting of ice or snow. These ones, usually more expensive, are used for specific needs (areas which are sensitive to chloride, corrosion, environmental aspects). Liquid products being already in solution form are effective quickly, but dosage must be double of solid products. This aspect highlights storage capacities, the capacity of spreaders and the dimensioning of circuits.**
- **Thus, alternative de-icers have different characteristics than salt. Some advantages (less corrosive, biodegradable...) are often counterbalanced by other disadvantages (higher dosages, lower adhesion level...).**
- **Any change of product therefore requires a thorough prior study of needs, but most of road managers find a satisfactory and sufficient answer to their needs with sodium chloride.**

# 8. ENVIRONMENTAL IMPACTS OF DE-ICERS AND ABRASIVES

All products spread in environment have an impact on different environmental compartments (water, biodiversity, vegetation, soil). These impacts are different and depend on the nature of the product (inorganic, organic). One certainty, these products are soluble, and the major vector is water.

## Groundwater

The increase of the salting operations leads to an increase in the salt concentration of shallow ground waters [33]. The concentrations of $Na^+$ and $Cl^-$ ions present in underground waters were also correlated with the permeable surface fraction which can receive road salt [35]. Although it is estimated that up to half of all de-icing salts end up in deep soil layers and groundwater, there are virtually no known cases where drinking water wells have been altered by de-icing salts, as these are mainly extracted from deep wells (exception: urea). It is generally accepted that major groundwater reservoirs remain insensitive to possible salt contamination because of their volume and flow rate [26].

## Surface water and biodiversity

Surface waters (standing and flowing waters) are more affected by winter maintenance activities. This saline polluting 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. Two main phenomena come into play here [36]:

- the osmotic regulation of organisms with a risk of dehydration of the cells which can lead to the death of the most sensitive organisms and microorganisms,
- stratification of lake water: naturally, the thermal stratification of some lakes leads to seasonal vertical mixing of the water, allowing the deeper, colder and denser layers to oxygenate and the warmer, surface layers to become richer in bio-available nutrients for phytoplankton. However, this mechanism is disturbed by water loaded with sodium

chlorides: salt water, which is denser than fresh water, flows to the bottom of lakes. In spring, the differences in density are no longer due solely to thermal stratification, leading to a reduction or even disappearance of seasonal mixing.

- o Thus, the deep layers become depleted in oxygen, and living organisms gradually disappear in favour of species tolerant to salinity and anoxia (absence of oxygen),
- o Surface aquatic organisms, lacking in nutrients, lose productivity.

Hypoxia (quantity of dissolved oxygen too low to ensure the life of living beings) and anoxia (absence of dissolved oxygen) have a major impact on biodiversity, mainly because of the mortality episodes they cause. Fish are particularly affected, but globally all animals and plants suffer from a lack of oxygen [37].

These phenomena can also be the result of the biodegradation of some products. Organic de-icers (urea, acetates, formates, glycerol...) have the property of being more or less biodegradable. The biodegradability is approached essentially through two parameters (Figure 33):

- The Chemical Oxygen Demand (COD), i.e.the oxygen $O_2$ consumption to oxidise the product by strong chemical oxidants. It represents the total organic material which can be degraded.
- The Biochemical Oxygen Demand ($BOD_5$), i.e., the amount of biodegradability material in 5 days by biochemical oxidation (oxidation by aerobic bacteria).

The ratio between COD / $DOB_5$ represents the biodegradability.

If it is essential for the environment that substances spread are biodegradable to avoid them accumulation in the ecosystem, quantities of oxygen required for their degradation must not be too high, to avoid asphyxiation into environment and phenomena as hypoxia or anoxia [27]. Although the biodegradability (ratio COD/$BOD_5$) shows that formate is difficult to biodegrade, the oxygen quantities required to their biodegradation are lower than for other products. This leads to the conclusion that formate products (solid or liquid) seem less problematic than acetate or glycerol-based products, the latter being particularly harmful for the environment [29].

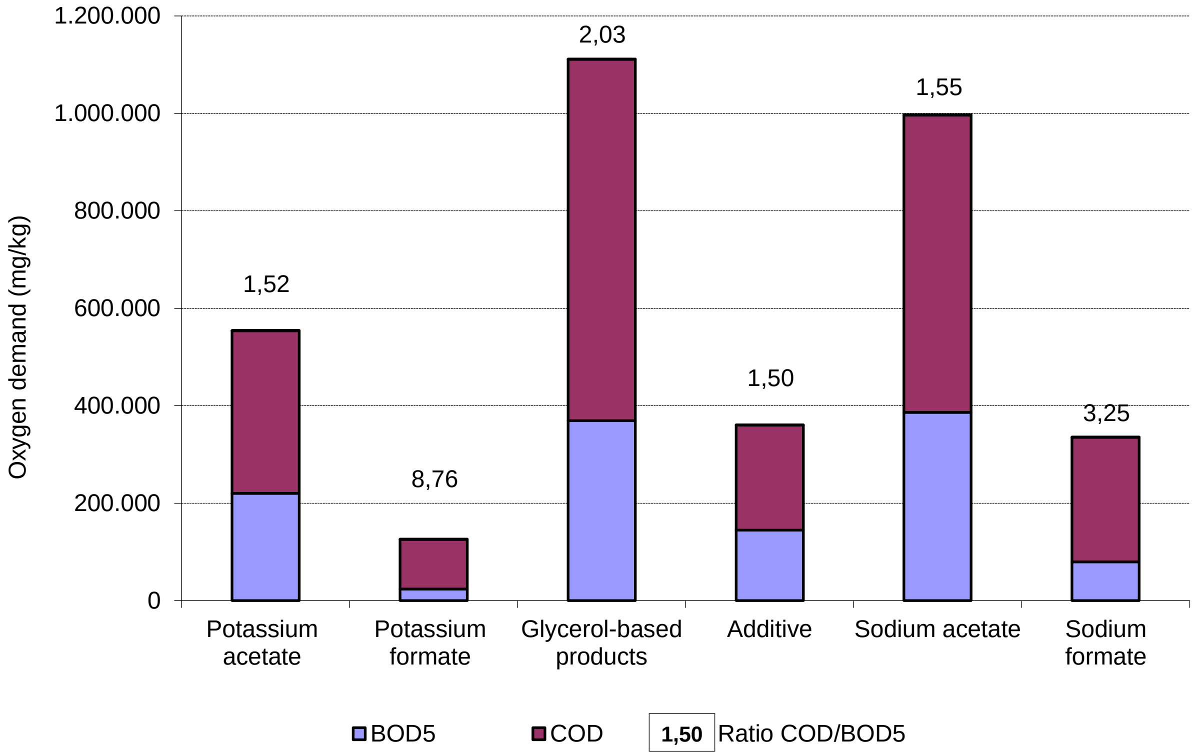



Figure 33: Biochemical Oxygen Demand in 5 days $BOD_5$ (NF EN 1899-1) and Chemical Oxygen Demand COD (NF T 90-101) of de-icers, ratio $COD/BOD_5$ [29]

### Soil and vegetation

Road salt accumulation in soils depends on several parameters: the soil permeability and its density, and its mechanical properties influence the salt transport and the physicochemical processes [38].

Many authors have shown a direct correlation between the content of Na+ and Cl− ions in the soil and the degree of plant damage [39]-[40]. Indeed, increases in Na+ concentration tend to leach out K, Ca, and Mg cations, which can result in nutrient deficiencies in certain soil types [41]-[42]. The most significant symptoms of salts on roadside trees are growth limitation/reduction in biomass, necrosis, defoliation, and in extreme cases, the entire destruction of a plant [43]-[44]. These symptoms can be caused by several salt effects: photosynthesis reduction, decrease of soil moisture, decrease of water content in leaf tissues, alteration of nutrient availability, etc. [37]

It was observed that Ca and Mg are present in higher concentrations in soils in the vicinity of roads [45]-[46]. Indeed, after salting operations, Na+ concentration increases in the soil solution. Sodium enters in competition with other cations at the sites of ionic exchanges leading to an increase in $Mg^{2+}$ and $Ca^{2+}$ concentrations in the soil solution [46][47]. Because of its stronger attraction to negatively charged soil particles, $Mg^{2+}$ may accelerate $Na^{+}$ leaching by displacing it in soils [45]. Thus, faster movement of Na+ through soils make $Na^{+}$ less available to plants, but more available to aquatic systems [48].

Sodium can also enhance the release of metals from soils to groundwater [47][48]. Hence, increased transport of heavy metals (Zn, Cd, Cu and Pb) coincident with road salt applications has been observed in roadside soils in Germany, Sweden, and the United States [49].

Urea has the additional characteristic of being composed of nitrogen. The human input of a substance containing this type of nutrient strongly stimulates the growth of plant organisms, leading to the sudden development of plants or algae, known as "plant proliferation". This is called eutrophication [37].

### Effect on vehicles, infrastructures / buildings

The main effect on vehicles and different metal materials is corrosion. Aqueous corrosion is an electrochemical process which has its origin in the electrically conductive nature of the two phases present: electronic conduction in the metallic phase and ionic conduction in the aqueous phase, also called electrolyte. The electrolyte depends on the nature of de-icers in water. All chemical salts increase the conductivity of water by dilution of de-icers in ice or snow.

Corrosion could be approached by test methods to have an estimation of degradation in µm/year for the metal, depends on the nature of electrolyte. Another way is to compare de-icers solutions conductivity (Figure 34) [29].

So, de-icers with high conductivity may affect metals such as steel, zinc. Because they are organic, glycerol-based products are less conductive than mineral de-icers. Formate and acetate products, used on airport sector, generally contain corrosion inhibitors in small amounts, which significantly reduce metal corrosion.

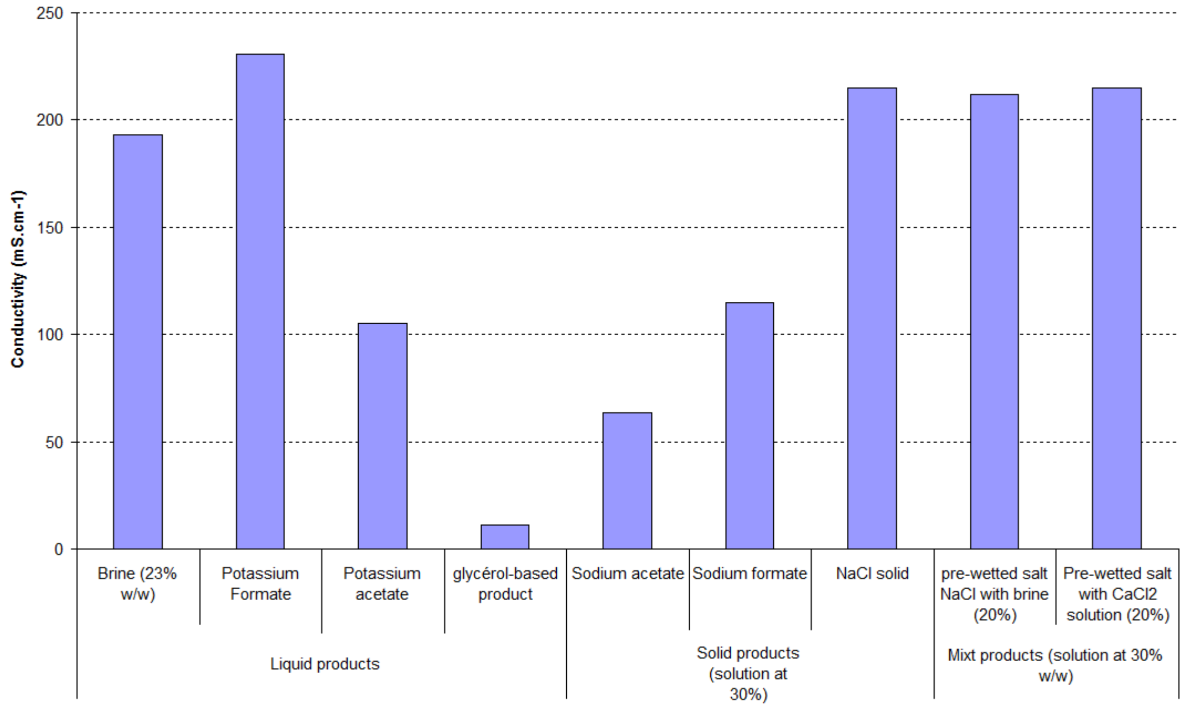



Figure 34: Conductivity of de-icers for winter maintenance [29]

To investigate the influence of solutions of the de-icing salts sodium chloride, calcium chloride and magnesium chloride onto the durability of concrete, concrete specimens, with typical qualities for roads and bridges, were subjected to different load cycles under practical conditions. Also, in the case of extreme load through repeated wet and dry phases with subsequent cyclical freeze-thaw-attack the physical and chemical effects on the concrete were low. The found differences of the different de-icing salts in the damage behavior are negligible for the practice.

The results prove that for the generation of pre-wetted salt, the solutions of the chlorides of sodium, calcium and magnesium are equally suitable with regard to the durability of concrete used in road construction and of XF4 concrete. Also, in the case of preventive liquid spraying with NaCl-brine only an extremely small attack is to be expected on roads constructed with concrete conform to the current standards [50].

### Animals

Stories about de-icing salt causing increased vehicular collisions with deer are almost inaccurate. Records show that deer-vehicle collisions are lowest during winter. More collisions are caused by deer feeding on road shoulders that offer highly palatable grasses and legumes resulting from better soil, seeding, fertilizing, and mowing. Deer are attracted to roads and highways at all times of the year because they are attracted to open spaces.

Dogs who walk in snow and ice may expect some foot pad irritation, but only of the pad is already irritated. Salt will irritate an existing cut or abrasion as will sand, cinders, and other chemical de-icers. However, fine grained salt and weak salt solutions have no adverse effect on the paws of healthy dogs.

### Fine dust

With the abrasives, in addition to the disposal problem, the 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 the fine dust pollution during the winter months [51]-[52]. The generated fine dust can enter the respiratory tract. Fine salt dust dissolves in the mucous membranes and does not pose a health risk [53].

### Biological sewage-treatment plants

In treatment plants, traceable damage can be found generally from concentrations of only about 10000 mg/litre activated sludge onwards. Usually, however, urban wastewater only shows chloride concentration of about 50 mg/litre and de-icing salt contamination in winter may temporarily at most double this figure. Any interference with the treatment process due to de-icing salt may be ruled out.

A greater problem for the biology of treatment plants is the sudden drop in temperature caused if large quantities of snow have to be disposed of via the drainage system [54]-[56].

### Product life cycle

Approach of environmental impact of de-icer require a larger scope study through widening of analyse with product life cycle.

Because of the European Green Deal, the road authorities must work to reduce their emissions while ensuring a safe service through winter maintenance work. The life cycle of salt used as road de-icer encompasses all activities related to its use, from production to spreading. Each stage of this life cycle has a more or less significant impact on the environment. The road operator is involved in part of the life cycle, particularly in relation to transport, storage and spreading. In the end, the salt used in winter road maintenance ends up in the various environmental compartments.

In order to determine the contribution of the salt to the overall environmental impact of the winter service, the entire system of the winter service with salt including the upstream and downstream process chains must be analyzed (Figure 35). Several researchers have already performed life cycle assessments of winter road maintenance and of the production of spreading materials under different scenarios.

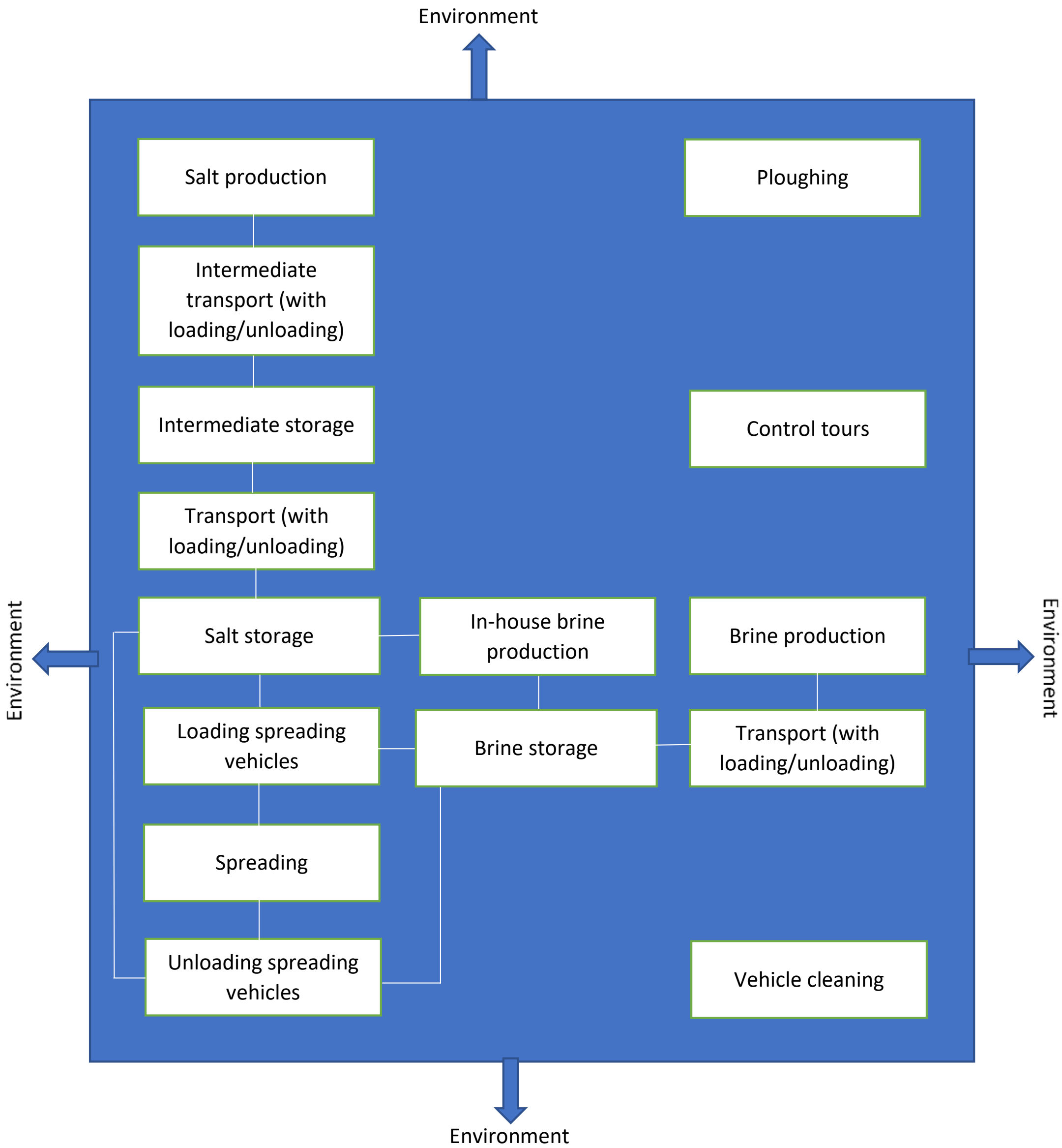



Figure 35: System of winter road maintenance for life cycle assessement

Life cycle assessment (LCA) was used to evaluate the environmental impact of the functional unit “average winter road maintenance on national and county roads per km lane” in Norway. The quantity of de-icer used is the main source of emissions contributing toward all impact categories. The representation of winter road maintenance in existing emissions data is limited despite the considerable amount of de-icer applied and the long distances that WRM vehicles travel. The results document how energy use throughout the system is another important source of emissions. Various parameters, such as road gradient, vehicle properties, driver behavior, and weather, affect the fuel consumption of WRM vehicles, with weather being the most important of these. The environmental impacts of de-icer application are especially high compared to the mechanical clearing of roads [57].

Life cycle assessments for major southern German cities have shown that the environmental impacts of winter service include energy consumption and emissions during the manufacture and delivery of the litter and the operation of winter service vehicles. In Munich, 1/3 of the total environmental impact of winter road clearance is caused by the production and transport of the spreading material (NaCl, $CaCl_2$, grit). In Nuremberg, the proportion of that used there contributes Expanded clay 2/3 of the environmental impact of winter road maintenance. It is recommended that energy-intensive spreading material, such as expanded clay, should only be used sparingly and that the spreading material should only be transported over short distances if possible. Transporting the spreading material by rail and ship is to be preferred to truck transport [58].

Previous investigations have shown that fossil energy consumption to manufacture sodium formate and urea is larger than for sodium chloride. Figure 36 compares the energy required to produce (blue) and the energy required to spread (red) different materials. It clearly shows that for sodium chloride, potassium formate and urea, the production share is predominant. For abrasives, it is the part related to spreading that consumes the most fossil energy [26].

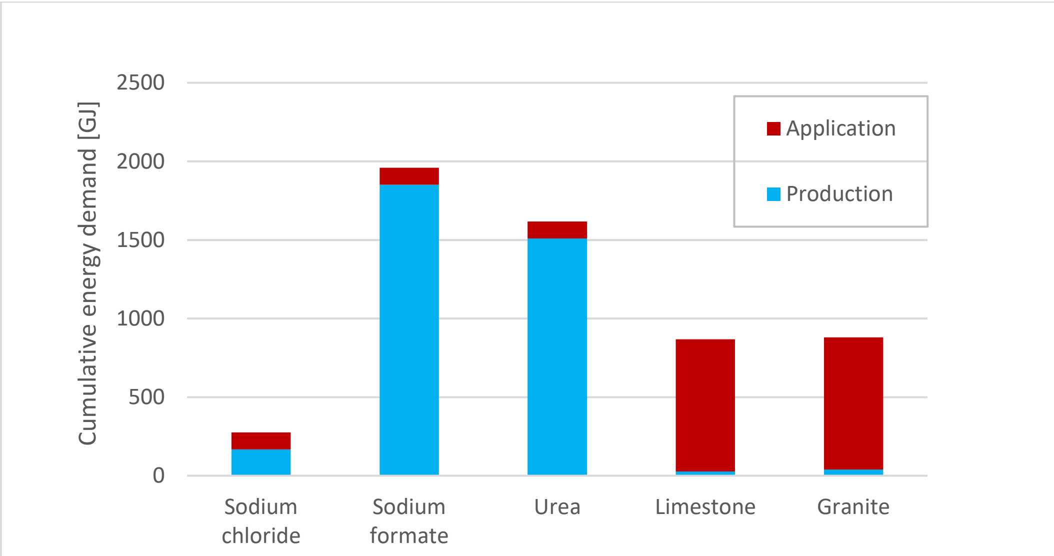



Figure 36: Consumption of fossil energy required for the production and application of several spreading materials for 1.000 km (4 $km^2$) road (spreading rates: de-icer 15 $g/m^2$, abrasives 120 $g/m^2$)

A comparison of the available data for organic and inorganic de-icers showed that the global warming potential for production of sodium chloride is the lowest (Table 8). Compared with sodium chloride, calcium chloride, CMA, formates and urea needs more primary energy and emits more $CO_2$. For exact calculations and comparisons, the production routes, and the real applications with the recommended spreading amounts for anti-icing and de-icing services on roads at different winter weather conditions must be taken in consideration [59].

Table 8: Comparison of global warming potentials for de-icer production (cradle-to-gate)

| De-icer | Global warming potential (kg $CO_{2eq}$ per kg de-icer) |
|---|---|
| Sodium chloride | 0,001 – 0,155 |
| Calcium chloride | 0,040 – 0,723 |
| Calcium magnesium acetate (25% solution) | 0,289 |
| Potassium formate | 1,287 |
| Urea | 0,910 |

Other parameters are taken into account such as the location of production, transportation modes used, the packaging.

For a comprehensive view of greenhouse gas emissions, it is necessary to consider the transport of the salt to the storage sites. Selected means of transport (truck, train, ship) and the distance of the salt producers' location to the salt destination are of big relevance. Therefore, the transport to customers has to be considered in the context of an analysis of sensitivity [59]-[60].

*Specklin* and *Matrat* have calculated GWG scenarios for France with domestic produced road salt and for imported road salt from Germany, Morocco, and Sardinia. They concluded that emissions of greenhouse gases can be minimized by a domestic production of sea salt and rock salt, and the right choice of means of transport [61]-[62].

To keep energy consumption and associated emissions low, transport distances between the place of production and the place of consumption should be kept as low as possible. This suggests that procurement should be from sources close to the place of consumption. With de-icing salt from local sources, the global warming potential is minimized. To minimize the consumption of fossil fuels, transportation by train or ship is preferred to transport by truck.

## Selection of de-icers

When choosing chemical de-icing agents, it is important to consider the performance and cost under various weather conditions and to evaluate the relative environmental impact. Table 9 compares de-icers with some of their known environmental impacts.

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 [61]-[62]-[62]. Calcium chloride is classified as hazardous substance. Solutions of calcium and magnesium chlorides may be used as prewetting agents for salt. These products are more expensive than salt.

Since there are large differences in the consumption of fossil fuels to produce de-icing products, the environmental assessment of alternative de-icing agents should be supplemented by the criterion global warming potential in addition to the criteria biological and chemical oxygen demand etc., as required by CEN/TS 16811-3. For this purpose, the results of a screening life-cycle analysis or a LCA according to ISO 14040 are necessary.

Table 9: Comparison of different de-icers on some known environmental impacts [36]

| 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. Significant symptoms on roadside trees. | 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. 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.<br><br>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]. Oxygen consuming biodegradation. | Its cost is about 20 times higher than NaCl cost [28] |
| 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. |

### Fate of anti-caking agent

Occasionally, the question of possible side effects from the de-icing salt additive sodium ferrocyanide (also known as Yellow Prussiate of Soda, or YPS) is raised. This harmless additive is not to be confused with poisonous cyanides. YPS is also the most commonly used anti-caking agent in table salt and salt for animal nutrition. It is approved by the Codex Alimentarius Standard 150 and the European regulations for food and feed as an anti-caking additive in salt for human and animal consumption. Ferrocyanide is vital if de-icing salt is to be available in a usable form that ensures free-flowing properties not only when it is supplied to the user but also after it has been in storage for a fairly lengthy period of time at motorway and road maintenance depots. The anti-caking agent is added according to the quantum satis principle (as much as necessary, as little as possible). This avoids negative effects on the environment from the outset. In view of the low amounts of salt currently used to grit roads, considerable significance is attached to the salt's free-flowing properties. Ferrocyanide is not persistent in the environment and is removed by precipitation, photolysis volatilization, and biological degradation [66]-[68].

### Re-use - Elimination

The issue of elimination or treatment of road effluent with de-icers depends on the nature of them.

To reduce the direct transfers of road runoffs into environment, treatment systems such as retention ponds are constructed alongside road. Their role is to regulate the flows going into environment.

For organic de-icers, such as formate or acetate, the previous chapter shows that the main impact is the oxygen consumption. In France, the Technical Centre for Civil Aviation recommends that the choice of de-icer should be driven by reglementary and environmental constraints / requirements [30]: products with slow biodegradation time, low COD and $BOD_5$, also with a low risk of environment asphyxiation can be used preferably in sewerage system which are able to manage effluents for long periods. On the other hand, de-icers with high COD and $BOD_5$ and fast biodegradation speed should be preferred when surface water is treated in wastewater facilities with oxygenation (wastewater collection systems, public water collection network, etc.)

While this approach may be effective in airport areas, it seems difficult to transpose it to interurban areas. Retention basins are not similar to wastewater treatment systems. In urban areas, rainwater collection rarely leads to a wastewater treatment system.

For products with chloride ($NaCl$, $CaCl_2$ and $MgCl_2$), a large part is collected in retention basins. Because of their solubility, it has been shown that all the collected salt is discharged into the environment [43]-[69]. However, one way to regulate the quality of road runoff water discharged into the environment is to optimise the water yield of the retention ponds. One study shows that phytoremediation by halophytic plants can desalinate road runoff [70]. Research is currently underway to test these halophytic plants under real conditions.

For abrasive materials, in interurban areas, sweeping and vacuuming of residual materials, although little practised and sometimes unrealistic, is recommended in case of presence of contaminants on the pavement (the presence of residual aggregates can generate a decrease of slip resistance) [25]. In urban areas, sweeping is necessary to prevent clogging of sewerage networks, the production of fine particles and slippage (pavements, cycle paths) due to residual materials.

Various studies indicate that it is possible to recycle abrasives for reuse provided that the fines previously produced by the different cleaning methods (dry (screening) or hot and water) are removed [26]. In France, reuse is also conditioned by the pollutant content [71]. If the pollutant content is too high, they can either be recycled in road construction for a type 1 or 2 use of the Setra guide or sent to a non-hazardous waste storage facility [72].

**In conclusion,**

- **all products spread in environment have an impact on different environmental compartments (water, biodiversity, vegetation, soil) and depends on their nature (inorganic, organic). One certainty, these products are soluble, and the major vector is water. Further research needs to be conducted for a more detailed comparison between the different de-icers.**
- **The impacts of salt are among the most studied because it has a more common use. It has effects on soils: increase in concentration of sodium in soil tend 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. Surface waters (standing and flowing waters) are more affected by winter maintenance activities. This saline polluting 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 contamination 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 is to be expected on roads and roads infrastructure constructed with concrete conform to the current standards.**
- **Concerning the other de-icers, their environmental impact can still be studied, due to their great variety. De-icers used in airport areas (formate, acetate, urea) are derived from organic chemistry. Although they are mentioned as biodegradable, the quantity of oxygen required for their biodegradation must nevertheless be considered. This oxygen consumed can asphyxiate the environment and lead to a loss of biodiversity. Their impacts on waters, soils, vegetation have to be still studied in function of their composition (potassium, sodium, additives…)**
- **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. Fine salt dust dissolves in the mucous membranes and does not pose a health risk.**

- **The issue of elimination or treatment of road effluent with 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 need 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. Recycling of collected abrasives is possible, depending on the pollutant content.**
- **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 because it is natural and not require an industrial process for its elaboration (with the exception of abrasives that are natural origin from quarries). The energy consumption for spreading is linked to the dosages, therefore predominant for abrasives and more important for liquid de-icers. Emission of greenhouse gases can be minimized by a domestic production of salt, and the right choice of means of transport.**

# 9. WINTER SERVICE AND CIRCULAR ECONOMY

Salt is used in the manufacture of many products, whether in the food industry, pharmaceutical industry, textile industry, animal nutrition, metallurgy, etc. At the end of the manufacturing process, salt, rather than being considered as waste, can be revalorised as a de-icing salt. Chemical reactions often produce salt as a by-product that cannot be used and therefore has to be disposed of. By using these salts in winter maintenance, a meaningful recovery is achieved. There are now an increasing number of examples of the use of by-product salts and of the secondary use of salts in winter maintenance.

A metallurgical company in Haute-Savoie (France) revalorises fine salt in the form of brine used by a neighbouring motorway manager. This avoids the need to transport several hundred km from the usual salt production site to the winter service facility. In addition, it is no longer necessary to dispose of the fine salt as waste [73].

Other projects exist in France, most often involving the reuse of brine from cheese production or the reuse of granular salt originally used for curing hams or fish. The main difficulty in this field is to obtain a granularity that is compatible with the spreading machines.

In flue gas treatment in waste incineration plants, salt is produced when the hydrochloric acid formed from the incineration of PVC (produced with the raw material salt) is neutralized with alkali. The resulting fine-grained salt can be used in winter service.

The increasing demand for biofuel in Europe has led to the installation of many production plants. A side product of the production of biodiesel from vegetable oils is sodium chloride, which can be used as de-icing salt. Examples of this can be found in the Netherlands.

Winter service in Bavaria (Germany) has been using brine from the production of pickled cucumbers in a food factory since winter 2019/2020. The diluted salt solution resulting from the production of cucumbers is filtered, neutralized, and concentrated with solid salt before use in winter service.

All these by-product salts and used salts (crystallized salt, brine) comply with the EN 16 811-1 standard.

The use of by-product salts and used salts in winter services contributes to resource efficiency and the circular economy.

**Conclusions:**

**Salt is used in the manufacture of many products (food industry, pharmaceutical industry, textile industry, animal nutrition, metallurgy, etc.) At the end of the manufacturing process, salt, rather than being considered as waste, can be revalorised as a de-icing salt. Different examples are available in Europe. All these co-products have to be conform with the standard EN 16 811-1.**

## 10. STRATEGIES AND TECHNOLOGIES TO OPTIMIZE THE USE OF SALT

All de-icers and abrasives that are distributed in winter service have a negative impact on the environment. For this reason, the salt industry welcomes and supports efforts to minimize and optimize salt consumption.

Reducing environmental impact of de-icers can be achieved by various measures:

- The first level to protect the environment is to optimise the quantities of de-icers spread, whatever the type of de-icers: calibration of spreaders, storage in good conditions, etc. [74].
- Increasing the use of brine (pre-wetted salt, over-saturated brine, brine alone). This inexpensive technique considerably reduces the amount of NaCl released into the environment. However, it must be accompanied by an organization and resources that allow for adequate decision-making [14].
- Favour the quality chain by ensuring that de-icers used complies with the standards to ensure its relevance to user safety [22]-[74]-[75].
- Reduction of the ecological footprint of some de-icers by favouring certain production methods, optimising distances and transport used from the place of supply [75].
- Development of management strategies according to the sensitivity of the environment: identifying and locating areas at risk and comparing winter maintenance strategies to limit pressure based on these areas [13].
- Reducing service levels for low-traffic roads.
- Encourage the use of winter tires.
- Contaminated soils and waters can be remediated by various methods which are not suitable for in situ treatment. The road runoff treatment is highly recommended for organic de-icers (formate/acetate), as in airport areas.

Conventional desalination techniques (reverse osmosis and membrane processes) are too expensive. Currently, preference is being given to in situ methods that are less environmentally disruptive and more economical. In this context, biotechnology offers phytoremediation techniques as a suitable alternative [66]. Phytoremediation is based on the use of plants and their associated microorganisms for the removal, degradation, or stabilization of toxic substances from the environment. Depending on the contaminant and on the plant characteristics, different phytoremediation techniques take place.

- When evaluating new products, it is important to assess the effects on the entire environmental system, but also on the roads and associated structures.

One of the most effective technologies for saving salt while providing excellent winter services is the application of brine alone (direct brine application) instead of applications of solid salt alone or in combination with brine (Figure 37). This technology can be used when temperatures are not lower than -10° C and only when there is little precipitation. Direct brine application is becoming increasingly interesting because of the rise in temperature caused by climate change.

The statistics of the last decades show that the salt consumption for winter maintenance in countries like France and Germany has not increased to the same extent as the traffic on the roads and the length and area of the roads. The aim is to continue to decouple the consumption of de-icing salt from the increasing development of passenger and freight traffic in Europe as well as from the increasing road lengths and paved road areas. At the same time, traffic accidents caused by slippery roads are to be further reduced.


Figure 37:  Preventive direct brine application on the German highway A61 (February 9, 2021)

**Conclusions:**

- **The study recommends further efforts to minimize and optimize salt consumption/use. 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… The 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 de-icing salt from the increasing development of passenger and freight traffic in Europe as well as from the increasing road lengths and paved road areas. 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 in winter 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 compartments (water, biodiversity, vegetation, 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, their environmental impact can still be studied, due to their great variety.
- Salt has effects on soils (leach out nutrients, release of heavy metals) and can cause significant symptoms on roadside trees (photosynthesis reduction, etc.). Surface waters (standing and flowing waters) are more affected by winter maintenance activities (loss of biodiversity).
- Some advantages (like less corrosive, biodegradable) of alternative de-icers to salt are often counterbalanced by disadvantages (like higher dosages, lower adhesion level, 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 be remain snowy/icy. With abrasives, the formation of fine dust (PM10) because of traffic must be taken into account. They 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 more important 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° C; low dosage possible; acceptable environmental impact; lowest cost compared to all other de-icers. Natural resources, production capacities of the industry and logistics concepts guarantee a high availability of salt.
- 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 phenomena's: less snow, more ice, more recurrent freeze/defrost cycles, more rarely 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/use. 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, adaption to weather phenomena, etc. The trend in Europe is the use of salt solution (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.

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