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Climate Change and Lithuanian Roads: Impacts, Vulnerability and Adaptation

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Abstract. In Lithuania, like in other countries, climate change causes and will cause changes in natural and anthropogenic environment. The entire transport sector will be impacted, influencing the way it plans, designs, constructs and maintains infrastructure in the future. Roads are already sensitive to current climate variability. If today's extreme weather events become both more frequent and extreme, so too will the level of disruption that they cause. Thus, roads must be adapted to changing climate conditions. The aim is to ensure resilience, to ensure that roads remain open under extreme weather conditions. The easiest and the most effective economically way is to implement adaptation measures for the new or reconstructed roads. But the existing older roads should be adapted also. The steps required to improve and maintain resilience of roads are definition of climate projections, identification of key roads and their vulnerability, identification and research on technologies for adaptation, preparation of methodologies, establishment of field operational trials. The aim of the research is to review Lithuanian roads in the context of climate change and its consequences. Methodology: climate and associated data collection and review, initial prognoses of the change (in short, medium and long term perspective) of meteorological elements, vulnerability assessment of the study area and the roads. Results: initial recommendations for adaptation action planning.

Keywords: climate change, adaptation, resilience, roads.

Conference topic: Roads and Railways.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) states that in recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans (IPCC 2014a). Climate change, as described by the projections from global, regional and local models, will bring about a number of challenges for the roads in Europe (Nemry, Demirel 2012) not excluding Lithuania. In most cases, these will be the same challenges as today, but on a larger scale, occurring more frequently and possibly at other locations than expected.

In its latest fifth assessment report IPCC pays attention not only to the physical science basis of climate change (2013), to mitigation of climate change (IPCC 2014b), but also to adaptation issues. IPCC defines adaptation as the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities (IPCC 2014a). Adaptation is actions undertaken to adapt to the conditions of ongoing climate change, for example, to more intense precipitation, higher temperature or more frequent storms (Nature Heritage Fund 2015). Throughout history people have adjusted to and coped with climate, climate variability and extremes. Variability of meteorological conditions, climate variability and extremes have long been important in many decision-making aspects. Climate-related risks are now evolving over time due to both climate change and development (IPCC 2014a). Whatever the warming scenarios, and however successful mitigation efforts prove to be, the impact of climate change will increase in the coming decades because of the delayed impacts of past and current greenhouse gas emissions. We therefore have no choice but to take adaptation measures to deal with the unavoidable climate impacts and their economic, environmental and social costs. By prioritising coherent, flexible and participatory approaches, it is cheaper to take early, planned adaptation action than to pay the price of not adapting (COM 2013). Due to the specific and wide ranging nature of climate change impacts, adaptation measures need to be taken at all levels, from local to regional and national levels (IPCC 2014a).

In 2013, the European Commission adopted the communication "An EU Strategy on adaptation to climate change", which includes several elements to support Member States in adaptation: providing guidance and funding, promoting knowledge generation and information-sharing, and enhancing resilience of key vulnerable sectors through mainstreaming. In addition, the EU has also agreed that at least 20% of its budget for the 2014–2020 period should be spent on climate change-related action, including mitigation and adaptation (COM (2013) 216 final).

In Lithuania the Strategy for National Climate Change Management Policy for 2013–2050 was adopted in 2012. Lithuania is the first among the three Baltic countries to have the adapted strategy on adaptation. The strategy sets the strategic goals of both – Lithuania's climate change adaptation and mitigation policies. In order to ensure the implementation of the Strategy the Inter-institutional Action Plan for the goals and objectives (2013–2020) was approved in

2013. Following the approval of the strategic planning methodology, the Plan is prepared for a three year period and is updated annually. The progress of the implementation of the Strategy is evaluated by a set of criteria established in the Plan. In addition, ministries and other governmental institutions are obliged to integrate the goals and objectives set out in the Strategy, to establish implementation measures and to ensure close inter-institutional cooperation while developing the strategies, their implementation plans and programmes of individual sectors of the economy.

Climate change is global but adaptation should be local. Therefore adaptation interventions should be context specific, reflecting national approaches and prioritising local knowledge and circumstances. Assessment of climate change risk on economic sectors, assessment of vulnerability of economic sectors, research on adaptation are scarce in Lithuania.

Adaptation to climate change is a relatively new policy and research area and the level of information is irregular. To foster adaptation to climate change in the transport sector, a common understanding of problems related to climate change as well as information on possible impacts are required, but often scarce. This paper provides an outlook about the present and future vulnerability of transport in Lithuania to climate change with a focus on roads.

The goals of the paper are to: 1) show the topicality and the possible consequences of climate change for roads and 2) propose initial recommendations for adapting the Lithuanian roads to climate change.

Material and methods

The review study is based on the existing scientific literature. No new modelling was done.

We collected climate and associated data (both written and cartographed). Based on the existing scientific research and evidence, applying expert method we provide initial prognoses of the change (in short, medium and long term perspective) of meteorological elements, climate factors which are relevant for roads.

A rapid vulnerability assessment of the study area and the roads was done:

- Step 1: identification and analysis of the relevant existing meteorological / climatic and related hazards, their probability and consequences.
- Step 2: Vulnerability of the territory and the roads.

Results and discussion

Lithuania is a country subject to strong impacts of meteorological conditions on transport sector (Kazys 2006). Climate change already has impacts on roads and can put its operation and reliability partially at risk.

Hazards of climate change and related phenomena on roads

The authors identified as relevant and reviewed the existing data (including cartographic data of meteorological / climatic phenomena) on fog, storms, freezing rain, precipitation (rain, very heavy rain, very heavy snowfall, sleet), snow cover (the mean number of days with snow cover and the mean maximum snow depth), soil freeze, hail, high (>25 °C) and low (<20 °C) weather temperature, melting cycle (temperature about 0 °C), drought, fires (of forest, grassland, peatbog), severe wind, flooding.

Chance of hazardous and unfavourable meteorological phenomena exists throughout a year, but the possible negative impact strengthen in cold season.

Hazardous meteorological phenomena can be grouped according to their impact (Nature Heritage Fund 2015):

- phenomena that impact visibility: fog, blizzard, rain, snowfall, sleet, dust-storm;
- phenomena that impact road pavement (slipperriness) or block roads: freezing rain, ice cover, very heavy precipitation, blizzard, snowslide, road inundation;
- phenomena that impact stability of vehicles and are dangerous for various engineering structures and infrastructure: severe wind, freezing rain, wet snow spatter, composite frost, hail, extreme high or low temperatures, freezing and melting cycles in cold season.

Besides direct meteorological impact roads are impacted by phenomena which are related to meteorological ones that is by flooding, drought, fire.

A detailed assessment (Table 1) of relevant climate impacts on road infrastructure is presented in the EC working document (SWD 2013).

Table 1. Climate risk and impacts on road infrastructure (Source: SWD (2013) 137 final)

Type of infrastructure	Climatic pressures	Risks	Time frame of expected impact	Regions mainly affected
Roads (including bridges, tunnels, etc.)	Summer heat	• Pavement deterioration and subsidence; • melting tarmac;	Medium negative (2025; 2080) to high negative (2080)	Southern Europe (2025), West, East and Central EU (2080)

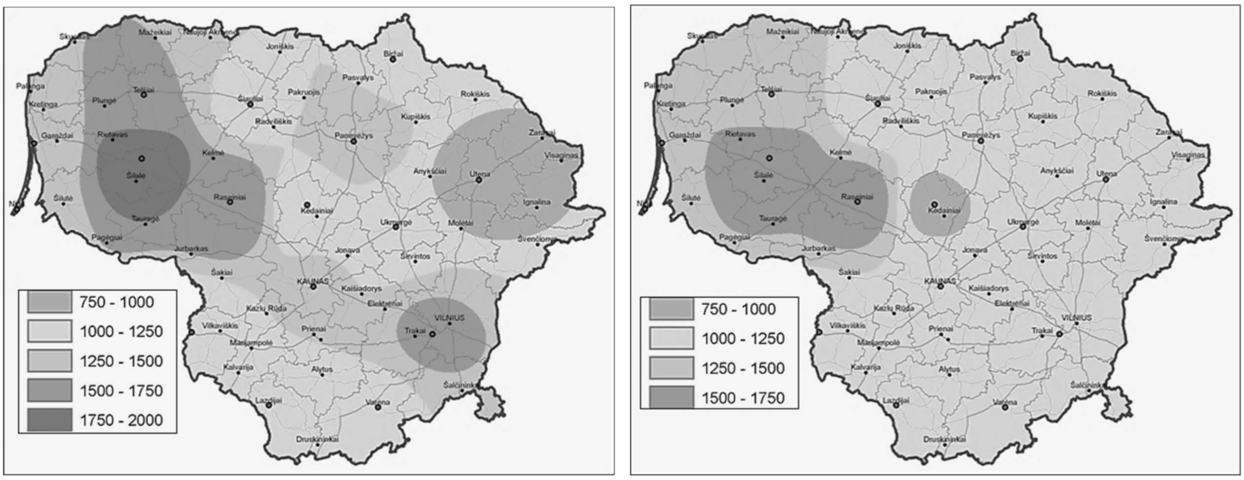
End of Table 1

Type of infrastructure	Climatic pressures	Risks	Time frame of expected impact	Regions mainly affected
Roads (including bridges, tunnels, etc.)		• reduced life of asphalt road surfaces (e.g. surface cracks); • increase wildfires can damage infrastructure; expansion/buckling of bridges.		
	Extreme precipitation/ floods	• Damage on infrastructure (e.g. pavements, road washout); • road submersion; • scour to structures; • underpass flooding; • overstrain drainage systems; • risk of landslides; • instability of embankments.	Medium negative (2025) to high negative (2080)	European wide
	Extreme storm events	• Damage on infrastructure; roadside trees/vegetation can block roads.	No information	No information
	In general:	• Speed reduction; • road closure or road safety hazards; • disruption of "just in time" delivery of goods; • welfare losses; • higher reparation and maintenance costs.		
Sewerage system	Heavy precipitation events	• Overloaded sewerage system can cause road flooding and water pollution.	Medium negative (2025) to high negative (2080)	European wide

Integrated meteorological risk assessment

Complexes of adverse meteorological phenomena are even more adverse; especially at night periods.

There are some scientific integrated meteorological risk assessments of the Lithuanian territory. J. Kazys (2006; Kazys *et al.* 2004) investigated the impact of meteorological factors on road traffic conditions and traffic safety in Lithuania. Kazys *et al*. (2004) evaluated the impact of weather conditions on accident risk in Vilnius in 2001–2002, analysed and mapped potential accident risk (PAR) in the territory of Lithuania caused by adverse weather conditions and presented PAR forecast for the 21st century. The analysed meteorological phenomena were rain, very heavy rain, snowfall, sleet, fog, blizzard and freezing rain. The PAR maps were produced for both warm and cold seasons (Fig. 1). An original technique was applied to statistically evaluate the influence of various meteorological phenomena on road accidents. The technique allows analysing the PAR for relatively large areas. The data on road accidents and meteorological phenomena were used to determine the process consistency. Because of the different traffic flow structure all data were separated into weekdays and weekends; moreover, because of different meteorological conditions all data were separated according to the cold (November–March) and warm (April–October) periods. At first, the background accident frequency rates were defined for 48 time points (every half an hour). This means that only accidents that occurred without meteorological phenomena were analyzed. The specific road accident frequency values were compared with analogous rates set under meteorological conditions unfavourable for traffic. The Comparative Accident Density (CAD) coefficients were obtained by calculating the increase of road accident number under dangerous meteorological conditions. Generalised CAD values were computed for each meteorological phenomenon, therefore at first the CAD coefficients were tallied up separately for weekdays and weekends. The CAD coefficients of different meteorological phenomena had only a few differences during the cold period. Only values of blizzard and freezing rain were a little lower than expected. During the warm period the coefficients were higher, though the CAD variations also were very small. Next, the mean duration (in hours) of every meteorological phenomenon according to long term meteorological data was calculated. The calculation was done for the 21 meteorological stations across Lithuania during the cold and warm periods. The mean values were multiplied by the prevailing CAD coefficients. The index showed Potential Accident Risk for every meteorological station. The final stage was laying out a cartographic scheme of PAR distribution. It was done using the PAR index values for cold and warm periods separately. Regions with a different PAR were marked during the cold period (Fig. 1a). Also regions with a different PAR were noted during the warm period (Fig. 1b). The index values are lower than for the cold period, though the duration of the warm period and the CAD coefficients are higher. It is determined by a smaller amount and duration of dangerous meteorological phenomena.



a) mean PAR index values (cold season) b) mean PAR index values (warm season)

Fig. 1. Mean potential accident risk (PAR) index for cold (a) and warm (b) season in the terirory of Lithuania
(Source: Kazys 2006)

K. Papsys (2012, 2013) presented methodology of development of cartographic information system for evaluation of risk of extreme events. The author analysed GIS layers of 14 meteorological risks (distribution of extreme events), set scores (1 to 10) and synthezed the map of Lithuania territory of integrated meteorological hazard. The researcher concluded moderately event distribution of meteorological hazards in the Lithuanian territory.

The integrated impact of meteorological conditions on engineering structures was calculated integrating long-term (1971–2000) parameters of snowstorm, strong wind (>15 m/s) and freezing rain (Lithuanian National Atlas 2014). Impact was graded into four impact groups (low, medium, significant very significant). Though, engineering climate assessment is more actual for various buildings, it is also important for road infrastructure elements, bridges, viaducts. Figure 2 shows that the most complicated exploatation conditions are in Zemaiciai (Samogitian) Highland (western part of Lithuania) and the most simple are in Central Lithuanian Lowland (central part of Lithuania).

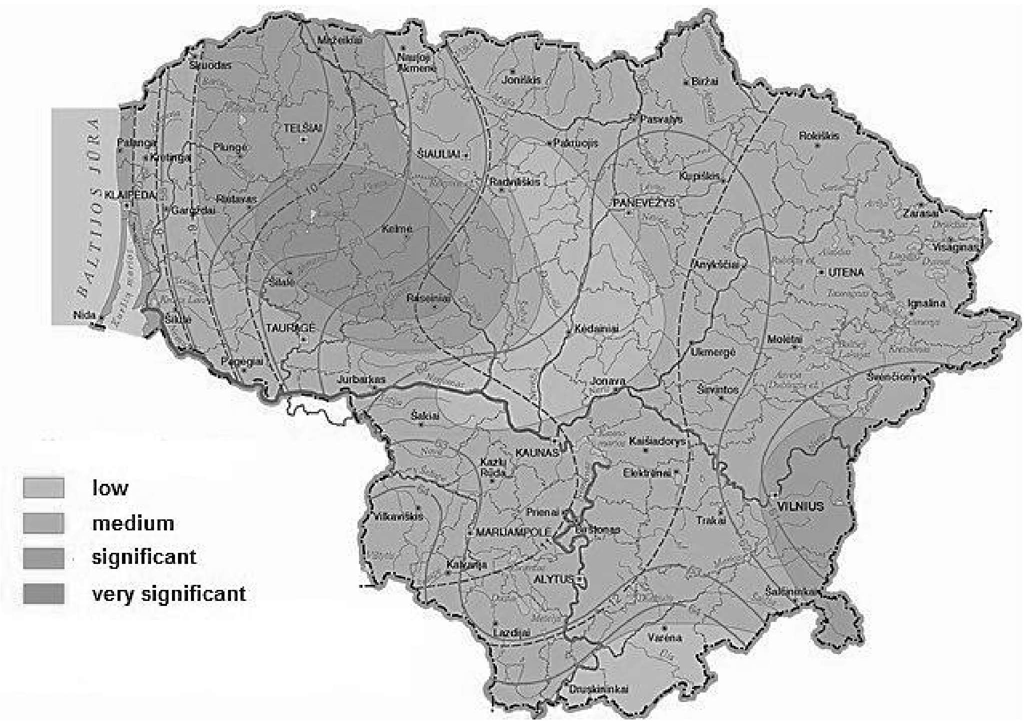


Fig. 2. The integrated impact of meteorological conditions on engineering structures
(Source: Lithuanian National Atlas 2014)

Forecasted changes of meteorological elements actual to roads in Lithuania in the 21st century

Investigations designed to analyse impact of future meteorological / climatic conditions on transport sector are lacking in Lithuania.

Most of the research works with quantifiable parameters forecasted for the 21st century are concentrated on the prognoses of the main meteorological parameters that is air temperature and precipitation (Bukantis *et al.* 2001; Rimkus *et al.* 2006, 2007, 2009, 2011, 2012; Vaitiekuniene *et al.* 2011; Mickevic, Rimkus 2013; Environmental Protection Agency 2015; Valiukas 2015; Kersyte *et al.* 2015). Other meteorological phenomena are analysed only qualitatively (Rimkus *et al.* 2006; Climate change: adaptation… 2007; Nature Heritage Fund 2015; Kornejevas, Volcek 2015).

The newest local forecasts of climate elements for the territory of Lithuania (Nature Heritage Fund 2015; Kersyte *et al.* 2015) are based on the newest greenhouse gas emission RCP (*Representative Concentration Pathways*) scenarious published in the latest IPCC report (2013).

Based on the existing scientific research and evidence, applying expert method this paper provides initial prognoses of the change (in short, medium and long term perspective) of meteorological elements which are relevant for roads.

Short term prognosis (to 2035)

According to the latest IPCC report (2013) short-term prognostic period comprises the contemporary 20 year period (2015–2035). Intensity and frequency of contemporary meteorological phenomena actual for roads will remain only slightly changeable.

Based on earlier (Kazys 2006; Kilkus *et al.* 2006; Rimkus *et al.* 2007; Gecaite, Rimkus 2010; Vaitiekuniene *et al.* 2011) and the most recently (Nature Heritage Fund 2015; Kersyte *et al.* 2015) made prognoses for the beginning of the 21st century, conclusions are drawn that the impact of meteorological conditions for roads will be similar to the existing conditions. Independently from the chosen climate change scenario, general conditions for transport systems should slightly improve. Probability of unfavourable meteorological phenomena will remain close to the existing ones.

In cold season slightly increase in mean precipitation, more frequent precipitation and related phenomena (freezing rain, wet snow spatter, storms) may increase additional costs in the roads sector. In warm season the biggest hazards will be related to severe rain (flooding) and heat (droughts).

Medium term prognosis (2035–2050)

According to the latest IPCC report (2013) medium-term prognostic period is related to the middle of the 21st century, that is to the year 2050. Significant changes are not forseen for the period but, depending on the chosen climate change scenario, more spatial changes and more changes in factors magnitude will reveal.

Air temperature changes predicted by various RCP scenarious up to the middle of the 21st century differ insignificantly. It is predicted that in the first half of the 21st centure internal fluctuations of climate system may be more significant than the impact of greenhouse gases. Therefore there are no big differences among different scenarious. However, starting 2040 it is forecasted that the impact of greenhouse gases will be more significant than internal fluctuations of climate system. Thus, climate change will directly depend on RCP scenarious (Nature Heritage Fund 2015).

Summarizing climate prognoses for the middle of the 21st century (Rimkus *et al.* 2007; Kersyte *et al.* 2015) conclusions are drawn that meteorological impact on the transport sector will be the lowest. The increased mean monthly air temperature and little variations in precipitation amount will determine favourable conditions for the transport system. The lower number of days with snow cover and temperature fluctuations at 0 °C, the lower frequency of meteorological phenomena typical to cold season (freezing rain, storm, very heavy snowfall, severe wind) will likely determine better driving conditions and less resources for maintenance. However, it must be borne in mind that the climatic conditions will depend on the real climate change scenario.

Long term prognosis (2080–2100)

According to the latest IPCC report (2013) long-term prognostic period comprise 20 year time period from 2080 to 2100. The most significant impacts of climate system are forecasted for this period.

The mean annual temperature may arise 1.5–5.1 °C up to 2100. The end of the 21st century will be the most unfavourable for the transport sector. Though general conditions might be more favourable, but significant increase in extreme events probability will determine unfavourable conditions.

The roads

The simplified rapid vulnerability assessment was applied to the roads of Lithuania. At this initial state it is practically impossible to make an indepth risk analysis of separate links. Infrastructure damage, traffic disturbance data are needed. The analysis can at a later stage be extended further to include computer simulations. Comprehensive vulnerability assessment should also include assessment of links with other infrastructure types, for example, telecommunications.

Despite the constant modernization, the Lithuanian roads could be defined as moderately vulnerable. A large part of them is an ageing infrastructure in which design climate change aspects were not included. The hazards for the roads have been identified and analyzed in the above sections. Climatic factors negatively impact road pavements (high temperatures, freezing melting cycle), vertical infrastructure elements like static signs (winds), may block roads, restrict, delay traffic, cause accidents, etc. Though, there is no specific monitoring, but overtime the magnitude (frequency) of damage and/or disruption caused by weather or climate related events is observed to increase. The users of the roads do not experience significant delays and operational problems. But physical damage is periodically reported. The observed trends of climate change impacts to some extent will require adaptation responses.

Existing actions, measures that contribute to resilience of the road network are:

- modernization of roads (for e.g. 437 km were built, reconstructed or repaired in 2015);
- besides the use of long-term climate norm data, application of the latest (10 year) local meteorological data starts in design process as the existing state is already the consequences of climate change;
- monitoring (Road Weather Information System) and early warning system (eismoinfo.lt);
- new technologies, investigations, materials and composites (for e.g. pavements adopted to local climate conditions (Vaitkus *et al.* 2016)).

The currently applied instruments for adaptation and improving resilience of new and / or reconstructed road infrastructure are:

- Standards at EU level and adopted nationally which include references to weather/climate related pressures. European Standardization Organizations are screening and will revise standards in order to better integrate adaptation to climate change issues (COM (2013) 216 final). Priciples of adaptation will be defined in the document under preparation ISO 14080.
- Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) will contribute to improving the climate resilience of roads. EIA is a procedural and systematic tool that is well suited to incorporate considerations of climate change impacts and adaptation for project design, approval and implementation. The revised EIA Directive proposes new, clearer amendments towards addressing new challenges including climate change and disaster risks. SEA can also serve as an effective tool for climate change adaptation, especially by introducing climate change considerations into development and planning processes. IPCC concluded that consideration of climate change impacts at the planning stage is key to boosting adaptive capacity (IPCC 2007).

Fulfilment of objectives in adaptation action planning could be planned stage by stage. Thus, in good practice critical (vital) roads are defined. The services of the roads can be limited for reasonable time, but the roads that are vital for European and national economy, for public can not be blocked due to meteorological and related phenomena. Thus, critical / vital roads could be defined as road assets that are significant to the continued delivery and integrity of the essential road services, the loss of which could lead to severe economic or social consequences. Suggested objects for the possible critical roads' list could be:

- Roads of Trans-European Transport Network (TEN-T); roads of the international E-road network;
- links with other transport modes;
- bridges, tunnels;
- all main roads;
- national, regional roads; roads without alternative routes.

According to the existing strategic documents development projects of roads must evaluate existing and prognostic climate change. Lithuania has not yet determined and published meteorological data suitable for planning and design.

Conclusions and recommendations

This review is based on the existing data. The analysis can at a later stage be extended further to include more detailed computer simulations.

Making roads resilient to climate change is an important (obligatory) and early adaptation challenge. We provide recommendations for future roads adaptation action planning:

- systematic data collection of damage (traffic disturbance, accidents, infrastructure damage, etc.) of meteorological / climate events (extreme events) to roads (e.g. creation of database of damage to roads from extreme weather events);
- setting of criteria for critical (vital) roads, identification of critical objects and definition of priorities;
- evidence based identification of vulnerable road elements;
- definition of the need and requirements for climate projections; structural (physical) measures are expensive measures, thus, their implementation should be argumented by confident and detailed climate change prognoses;
- definition of lifetime for different road elements;

- revising of actual methodologies, recommendations;
- identification of new methodologies, technologies for climate change adaptation;
- investigation for cost-effective adaptation.

Disclosure statement

The authors declare that they have no competing financial, professional, or personal interests from other parties.

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