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Available methods for treatment and/or prevention of de-icing salts impacts and Cost-benefit analysis and alternative de-icers

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Deliverable 3.1: Available methods for treatment and/or prevention of de-icing salts impacts

Deliverable 3.2: Cost-benefit analysis and alternative de-icers

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Author(s) of this deliverable:
Tone Merete Muthanna, Norwegian University of Science and Technology (NTNU), Norway
Jan-Willem Knegt, TAUW, The Netherlands
Sanne Bink, Tauw bv, The Netherlands
Iris van der Veen, Tauw bv, The Netherlands
John van Tol, Tauw bv, The Netherlands

PEB Project contact: Lene Sørlie Heier

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Executive summary

A literature review of alternative de-icing methods was carried out. The alternative de-icers are defined as non chloride based de-icing methods. These methods consist of chemical and mechanical methods. This report focuses primarily on the chemical alternatives. Mechanical alternatives as anti-slip agents such as sand and gravel, and mechanical ice removal with scraping are briefly mentioned but not evaluated in depth.

The main purpose of this report was to identify the most suitable alternatives to chloride based de-icers on different temporal and spatial scales. It was found that the majority of work done on alternatives to chloride based de-icers has been conducted on small pilot scale projects. Very few are tested in large scale, and even fewer are implemented. The most common alternatives are acetate based, such as potassium or sodium magnesium acetate, or formate based such as potassium and sodium formate. Even though these are chloride free alternatives, they all contain cations, which have been shown to alter soil aggregation and cause metal leaching from soils depending on the soil cation exchange capacity (CEC).

There are some organic alternatives which are both cation and chloride free, like fermented beet-juice and fructose based de-icers. However, they all have in common that they introduce a high chemical and biological oxygen demand (COD and BOD) load to the receiving waters, which can cause oxygen depletion leading to fish kills and a poor ecological habitat. Though this is clearly an undesirable side-effect, these de-icing options still have the advantage that COD and BOD can be easily removed in point source treatment options. These treatment options are generally operating intensive and costly constructions, which all in all could indicate these the organic de-icers are still less desirable alternatives.

All winter maintenance strategies will have some trade-offs. In order to be able to compare them towards the needs it is necessary to establish a better understanding of the respective costs and benefits associated with the materials and operations utilized for each type and choice of service. This understanding will both identify the quantitative values associated with the various costs and benefits of these strategies, and identify those for which a value has not been quantified. Collectively, this information can serve as a starting point to identify and address any gaps in cost and benefit information and to support the analysis and organization of this information into a format to communicate to stakeholders.

List of Abbreviations

NRA	-	National Road Authority
CEC	-	Cation Exchange Capacity
EQS	-	Environmental Quality Standard
SUDs	-	Sustainable Urban Drainage
BOD	-	Biological Oxygen Demand
COV	-	Chemical Oxygen Demand

Deliverable 3.1: Available methods for treatment and/or prevention of de-icing salts impacts

1 Introduction

Alternative methods for de-icing of road surface involves the use of non- chloride based de-icing agents or abrasives. Additionally, there is an option of prevention of salt impacts with methods to treat road runoff with chloride-based de-icing agents.

This report will give an overview of currently available methods for de-icing using de-icing agents, abrasives and snowmelt through thermal/mechanical methods. The report gives a brief overview of the properties and known use of each of the methods.

Following the brief summary of properties of each alternative, the fate and transport of the compounds will be summarized. This summary only includes fate and transport in water courses. At the end there is a short discussion regarding cost of materials and applications for the different alternatives. This is not a comprehensive cost-benefit analysis partly due to the scope of this work, and partly due to limited data availability, which is insufficient for a more in depth comparison.

The structure of this report will first give an overview of alternative de-icing agents composition, characterization and methods followed by a summary of case studies found from around the world. Finally, there is a qualitative discussion on pros and cons of each alternative, including cost considerations.

2 Objectives

The objectives of this report are based on the third objective of the project description which states that a comparison of alternative de-icing chemicals and strategies should be performed. This report answers two of the three tasks (for the third task see deliverable 3.2). The tasks in this report focuses on alternative chemicals where full-scale testing has been performed. Alternative application strategies include operation and maintenance actions that reduce the application rate of chemicals. Specifically, this will include a review of the alternative de-icers performance in the full scale tests. A qualitative analysis is performed, in which de-icing chemicals are evaluated and compared with other measures for maintaining safe road winter conditions. Two main tasks are specified:

1. Identification of available methods / treatment options / prevention options, through a literature review report.
2. alternative de-icing chemicals and strategies – review of available case studies of application. It will only include a review of existing full scale applications and cases, excluding new studies and the evaluation of new chemicals without a full scale application.

3 Sources of information and reference overview

This literature review is based on scientific reports and published articles in international journals. There are only a small number of pre-reviewed articles that have been found to be relevant (less than 15 in total). This is in contrast to the extensive number of scientific articles available for chloride based de-icers. The main explanation for this is that scientific studies regarding chloride based de-icers to a large extent deal with the fate and transport of chloride in the environment and the harmful effects of the chloride. With limited studies and even more limited use of alternative de-icers there has been less focus on than the environmental consequences. Typically, there is an increased focus on environmental consequences as the adaptation of a compound become more widespread, as potentially negative effects then become evident.

The available scientific reports on the topic are mainly produced for an European or North American NRAs by a group of expert scientists, or by the in house expertise at the NRAs. The majority of the available studies were from North America, with only a handful from Europe. Conducting the interviews with the NRAs as part of the questionnaires for deliverable 1.2, some knowledge of limited tests of alternative de-icers was presented, but with only sparse written information available.

In general a scoping review according to May et al., (2001) with the list of keywords found in Figure 1 were performed for the literature search part.

Sources for literature search:

- Research data bases
- NRA report databases
- Review of Literature references
- National Environmental Agencies

Output from the literature search:

- Scientific papers
- Published conference proceedings
- PhD thesis
- Reports
- Books and chapters in books

"Alternative de-icers" AND …

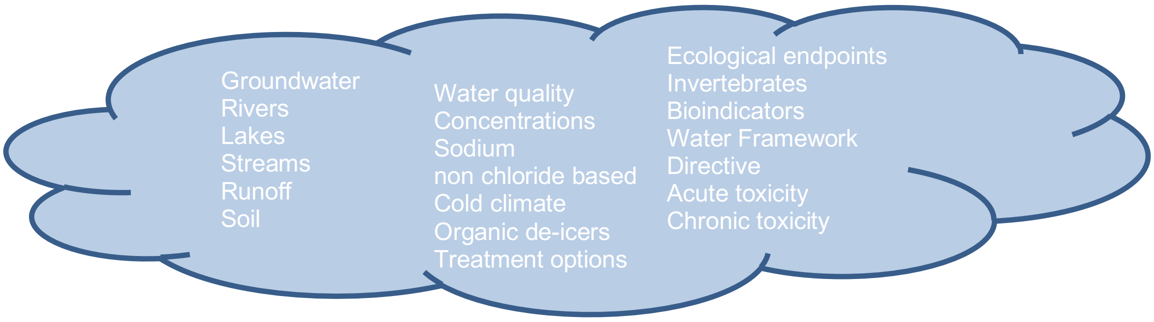

Figure 1. Keywords and -phrases used in the literature search, on the form "Alternative de-icers AND ___".

4 De-icing agents

De-icing agents can be divided in three main groups; (1) the chloride based de-icers, (2) the organic based de-icers, and (3) the other group, which contains agents with different action mechanisms (Table 1). Additionally, there are abrasive materials, which does not melt the snow and ice, but rather creates a less slippery surface by increasing the friction. This report, as mentioned in the introduction will only discuss group 2 and 3. An extensive review on the use of chloride based de-icers from group 1 can be found in deliverable 1.1.

Table 1. List of de-icing agents by group

Name	Chemical formula
Group 1: Chloride based	
Sodium chloride	NaCl
Madgnesium choride	MgCl
Potassium chloride	KCl
Group 2 - Organic based	
Potassium formate (K-formate)	KCOOH
Sodium formate	NaCOOH
Calcium-magnesium-acetate	$CaMg(CH_3COO_4)$
Sodium-magnesium-acetate	$NaMg(CH_3COO_4)$
Potassium acetate	KCH_3COO
Sodium acetate	$NaCH_3COO$
Mono-propylenglycol (MPG)	CH_3CHOCH_2OH
Fructose/glocosem sodium chloride	$C_6H_{12}O_6/C_6H_{12}O6/NaCl$
Beet juice	
Group 3 - Other	
Urea	$(H_2N)_2CO$
geothermal heat (hydronic heating)	

4.1 Group 2 – organic based de-icing agents

The two most common organic, non-chloride based de-icers are primarily either acetate based or formate based. In addition, there are some limited scale test using other industrial waste products, like fructose based and beet juice.

4.1.1 Formate and Acetate based

De-icers that include acetates are sodium acetate, calcium magnesium acetate (CMA), and potassium acetate. De-icers that include formate are sodium formate and potassium formate. Acetate, (chemical formula H_3COO) is a salt formed by the combination of acetic acid with a base, which can be metallic or nonmetallic. Formate, (chemical formula HCOO), is a salt derived from formic acid combined with a salt. The primary benefit of acetate based de-icing chemicals is its non-corrosive properties, reducing the wear and tear on vehicles, and road infrastructure. The most common production method for acetate is as a by-product of fermentation processes.

The number one environmental issue related to acetate-based de-icers, which are organic compounds, is the increase in the biological oxygen demand (BOD) in receiving waters, which results in reduced available oxygen for the organisms in the soil and aquatic environments (Bang and Johnston, 1998). The formate and acetate de-icers work by interfering with the bond between snow particles and the road surface; in contrast, road salt chemically breaks down snow and ice as it moves downward from the surface. They are probably the most studied and well documented alternative de-icers. There are a number of studies from North America from the late 1980s and early 1990 looking into acetate based de-icers, however a limited amount of more recent studies have been found.

Calcium magnesium acetate is an acetate which works by interfering with the bond between snow particles and the road surface, as described above. The performance, corrosivity, and environmental impacts have been reviewed more extensively for calcium magnesium acetate, compared to other alternative de-icers. While acetate itself is readily biodegradable by microorganisms, as reported by the Transportation Research Board (1991), the decomposition of calcium magnesium acetate in the water phase is a much slower process, shown to be up to 3.5 times as long as in soil (Strong and Amrhein, 1990). The decomposition can both result in anaerobic conditions in soils and oxygen depletion in receiving waters due to the high BOD load in the acetate. This can lead to serious environmental impact in sensitive recipients, especially for smaller water bodies and streams and creeks (LaPerriere and Rea, 1989; Burkett and Gurr, 2004).

Degradation of formate and acetate has been study to limited extent in a road de-icing application setting. Hellstén et al. (2005) used a lysimeter based field experiment to investigate the fate of potassium formate in the soil. The study looked at biodegradation and transport mechanisms through the soil. The results showed that while the formate degraded in the unsaturated zone and did not cause undesirable changes to the water quality in the underlying sandy aquifer, it had a detrimental effect on the vegetation in the lysimeter. Another study by Hellstén et al. (2005), studied the fate of the formate by monitoring the groundwater chemistry in the underlying aquifer, combined with a conceptual model. The results show that the formate did not enter the saturated zone through the thin vadose zone;

thus, no undesirable changes in the groundwater chemistry were observed. This caused the study to indicate that formate can potentially help diminish the negative impacts of road winter de-icing. While these two previous studies discussed the impact in the soil unsaturated zone, two other studies looked at the impact of acetate based de-icing chemicals on receiving waters. Both Ostendorf et al., (2002) and Brenner and Horner (1992) conclude that calcium magnesium acetate, (CMA), can potentially impair groundwater quality by increasing organics and iron in an anoxic plume. Brenner and Horner (1992) also made a recommendation that CMA applications be avoided where receiving waters are close to the road or have other sensitive factors making it sensitive to low dissolved oxygen concentrations.

4.1.2 Glycol based

De-icers composed of glycols—propylene glycol and ethylene glycol—are generally used only as airplane and runway de-icers. Environmental issues associated with glycol-based de-icers are the same as other organic based de-icers, where increased BOD leads to oxygen depletion and carcinogenic effects to the stream fauna (Johnson et al, 2001). Glycol based de-icers are primarily used in airport operations and no known application of road infrastructure was found from new studies or considered relevant for this report.

4.1.3 Methanol

Methanol is an alcohol, also known as methyl alcohol with the chemical formula CH_3OH. As a deicing liquid it works by penetrating the packed snow, which it does faster than common road salt (sodium chloride). Methanol is effective at lower temperatures, with a melting point of -97.6 °C, compared to common road salt which can be applied down towards -20°C only. However, it volatilizes into gas form very quickly, resulting in the need for frequent reapplication. During the volatilization process it can emit vapors that can contribute to the ozone pollution in Earth's lower atmosphere. The cost of applying methanol has been estimated to about 5 ½ times of that of common road salt by the Michigan Department of Transportation, Transportation Research Board (1991).

4.1.4 Bio-based de-icers

Bio-based de-icers are the newest group of alternative de-icers. They are often made from the fermentation and processes. The source material options include cane or beet sugar syrup as well as corn, barley and milk, have been added to the list of winter maintenance materials (Nixon and Williams, 2001). In this group there are various (bi-) products from agriculture and food industry that have been tested as alternative de-icers. It is a group of organic substances that can be used for road de-icing by the same method as acetate and formate based de-icers. They are typically mixed with a low concentration of another deicer as pre-wet de-icers including chlorides, acetates and abrasives to increase ice-melting capabilities, and act as corrosion inhibitors. They are different products of hydrated starch which all have a low toxicity, however still consuming oxygen by decomposition in soil or release to water (Albright, 2005).

One example of such a bio-based deicer that has been tested for several different applications is beet-root juice mixture. This is a by-product from processing and extracting sugar from sugar beets. The waste water from the production has a high concentration of organic matter, which can be mixed with 12% either sodium chloride or potassium chloride compared to regular chloride based de-icers, to make a highly effective de-icing mixture. The concentration of carbohydrates in the liquid reduces its freezing point to well below -20°C, and mixed with salt, it makes it stick to the ice, which reduces bouncing and scattering of salt rocks when cars drive over it. This further reduces the amount of salt needed. It is a biodegradable product, and less corrosive than standard solution of chloride based de-icers.

Some newer studies have shown that though these organic derived de-icers like beet juice might be a good natural alternative to road salt which can potentially be an eco-friendlier winter road management solution, it might have negative impact on aquatic species in receiving waters. A study by Cuciureanu (2018) investigated the physiological effects of beet juice deicer in freshwater animals. The research team examined the physiological responses of immature mayflies (*mayfly nymphs*), a freshwater insect, when exposed to beet juice based de-icers. The Mayflies are considered to be a good indicator of water pollution as they are particularly sensitive slats and metals commonly found in road and urban runoff. The study found that compared to a control group, the insects exposed to the organic de-icing mixture retained significantly more fluid while blood salt levels were elevated, which can compromise organ function. The study indicates that the salts in the mixture can cause this as Mayflies are sensitive to potassium. However, the potassium levels alone were too low to cause this physiological effect, indicating that the combinations of factors in the mixture can be harmful to aquatic species.

There is a need for more studies on the ecological effects of these organic de-icers which mixes salts with high organic load. They clearly offer some potential as alternative de-icers, but, a complete assessment of impacts and benefits is necessary before conclusions can be drawn.

4.2 Group 3 – other de-icing agents

4.2.1 Thermal-based methods and built-in de-icers

The thermal-based methods can be divided in the thermally heated options and the material science methods where additives to the asphalt make built in de-icing properties.
The thermal group includes geo-thermal based heating, which is a good option in very specific locations, like Iceland, where geothermal heat is readily available. However, traditional geothermal based solutions are not a realistic option at the moment for the rest of Europe with the current technology, hence these methods are not given any further consideration at this point, though through technological advances this might become a viable option in the future.

The second group, the material science based de-icing additives to the asphalt blend is something that is currently receiving some attention, and might become an interesting option in the future. A recent study by Ma et al. (2016) investigated the performance evaluation of de-icing asphalt mixtures with anti-icing additives. Currently the anti-icing additives tend to have negative impacts on the engineering properties of asphalt mixtures; like thermal cracking resistance and moisture susceptibility. The study further investigated the potential of adding fiber-reinforced de-icing asphalt mixtures, which showed promising results. One study by Li et al, (2013), investigated the use of nanotechnology and solar power to make a self-de-icing road system. This resulted in a novel self-de-icing road system coupling solar energy with a carbon nano-fiber polymer (CNFP) thermal source. This is research that is still at an experimental stage, but indicates that there might be environmentally superior solutions available in the near future.

4.2.2 Urea

Urea products are alternative de-icers that are commonly used as de-icers on runways of airports, however, due the harmful effects on aquatic life from the elevated nitrogen (N) content of in form of ammonia in urea, there are concerns about the application (Ritter, 2001). There is also a concern of the toxicity level of some of the additives that are added to the mixture. The elevated nitrogen in the effluent can cause increased risk of algal blooms.

Although urea is not very harmful with a relatively low toxicity with respect to terrestrial and aquatic life are concerned, ammonia and nitrate do pose environmental problems. The toxicity of ammonia to aquatic life is relatively high. One study finds that when exposed to as little as l-10 ppm of ammonia, 50 percent of the aquatic biota present will die (Fay et al., 2009).

5 Application experiences

As described in the introduction only a few relevant studies documenting the result of using alternative de-icing agents have been found. This limited number makes any quantitative comparisons difficult and with low confidence in the analysis. A qualitative report of the few studies that have been found are summarized below.

The use of CMA in several states across the USA has been summarized in a report by the Transportation Research Board (1991). The report summarizes the CMA users in California, Colorado, Massachusetts, Michigan, Nebraska, Nevada, Ontario, and West Virginia using a survey based approach to determine its experienced performance in tests. In general, CMA is described as an adequate deicer, however early application is important for optimal effect as it is found to be slower acting than road salt, frequently taking 15 to 30 minutes longer to induce melting. It is therefore important that this is applied with a proactive application strategy. The effectiveness of CMA diminishes in temperatures below -5°C, as well as for freezing rain events, and drier snowstorms.

A study from the North Island of New Zealand investigated the effect on soil, vegetation, and streams where CMA had been used for both anti-icing and de-icing. The study found no negative impact for soil, vegetation or streams. The overall cost of the CMA however, was reported as the major principal disadvantage (LaPerriere and Rea, 1989). However, this study is outdated, and potential negative impact of CMA has later been reported in other studies.

The only study found there a bio-based deicer was assessed was a few districts in Montreal, Canada, where they have experimented with beet-salt mixtures. There were several negative impacts reported, where an unpleasant smell and the stickiness of the mixture applied to the road were two of the major concerns. It was also a concern that the beet-juice would cause high organic loads in the downstream streams attracting bacteria, which again will cause oxygen depletion, depriving its aquatic life of it. However, the study did not include any environmental measurements data documenting this concern.

Potassium formate (KCOOH) has seen a wide uptake in Finland over the past 15 years. This has come about as a result of the Finnish Transport Agency applying a stringent approach to use of harmful compounds. This has resulted in prioritizing of the mitigation of harmful environmental effects caused by traffic and highway maintenance on groundwater and surface waters. One such example is then choice to use only biodegradable deicing agents instead in watersheds draining to aquifers classified as significant for water supply solely, (Nissinen, 2017). The increased use in Finland came about as a result of the MIDAS project comparing alternative de-icers, carried out by Finnish Environmental Institute SYKE. In this study that potassium formate was the best alternative road de-icer. Ove the past 15-18 years the number of application sites has steadily increased to more than 100 km in 2015-16 season, (Mattila et al., 2016).

6 Conclusions

This report is answering to objective 3, a review of alternative de-icing agents for road applications. A summary of the available methods grouped in functional groups was provided. There are organic alternatives based on acetate, formate and bio-based products. Most of them are mixed with a low concentration chloride based salt (typically 10-12 %) resulting in a cocktail of salt and organic load for the receiving waters. Some newer research has shown that this might have more negative impact on aquatic species than first indicated. More research is needed to fully understand the impact for these alternative de-icers. Research that should be supported with more full scale application tests before any conclusions about best fit alternative de-icers are made.

Deliverable 3.2: Cost-benefit analysis and alternative de-icers

7 Introduction

A cost-benefit analysis was part of the original project proposal, where it was desired to increase the knowledge and understanding of the various choices for alternative de-icers. In the partner meetings for the PEB group during the first year of the project, 2018, it was discussed that this item in the project proposal was of less importance than the other items. This resulted in an agreed smaller scale of this cost benefit analysis. Furthermore, it has been discovered through extensive literature review that there is very limited information available for cost-benefit analysis and even fewer comparable studies. Based on the decision in the early project meetings and the lack of quality data this cost benefit analysis is a qualitative summary of the pros and cons of the various alternative de-icing chemicals. Followed by a discussion on receiving water classifications that should be considered in the selection.

8 Objectives

The objectives of this report are based on task II of the third objective of the project description which states that a comparison of alternative de-icing chemicals and strategies. should be performed. This report focuses on a qualitative review of methods and strategies with respect to climate zone specific and cost benefit focused on the seven countries.

9 Sources of information and reference overview

This literature review is based on scientific reports and published articles in international journals. For the cost – benefits the only sources found to be of relevance were reports produced by a few North American road agencies. this makes direct cost comparisons difficult, but these reports have been used in a qualitative discussion around the different alternative solutions.

The available scientific reports were mainly produced for one of the NRAs by a group of expert scientists, or by the in house expertise at the NRAs. The majority of the available studies were from North America, with only handful from Europe. Conducting the interviews with the NRAs as part of the questionnaires for deliverable 1.2 there were some knowledge of limited tests of alternative de-icers, but with only sparse information available.

In general a scoping review according to May et al., (2001) with the list of keywords found in Figure 1 were performed for the literature search part.

Sources for literature search:

- Research data bases
- NRA report databases
- Review of Literature references

- National Environmental Agencies

Output from the literature search:

- Scientific papers
- Published conference proceedings
- Reports

“Alternative de-icers” AND …

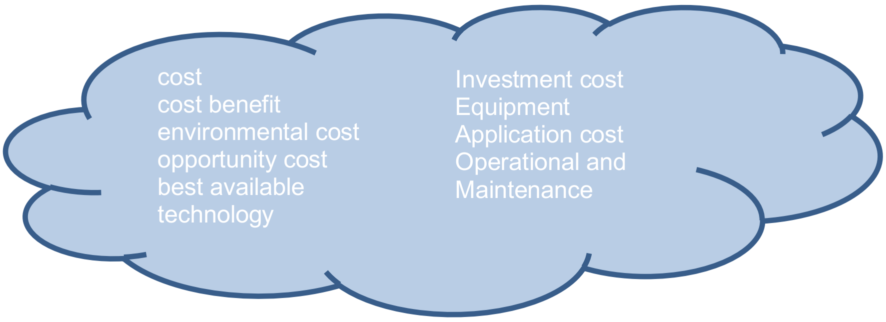

Figure 2. Keywords and -phrases used in the literature search, on the form “Alternative de-icers AND ___”.

10 Cost of de-icers

There are limited information about the cost of de-icers, and no complete European cost comparison could be found. However some cost information from North America was found, and though this cannot be directly translated to Europe, it can be used for a relative comparison.

Table 2. The cost of de-icers based on North American references*

Deicing chemical	**Chemical formula**	**Cost in €/metric ton**
Sodium chloride	$NaCl$	37
Calcium chloride	$CaCl_2$	125
Magnesium chloride	$MgCl_2$	99
Calcium magnesium acetate	$CaMg(CH_3COO_4)$	1328
Potassium acetate	KCH_3COO	1038
*Based on numbers from Kelting and Laxson (2010).		

From this straight cost of deicer comparison it is easy to deduct that there is a factor of 10 to 30 times more expensive to use acetate based de-icers compared to chloride based. This represents the first hinderance for a wider uptake and use. In addition using different compounds will require different procedures, storage facilities and application manuals, which all adds up to a high initial investment as well as a significantly higher running cost.

11 Cost-benefit discussion

11.1 Acetate and formate

The cost of calcium magnesium acetate was found in literature to be \$650- \$675 per 1000 kg based on numbers from a report by Fey et al., (2015) from USA. Bacchus (1986) concluded at the time that the relatively high costs of CMA as compared to salt were too high to offset the costs of damages to the identified parameters. For CMA to break-even, costs need to be around \$343 to \$481 per ton. These numbers are outdated, however it is still the case that the mass of CMA applied compared to a pure chloride based de-icers is between 1.7 to 2.6 times (Fey et al., 2015).

The only European based study with partial relevance here was the study by Salminen et al(2011). reporting a 35% reduction in chloride-based road salt applications in Finland since 1990 as a results of an active campaign to reduce consumption, and risk management based action plan including proactive steps towards protection groundwater sources. Here there are clear cost and environmental benefits. though they have not been quantified in the report local language in these reports. .

A study from Vitalino (1992) conducted an in-depth review of the cost of use of CMA compared to sodium chloride for deicing. The article could from a pure numbers' perspective be argued to be outdated, however there are still some relevant important points in the article. First the article assigned a value to the social cost of infrastructure due to salt applications, valued at \$615 per 1000 kg applied NaCl, which would be equivalent to €547 using a 0.89 conversion rate. Further the annual cost of vehicle corrosion is set at \$113 per 1000 kg NaCl, equivalent of €100 per 1000 kg NaCl, and \$75 (€67) per 1000 kg NaCl in degradation in environmentally sensitive areas. The total negative cost of NaCl applications summed up to \$803 or €715 per 1000 kg NaCl applied. In 1992 the difference in cost between CMA and NaCl was estimated at an average of \$600 (€534) per 1000 kg. Comparing these totals, it can be seen that the total cost of CMA would have been about \$200 (€178) net cheaper than NaCl accounting for the cost of negative impacts of NaCl. No comparative comprehensive newer study could be found for an updated cost comparison, but these are the numbers needed to make a real cost benefit analysis.

If we assume the ratios of the costs from the study be Vitalino to still be valid, one can argue that in non-environmentally sensitive areas the cost of CMA offsets the negative impact of sodium chloride (roughly \$730 in negative costs versus \$ 600 more expensive), which would be a choice of spending the money in CMA for deicing chemicals versus spending the money in road infrastructure maintenance due to salt damage and cost of vehicles corrosion. In environmentally sensitive areas there would be a slight net benefit to CMA applications versus NaCl which would bear the additional cost of negative environmental impact.

The experience from the Finnish NRA based on communications it is not necessarily a straight cost benefit analysis that is the most informative approach, as it generally fails to properly assess the value of natural resources, which for example for ground water drinking water sources are, in human timelines a non-renewable resources and should be protected at all costs.

11.2 Bio-based

No cost numbers can be found for any bio-based products. The fact that these products are often waste products complicates the calculations as well. The limited small scale studies using bio-based products have not been extensive enough include a cost-benefit component. Probably largely also due to the fact there is more research needed on environmental impact before we can have numbers comparing environmental cost – bene fit with satisfactory confidence levels.

11.3 Summary discussion

The in-depth cost comparisons study by Fey et al, (2015) give the most in-depth cost comparisons that has been found so far. A summary of the various commercial products on the marked reveals a cost ranging from just over €0.25 /liter to several euros for some others. The report by Fey et al. (2015) concludes that application methods, and equipment maintenance is perhaps more important than choice of de-icing chemical. This in exemplified in for CMA where the residual CMA on roadways can last up to two weeks, creating a carry-over effect for subsequent storms.' While initial application rates are higher than with road salt, subsequent applications tend to be fewer. This can outweigh that the CMA needs a higher ton /km road application rate. In the discussion up until this point the environmental cost related application and impact, however, if one were to consider the total environmental life cycle cost as done in the study by Fitch et al. (2013). In production process the salt-based treatments consume considerably less water, energy, and generate fewer greenhouse gases and biochemical oxygen demand in receiving waters. These costs should also be considered in the overall assessment. It is also worth noting that applying the chloride chemicals as a brine rather than in the dry form, which are becoming more and more frequent also from a efficiency point of view, results in important reductions in all environmental impacts over the entire life cycle.

Due to the trade-offs associated with winter maintenance strategies, it is necessary to establish a better understanding of the respective costs and benefits associated with the materials and operations employed in the scenarios. This understanding will both identify the quantitative values associated with the various costs and benefits of these strategies, and identify those for which a value has not been quantified. Collectively, this information can serve as a starting point to identify and address any gaps in cost and benefit information and to support the analysis and organization of this information into a format to communicate to stakeholders.

While there has been some effort to assign a cost value to environmental impacts from de-icers, another approach to consider is ranking the products based on their relative impacts compared to one another. Work completed by Fitch et al. (2013) and Pilgrim (2013) can be used to assign a relative value based on product type, so that products other than just rock salt can be considered.

12 Conclusions and Recommendations

This report is answering to the third objective, second tasks from the description of where; a cost-benefit comparison of the alternative de-icers should be performed with relation to the climatic regions of the seven countries participating in the study. There are very little data available for cost comparisons and cost- benefits of alternative de-icers. Almost all available data was from north American studies, making a direct comparison to Europe challenging. Though there could be argued that there are limited number studies and published scientific work for the topic at hand, it has also become apparent in the review process that there is a large untapped knowledge bank at several of the NRAs. Information from studies and field cases that are very relevant. It is therefore difficult to conclude if there is a real lack of information available about the environmental impact for aquatic flora and fauna, and the cost of application and materials, or if it is rather a problem of making the data available. Research should focus on bridging this research gap in order to make decision based on the best available information.

Recommendations:

1. The CEDR should jointly work on making national and local language studies on alternative de-icders conducted directly for the NRAs available to all in a common language. This will make it possible to assess the real knowledge gap.
2. In order to perform cost comparisons, it is essential that one knows exactly what is included and not in the studies. The NRAs should work on making a standard among the participating countries for aligning this data.
3. A true cost comparison can only be performed when we have placed a value on nature, which is a difficult but needed task.

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