GEOTHERMAL ENERGY FOR ROAD SURFACE HEATING IN WINTER TIMES

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ABSTRACT

Adverse road surface conditions in winter times lead to restrictions in capacity as well as decrease of traffic safety. The aim of road authorities is to avoid adverse road surface conditions by winter maintenance with ploughing and salting technique or at least to clear the road surface very quickly. It is not possible respectively not reasonable, to carry out winter maintenance operations everywhere at the same time. Therefore in some cases automated facilities for prompt de-icing are added to the traditional winter service.

One possibility of automated facilities for de-icing is heating the road surface with geothermal energy. A few of these facilities are used worldwide, but there is no general adaption in road networks. Based on a variation calculus considering various influences on effectiveness and efficiency of such facilities an evaluation of the interrelations is performed. It turns out that a detailed investigation of the individual circumstances in each road section is mandatory for an assessment. In a network wide assessment the use of geothermal energy seems to be an option, if there are several, wide distributed road sections to be equipped and after instrumentation of these road sections with geothermal energy no preventive operations are needed any more.

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1. INTRODUCTION

By winter maintenance with ploughing and salting technique, road authorities should avoid slickness in winter times or clear the road surface very quickly to avoid restrictions in capacity and traffic safety. However, with vehicle based winter maintenance the appearing slickness cannot be defeated everywhere at the same time. With the appearance of specific weather conditions some road sections, e.g. bridges, become icy earlier than the rest of the road network. In addition in some road sections the consequences of adverse road surface conditions, e.g. at high grades, are more severe than in the rest of the road network.

The mentioned road sections need earlier winter maintenance operations and therefore cause un-productive empty trips. Present approaches to meet this challenge are preventive winter maintenance and the use of automated de-icing spray units. Geothermal energy is an almost inexhaustible energy source for the tempering of buildings. This source of energy is increasingly used for the heating of apartments and office buildings. Possibly it is suitable to temper roads, too. The usage of geothermal energy could reduce the logistical challenges of winter maintenance by heating dangerous road sections.

On these road sections slickness would not appear at all. Therefore the avoidance of restrictions of capacity and traffic safety plus a reduced impact for the environment caused by traffic and the avoided salt entry into close-by areas are anticipated. The costs of investment and operation can be justified with saved salting activities and – in case the installation is also used to cool the road surface in summer times – with the longer lifetime of asphalt layers.

2. METHODOLOGY

To evaluate the interrelationships of advantages and disadvantages the potential installations and the suitability for daily use of geothermal energy as an addition for the winter maintenance are investigated. Under consideration of the actual state of the art and the legal conditions the adoption of geothermal energy is compared with vehicle based winter maintenance and automated spray technology in a business, economic and ecological view.

Based on the experience of worldwide existing facilities, additional collection of economic and traffic related data plus laboratory tests with road construction materials a variation calculus is performed. Its results allow the comparison of the use of geothermal energy with vehicle based winter maintenance and automated spray technology.

2.1. Geothermal Energy

The difference technologies for the use of geothermal energy can be divided into near to the surface and deep geothermal energy. Usually the geothermal energy near to the surface is sufficient for the heating of road surfaces. Except for the use of hot ground water it is widely independent from the location. The facilities do not require specific geological preconditions, but may be subject to geological caused restrictions because of the essential drilling.

Basically, facilities for the use of geothermal energy can be divided into closed and open systems. In closed systems tubes are used for the carriage of heat which are either vertically (borehole heat exchangers) or horizontally (geothermal heat collectors) installed. Open systems use natural resources of ground water assisted by standpipes.

The dimensioning of tubes for geothermal energy exploitation respectively storage depend primarily on the thermal characteristics of the stone. After the geothermal energy has been transported from the underground, it can be put on a higher temperature level by heat pumps and be transferred to the heat transfer fluid of the heating system.

Around the world, there already exist several facilities based on different systems for energy exploitation, where traffic areas are heated for de-icing. We are thankful for the evaluation being supported by experience and characteristic data from some of the facility operators. Installations with borehole heat exchangers are the Swiss SERSO-Plant near Därligen, the Japanese Snow Melting System GAIA, which has been installed e.g. in Ninohe and Aomori City, and a facility heating a bridge in Amarillo in Texas, USA. Figure 1 shows the principal layout of such facility.

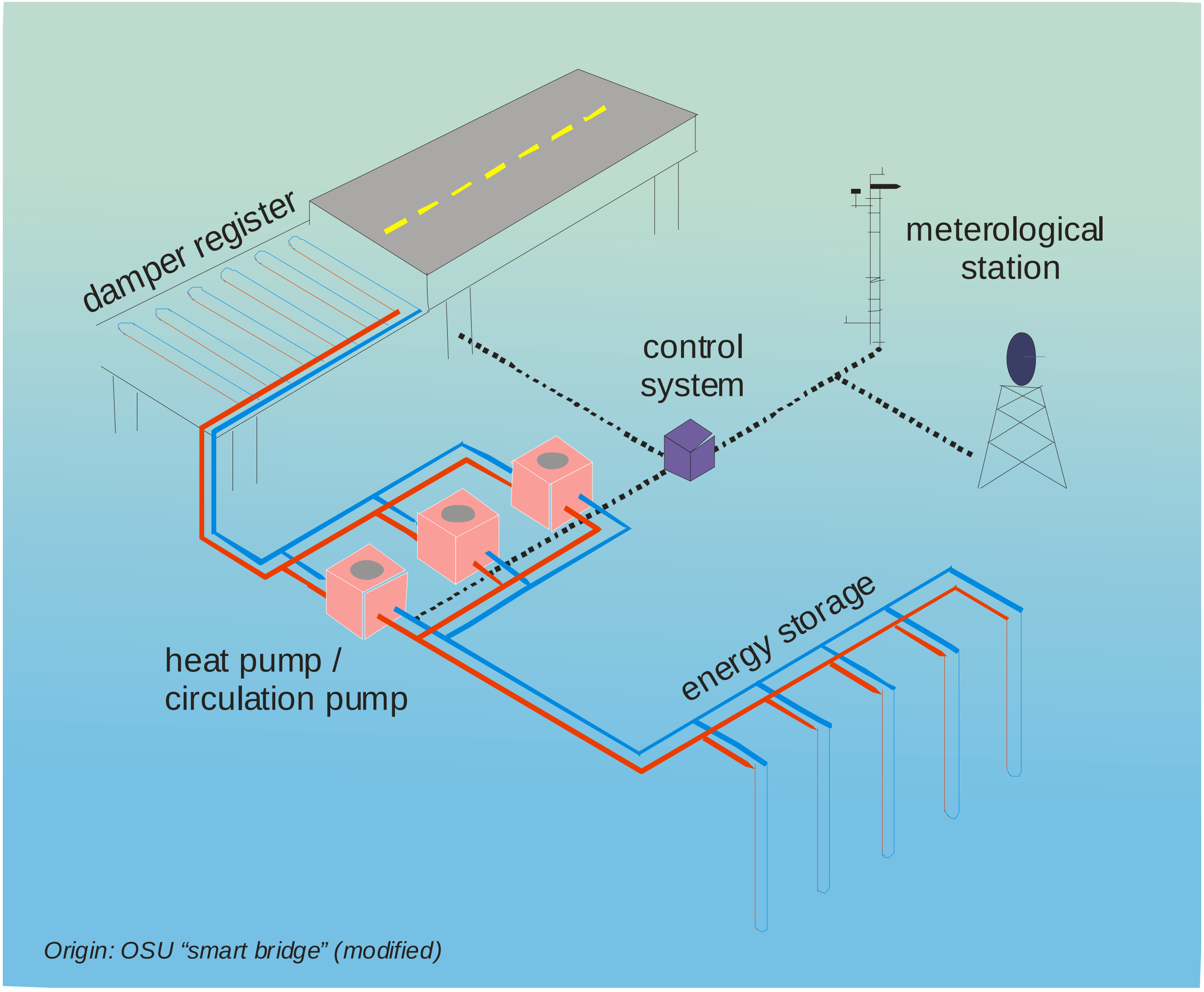

Figure 1 - Principal layout of a geothermal unit to temper a road surface

Instead of borehole heat exchangers several projects use ground water for tempering road surfaces. Such installations exist in the Netherlands, Belgium, Great Britain, Japan and USA, e.g. an installation for the heating of a bridge in Silver Creek in Oregon, USA. In Klamath Falls (USA), several traffic areas are heated by the use of hydrothermal resources, e.g. the Wall Street Bridge. An installation in Sapporo, Japan uses the hydrothermal resources, too, those of the Jozankei Spa. Installations which use heat pipes are located in Cheyenne (Wyoming, USA), and Oak Hill (West Virginia, USA). In other facilities geothermal heat collectors are installed. Exemptions are facilities using conventional energy, e.g. a bridge in Amherst County (Virginia, USA), which is heated with by a propane burner.

In particular, the plants SERSO, GAIA in Ninohe, Amarillo, Jozankei Spa, Silver Creek, and the plant at the Wall Street Bridge in Klamath Falls had comprehensive data available, which have been considered in this study for economic evaluation.

2.2. Data Collection

With the measurement of traffic and climate data as well as the examination of winter maintenance operations, selected road sections have been observed over a complete winter. With the comprehensive data collection of these field tests, an estimation of the traffic flow in dependence of the weather conditions and the winter maintenance should be performed. The traffic data have been collected with automatic traffic counters and radar meters which have been installed by the research group. Climate data was collected from automated ice detection stations and in road sections without such stations sensors for the measurement of temperature and humidity have been used by the research group to obtain climate data.

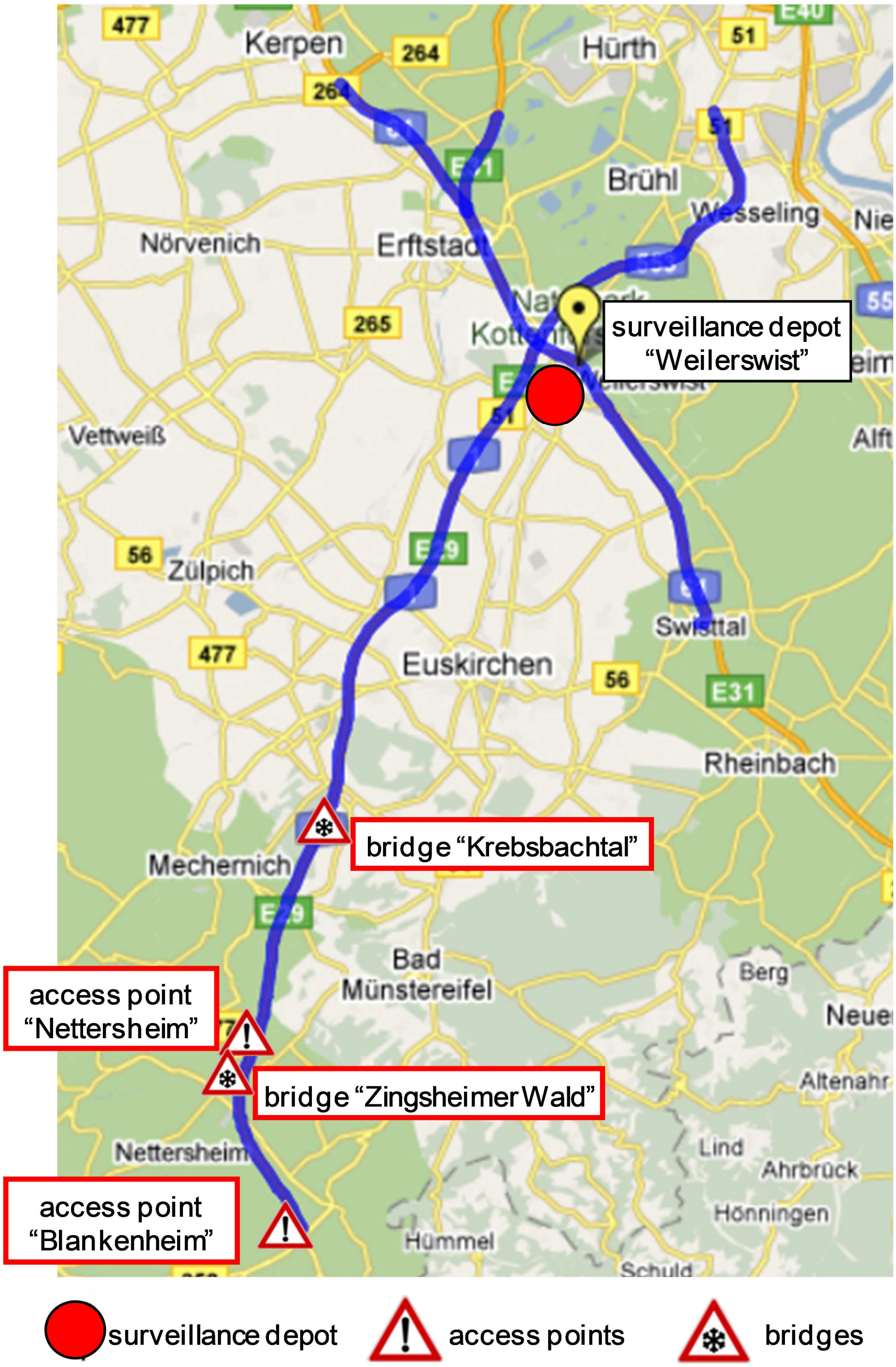

Figure 2 - Dangerous spots in the network of a surveillance depot

In order to allow an extrapolation of winter maintenance activities to complete road networks reference values were obtained. The winter maintenance data of several surveillance and road maintenance depots have been evaluated concerning the location of dangerous spots in their supported networks and concerning the frequency of their individual (preventive) salting activities (Figure 2). Based on a detailed examination of all mission reports of one winter period in the supported road networks followed an extrapolation on the background of automatically recorded operation data of several winters and diverse maintenance departments.

The heating register installed in the pavement structure which is used to heat the road surface can also be used to cool this road surface in summer times. Laboratory testing has been applied to common used kinds of asphalt to analyse how the temperature lowering of the road surface can influence the economic lifetime of the surface course. Asphalt concrete and stone mastic asphalt has been investigated by the cyclic compression test, Gus asphalt has been investigated by the indentation testing with indenter pin.

2.3. Variation Calculus

The supply of dangerous road sections with vehicle based winter maintenance, with automated spray technology and with geothermal energy will be compared for business, economically and ecologically aspects in a calculation model.

The consequent segmentation of the calculation model into micro models for each influence respectively each component allows a very detailed evaluation of the use of geothermal energy by the determination of the business, economically and ecologically aspects. The variation calculus is based on the evaluation of national and international experiences with the installation and operation of geothermal facilities. Because of the described approach facilities which are not use to heat road surfaces are helping, too. In addition this approach allows investigating the heating of road surfaces as well as the cooling of surface layers.

Therefore the model is divided into a macro model and independent micro models describing each influence respectively component. The data of the micro models “installations”, “winter maintenance”, “traffic”, “road structure” and “environment” are finally overlaid in the macro model. So the supply of the dangerous road sections with the three different approaches in dependence of the number and the surface area of the dangerous road sections can be compared.

- Installations: With the help of available data of existing geothermal facilities are done regression calculations for the investment and operation costs in dependence of the heated surface area. Through that it is possible to calculate cost fractions dependent or independent of the amount of the heated surface area. Also the working life of the geothermal installations is estimated with the available data. The automated spray technology is analysed by the same principle.
- Winter Service: Regarding only the special supplied dangerous road sections the data from the mission reports are analysed to receive the minimum, average and maximum distance of full service and empty service for every dangerous road section. Beside that the extreme and average value for the number of annual special operations are analysed from automatic captured operation data. With the help of empirical value and estimations the associated annual costs per dangerous road section and per overall surface area are calculated. These costs are the amount of personnel costs and operation costs for the trucks and salt.

- Traffic: In the micro model traffic the effects of adverse road surface conditions on the traffic flow are determined with collected data of traffic and climate. It is assumed, that the loss of time, caused by wintry weather, in dangerous road sections equipped with automated spray technology or geothermal installations, can be neglected. So only at road sections with vehicle based winter maintenance costs of loss of time are considered. Furthermore the traffic safety consequences of fixed installations are considered regarding the level of accidents in sections with and without automated spray technology. It is assumed, that road sections equipped with automated spray technology have nearly the same impact on traffic safety as road sections equipped with geothermal energy. Through that it was possible to receive different accident costs for dangerous road sections supplied with fixed installations, even though there is currently no experience with geothermal installations used for heating road surfaces in Germany.
- Road Structure: The cooling of the wearing course in summer leads to less rutting and with that to a longer lifetime of the wearing course. The costs of structural maintenance with the wearing course in the area of dangerous road sections, equipped with geothermal energy for heating or cooling, can be written off for a longer period of time. This does not apply for dangerous road sections equipped with automated spray technology as well as those served by vehicle based winter maintenance. These different annual deductions for the structural maintenance of the wearing course are estimated with the micro model.
- Environment: In the micro model environment the produced CO_2 output, the index of used salt and the external environment costs of the winter maintenance services are compared for all three approaches of winter maintenance. Regarding the vehicle based winter maintenance the CO_2 output is the amount of the emission by cars in traffic congestion caused by wintry weather conditions and the emission of trucks for the winter maintenance. With the help of the data from the micro models winter maintenance and traffic the annual CO_2 emission is calculated per dangerous road section and per salted surface area. CO_2 output by automated spray technology and geothermal installations is caused by the power station for the generation of electricity for pumps. The annual CO_2 output of the power stations is determined with the data of the "Umweltbundesamt" (German Federal Environmental Agency) and data for energy consumption of the facilities. It is assumed, that using fixed installations (geothermal energy or automated spray technology) no CO_2 output will occur from traffic congestions in winter. The environmental costs as an amount of the driving winter maintenance trucks, the CO_2 output by cars in traffic congestions and the electricity consumption of the fixed installations are converted with expense ratios from the German Federal Environmental Agency into annual costs per area unit and per dangerous road section. The salt used annually per area unit in winter maintenance is determined by data from the micro model winter maintenance. For the automated spray technology data from literature is used. Avoided salt entry is not converted into monetary units.

The received data from the micro models are overlaid in the macro model. With that, it was possible to plot balance sheets for business, economy and ecology effects. With these balance sheets the annual effects of road sections either equipped with geothermal installations, automated spray technology or serviced by vehicle based winter service can be compared. To interpret the very complex relations the results are plotted over the variation of the number (Figure 3) and the total surface area of the dangerous road sections.

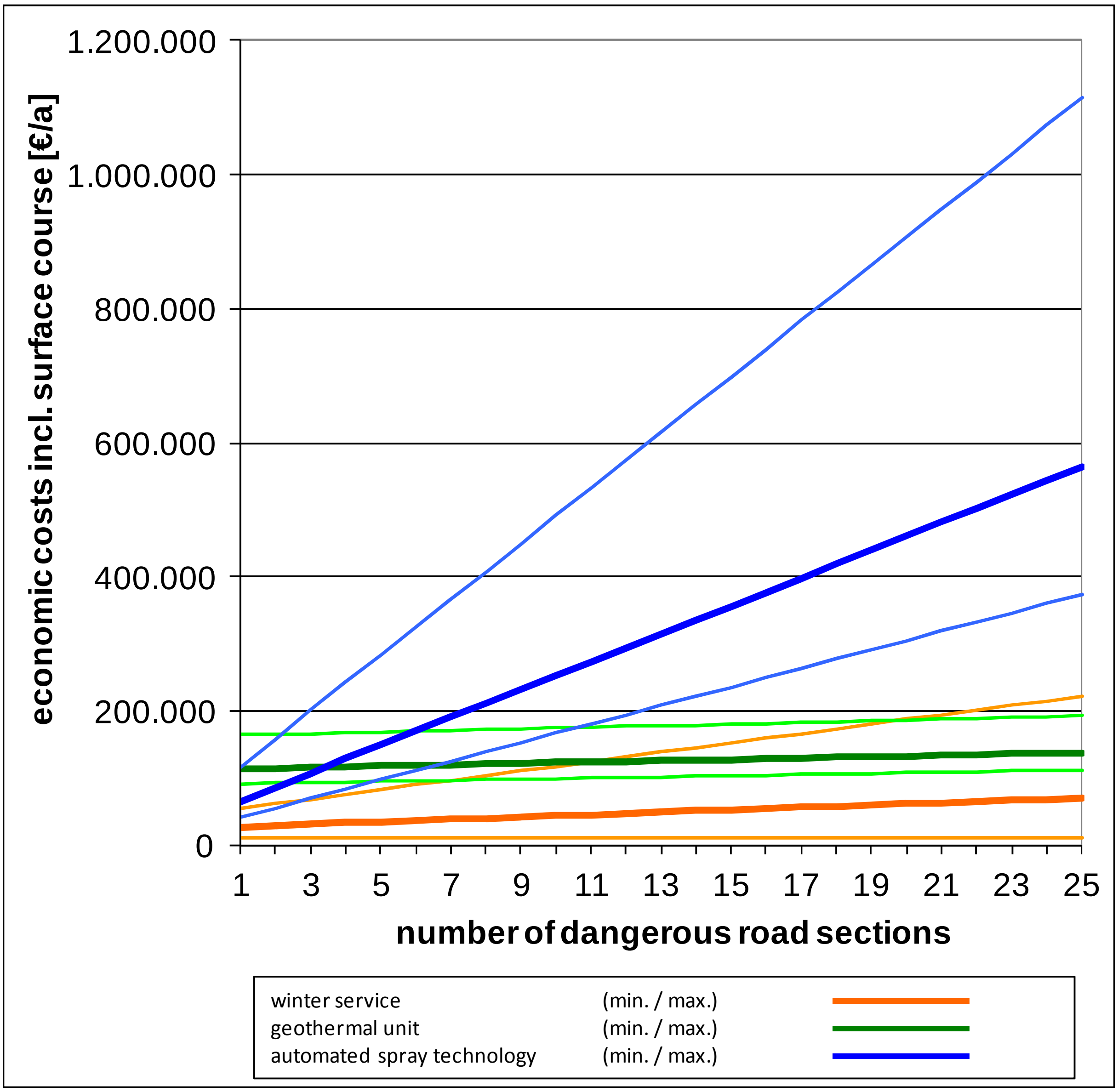

Figure 3 - Business costs including the change of the surface course at 10.000 m²

Furthermore the spectrum of the results considering the spectrum of real conditions found during the investigation is shown. The spectrum in the results of the macro model date back to the spectrum observed in the micro models.

3. FINDINGS

Under utilization of the start-results by real observation in dependence of the number and total surface area of the dangerous road sections, a wide spreading of the results is given. Figure 3 shows an example for the economic costs including the deduction for the structural maintenance measures at the surface course. The costs are plotted over the total number of dangerous road sections in the road network based on an overall surface area of 10.000 m^2.

Obviously the average costs for the vehicle based winter maintenance in every constellation are less than the costs for automated spray technology and geothermal energy. Based on the shown overall surface area of 10.000 m² the result is independent from the number of dangerous road sections. Considering the whole spectrum overlapping points are visible. The costs to equip road sections with automated spray technology are overlapping as well as the costs of geothermal energy installations. This indicates, that under certain conditions (location of the dangerous road sections in the served road network, size of the surface area of each dangerous road section, topographical and climatic circumstances, lifecycle of the installation etc.) the effort of geothermal installations can be appropriate from the business point of view.

From the economic point of view, considering loss of time, accident costs and ecologic costs, is the equipment of dangerous road sections with fixed installations in every case more reasonable than the vehicle based winter maintenance. Because of the possible traffic congestion resulting in higher CO_2 output the CO_2 balance with vehicle based winter maintenance is many times higher than with fixed installations. Because of the lightly higher need of electricity and the associated higher environmental costs in this investigation the geothermal installations produce higher economic costs than automated spray technology. However, this has to be put into context of the not monetised pollution of the nature with the salt spread for de-icing.

The difference in annual index of used salt per area unit of dangerous road sections between vehicle based winter maintenance and fixed automated spray technology is not significant. The full amount of used salt can be avoided by the equipment with geothermal energy installations.

4. CONCLUSION

From the distribution of the results follows that a fundamental statement concerning the potential of geothermal energy as a contribution to winter maintenance is not possible. In fact a very detailed investigation of the individual case is still necessary. Additionally the comparable high costs of the drilling for the borehole heat exchanger is the reason, that a geothermal system just for heating a road surface is economically not reasonable as a rule.

Other constellations are found with the combination of heating in winter times and cooling in summer times as well as from the possibility of having multiple use of the geothermal energy. Combining heating in winter times and cooling in summer times the climatic conditions in Germany allow to calculate the installation in such a way that a surplus of energy from the summer can be used in winter. Additionally, the cooling in summer times increases the life time of the surface layers in road constructions and therefore decreases the effort in constructional road maintenance.

In a network wide assessment the use of geothermal energy seems to be an option, if there are several dangerous road sections to be equipped, but each of them with a small surface area. On one hand there must be several dangerous road sections in the road network that need a preventive winter service operation and, on the other hand, these road sections must be definable by the climatic condition in such a way, that by instrumentation with geothermal energy no preventive operations are needed any more.

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