Project No. 18003094

Final Report

Study on climate change impact assessment for the design, construction, maintenance and operation of Rail Baltica railway

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Executive summary

Study on climate change impact assessment for the design, construction, maintenance and operation of Rail Baltica railway (hereinafter – the Study) is aimed to identify climate change associated risks for the design, construction, maintenance and operations of Rail Baltica railway. Furthermore, the Study shall assess pre-designed infrastructure vulnerability and propose feasible climate change adaptation measures for the railway design, construction and operation phases.

Aim of the Study is to help manage the additional risks arising from climate change, consider how Rail Baltica project is vulnerable to climate variability and change, assess current and future climate risks to the success of the project, identify and appraise relevant and cost-effective adaptation options to build climate resilience, and integrate adaptation measures (resilience measures) into Rail Baltica project lifecycle. A common and more comprehensive understanding of future risk and vulnerability will be developed and appropriate interventions for reducing this risk, will be identified.

It is important to note that considering the geographical location, topography, and settlement structures in relation to weather pattern, hydrology and historic extreme events, the risks related to climate change are relatively low in the Baltic states compared to the Central or Southern Europe (KATI 2015).

The study outcomes are not intended to override, nor define, the design standards that project developers should be working to, and they are not a substitute for detailed design at the project level. Project design should always be undertaken in accordance with Rail Baltica Design Guidelines, national requirements and/or professional codes of practice as appropriate. However, in cases where national requirements or design codes do not yet incorporate consideration of climate change, these study outcomes may help to improve risk management still further. Design standards need regular reviewing in the light of evolving understanding of the impact of climate change on extreme weather.

Geographical area covered by the Study includes territories of Republics of Estonia, Latvia and Lithuania which Rail Baltica railway corridor passes through.

The Study is divided into 3 work packages:

- ✓ **WP1** - Analysis of climate projections, relevant studies and strategies,
- ✓ **WP2** - Risk identification and assessment, vulnerability assessment,
- ✓ **WP3** - Adaptation option development.

Purpose of WP 1 is to identify meteorological indicators and climatic hazards with potential significant impact on Rail Baltica railway infrastructure during construction, maintenance or operation stage. This will be achieved by compiling and analysing climate data, results of similar previous analyses and national strategies. The expert team will gather, focus and analyse evidence to understand the challenges that long-term climate projections and current and future extreme weather present specifically to the Rail Baltica railway.

The impact assessment of rail infrastructure needs to be informed by a deeper understanding of climate change and weather in three domains:

- ✓ **Climate normal:** the typical weather patterns in the Rail Baltica corridor, climate normal as an average over a 30-year period (1981–2010);

- ✓ **Extreme weather events:** the characteristics of extreme weather events during last decades (1981–2017);
- ✓ **Future climate:** the expected climate change anticipated in the light of long-term climate projections (moderate RCP4.5 and extreme RCP8.5 scenario in EURO-CORDEX ensemble).

Historic weather data from the 11 closest Baltic meteorological stations of the national World Meteorological Organization (WMO) standard network, was obtained during the Study.

Analysis of the future climate projections resulted on defining most relevant climatic trends in the region for Rail Baltica project:

- ✓ **Mild winters, less snow and lower spring peak runoff (high confidence).** Frost days will reduce by up to 80 days per year for 2100. There is a very high peak of around 0 °C. The snow cover will decrease substantially and not permanently formed and the spring peak runoffs are earlier, lower and less steep. The frequency of freezing rain and hail will grow highly probably. Still, short periods of intense cold weather. The biggest direct human risk where weather is a factor is passenger slip.
- ✓ **More heatwaves (high confidence).** Heatwaves occur more often, rise of future temperatures, including summer maximum temperatures up to approximately 5° C, which could lead to maximum temperatures around 40° C, according to worst case climate change scenarios. Wildfire risk will increase.
- ✓ **More storms, winter storms (medium confidence).** An increase in the average wind velocity in winter, with increased likelihood of storms, is forecasted, but average annual wind speed not expected to change much. Wind gust speeds and likelihood of storms may increase, especially during the summer period. The number of thunderstorms will grow.
- ✓ **More heavy rainfall (medium confidence).** Climatic projections estimate increased likelihood of more severe heavy rains and flash floods in the future, with likelihood of extreme precipitation (over 30 mm per day) can be increased up to 4 times in winter period and over 1.5 times in summer period according to the RCP8.5 scenario. Heavy rainfall is characterised by a very high spatial-temporal variability causing pluvial floodings, ground instabilities.

Historic data from the meteorological stations near Rail Baltica (Figure 2.2 in Chapter 2.3.1) during period 1981-2017 (see exceptions, due to data availability, for each variable in Chapter 4) and future projections of most relevant climatic variables are presented in the Table below.

Registered climatic extremes or events near Rail Baltica corridor	Future trend based on climate change
Maximum recorded air temperature – 35.5 °C (Panevėžys in August 1992)(Chapter 4.1.1)	Maximum air temperature in the South-East part of Lithuania can reach almost 40 °C (Bukantis, A. et al, 2015) (Chapter 4.2.4 - Figure 4.93)
Minimum recorded air temperature – -35.7 °C (Ainaži 2003) (Chapter 4.1.1)	**Clear trend of increased temperatures in the winter periods.** However, the absolute minimum temperatures are modelled with very low certainty by current climate scenarios. (Keskkonnaagentuur, 2014; Latvijas Vides,

Registered climatic extremes or events near Rail Baltica corridor	Future trend based on climate change
	ģeoloģijas un meteoroloģijas centrs 2017; Kilpys, J., Pauša, K., Jurkus, N., 2017) (Chapter 4.2.4)
Maximum sum of 24-hour precipitation – 86,8 mm (Pärnu in June) (Chapter 4.1.2 - Table 4.4)	**Precipitation will be increased, especially during winter period. Climatic projections estimate increased likelihood of more severe heavy rains and flash floods in the future, with likelihood of extreme precipitation (over 30 mm per day) can be increased up to 4 times and over 1.5 times in summer period according to the RCP8.5 scenario.** However, the distribution of precipitation by intensity is not modelled by climate scenarios and the uncertainty of statements and forecasted data remains extremely high. (Keskkonnaagentuur, 2014) (Chapter 4.2.5 – Tables 4.29 and 4.31 and Figures 4.97 and 4.98)
Maximum sum of one-minute precipitation – 6,6 mm (one-minute data only available for Lithuania) (Panevėžys in July 2010) (Chapter 4.1.2)	**As above.**
Maximum snow cover depth – 66 cm (Kuusiku) (Chapter 4.1.3, Table 4.7)	**Clear trend of increased temperatures in the winter periods, projections for the end of 21th century show significant decrease of snow cover in Estonia.** (KAUR, 2014) **It is predicted that until 2035 the maximum snow cover thickness <u>will</u> decrease by 4-5 cm, until 2065 - by 5-9 cm, and until 2100 - by 5-14 cm in Lithuania.** (Rimkus, E.; Pasiskeviciute, R. 2017) (Chapter 4.2.6)
Rail Baltica crosses or is located near **14 national level flood risk zones** (13 rivers and one lake) (Chapter 4.1.4, Figures 4.19-4.37)	**Spring floods (main flood risk) will be less severe due to milder winters and inconsistent snow coverage. Maximum discharges of spring floods have decreased in the Baltics over the period 1922-2010** (Sarauskiene et al 2015). (Chapter 4.2.7)
Maximum average wind speed – 20 m/s (Riga in January)	**The average wind speed is unlikely to change much, but wind gusts may increase, especially during the summer period. It is likely that the recurrence of storms and**

Registered climatic extremes or events near Rail Baltica corridor	Future trend based on climate change
(Chapter 4.1.6, Table 4.11, Figures 4.45-4.47)	**hurricane winds will increase, especially during the cold season**. (Lithuania's 7th UNFCCC report, 2017) **Likelihood of severe storms (21 m/s or more) might increase,** but there is much uncertainty in long-term predictions. (KAUR 2014) (Chapter 4.2.9)
Maximum wind gust speed – 40 m/s (Ainaži in November and Bauska in January) (Chapter 4.1.6, Table 4.12, Figures 4.48-4.50)	**As above.**
Highest average annual number days with thunder – 26 days (Lazdijai) (Chapter 4.1.7, Tables 4.13 and 4.14, Figures 4.61-4.63)	**Higher air temperature causes more intense formation of typical summer thunder clouds. Natural phenomena associated with thunder clouds will be more likely and with more severe consequences**, but more detailed projections are not possible due to uncertainty and random spatial nature of the thunder events. (KAUR 2014) (Chapter 4.2.10)
Highest average annual number days with freezing rain – 7,7 days (Panevėžys) (Chapter 4.1.8, Table 4.15, Figures 4.64-4.66)	Projections of increased temperatures in the winter periods with more precipitation and **increased likelihood of wet snow, freezing rain, glazed frost and ice forming events** (Keskkonnaagentuur, 2014; Latvijas Vides, ģeoloģijas un meteoroloģijas centrs 2017; Kilpys, J., Pauša, K., Jurkus, N., 2017). (Chapter 8)
Maximum frost penetration of soil – 190 cm (Keo measure point, located near Kuusiku station, in 2014) (Chapter 4.1.9, Tables 4.18 and 4.19, Figures 4.74 and 4.76)	No clear projections available about frost penetration of soil for Estonia, Latvia and Lithuania, though **the soil frosting would be affected by much warmer winters.** (Chapter 4.2.11)

Vulnerability assessment (Chapter 6) was carried out as a first step in the WP2 and it combined climatic analysis (Chapter 4) of WP1, exposure assessment and sensitivity assessment (Chapter 5) to determine assets, systems and processes with medium to high vulnerability to climate variables and hazards.

Risk assessment (Chapter 7), based on the IPCC risk concept (IPCC 2014), was then carried out as a next step for exposure and consequences defined having medium or high vulnerability to the future climatic conditions and hazards during the vulnerability assessment. Purpose of the risk assessment was to define likelihood and magnitude of a certain consequence to produce a risk rating for each consequence.

Historic values and future climatic trends were benchmarked considering exiting design standards, principles of Rail Baltica and other relevant aspects, which could decrease service or asset exposure, to produce the consequence likelihood estimation during the risk assessment. It was imperative to understand, in detail, potential consequences of climatic hazards and variables and cause-effect chains to the assets and services of Rail Baltica. For this purpose, a risk assessment workshop, with the technical experts of various fields, was organized to discuss all the technical aspects relevant to the risk assessment. Risk rating was then defined based on the agreed consequence likelihood and magnitude estimations. Confidence level for each risk rating, was defined as a last step, to validate the results based on the type, amount, quality and consistency of evidence.

Summary of the risk assessment (Chapter 7) results are presented in the table below.

Climatic hazards and variables	Assets or services at risk	Consequences	Risk rating
Flooding and heavy rains	Track and embankment, catenaries, bridges, culverts, access and maintenance roads and road infrastructure	Fluvial and pluvial flooding of track or embankment resulting in instability problems in cutting areas, tunnels and lowlands with unfavourable runoff and drainage conditions (incl. problems with culverts). Fluvial flooding damage to bridge structures and embankment crossing rivers and streams and ditches. Damage to the access roads or road infrastructure and/or possible access restrictions to stations, track, substations, etc. due to general flooding of nearby areas.	**Medium**
Wind and storms	Train traffic and all infrastructure, but especially catenary, noise barriers, fencing and drainage	Failure of or direct damage to parts of structure or infrastructure as a result of changes in extreme winds and gustiness. Noise barriers, OLE and fencing are likely to be most at risk. Possible blockage of railway drainage systems due to obstructions and windborne debris from domestic or third-party objects, as well as potentially trees landing on track and causing damage to catenaries and fencing. Speed restrictions to trains due to high wind events.	**Medium to High**
Ground instability and landslides	Earthworks and structures (mainly bridges, OLE, access roads, noise walls, passenger stations, signs, safety barriers, utilities and cables)	Increased instability can lead to landslides, earthworks failures and damage to structures (mainly bridges, catenaries, noise walls, passenger stations, signs, safety barriers and cables).	**Medium**
Lightning	Buildings, structures and lineside equipment (signalling and track circuit) and traffic	Direct damage to buildings, structures and lineside equipment (signalling and track circuit) and indirect impacts (maintenance, traffic).	**Medium**
Low temperatures	Rails, underground cables and utilities	Increase risk of rail and weld breaks due to extreme cold conditions due to bad quality rail or rollingstock. Cable breaks due to embankment processes.	**Medium**

Climatic hazards and variables	Assets or services at risk	Consequences	Risk rating
Snow, freezing rain and glazed frost	Points operating equipment (POE), catenaries and overhead power lines, Station platforms, footways, stairs, etc	Points operating equipment (POE) failures due to snow and ice accretion. Damage to catenaries. Accidents due to slippery surfaces in station platforms, passenger walks, stairs, etc.	**High**
Frost penetration of soil	Railway and maintenance road embankments	Potential damage to the railway and maintenance road embankments through frost heave.	**Medium**
High temperatures	Rails, expansion joints and electrotechnical equipment	Rail buckling and/or associated misalignment problems due to Critical Rail Temperature (CRT) . Increased risk of thermal expansion joints being pushed beyond their design capability, presenting a direct risk of damage to bridges structures and indirect of damage of other assets dependent upon bridge.	**Medium**
Fog	Operations, maintenance, staff and passengers	Operations (e.g. shunting), maintenance could be disrupted and passengers and staff risks increased.	**Medium**
Draught and wildfires	All infrastructure and services	Direct damage, disruptions due to flying ash and precautionary measures caused by wildfires.	**Medium**

Adaptation measures were developed (Chapter 8) for all the consequences and associated services or assets assessed during the risk assessment, as a last step during WP3. These measures could be divided into four general categories (Chapter 8.1):

- ✓ Changes, additions and considerations in the Rail Baltica Design Guidelines (tasks for designers),
- ✓ Additional surveys and studies,
- ✓ Weather monitoring, forecasting and alerting – Rail Baltica Weather Service.

Principles for Rail Baltica Weather Service development and implementation, including suggestion to **integrate the Rail Baltica Weather Service with traffic control systems,** were defined as a final step of this report.

It is important to note that management of climate risks should be integrated into the general risk management, monitoring and control systems of Rail Baltica and not managed as a stand-alone subject.

1. Introduction

This is a final report of "Study on climate change impact assessment for the design, construction, maintenance and operation of Rail Baltica railway". This report provides methodological framework, the results of climate change risk assessment by assets and services and proposes adaptation measures presented in the adaption plan. Climate risks assessments for Rail Baltica railway is undertaken to support decision making, planning, and designing. The selection of climate hazards and vulnerable assets is based on a climatic analysis, exposure, sensitivity and vulnerability assessments.

2. Methodology

2.1. General description of the Study

Study on climate change impact assessment for the design, construction, maintenance and operation of Rail Baltica railway (hereinafter – the Study) is aimed to identify climate change associated risks for the design, construction, maintenance and operations of Rail Baltica railway. Furthermore, the study shall assess pre-designed infrastructure vulnerability and propose feasible climate change adaptation measures for the railway design, construction and operation phases.

Aim of the Study is to help manage the additional risks arising from climate change, consider how Rail Baltica project is vulnerable to climate variability and change, assess current and future climate risks to the success of the project, identify and appraise relevant and cost-effective adaptation options to build climate resilience, and integrate adaptation measures (resilience measures) into Rail Baltica project lifecycle. A common and more comprehensive understanding of future risk and vulnerability will be developed and appropriate interventions for reducing this risk, will be identified.

The key objective in the face of uncertainty is therefore to define and implement design changes (adaptation options) which both provide a benefit in the current climate as well as resilience to the range of potential future climate change effects.

The study outcomes are not intended to override, nor define, the design standards that project developers should be working to, and they are not a substitute for detailed design at the project level. Project design should always be undertaken in accordance with Rail Baltica Design Guidelines, national requirements and/or professional codes of practice as appropriate. However, in cases where national requirements or design codes do not yet incorporate consideration of climate change, these study outcomes may help to improve risk management still further. Design standards need regular reviewing in the light of evolving understanding of the impact of climate change on extreme weather.

2.2. Scope of the Study

The Study will cover full asset lifetime as defined by Design Guidelines of Rail Baltica railway.

Geographical area covered by the Study includes territories of Republics of Estonia, Latvia and Lithuania which Rail Baltica railway corridor passes through (Figure 2.1). The rail corridor is considered a space of approximately 20 km to each side of railway axis.

Figure 2.1 Overview map of Rail Baltica (RB Rail AS)

The following Rail Baltica assets and processes shall be considered for the Study:

- ✓ **On-site assets and processes** - climate data processing and climate risk management, measures/actions/operations in extreme weather conditions and vegetation control
- ✓ **Inputs** – energy, water and building materials
- ✓ **Outputs** – passenger and freight service, logistics, products and customer demand
- ✓ **Transport links** – multimodal linkages (road, air and marine and light traffic)
- ✓ **Project types** – embankment and earthworks, ballast, track (rails and sleepers), hydraulic, drainage and culverts, bridges, viaducts, overpasses, tunnels and similar structures, power supply and catenaries (overhead line equipment - OLE), control-command signalling system, telecommunication system, SCADA[1],

1 Supervisory control and data acquisition (SCADA) is a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level process supervisory management, but uses other peripheral devices such as programmable logic controller (PLC) and discrete PID controllers to interface with the process plant or machinery. The operator interfaces which enable monitoring and the issuing of process commands, such as controller set point changes, are handled through the SCADA computer system. However, the real-time control logic or controller calculations are performed by networked modules which connect to the field sensors and actuators.

station and passenger platforms, acoustic screens, roads (light, heavy, extraordinary heavy access roads and maintenance roads) and fences.

Risk on the Rail Baltica network is to be conceived mainly as single stakeholder concept, the implications of this for how solutions are designed, appraised and delivered. The following plans/strategies will be considered in the Study:

- ✓ EU and national Climate Change studies and strategies,
- ✓ Relevant river basin management plans and flooding surveys,
- ✓ Relevant climatic and hydrological data on the study area,
- ✓ EIA, spatial planning and technical studies on Rail Baltica alignment in Estonia, Latvia and Lithuania,
- ✓ National design values of climatic data.

Taking into consideration the geographical location, topography, and settlement structures in relation to weather pattern, hydrology and historic extreme events, the risks related to climate change are relatively low in the Baltic states compared to the Central or Southern Europe (KATI 2015).

2.3. Study stages

The Study is divided into 3 work packages:

- ✓ WP1 - Analysis of climate projections, relevant studies and strategies, sensitivity assessment;
- ✓ WP2 - Vulnerability assessment, risk identification and assessment;
- ✓ WP3 - Adaptation option development.

2.3.1. WP1 – Analysis if climate projections, relevant studies and strategies, sensitivity assessment

Main purpose of the WP1 was to identify meteorological indicators and climatic hazards with potential significant impact on Rail Baltica railway infrastructure during construction, maintenance or operation stage. This was achieved by compiling and analysing climate data, results of similar previous analyses and national strategies. The expert team gathered, focused and analysed evidence to understand the challenges that long-term climate projections and current and future extreme weather present specifically to the Rail Baltica railway.

Climate hazards are defined as the magnitude of the climate variable that may harm the railway system and asset. Various forms of extreme weather events can impact rail construction, maintenance and operations. Extreme weather events can include significant anomalies in temperature, precipitation and winds and can manifest as heavy precipitation and flooding, heatwaves, drought, wildfires and windstorms (including tornadoes and tropical storms). Extreme weather events are classified by threshold values and frequency based upon criterion exceedances, set warning and limiting values, variables and indices. Consequences of extreme weather events can include primary safety concerns, damage, destruction, and/or economic loss. Climate change can also cause or influence extreme weather events. Natural rhythms in atmospheric flows drive variations to the Rail Baltica corridor's weather and climate which requires comprehensive meteorological dataset.

The impact assessment of rail infrastructure needed to be informed by a deeper understanding of climate change and weather in three domains:

- ✓ **Climate normal:** the typical weather patterns in the Rail Baltica corridor, climate normal as an average over a 30-year period (1981–2010),
- ✓ **Extreme weather events:** the characteristics of extreme weather events during last decades (1981–2017),
- ✓ **Future climate:** the expected climate change anticipated in the light of long-term climate projections (moderate RCP4.5 and extreme RCP8.5 scenario in EURO-CORDEX ensemble).

Historic weather data from the closest meteorological stations of the national World Meteorological Organization (WMO) standard network was used (see Table 2.1 and Figure 2.2):

Table 2.1 Reference meteorological stations near Rail Baltica railway

Country	Station	WMO code	Coordinates	Elevation
Estonia	**Tallinn-Harku**	26038	N 59°23´53´´ E 24°36´10´´	33,15 m (NAP)
	Kuusiku	26134	N 58°58´23´´ E 24°44´02´´	52,91 m (NAP)
	Pärnu-Sauga	26231	N 58°25´11´´ E 24°28´11´´	11,89 m (NAP)
Latvia	**Ainaži**	26229	N 57*52' 04.45" E 24*21'57.48	6.28 m (las-2000,5)
	Skulte	26326	N 57*18'2.27" E 24*24'43.87"	7.68 m (las-2000,5)
	Rīga	26422	N 56*57'2.16" E 24*06'57.86"	6.15 m (las-2000,5)
	Bauska	26429	N 56*22'45.1" E 24*13'18.4"	30.94 m (LAs-2000,5)
Li th ua ni	**Panevėžys**	26529	N 55°44´ 05´´ E 24°25´06´´	57.09 m (LAS)

	Kaunas	26629	N 54°53´ 00´´ E 23°50´06´´	76.1 m (LAS)
	Vilnius	26730	N 54°37´ 34´´ E 25°06´25´´	162.0 m (LAS)
	Lazdijai	26728	N 54°13´57´´ E 23°30´38´´	133.2 m (LAS)

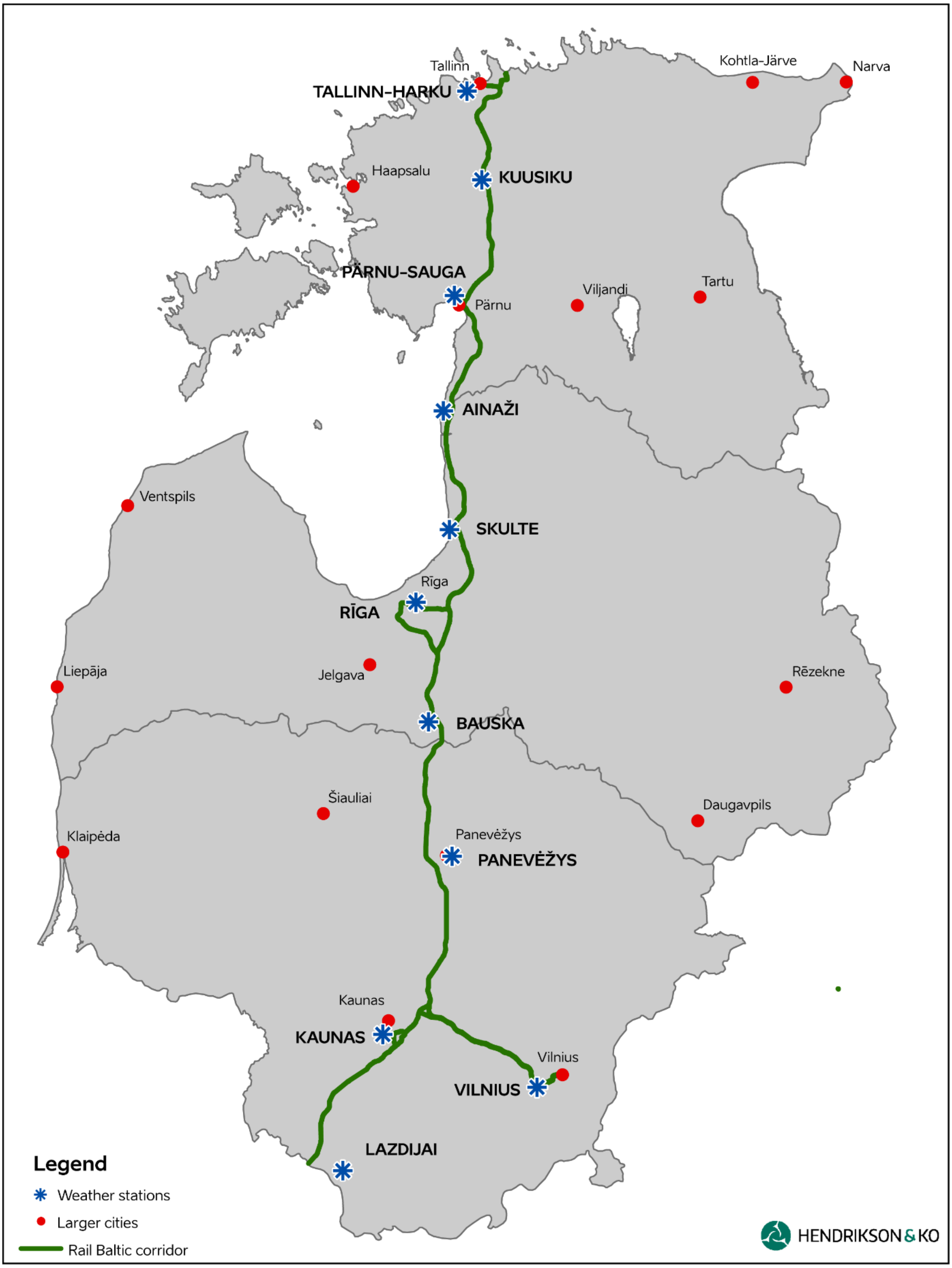


Figure 2.2 Rail Baltica railway and national weather stations used as climatic data sources.

The process of identifying meteorological, climatic and hydrological hazards is one that begins with a review of historical experience to indicate the types of incidents that are of primary concern. Future climate conditions can be reported with respect to these historical events in terms of the frequency and severity of recurrence, within the scientific limitations of error and uncertainty associated with climate forecasting. Climate change is likely to change both the types and frequency of events that occur, it is therefore important to explore potential future hazards. There is a general acceptance now that several types of extreme events will likely increase over coming decades, and that is already becoming clearer for superstorms, intense rainfall and heat waves. As initial hazard identification, minimal list of the most important climate-related hazards with primary weather risks and secondary impacts considered in the Study was compiled:

- ✓ snow,
- ✓ wind,
- ✓ thunder,
- ✓ high temperatures,
- ✓ low temperatures,
- ✓ adhesion,
- ✓ sea level rise,
- ✓ flooding,
- ✓ ground instability and landslides,
- ✓ wild fire,
- ✓ urban heat island effect,
- ✓ draught,
- ✓ solar radiation,
- ✓ hail,
- ✓ glazed frost,
- ✓ freezing rain,
- ✓ frost penetration of soil,
- ✓ coastal erosions,
- ✓ sea water temperature change
- ✓ fog,
- ✓ vegetation season length,
- ✓ karst.

Final selection of the relevant indicators and climatic hazards was agreed with the Contracting Authority before collection of historic climatic data and future projections of these climatic variables started. Importantly, meteorological and climatic knowledge must be interpreted into a form that is relevant to railway sector, the sector-specific impacts of railways and their spatialization in the stage of hazard analysis.

Frequency of relevant extreme climatic variables and hazards, defined by the expert group and agreed by the Contracting Authority, were analysed either the period 1981–2010 as climate normal or the period 1981–2017 as occurrence of extreme weather events. In the conditions of data scarcity and inconsistency, relevant baseline studies were employed addressing hazards, consequences and uncertainties of events. Stating trends in storminess and other extreme weather events remains uncertain due to the low number of events annually. Data on extreme weather events, which have negatively impacted on infrastructure or have caused disruption to rail services for the recent decades were constructed through consultation of a variety of archival meteorological, sectoral and emergency reporting sources. Among others, the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) were applied (IPCC 2012), as well the surveys which served as a basis for drafting the Baltic states' national adaptation plans.

Analysis and overview of the climatic projections in the region was carried out as a next step. Comprehensive reference data tables and schematic maps of the future climate were compiled to visually present most relevant results. Key conclusions about the projected climate change were drawn in the context of rail infrastructure.

The scientific basis for the future climate used here is the report are based on future climate change scenarios in Estonia, Latvia and Lithuania until 2100, drawn up by national climate agencies, accordingly the Estonian Environment Agency (ESTEA), Latvian Environment, Geology and Meteorology Centre (LEGMC) and Kaunas Regional Energy Agency (KREA). Estonian report forms the basis for the assessment of the sectors that are influenced by atmosphere and ground conditions, in some cases CMIP5 as Coupled Model Intercomparison Project's regional fine-scaling was applied. The period of 1971–2000 was used as the base climate period (reference period) for long-term forecasting, periods of 2041–2070 and 2071–2100. The same modelling scope, approach and techniques in terms of temporal and spatial scale are applied in Latvia and Lithuania, presented in Latvia's and Lithuania's Seventh National Communication under the United Nations Framework Convention on Climate Change (Latvia 7th Comm. 2017, Lithuania 7th Comm. 2017).

The climate forecasts of Estonia, Latvia and Lithuania are based on the global climate change scenarios RCP4.5[2] (as moderate) and RCP8.5 (as extreme), selected from EURO-CORDEX ensemble. The scenario analysis is limited to those widely accepted projections, marking the mean and the extreme, considering possible changed circumstances.

Analysis of flood risk maps adopted by the Ministries of environment of the Baltic states considers frequent events with return period 10, 50, 100 years as well higher uncertainties of 1000 years extreme flooding. The time series of meteorological and hydrological data is not sufficiently long enough to draw any robust conclusions on 1000 years floodings.

Ground stability data was collected from special national surveys and relevant railway, road and geotechnical sources in the Baltic countries as well in Europe. Though, ground stability risks are often triggered by weather conditions.

The study scoping and climate work-package is shown in Figure 2.3.

2 RCP – Representative Concentration Pathway, i.e. the scenario for increase in the value of the radiative forcing of the Sun affecting the surface of the Earth depending on the concentration of greenhouse gases by 2100, which is used in the IPCC climate report, where the radiative forcing value will increase by 4.5 w/m^2 in the RCP4.5 scenario by 2100 and by 8.5 w/m^2 in the RCP8.5 scenario compared to the control period of 1986–2005.

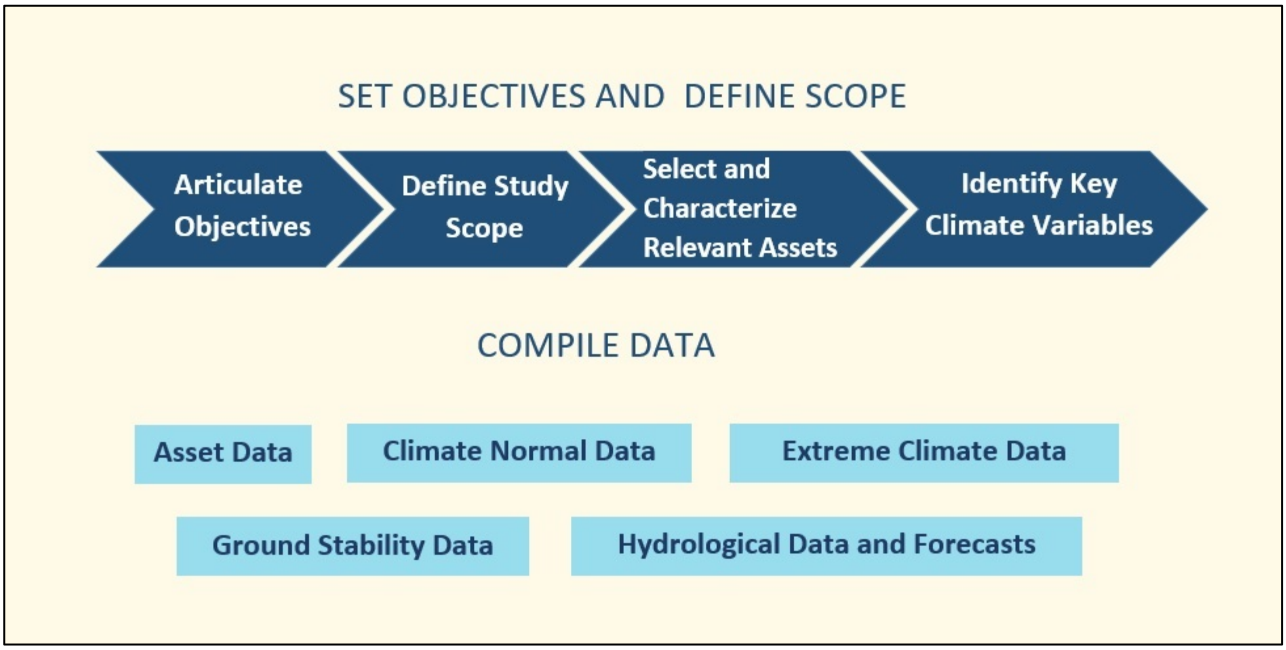


Figure 2.3 Flow chart of WP1 of climate data, projections and analysis.

There is a review of related literature pertaining to climate change risks, lessons learned in railways asset construction, management and operations. Analysis and benchmarking of strategies and studies with relevance to climate change adaption in railways in EU and in particular in the Baltic Sea Region were carried out as a part of **sensitivity assessment**. There are no detailed climate change adaption strategies for railways for Baltic Sea Region, only national strategies where railway is stated among other infrastructure (e.g. Zaļā brīvība 2017). Therefore Swedish (Riksdagstryckeriet, 2018), Finnish (Leviäkangas, P. et al, 2011) and United Kingdom studies (ARUP, ERM 2017; Network Rail 2015; TRaCCA, 2012, TRaCCA2, 2016, Quinn, A. et al. 2017; WRWRP 2016; RSSB 2009) were mainly used for railway-specific analyses. Main purpose of these analyses was to determine which hazards are relevant for railway planning, construction, maintenance and operation, what are the risks associated with these hazards and what kind of measures are used to mitigate these risks.

'Call for evidence' was applied seeking written and oral contributions from a range of stakeholders, Baltic railway infrastructure managers and train operating companies, road administrations and high voltage transmission grid operators, which serves as screening for risks and prioritisation climate data and hazard case collection and was part of the sensitivity assessment as well. A phone interview or email communication was used so that relevant parties can described main problems and give a severity estimation about impacts of climatic-related hazards based on their experience. The national railway companies and major operators from all three countries contributed evidences, climate-related events and cases in 'call for evidence'. Though those cases need to be interpreted as current operation and maintenance practice is upgraded and 'historic' infrastructure, applying mainly the inherited engineering code and standards.

2.3.2. WP2 – Risk identification and assessment, vulnerability assessment

This work-package integrated the hazards and railway specific climate impact. A central challenge was to understand how weather events relevant to rail and civil engineering practice may change in terms of frequency, duration and intensity of climate change in long-term prospects during maximum 100-years lifespan of Rail Baltica assets. Climate variables and hazards which were identified by the expert group by considering results of WP1, previous studies and strategies in Baltic states and EU and consultations with Estonian, Latvian and Lithuanian railway infrastructure managers and train operating companies and relevant stakeholders were analysed and applied in further steps of this survey having the critical importance in terms of integrity, consistency and comprehension to avoid far too speculative assumptions and modelling framework. Risks identification and assessment was carried out for the design, construction, maintenance and operations of Rail Baltica railway. Risk identification and assessment and vulnerability assessment of the Rail Baltic infrastructure was then carried out following exiting up-to-date methodology (IPCC 2014; Filosa et al, 2017, Forzieri, G., 2018, IPCC 2014, Network Rail 2015, Riksdagstryckeriet, 2018, UK Climate Change Risk Assessment 2017; Quinn et al. 2017,). Also, multiple recent EU research project were considered such as ENHANCE (2016), MOWE-IT (2014), TRaCCA (2016).

Understanding and interpreting climate information, including the uncertainties inherent in projections, for the context of the railway requires expertise both in railway systems, engineering and of meteorology and environment required an experience of experts from different fields (experts involved in the study are presented in Chapter 3.1) and an extensive cooperation with the Rail Baltica project technical team. The risk assessment carried out in this report is based on IPCC risk concept (IPCC 2014) shown in Figure 2.4.

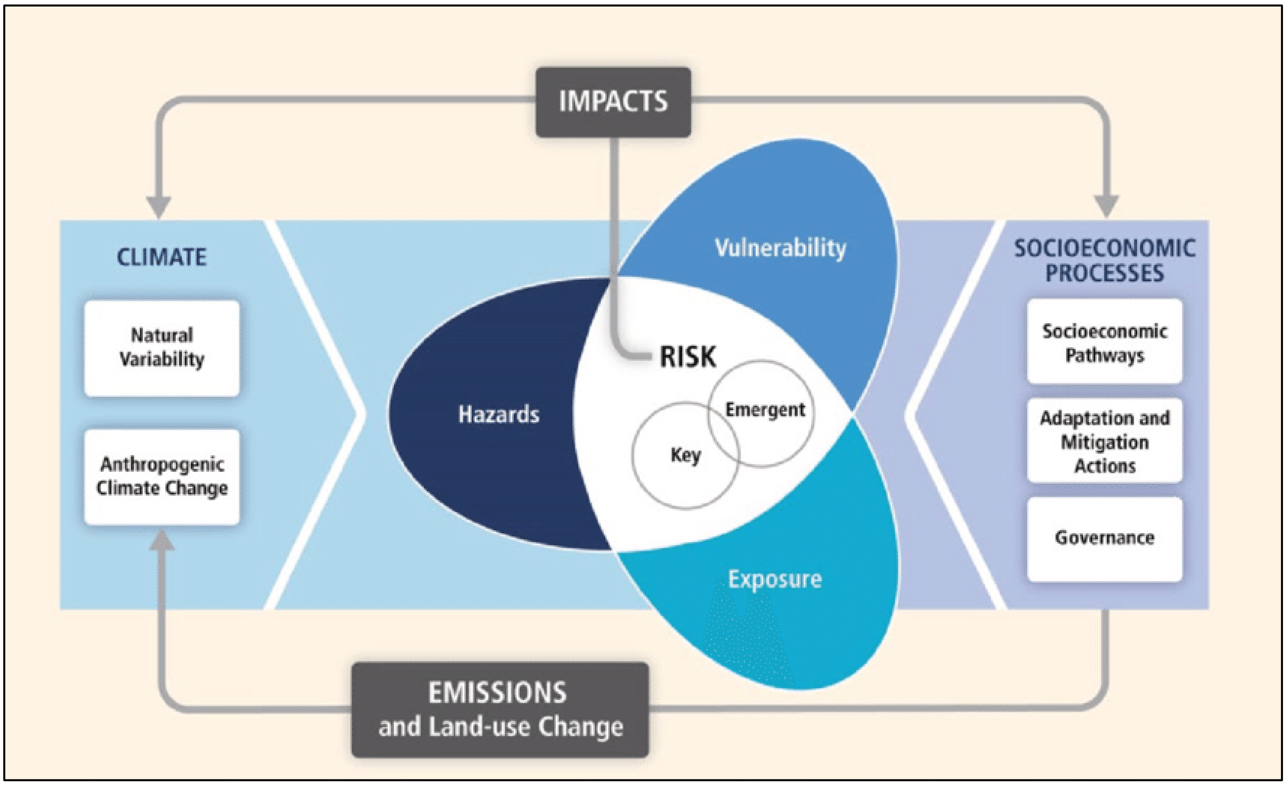


Figure 2.4 The IPCC AR5 conceptual framework of risk and vulnerability to climate change (IPCC, 2014)

Risk (R) is defined by the combination of likelihood and magnitude of consequences if these are realized. Likelihood is the 'chance of something happening' and can be measured qualitatively or quantitatively. Consequences may include technical performance and functionality impacts as well additional cost in asset management. Risks will be determined and evaluated by systemic analysis of multiple vulnerability factors. IPCC's definition of risk, which notes that risk arises from the interaction of climate hazards with exposure and vulnerability to impacts, is used in the risk assessment. Multiple circumstances and various implication play the role in single hazard and multi-hazard events. **Hazard (H)** can be defined as a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. **Exposure (E)** refers to whether the asset or system is located in an area experiencing direct effects of climate variables. **Sensitivity (S)** refers to how the asset or system fares when exposed to a climate variable. **Vulnerability (V)** is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. **Adaptive capacity (AC)** refers to the system's ability to adjust to or cope with existing climate variability or future climate impacts. As current railway systems bear different qualities, adaptive capacity remains secondary in the assessment. Combining exposure and sensitivity evaluates impacts, with the addition of adaptive capacity, overall vulnerability scores for potential risks can give and risks characterised in probabilistic approach of their likelihood (IPCC, 2014). Extensive data and knowledge on systems and assets is required to complete a risk assessment.

In this study, the risk assessment process, based on hazard(H), exposure(E), sensitivity(S) and vulnerability(V) is given below (Figure 2.5).

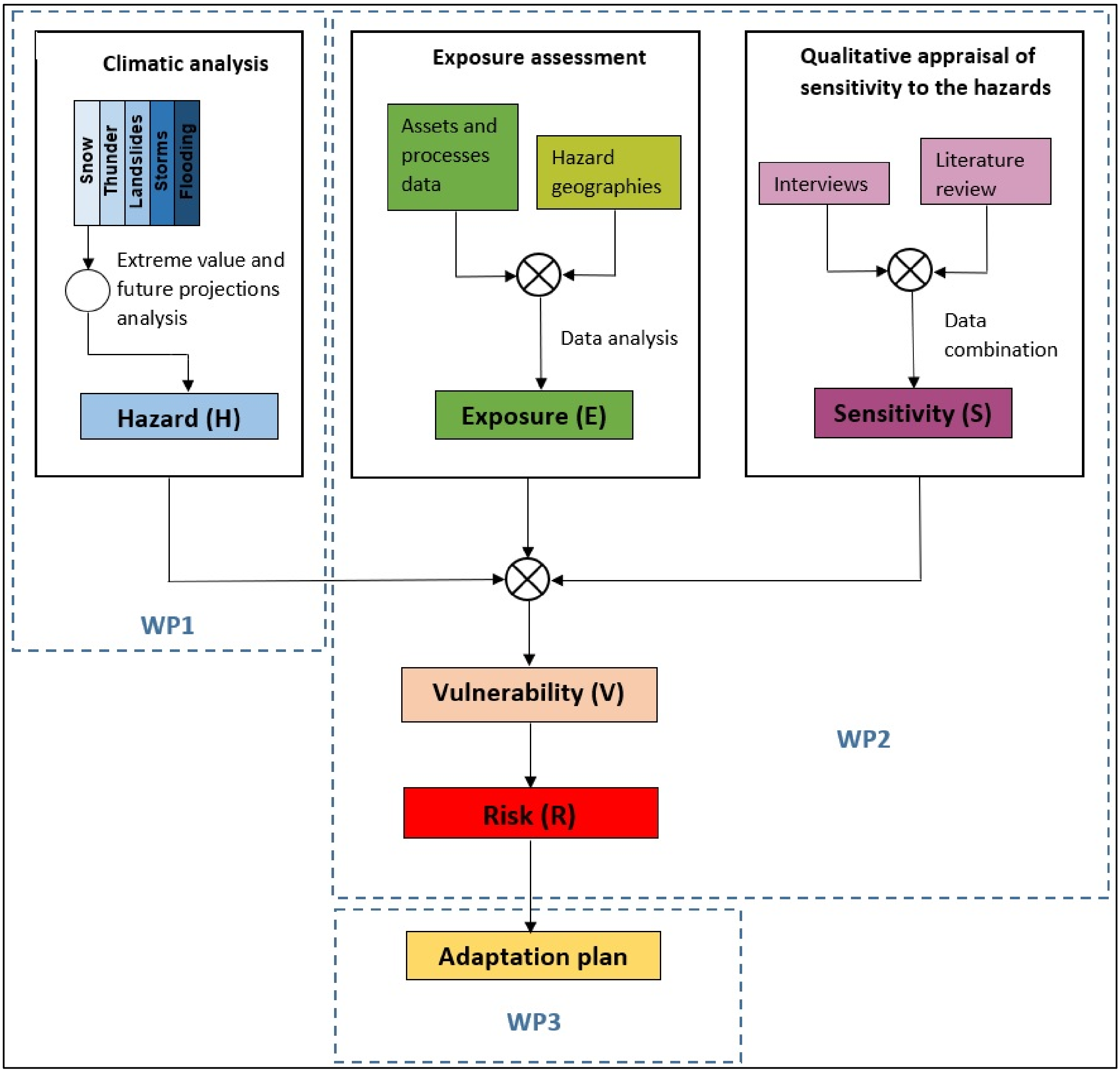


Figure 2.5 Workflow of risk assessment operationalised as WP2, supported by WP1 of climate analysis and progressed as adaptation plan deliverable as WP3. (based on Frosieri et al 2018)

A significant amount of climate change impacts on the railways are as a result of, or influenced by, third parties. Critical dependencies for the safe, efficient and reliable operation of rail assets should require robust utility supplies; specifically, electricity and telecommunications, third party flood risk asset management and third-party land management. Hydrological hazards could be exposed to the infrastructure depending on regime management in the whole water basin. Earthwork risks could be heightened by harmful and risky actions neighbouring land users. These external risks can be more difficult to manage due to difficulties obtaining access to land, lack of data on third party assets, and difficulties determining who is responsible for assets.

Also, modern transport systems are increasingly dependent upon Information and Communication Technology, smart systems. These are critical firstly in the operation of the system, for example computer-based signalling systems on the railways though safety standards are very high.

Technology and engineering options for resilience and sensitivity of Rail Baltica assets to climate variables were elaborated as follows. Sensitivity refers to how much the asset or system is affected when exposed to a climate hazard. Assets, systems and processes were divided into three groups based on the sensitivity to climate variables and hazards:

- ✓ No or low sensitivity,
- ✓ Medium sensitivity,
- ✓ High sensitivity.

No impact means missing occurrence of hazard and exceptionally rare or insignificant impact. Low sensitivity to risk applies to assets that have a low likelihood of being impacted by a current and future climate hazards/conditions and a minimal consequence of being impacted by that condition. High sensitivity to risk applies to assets that have a high likelihood of being impacted by a current and future climate hazards/condition and major consequences of being impacted by that condition.

The Study considers impacts on following risk areas:

- ✓ railway service availability,
- ✓ asset damage asset deterioration and reduced life of an asset,
- ✓ infrastructure and operations reliability,
- ✓ operations safety,
- ✓ variance in OPEX and the need for additional CAPEX,
- ✓ railway business operations, including loss of income,
- ✓ increased risks of environmental damage and litigation,
- ✓ reputation damage,
- ✓ changes in market demand for goods and services,
- ✓ increased insurance costs or lack of insurance availability.

Exposure was defined by infrastructure elements and locations. Results of localised exposition were presented on schematic maps of exemplary hazard-exposed sites, with the layout previously agreed with the Contracting Authority. It is important to define a critical elements in assets and paying full attention possible 'single points of failure' either site-specific or risk zone/corridors in the route or structure- and engineering-specific by assets and technologies. 'Blue spots', flood-sensitive sections are identified where focus is placed on flooding risks, landslide and collapse risk. Carrying capacity plays important role how asset and facility management policy, maintenance and operation is set.

When designing new assets, design specifications should be based upon the concept of probabilistic 'return periods' for extreme weather events. Risk is represented as the estimated frequency of experiencing an event of a given magnitude within a defined time period. For example, at flooding risk areas (e.g. in Pärnu and Rīga etc), a 1% probability of 100-year flood would refer to a threshold only expected to be exceeded once in one hundred years on average. Extreme weather events are summarised during 1981-2017 period and presented by event totals. Rail Baltic assets should therefore be engineered so that they should be resilient to extremes projected to occur during the asset lifetime.

Having assessed the available information on current and future climate hazards, single factors of vulnerabilities and the consequences of failures and disruptions, these can be combined into an overall risk appraisal of medium or high sensitivity elements of the railway. Rail asset and weather impact relationships are complex as a rule and hazards may induce or reinforce other hazards, and they may overlap spatially and temporally, increasing in multi-hazard cases risk levels.

Rail Baltic assets and services were divided into three groups during the vulnerability assessment:

- ✓ No or low vulnerability,
- ✓ Medium vulnerability,
- ✓ High vulnerability.

Further risk analysis was built upon the vulnerability analysis and focused on identifying risks and opportunities associated with the medium and high vulnerabilities.

Vulnerability and risk assessment were mainly carried out as qualitative assessments (using expert judgement or qualitative risk raking) to combine results of climatic analysis, exposure assessment and sensitivity appraisal (see Figure 2.5), which often do not have specific and meaningful numerical values that could be used in quantitative analysis.

Advantages and disadvantages of qualitative and quantitative risk analyses are presented below:

Qualitative risk analysis (RSSB 2009)

Qualitative risk analysis commonly takes two forms in the railway sector; expert judgement, and qualitative risk ranking.

a) Expert Judgement

Assessing the risks from climate change is inherently uncertain, and precise estimates for the likelihood of different events and impacts cannot always be given. As not all the climate statistics and projections of relevance will be available, thus justified expert's guess-based assumptions may be used.

Decisions about safety are made by gathering together the relevant experts to discuss an issue and agree a sensible safety argument and resolution. Various structured or semi-structured techniques are applied to support expert discussions for example; surveys, questionnaires, consultations, incident data trends etc. The record of such discussions, describing the problem or hazard, and the agreed resolution for it, represents a type of qualitative analysis.

b) Qualitative Risk Ranking

Risk ranking is a key method of scoring hazardous events according to the frequency and the severity of their potential consequences. It is used in combination with a risk ranking matrix, which is a robust method of representing the important hazardous events in terms of their risk graphically.

The aim is to order the hazards on the basis of how likely it is that each will lead to harm. Risk ranking matrices can be qualitative, or semi-quantitative having thresholds or occurrences etc event indicators. Qualitative risk ranking matrices use subjective categories for assigning frequency and consequence rankings and estimating risk (e.g. 'high', 'medium' or 'low' risk). Matrices are used to rank hazards in order of their estimated risk, not to gain any understanding of absolute risk or evaluate potential losses or damages.

Quantitative risk analysis (RSSB 2009)

The estimation of risk is sometimes undertaken numerically using a quantified risk assessment (QRA). This will comprise analysis supported by available data and the use of expert judgement. QRA is useful because it provides an objective basis for decisions and provides some bounds to the risk assessment. It also helps the analyst to understand the potential accident sequences that must be prevented and this helps with the identification of preventative measures. However, it is worth noting that there are some pitfalls that any decision taker using the outputs of such an assessment to inform a decision needs to be aware of. In particular:

a) Stating numerical risk estimates can sometimes lead to a false perception that the figures are precise. They are normally only indicative estimates.

b) Risk can vary greatly depending on the particular situation or location. The assumptions underpinning a risk assessment need to reflect the particular circumstances in which the risk is considered. Anyone using such analyses to inform a judgement should be aware of the weaknesses, sensitivities, and assumptions of the model so that they can be factored into the judgement that the QRA influences

Decision rules applied to rank-order identification from most to least critical by likelihood and impacts.

Risk identification and assessment initial results were presented and discussed on the workshop with the Contracting Authority after initial vulnerability assessment and risk register had been finished. Main purpose of the workshop was to validate the initial results and offer more detailed asset or service specific input to the study by the experts on various fields.

More detailed methodology of vulnerability and risk assessments are presented in respective chapters 6 and 7.

2.3.3. WP3 – Adaptation option development

Climate change adaption measures were developed for processes and assets defined having high or medium risk to observed or future climate conditions during previous risk and vulnerability assessment. The plan was drafted by hazards, excepted change and assets.

Professionals may be invited to develop solutions to mitigate the risk which fit within Rail Baltica jurisdiction, and feasible assumptions about solutions. Rail Baltica officials may approach public bodies, land owners and other parties to open a consultation on the resilience scheme, though the traditional engineering paradigm has already shaped. A stakeholder input approach primarily relies on institutional knowledge to identify and rate potential vulnerabilities.

Safety is major part of impact. Incorporating climate change into rail engineering practice will require engineering judgment to balance costs and potential consequences of failure. An engineering-economic evaluation of the costs for resilience of critical Rail Baltica infrastructure should be undertaken.

Climate change resilience will be driven predominately by Rail Baltica functions through revision to asset policies and design standards, technology adoption and root cause analysis. The location specific nature of weather impacts will require analysis and response specifically at detailed route level.

Design Guidelines relevant parts including climate change adaptation section was reviewed and upgraded as part of this Study. Further in-depth studies were proposed to assess the most critical risks in more detail.

Update proposals for the Design Guidelines respective parts (within the scope of this Study) were suggested.

Weather resilience and climate change adaptation actions include a range of measures appropriate to the strength of evidence and level of risk which may include changes to processes, standards and specifications, increasing knowledge and skill base, measures that increase the resilience of the assets to current and future impacts, cost - efficient adaptations and investments.

Any adaptation action must take into account the financial costs and benefits of interventions considering:

- ✓ the Rail Baltic *per se*,
- ✓ the clients and stakeholders of Rail Baltica,
- ✓ the governance, policy and economic context.

The following assumptions need to be considered in risk management.

1. The cost of adaptation may be mitigated through an asset management that integrates adaptation with business as usual rather than regarding it as special action.
2. The cost of delivering an 'always available' weather proofed railway may well exceed the benefit to society as a whole from doing so and may still impart unacceptable risks to railway employees and others.
3. There will be a financial crossover point where the cost of additional adaptation becomes disproportionate to the additional benefits derived.
4. A focus on whole life value, taking account of the range of operating conditions of the railway under consideration will lead to a solution which offers best value over time.
5. Addressing risks early and in a structured manner may require no additional cost because risk mitigation measures can be factored into routine maintenance.
6. As safety is a key aspect for railway undertakings this will be a factor in addition to climate and environmental considerations.
7. Reviews of design standards are one aspect of the emerging ISO14090 on climate adaptation and an important way in which adaptation can be codified within the standards process.

More detailed methodology of adaptation options development is presented in chapter 8.

3. Organization

3.1. Expert group involved with the Study

Martin Ruul – Project manager, Hendrikson & Ko

Antti Roose – Climate change expert, Tartu Regional Energy Agency

Guido Laagus - Railway design engineer, Reaalprojekt

Olavi Grünvald - Economic appraisal expert, Finantsakadeemia

Ivars Pavasars – Environmental assessment expert, Vides experti

Līva Asere - Environmental assessment expert, Vides experti

Gediminas Cyzius – Hydrogeologist, DGE Baltic Soil and Environment

Laurynas Šaučiūnas – Environmental assessment expert, DGE Baltic Soil and Environment

Jaanus Padrik – Cartographer, Hendrikson & Ko

The individual team members have been selected on the following basis:

- ✓ They are known to the consultant and well acquainted with the professional standards, quality procedures, and the style of working for a Contracting Authority.
- ✓ All of the proposed team members have high academic qualifications and are fully familiar with the latest technical advancement in their respective professional fields.
- ✓ They all have extensive experience of successfully completing similar assignments.
- ✓ They are able to relate and establish management and technical communication with one another.

3.2. General overview of the companies involved

Hendrikson & Ko

Hendrikson & Ko is one of the oldest environmental management and spatial planning companies in Estonia. Since May 2017 Hendrikson & Ko belongs to international DGE Group.

The services include strategic and regional land-use planning, detail planning, design, environmental management and various kinds of related studies. To provide full range of services and promote sustainable development on all levels Hendrikson & Ko has added mobility analyses and assessment of socio-economic impacts as most recent services.

Reaalprojekt

Reaalprojekt is a company that offers a full range of services for infrastructure design - from surveys to completed projects. Reaalprojekt also conduct expert assessments, construction supervision and project management. Reaalprojekt is one of the four key players in its field in Estonia.

Finantsakadeemia

Finantsakadeemia is a professional company, working with various kinds of financial analyses.

Finantsakadeemia has analysing capacities and skills in the field of financial modelling, market analysis and estimations, experience in the valuation of the cost of capital, the assessment of options and decision-making processes at large.

Tartu Regiooni Energiaagentuur (Tartu Regional Energy Agency)

Tartu Regiooni Energiaagentuur (TREA) was founded in 2009 in cooperation of city of Tartu and Tartu Science Park to promote sustainable energy and energy management in the region. The agency concentrates on promoting energy management and relieving the key problems of modern energy management: energy efficiency, sustainable transport and renewable energy.

Vides experti

SIA Vides eksperti is a Latvian environmental consulting services company that became operational in 2006 and today are providing services within areas such as Environmental Impact Assessment (EIA), Strategic EIA, pollution modelling, Environmental Due Diligence, Clearance of legal environmental requirements (permit application, environmental tax a.o.).

DGE Baltic Soil and Environment

DGE Baltic Soil and Environment is providing services in different environmental fields for all public and business sectors – Environmental Impact assessment, Strategic Impact assessment, Contaminated land management, etc.

4. Climate variables and hazards considered in the Study

4.1. Historical data of relevant climate variables and hazards

This section presents data for the current climate and extreme weather events experienced in and around the Rail Baltica corridor in mid-Estonia, coastal Latvia and mid-Lithuania. Historic climate data for the Rail Baltica corridor is based on climate normal 1981 to 2010. Extremes are totalled during the period 1981 to 2017 (36 years).

The weather types and events generalised and localized by meteorological stations could potentially occur anywhere along the Rail Baltica corridor, effected by local (meso)climatic conditions combined with microclimatic implications such as relief, inland open or forested areas, built environment etc.

Historic data from Latvian weather stations was acquired for only more critical climatic variables, as the price of the data was significantly more expensive compared to other two Baltic countries (initial price offer was approximately 80 times higher compared to price of same data from Estonian).

4.1.1. Temperatures

In general, southern Rail Baltica routing tend to be warmer and sunnier than those further north. The mean annual temperature in Rail Baltica corridor varies from about 5.5 °C to 7,1 °C, with the higher values occurring in Lithuania. Winter temperatures are lower in Estonia, summer temperatures are higher in Lithuania. The mean temperatures are higher 1-1,5 degrees higher in Lithuania compered to Estonian route.

In winter, temperatures in the Rail Baltica corridor are influenced to a very large extent by proximity of the surrounding sea. February is normally the coldest month. The lowest temperatures occur on the floors of inland valleys into which cold air can drain. July is normally the warmest month, with mean daily maximum temperatures around 18°C.

Registered extreme temperatures during period 1981-2017 in the 11 stations in various regions of Baltic States do not have significant difference and the absolute maximum temperatures can be explained by microclimatic factors. The greatest difference is in the absolute minimum temperature, which varies from -30,5 °C in the Lazdijai station located in Southern Lithuania to - 35,7 °C in the Ainaži station located in Northern Latvia. Extreme cold waves occurred most often in Panevėžys - six times since 1981, but it should be noted that extreme cold wave definition is less severe compared to Estonia.

Absolute maximum temperature varies from 33,2 °C in the Kuusiku station located in Central Estonia to 35,5 °C in the Panevėžys station located in Central Lithuania. Obviously, extreme heat waves occurred more often (14-19 events) in Lithuanian routing. It is harder to compare cold and heat wave occurrences, because they are defined differently in each state. The variation of ground temperature is higher than air temperature along the Rail Baltica corridor. Average air temperatures (Estonia and Lithuania) and average ground temperatures (Estonia, Latvia and Lithuania) meteorological stations representing the Rail Baltica north-south corridor are presented in the Tables 4.1, 4.2 and Figures 4.2, 4.3, 4.4, 4.5 and 4.6.

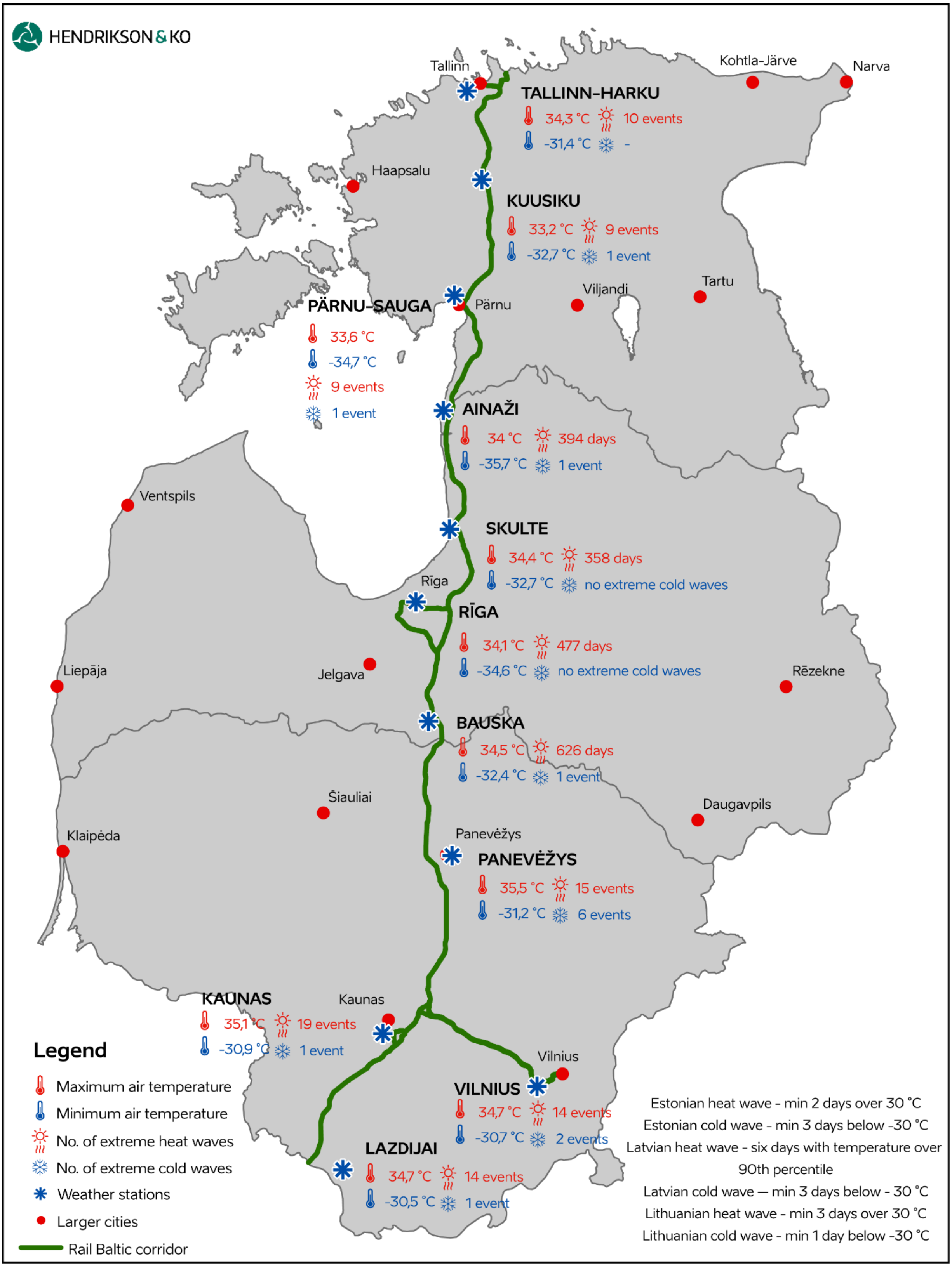


Figure 4.1 Extreme temperatures and cold and heat waves during period 1981-2017 in 11 stations along Rail Baltica

Table 4.1 Monthly average temperatures in meteorological stations during period 1981-2010

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	-3,3	-4,3	-1	4,5	10,1	14,1	17,2	16	11,3	6,5	1,3	-1,9	**5,9**
KUUSIKU	-4,2	-5,1	-1,5	4,7	10,6	14,4	17	15,7	10,7	5,8	0,7	-2,8	**5,5**
PÄRNU	-3,5	-4,5	-1	4,8	11,4	15,2	18	16,9	11,9	6,9	1,6	-1,9	**6,3**
PANEVĖŽYS	-3,3	-3,4	0,4	6,9	12,7	15,7	18,1	17,1	12,1	7,0	1,7	-2,2	**6,9**
KAUNAS	-3,3	-3,0	0,6	7,1	12,9	15,7	18,1	17,2	12,3	7,2	1,9	-2,0	**7,1**
VILNIUS	-4,0	-3,8	0,2	7,0	12,8	15,7	18,0	17,1	12,0	6,8	1,2	-2,8	**6,7**
LAZDIJAI	-3,4	-3,0	0,8	7,2	12,8	15,6	17,9	17,1	12,2	7,2	1,9	-2,1	**7,0**

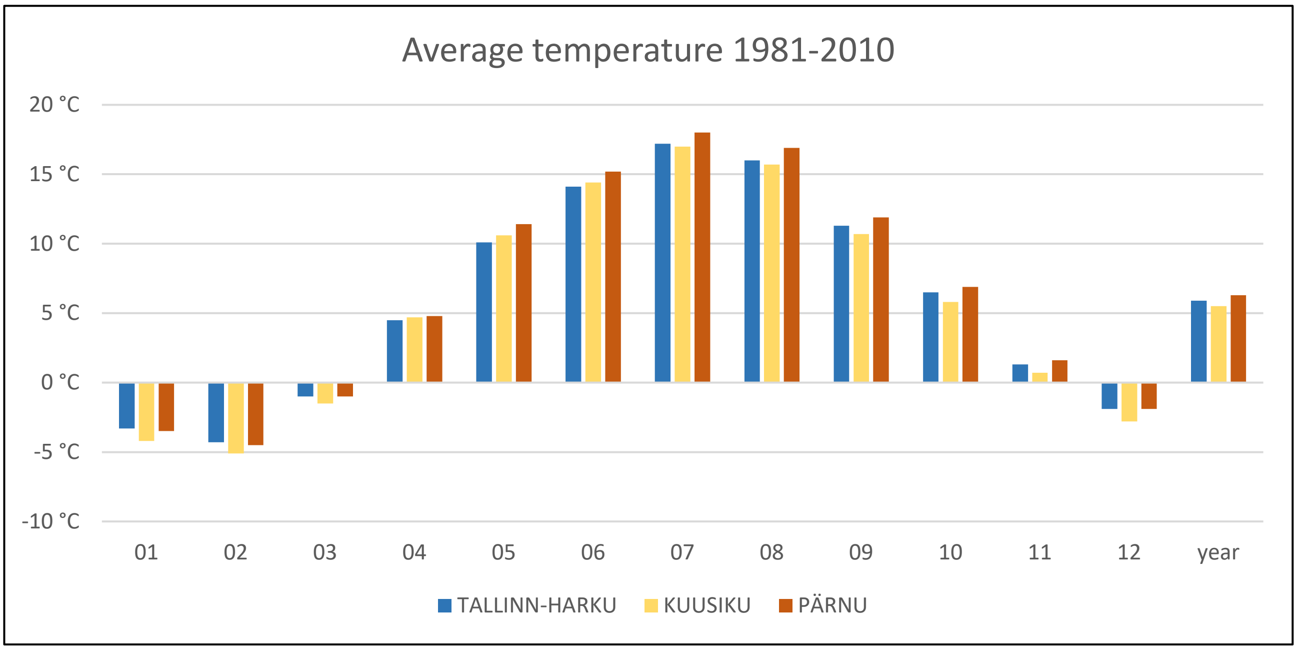


Figure 4.2 Monthly average temperatures in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2010

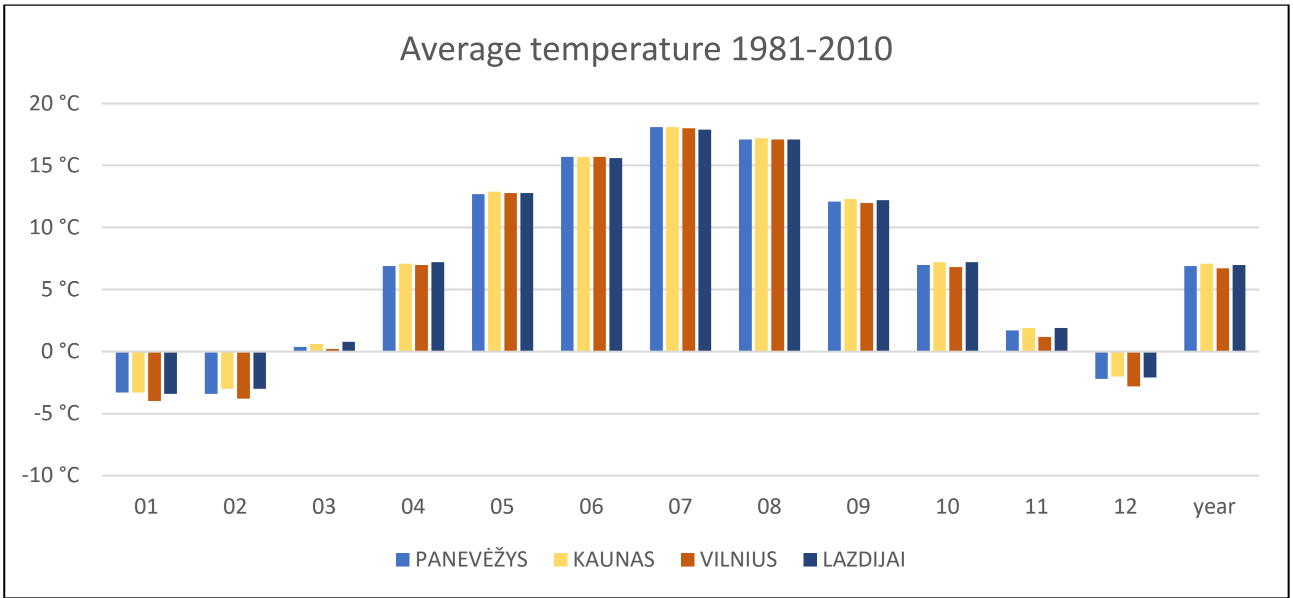


Figure 4.3 Monthly average temperatures in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010

Table 4.2 Monthly average ground temperatures in Estonian, Latvian and Lithuanian meteorological stations during period 1981-2017 and (Kuusiku period 1981-2013; Latvian stations 1985-2017).

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	-4,3	-4,9	-1,8	5,4	13,6	18,4	21,1	18,1	11,8	5,7	0,7	-2,4	**6,8**
KUUSIKU	-4,5	-5,4	-2,1	5,6	15,0	19,9	22,5	19,3	12,4	6,2	1,1	-2,5	**7,2**
PÄRNU	-5,2	-6,5	-3,0	5,0	13,1	18,1	20,9	18,2	11,6	5,6	0,3	-3,3	**6,3**
AINAŽI	-2	-2,8	-0,6	5,3	12,6	17,4	20,5	18,5	12,9	7,3	3,4	0,4	**7,7**
SKULTE	-1,8	-2,4	-0,3	6,2	13,5	18,5	21,3	19,2	13,2	7,4	3,3	0,3	**8,2**
RĪGA	-1,4	-2,1	0	5,1	11,5	15,9	18,8	18	13,2	8	3,7	0,7	**7,6**
BAUSKA	-2,5	-2,4	0,2	6,8	14	18,1	20,4	18,5	12,6	6,7	2,1	-1	**7,8**
PANEVĖŽYS	-3,9	-4,4	-0,6	7,1	14,1	18,4	21,1	19,1	12,9	6,6	1,2	-2,6	**7,5**
KAUNAS	-3,8	-3,7	-0,1	8,3	16,3	19,7	22,1	20,0	13,5	7,1	1,6	-2,3	**8,2**
VILNIUS	-4,6	-4,5	-0,7	8,2	16,2	19,8	22,0	20,1	13,3	6,7	1,0	-3,1	**7,9**
LAZDIJAI	-3,8	-3,4	0,3	8,7	16,4	19,8	22,1	20,2	13,5	7,1	1,6	-2,3	**8,4**

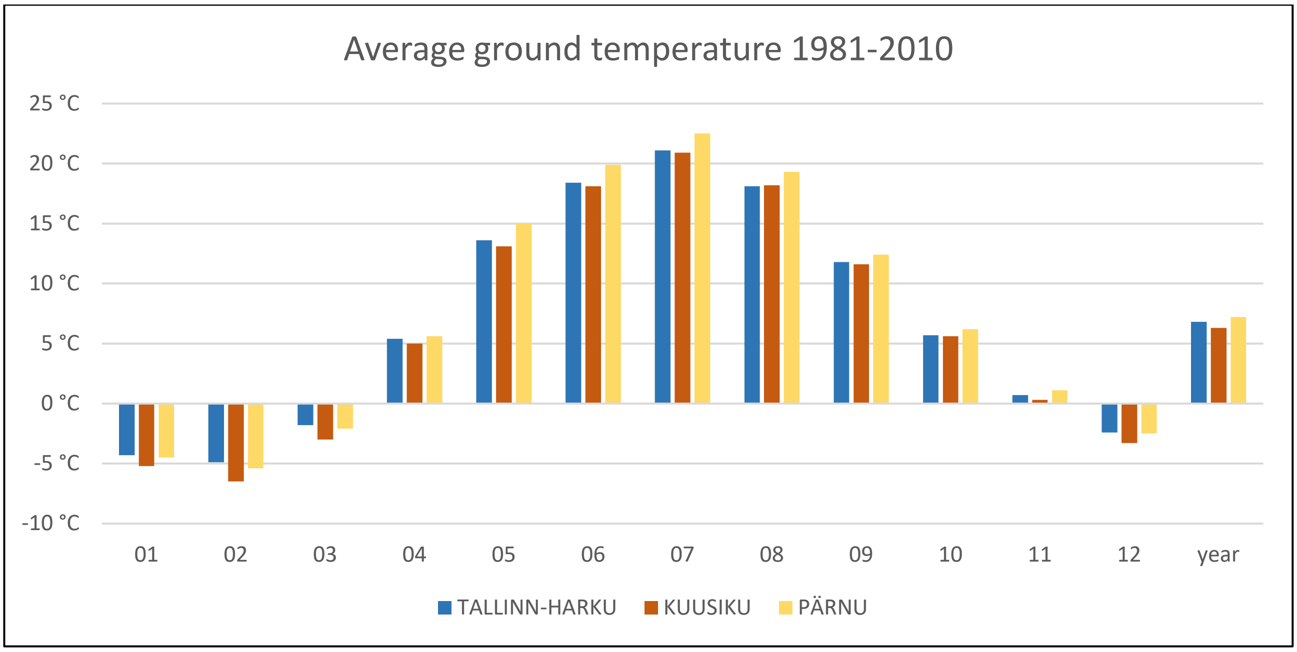


Figure 4.4 Monthly average ground temperatures in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2017 and period 1981-2013 for Kuusiku station

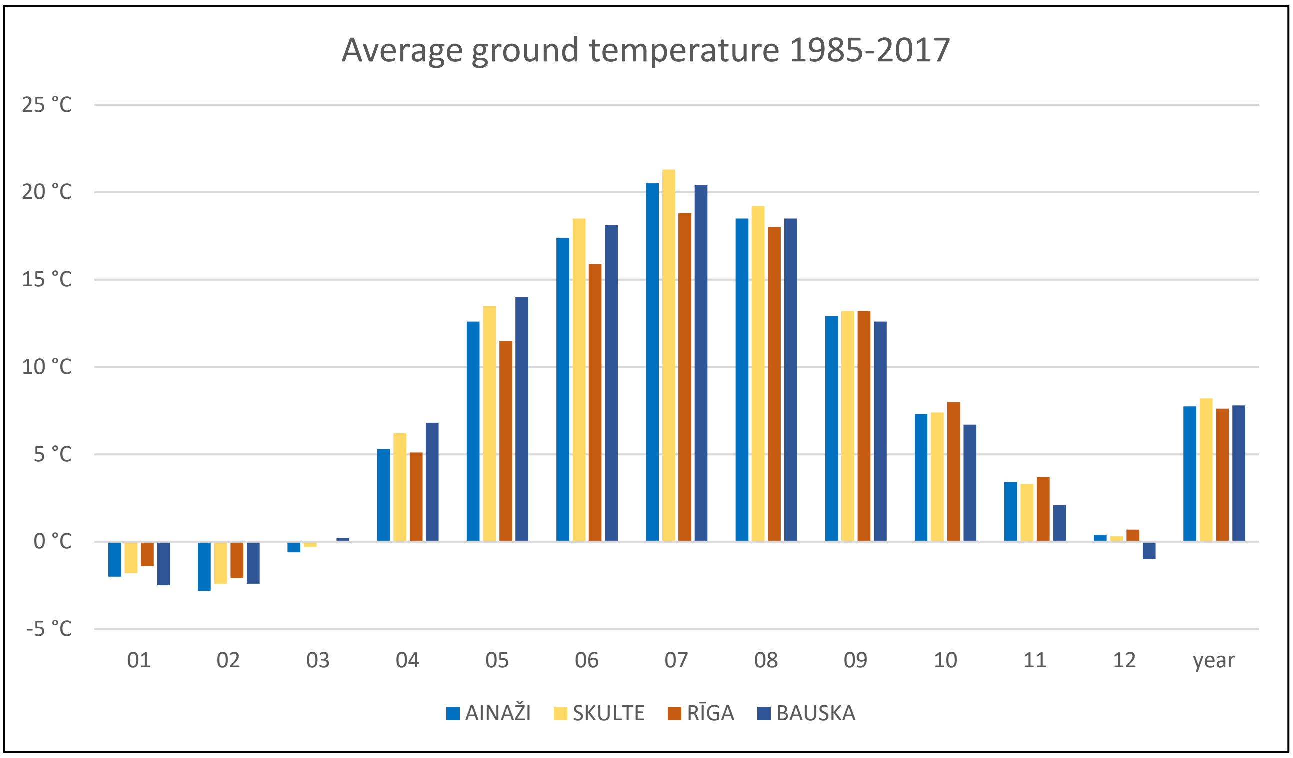


Figure 4.5 Monthly average ground temperatures in Ainaži, Bauska, Riga and Skulte stations during period 1985-2017

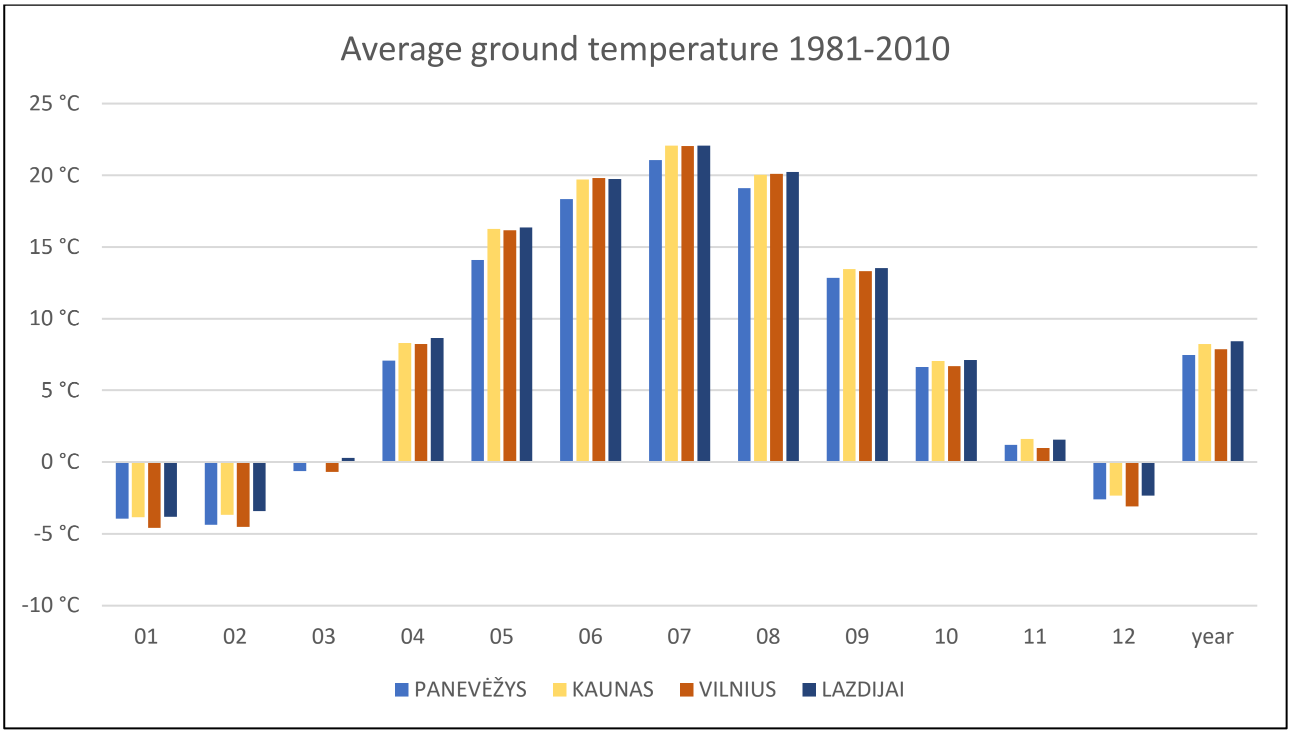


Figure 4.6 Monthly average ground temperature in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010

Maximum absolute air temperatures registered during the period 1981-2017 in the weather stations near Rail Baltica:

- ✓ Tallinn-Harku – **34,3 °C**
- ✓ Kuusiku - **33,2 °C**
- ✓ Pärnu – **33,6 °C**
- ✓ Ainaži – **34,0 °C** on 1992
- ✓ Skulte - **34,4 °C** on 1992
- ✓ Rīga - **34,1 °C** on 2002
- ✓ Bauska – **34,5 °C** on 2006
- ✓ Panevėžys – **35,5 °C** in August 1992
- ✓ Kaunas - **35,1 °C** in August 1992
- ✓ Vilnius - **34,7 °C** in July 1994
- ✓ Lazdijai – **34,7 °C** in August 1992

Minimum absolute air temperatures registered during the period 1981-2017 in the weather stations near Rail Baltica:

- ✓ Tallinn-Harku – **-31,4 °C**

- ✓ Kuusiku – -**32,7 °C**
- ✓ Pärnu – -**34,7 °C**
- ✓ Ainaži – -**35,7 °C** in 2003
- ✓ Skulte - -**32,7 °C** in 2003
- ✓ Rīga - **-34,6 °C** in 1985
- ✓ Bauska – -**32,4 °C** in 1987
- ✓ Panevėžys – -**31,2 °C** in January 1987
- ✓ Kaunas - -**30,9 °C** in December 1996
- ✓ Vilnius - -**30,7 °C** in January 1987
- ✓ Lazdijai – -**30,5 °C** in January 2003

Number of extreme heat waves (2 days + 30 °C) during the period 1981-2017 in Estonia:

- ✓ Tallinn-Harku – **10 events** with total 27 total number of days
- ✓ Kuusiku- **9 events** with total 27 total number of days
- ✓ Pärnu – **9 events** with total 32 total number of days

Number days with extreme heat waves (six days with temperature over 90th percentile) in Latvia (Ainaži: 1985-2006; 2008-2009; 2012-2017; Skulte: 1985-2013; 2016; Riga: 1985-2017; Bauska 1985-2007; 2009-2010; 2012-2015; 2017):

- ✓ Ainaži – 394 days
- ✓ Skulte - 358 days
- ✓ Rīga - 477 days
- ✓ Bauska – 626 days

Number of extreme heat waves (3 days + 30 °C) during the period 1981-2017 in Lithuania:

- ✓ Panevėžys – **15 events** with longest duration of 9 days
- ✓ Kaunas - **19 events** with longest duration of 6 days
- ✓ Vilnius - **14 events** with longest duration of 8 days
- ✓ Lazdijai – **14 events** with longest duration of 7 days

Number of extreme cold waves (3 days - 30 °C) during the period 1981-2017 in Estonia:

- ✓ Tallinn-Harku – **no extreme cold waves**
- ✓ Kuusiku - **1 event** with duration of 3 days
- ✓ Pärnu – **1 event** with duration of 4 days

Number of extreme cold waves (3 days - 30 °C) during the period 1981-2017 in Latvia:

- ✓ Ainaži – **1 event** with duration of 3 days
- ✓ Skulte - **no extreme cold waves**
- ✓ Rīga - **no extreme cold waves**
- ✓ Bauska – **1 event** with duration of 3 days

Number of extreme cold waves (1days - 30 °C) during the period 1981-2017 in Lithuania:

- ✓ Panevėžys – **6 events**, with one lasting 2 days
- ✓ Kaunas – **1 event**, one day duration
- ✓ Vilnius - **2 events**, both one day duration
- ✓ Lazdijai – **1 event**, one day duration

4.1.2. Precipitation

The weather risk is characterised by intense rainfall and prolonged rainfall. A rainfall of 30 mm or more for 1 hour or less and 50 mm or more for 12 hours or less qualifies as dangerous, causing flash floods and pluvial floodings etc.

Rainfall tends to be associated with Atlantic depressions or with convection. The Atlantic Lows are becoming more vigorous in autumn and winter and bring most of the precipitation, more as rain than snow. In summer, convection caused by solar surface heating forms shower clouds and a large proportion of rainfall is from showers and thunderstorms.

The course of mean monthly rainfall for 1981-2010 for stations is shown below. The pattern of rainfall is quite similar at each station, with the summer-autumn months the wettest and the winter and spring months the driest. The Estonian routing has more precipitations up to 762 mm annually in Kuusiku with less southwards 615 mm in Panevezys. Annual record of precipitations 1158 mm is registered in Rapla county in Estonia in 1990.

Daily maximum precipitation amount in 1981–2017 in Estonia 86,8 mm (Kuusiku), 75 mm in Latvia (Ainaži) and 86,2 m in Lithuania (Panevėžys). Maximum daily precipitation amounts are somewhat lower in Latvian stations compared to Estonian and Lithuanian stations (Table 4.4). The historic maximum of daily precipitation in Estonian meteorological stations in 1889–1960 is 83 mm in Tallinn and 95 mm in Pärnu.

To indicate heavy rainfall records, one event with over 80 mm of precipitation during 12-hour period was registered in Kuusiku (in June) and 1 event in Panevėžys (13 hours and 19 min) during period 1981-2017. The number of days with daily precipitation of 50 mm and above in 1961–2006 occurred 8 times in Tallinn, 2 times in Kuusiku and 0 times in Pärnu. The maximum duration of rain lasted 35 hours in Tallinn 16.6.1982 and 33 hours in Pärnu 1.11.1995 (1981-2005). The excessive precipitation occurs in July and August (the average monthly number of days with excessive precipitation is 14 days in July and 15 days in August, period 1961–2006).

Maximum sum of one-hour precipitation in Latvia was recorded in 32,7 mm in Ainaži in May. Similar amount – 32, mm - was also recorded in Riga. Skulte 25,5 mm and Bauska 17,4 mm one-hour precipitation records are substantially lower, compare to Ainaži and Riga.

Only Lithuania has one-minute precipitation data available and 6,6 mm was the highest registered (Panevėžys July 2010) one-minute precipitation amount during period 1981-2017.

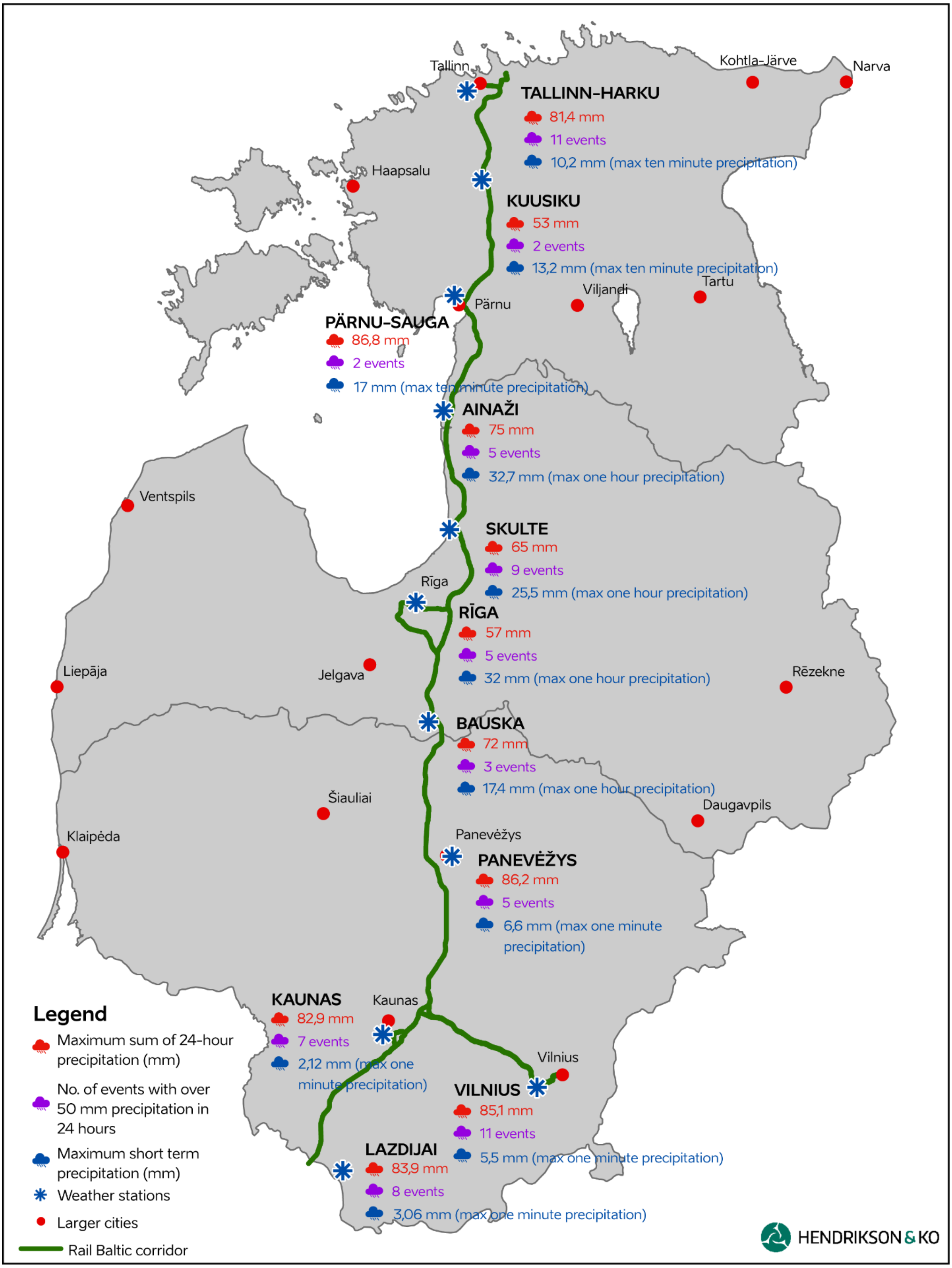


Figure 4.7 Extreme precipitation events during period 1981-2017 in 11 stations along Rail Baltica

Table 4.3 Monthly average precipitation (mm) in meteorological stations during period 1981-2010

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	56	36	37	32	36	64	84	86	67	78	70	57	**703**
KUUSIKU	62	43	43	34	44	74	82	89	69	87	71	64	**762**
PÄRNU	60	44	44	37	37	73	79	79	67	83	75	67	**745**
PANEVĖŽYS	38	32	36	38	54	67	84	63	55	56	47	45	**615**
KAUNAS	46	32	40	37	54	73	78	75	53	55	48	46	**637**
VILNIUS	48	37	42	43	57	73	89	75	66	55	47	53	**685**
LAZDIJAI	41	32	37	36	59	74	87	68	57	48	45	44	**628**

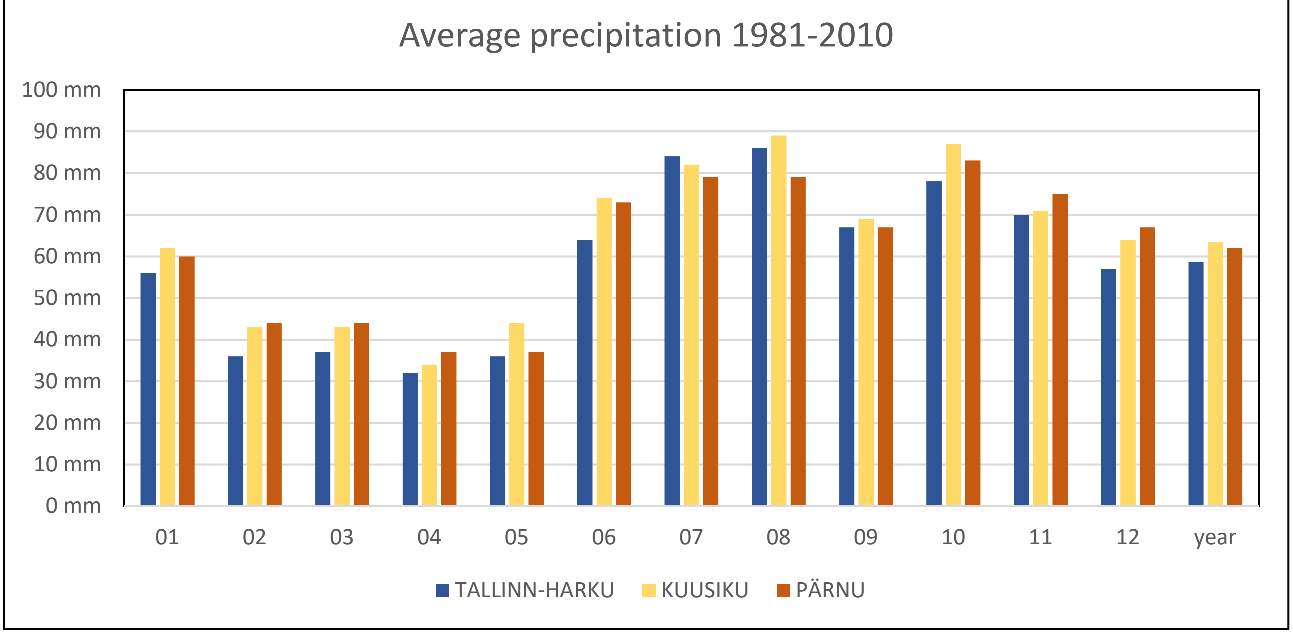


Figure 4.8 Monthly average precipitation (mm) in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2010

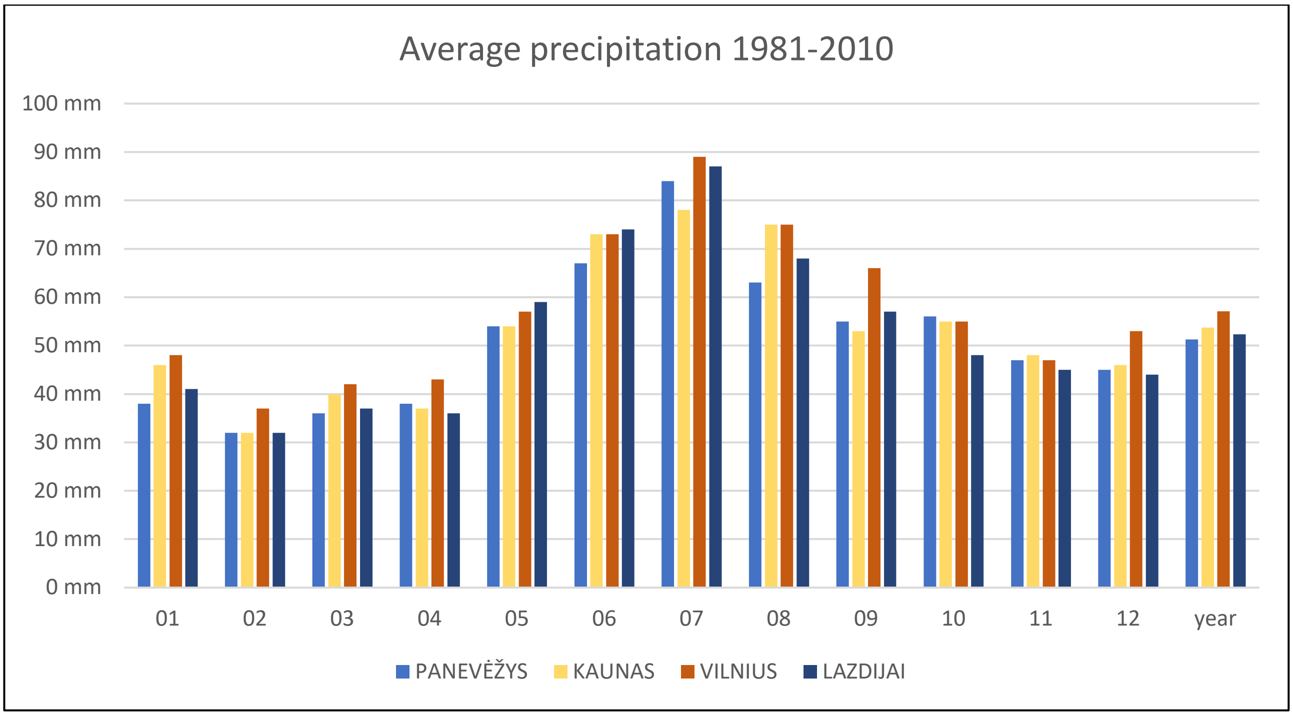


Figure 4.9 Monthly average precipitation (mm) in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010

Table 4.4 Maximum sums of 24-hour precipitation (mm) in each month in meteorological stations during period 1981-2017

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	28,2	28,4	18,9	22,7	30,1	50,1	81,4	56,4	74,5	36,2	27,6	22,5	**81,4**
KUUSIKU	20,0	23,9	20,7	27,9	24,7	47,6	51,8	53,0	37,3	48,8	32,8	21,8	**53,0**
PÄRNU	23,8	28,1	17,3	25,0	44,0	86,8	56,9	49,7	43,9	38,9	30,7	29,4	**86,8**
AINAŽI													**75,0**
SKULTE													**65,0**
RĪGA													**57,0**
BAUSKA													**72,0**
PANEVĖŽYS	18,9	21,3	25,5	31,9	61,9	48,7	86,2	31,7	53,0	32,1	26,1	22,4	**86,2**
KAUNAS	31,5	17,3	22,2	23,4	37,7	44,9	57,5	82,9	45,3	61,7	27,7	20,9	**82,9**
VILNIUS	21,4	16,2	19,3	62,5	53,7	63,9	84,7	85,1	55,8	26,5	21,0	31,0	**85,1**
LAZDIJAI	19,1	15,7	20,4	25,8	44,8	83,9	60,8	62,7	68,1	33,5	27,5	18,9	**83,9**

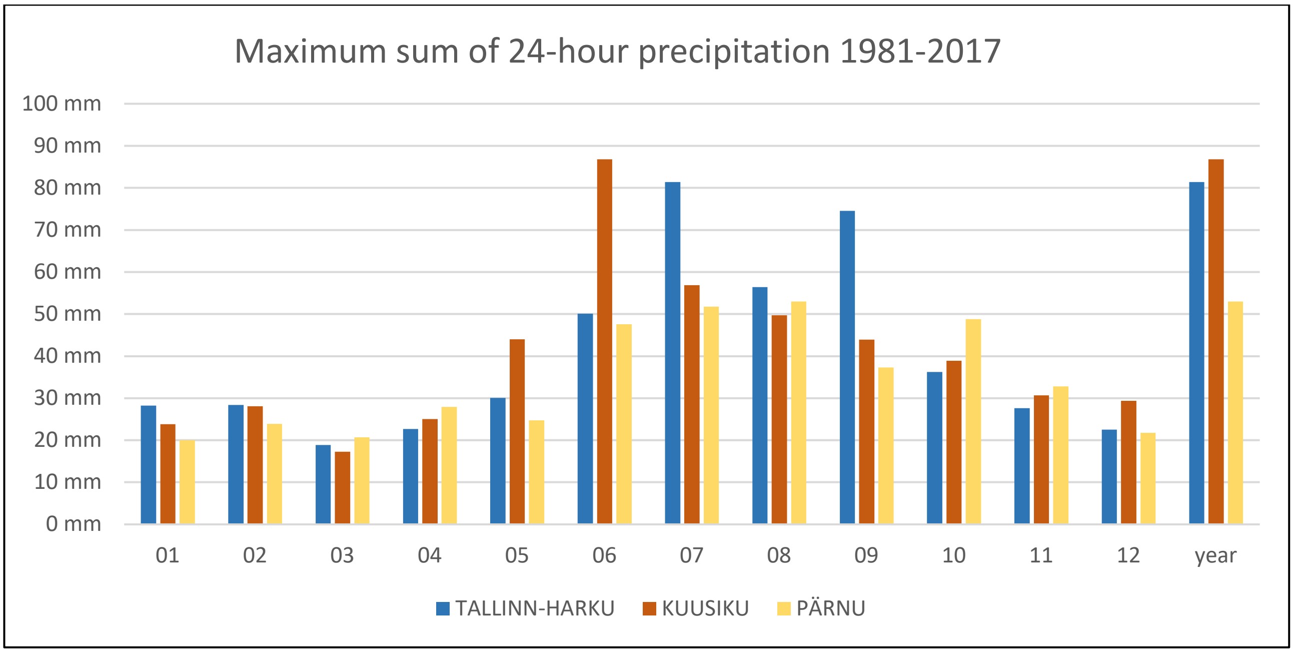


Figure 4.10 Maximum sum of 24-hour precipitations (mm) in each month in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2017

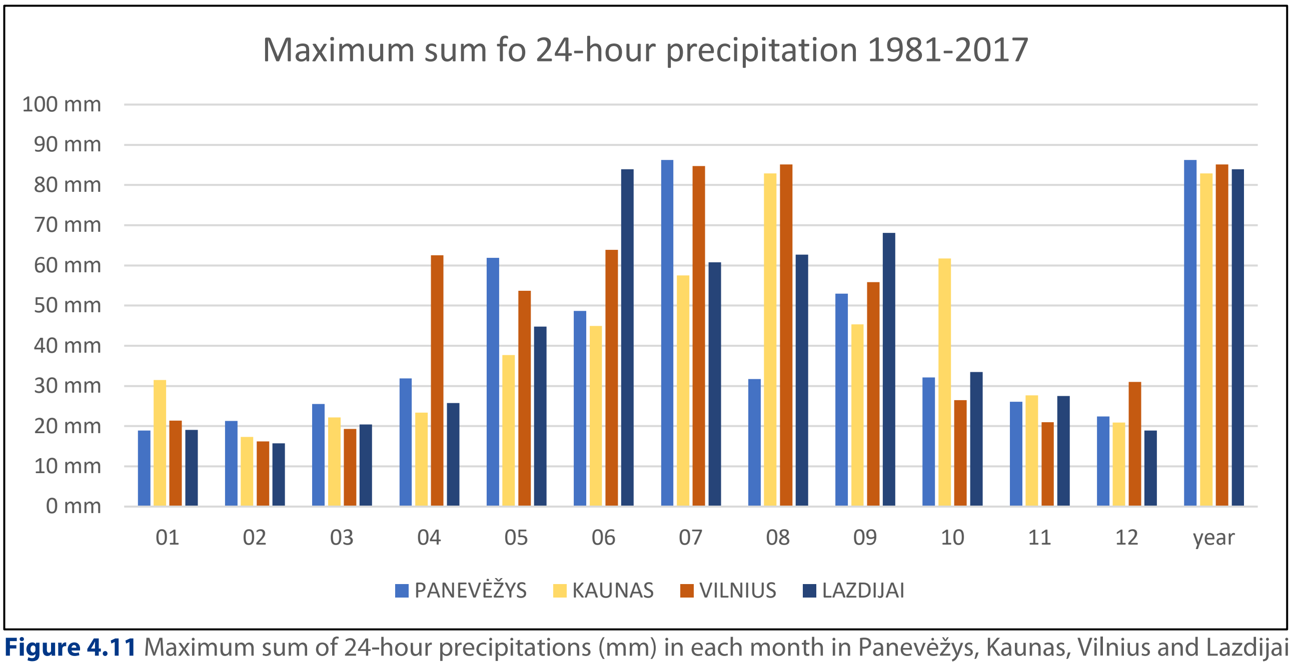


Figure 4.11 Maximum sum of 24-hour precipitations (mm) in each month in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2017

Number of events, where 24-hour precipitation sum is 50 mm or more during the period 1981-2017 (1985-2017 for Latvian stations) in the weather stations near Rail Baltica:

- Tallinn-Harku – **11 events**; 5 in July, 3 in August, 2 in September and 1 in June
- Kuusiku – **2 events**; 1 in June and other in July
- Pärnu – **2 events**; 1 in July and other in August
- Ainaži – **5 events;** 3 in June, 1 in May and 1 in August
- Skulte – **9 events;** 4 in August, 3 in July, 1 in June and 1 in September
- Rīga – **5 events;** 2 in September, 1 in June, 1 in July and 1 in August
- Bauska – **3 events;** 2 in July and 1 in June
- Panevėžys – **5 events**; 2 in May, 2 in July and 1 in September
- Kaunas – **7 events**; 4 in August, 2 in July and 1 in October
- Vilnius – **11 events**; 4 in July, 2 in August, 2 in September, 1 in April, 1 in May and 1 in June
- Lazdijai – **8 events**; 3 in August, 2 in July, 2 in September and 1 in June

Number of events, where 12-hour precipitation sum is between 50 and 80 mm during the period 1981-2017 in the weather stations near Rail Baltica:

- Tallinn-Harku – **8 events**; 4 in July, 2 in August, 1 in June and 1 in September
- Kuusiku – **1 event**; in July
- Pärnu – **1 event**; in July
- Panevėžys – **4 events**; 2 in May and 2 in July
- Kaunas – **4 events**; 2 in August, 1 in July and 1 in October
- Vilnius – **8 events**; 3 in July, 2 in June, 2 in September, 1 in April, 1 in May and 1 in August
- Lazdijai – **8 events**; 4 in July, 1 in June and 1 in August

Table 4.5 Maximum sums of 10-minute precipitation (mm) in each month in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 2011-2017

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	3,24	2,04	1,86	3,13	10,22	7,33	8,99	10,27	8,23	2,64	1,46	3,14	**10,22**
KUUSIKU	3,11	1,75	2,02	2,48	5,41	5,97	8,82	13,23	5,47	3,63	1,97	2,44	**13,23**
PÄRNU	3,76	2,69	1,99	1,40	3,83	3,31	11,83	17,00	4,13	4,77	1,44	3,06	**17,00**

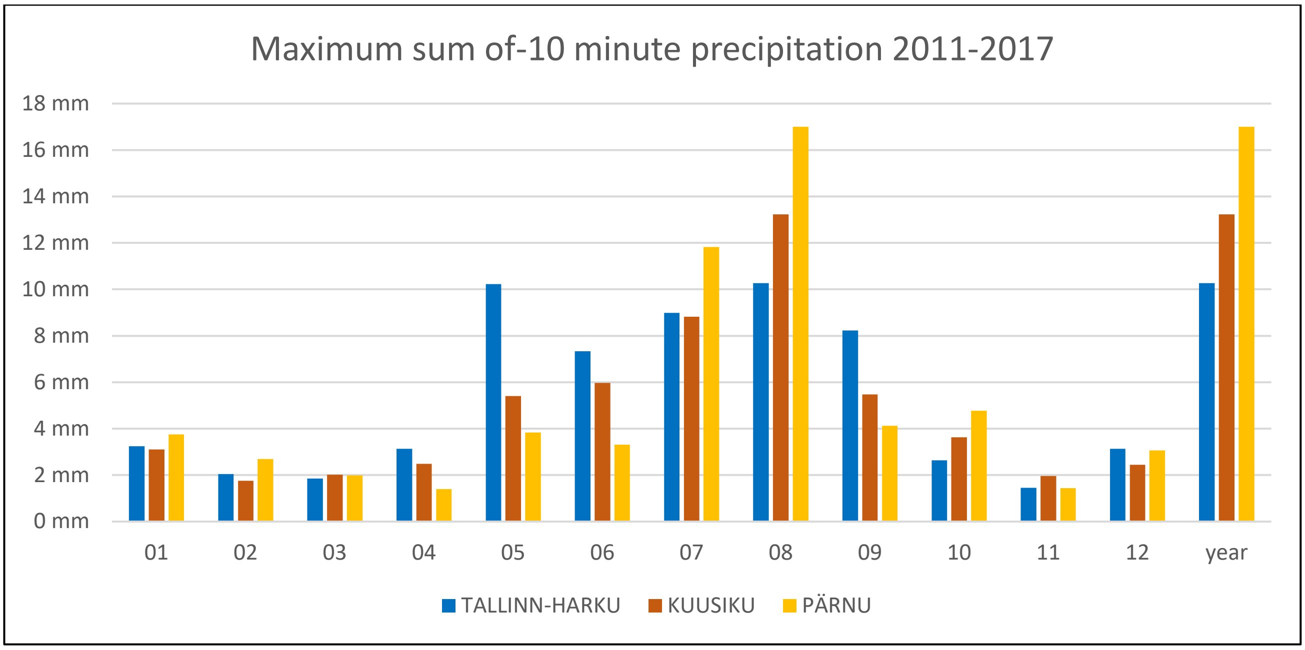


Figure 4.12 Maximum sums of 10-minute precipitation (mm) in each month in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 2011-2017

Table 4.6 Maximum sums of one-hour precipitation (mm) in each month in Ainaži, Skulte, Riga and Bauska meteorological stations during period 2004-2017

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
AINAŽI	3,2	2,1	5,9	4,6	32,7	12,4	8,1	22,2	27,5	5,6	5,5	5,5	**32,7**
SKULTE	3,4	2,2	3,2	6	5,2	10,3	16,9	25,5	7	8,9	3,6	2,7	**25,5**
RĪGA	5,6	2,4	3,6	9,8	11,2	15,2	32	18	11,4	6,2	5,2	3,2	**32**
BAUSKA	3,3	2,5	4,5	4,5	13,2	8,3	12,1	17,4	11,5	5,6	4,5	3,5	**17,4**

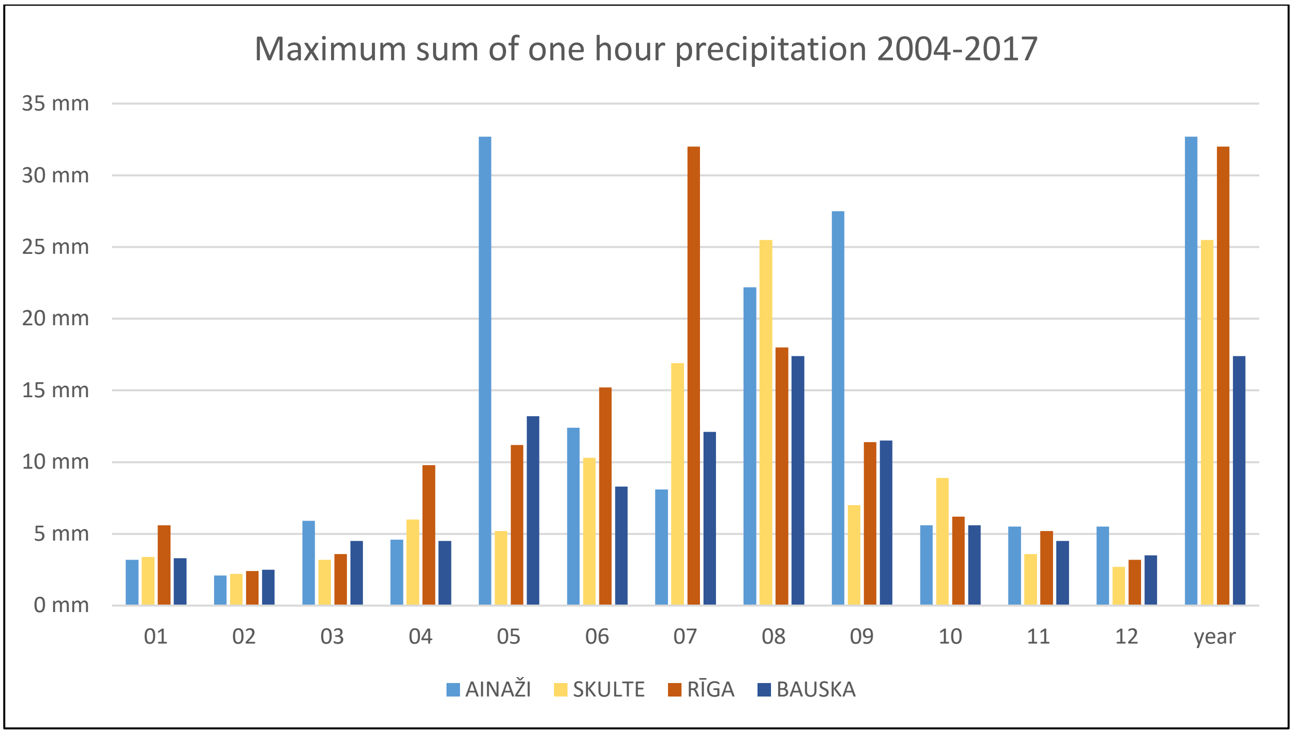


Figure 4.13 Maximum sums of one-hour precipitation (mm) in each month in Ainaži, Skulte, Riga and Bauska meteorological stations during period 2004-2017

Maximum precipitation amounts during one minute in Lithuanian stations during period 1981-2017:

- ✓ Panevėžys – **6,6 mm** (duration of one minute for such an intensity) in July 2010
- ✓ Kaunas – **2,12 mm** (duration of ten minutes for such an intensity) in August 1999
- ✓ Vilnius – **5,5 mm** (duration of one minute for such an intensity) in June 1999 and – **5,27 mm** (duration of three minutes for such an intensity) in July 2010
- ✓ Lazdijai – **3,06 mm** (duration of one minute for such an intensity) in June 2007

4.1.3. Snowfall and snow cover

Snow on the ground is historically the defining feature of the winter season. The analysis of snowfall and snow cover is based on monthly average and annual average values of snowfall and snow coverage duration. In Rail Baltica context, extreme snowfall is analysed by its frequency and magnitude, as example maximum daily precipitation, maximum monthly precipitation, frequency and duration of such situations.

The annual total number of days with snow cover exhibited a widespread decline during last decades. Snow coverage has been intermittent, characterised by an unexpected appearance and disappearance, with wet snow. In general, the numbers of days with snow falling and lying show an increase with inland conditions, so values reflect proximity to the seacoast. During last decades the snow cover tended to be melted and interrupted multiple times during winter.

The number of days of snowfall and snow cover varies enormously from year to year. The maximum snow depth recorded in Tallinn is 49 cm, in Pärnu is 51 cm and Kuusiku is 66 cm (in 1992–2011, based on monthly average). The maximum increment of snow depth is recorded 31 cm, reaching 44 cm in Kuusiku in November 2008 (period 1991–2010) (Eesti ilma riskid 2012). Maximum recorded snow depth in Estonia during period 1981-2001 was 74 cm, which was measured in Väike-Maarja station, in the Central Estonia in winter 1983/1984. (Handbook of Estonian snow cover, 2016). Rail Baltica corridor represents the average and below snow depth zone in the Estonian snow geography.

In terms of Rail Baltica vulnerabilities, the average annual number of blizzards was 5,78 in Tallinn and 3,86 in Pärnu during 1981-2017(2015). The long-lasting blizzard, 32 hours in total was recorded in Tallinn 20.-21.12.1981 and 25 hours in total in Pärnu 10.-11.12.1983. According to historic records, the blizzard risk is quite high in Pärnu (compared to other Estonian areas) (Eesti ilma riskid 2012). In Latvia, the average annual number of blizzards is highest in Ainaži (7,2), the lowest in Skulte (3,9). In Lithuania, the average annual number of blizzards is highest in Panevezys (12), the lowest in Lazdijai (5).

Extreme snowfall (snow depth increments 20 cm or more during 24 hours) in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2017 is presented in Figure 4.14.

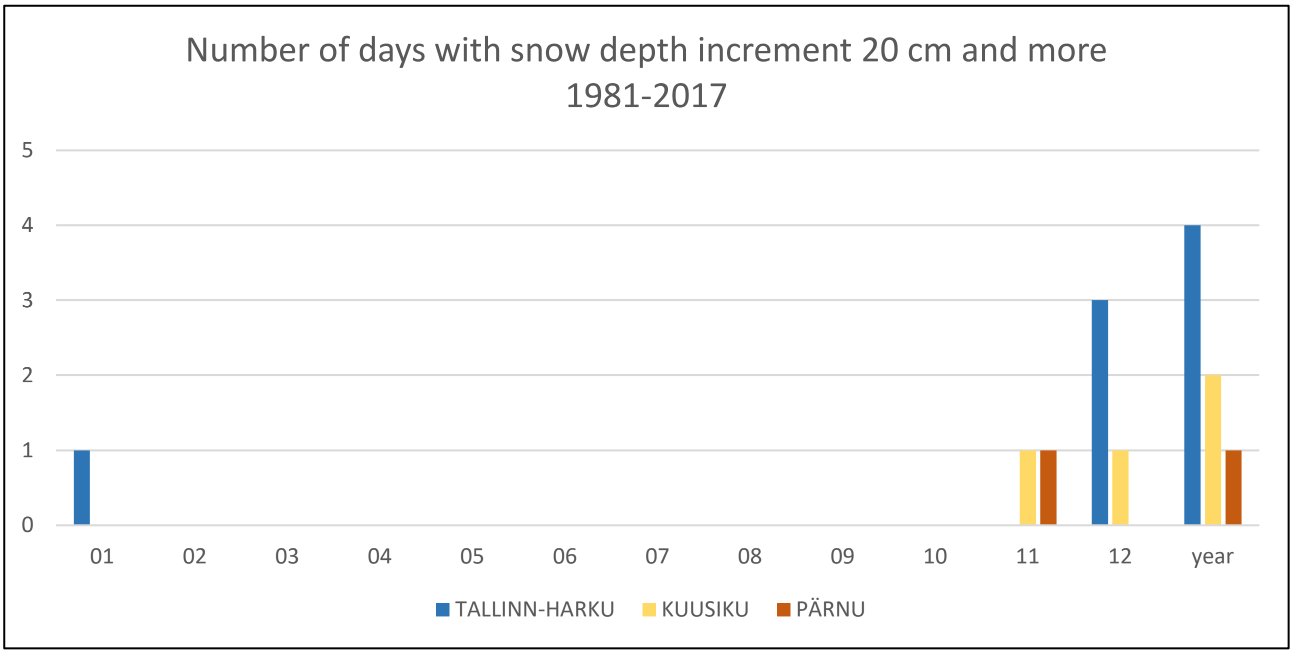


Figure 4.14 Number of days with snow depth increment 20 cm or more during 24 hours in each month in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2017

In the time periods, when the snow cover thickness at Ainaži, Bauska, Riga-University and Skulte was registered more frequently than once a day (Ainaži and Bauska information is for the period from 2012 to 2017, in the observation station Riga-University - from 2010 to 2017 and at the observation station Skulte - in 2011 and from 2016 to 2017), **none of the observation stations recorded a snow cover increase of at least 20 cm in a 12-hour period**.

During the period 1981-2017 only **one event with snow cover increase of at least 20 cm in a 12-hour period** was registered in the four Lithuanian stations – on 2009 in Kaunas.

Table 4.7 Maximum snow cover thickness in Tallinn-Harku (1992-2011), Kuusiku (1992-2011), Pärnu (1992-2011), Ainaži (1986-2002; 2006-2009), Skulte (1986-2002; 2006-2012; 2016-2017), Riga (1986-2017) Bauska (1986-2017), Panevėžys (1981-2017), Kaunas (1981-2017), Vilnius (1981-2017) and Lazdijai (1981-2017) meteorological stations

STATION	01	02	03	04	10	11	12	year
TALLINN-HARKU								49

KUUSIKU								**66**
PÄRNU								**51**
AINAŽI	29	37	58		48	29	37	**58**
SKULTE	41	60	63		44	41	60	**63**
RĪGA	46	62	60		45	46	62	**60**
BAUSKA	6	10	39		19	6	10	**39**
PANEVĖŽYS	34	51	50	50	11	16	32	**51**
KAUNAS	44	37	32	30	4	12	36	**44**
VILNIUS	50	54	50	47	19	21	39	**54**
LAZDIJAI	32	36	44	40	11	16	30	**44**

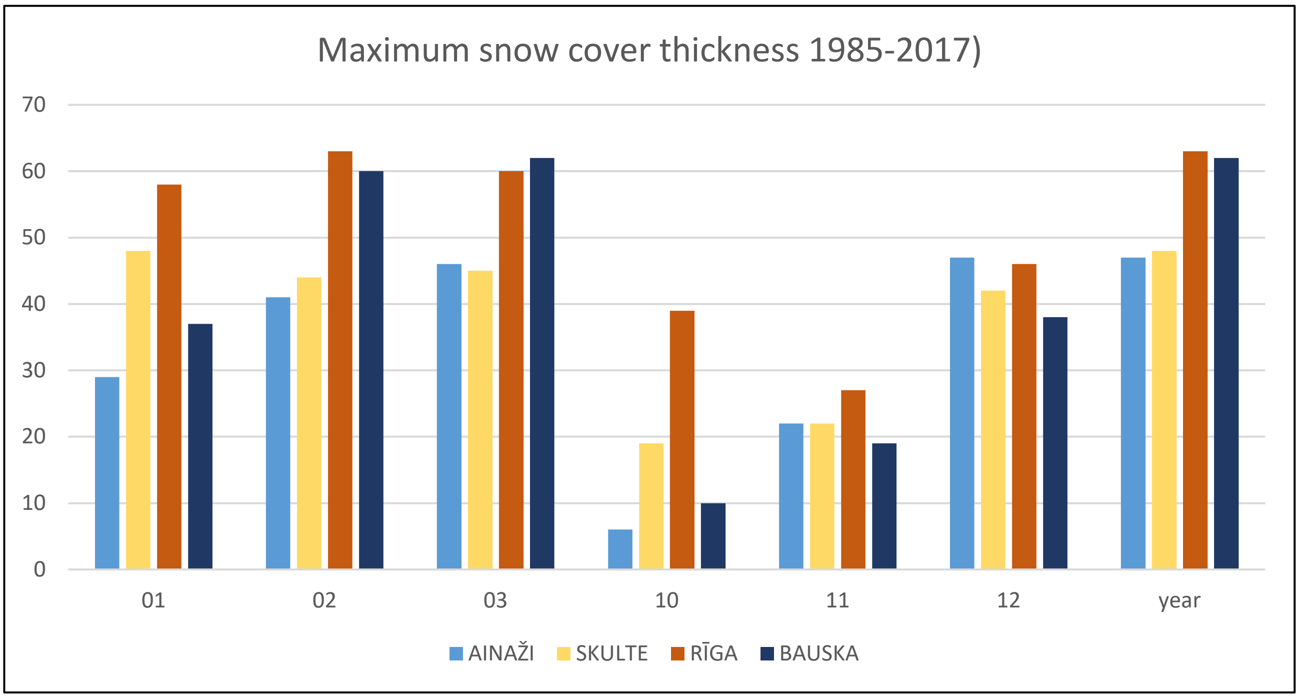


Figure 4.15 Maximum snow cover thickness in Ainaži (1986-2002; 2006-2009), Skulte (1986-2002; 2006-2012; 2016-2017), Riga (1986-2017) and Bauska (1986-2017) meteorological stations

Table 4.8 Mean days with blizzard in each month in Tallinn-Harku, Pärnu, Ainaži (1986-2002; 2006-2009), Skulte (1986-2002; 2006-2012; 2016-2017), Riga (1986-2017) and Bauska (1986-2017) meteorological stations

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	1,11	1,38	0,73	0,32	0,00	0,00	0,00	0,00	0,00	0,11	0,68	1,46	**5,78**
PÄRNU	1,11	1,17	0,51	0,06	0,00	0,00	0,00	0,00	0,00	0,00	0,29	0,71	**3,86**

AINAŽI	2,00	1,50	0,80	0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,50	2,00	**7,20**
SKULTE	1,20	0,90	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,30	1,00	**3,90**
RĪGA	1,30	1,10	0,30	0,10	0,00	0,00	0,00	0,00	0,00	0,10	0,30	1,60	**4,80**
BAUSKA	1,10	0,90	0,60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,60	1,30	**4,50**

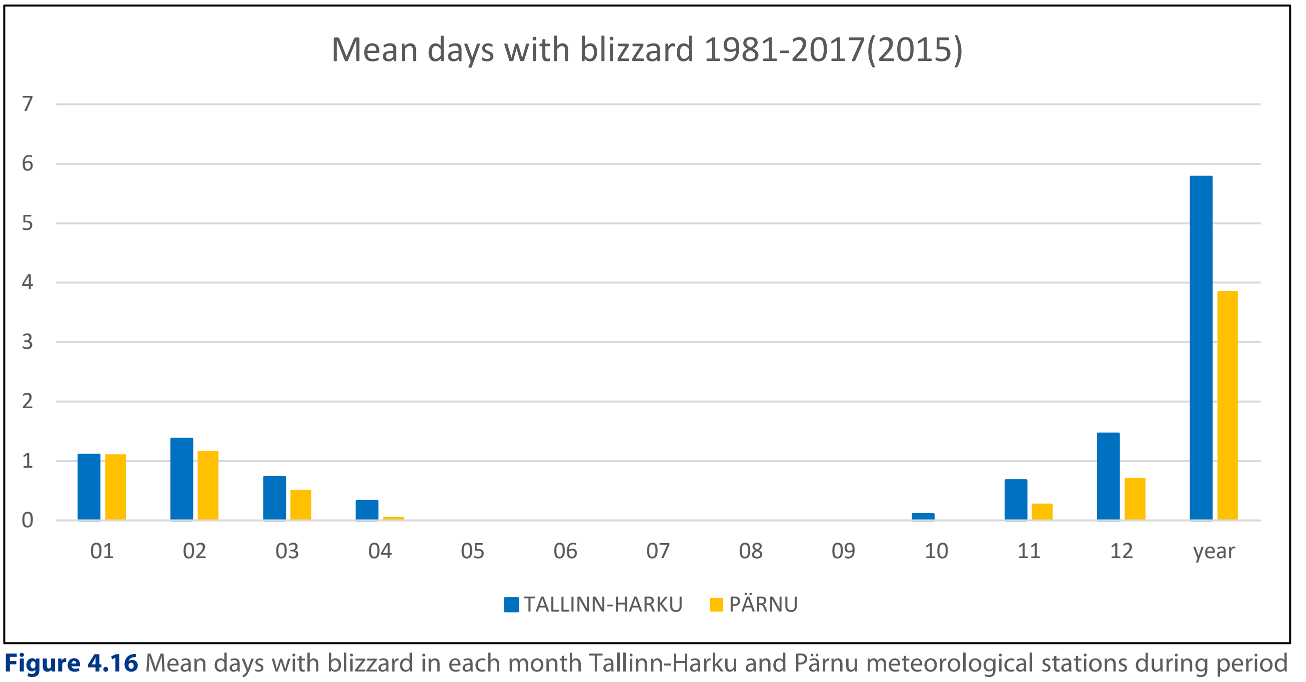


Figure 4.16 Mean days with blizzard in each month Tallinn-Harku and Pärnu meteorological stations during period 1981-2017 in Tallinn-Harku station and 1981-2015 in Pärnu station

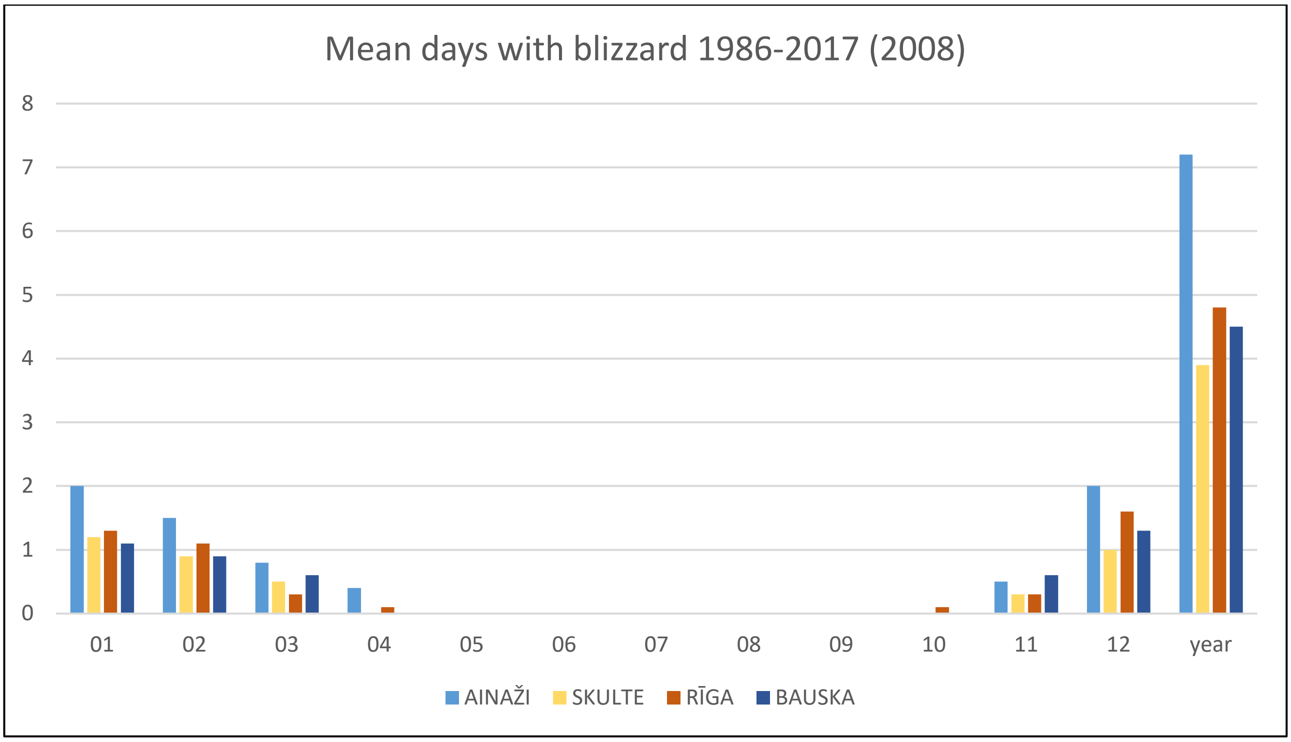


Figure 4.17 Mean days with blizzard in each month in, Ainaži (1986-2002; 2006-2009), Skulte (1986-2002; 2006-2012; 2016-2017), Riga (1986-2017) and Bauska (1986-2017) meteorological stations

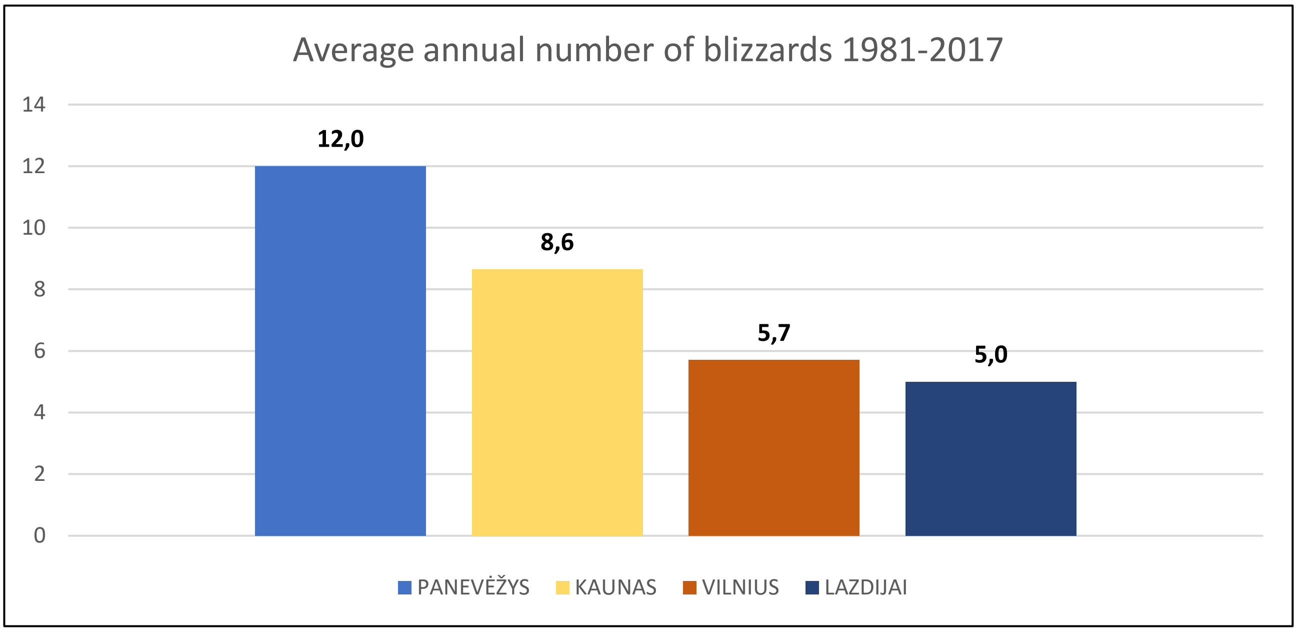


Figure 4.18 Average annual number of blizzards in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2017

4.1.4. Floods

Flooding zones located in Rail Baltica routing are shown in the maps below.

Estonia

Initial Estonian flood risk assessment was finished on 2011, being updated regularly. 20 flood risk areas with dense population were defined in total (Keskkonnaministeerium, 2011). Areas with 100-year flood risk near Rail Baltica railway are presented on Figure 4.19. Two of these areas Maardu (Figure 4.20 and 4.22) and Pärnu (Figure 4.21 and 4.23) are in the near proximity of the track and are analysed in more detail.

There were very little historic measurements (2003-2005) about historic Maardu water levels and therefore interviews and site inspections and Kritsky-Menkel (G) were function mainly used to predict future flood events. Flood maps were compiled using data from year 2013 LIDAR database (Keskkonnaministeerium, 2014). Maximum absolute water level for 100-year flood is considered 34.11 m.

Pärnu flood areas were determined by using historic data from 1923-2010 Pärnu river hydrological station and Gumbel II type (EV2) function. Flood maps were compiled using data from year 2012 LIDAR database (Keskkonnaministeerium, 2014). Maximum absolute water level for 100-year flood is considered 3.07 m.

Estonian Environment Agency is also able to calculate maximum water flow and levels for specific locations on rivers with hydrometeorological stations, when asked. In 2015 these calculations were ordered within Rail Baltica preliminary design stage for Reiu, Pärnu, Sauga and Velise river.

Table 4.9 Maximum water flow and level estimations by Estonian Environment Agency (2015) in Rail Baltica route locations

River	Coordinates	Long term average water level	Maximum water level	Probability, water flow m^3/s,		
				2%	5%	10%
Reiu	X6458600; Y538162	3.70	6.84	125	104	90.1
Reiu	X6465558; Y535916	1.81	4.95	180	150	130
Pärnu	X6470943; Y532592	-0.02	2.81	846	698	606
Sauga	X6488757; Y543908	23.74	25.46	19.6	16.4	14.3
Velise	X6521457; Y547026	48.29	49.76	15	12.8	11.4

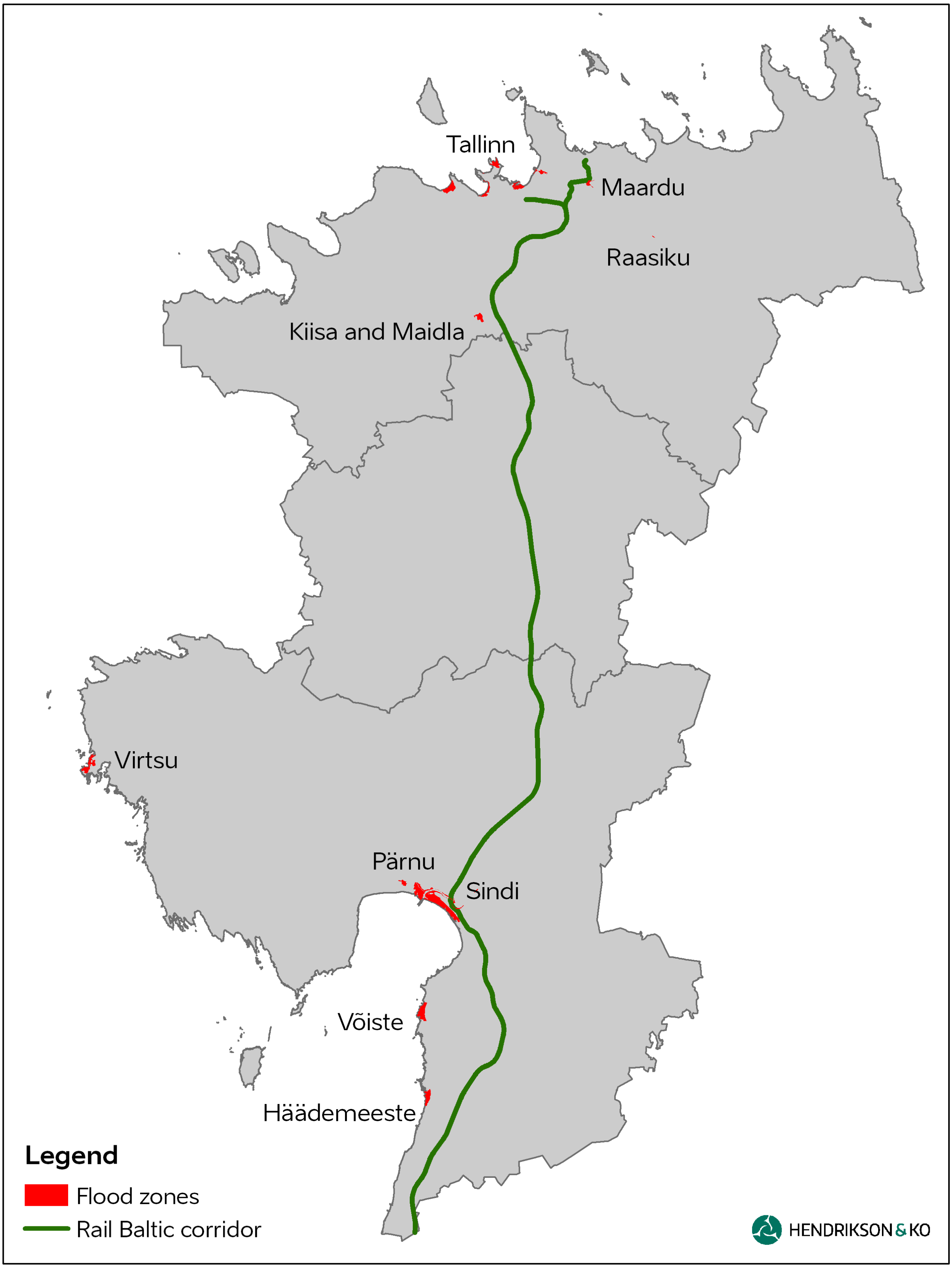


Figure 4.19 Areas with 100-year flood risk near Rail Baltica railway in Estonia

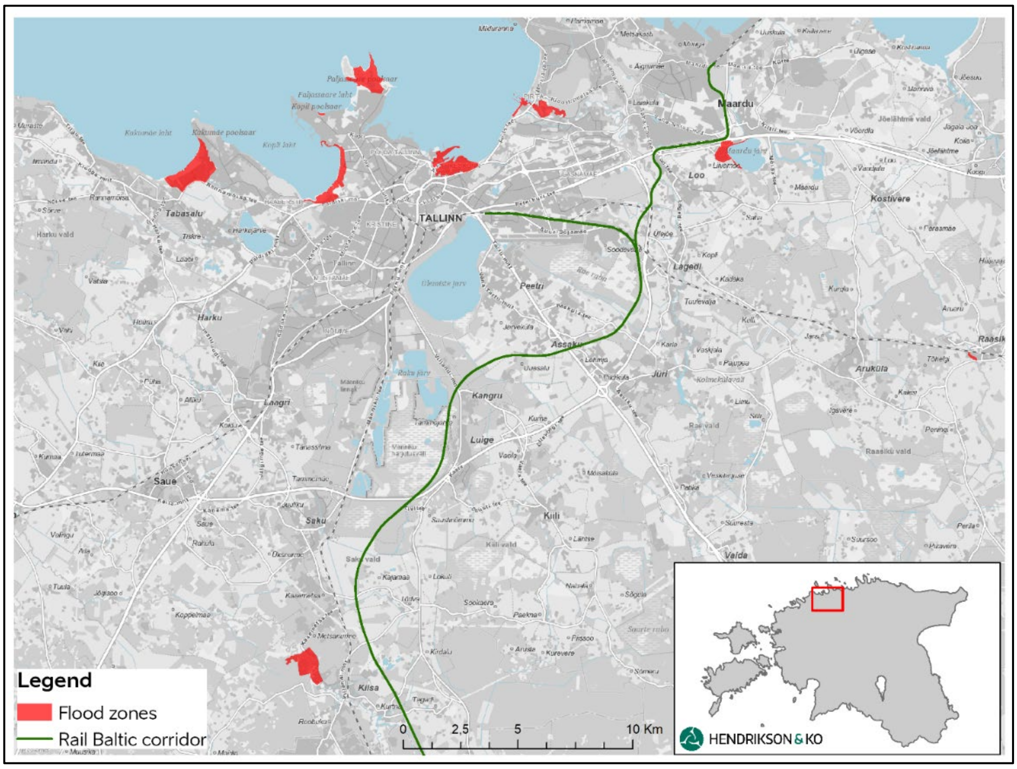


Figure 4.20 Areas with 100-year flood risk near Rail Baltica railway near cities of Maardu and Tallinn in North Estonia.

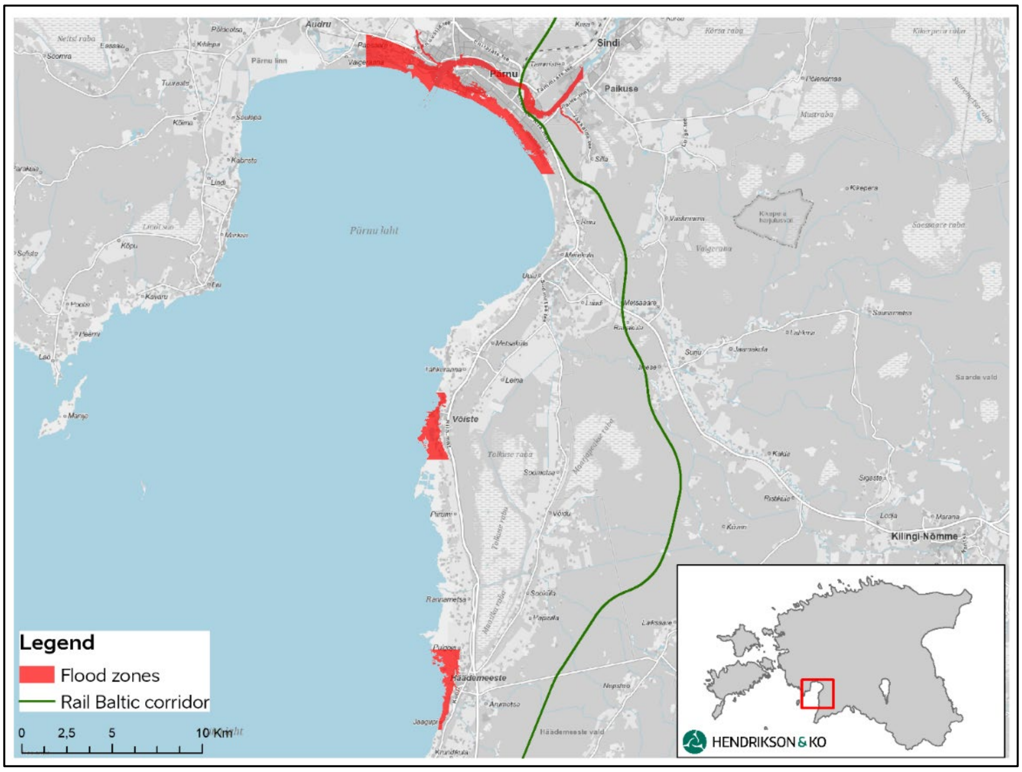


Figure 4.21 Areas with 100-year flood risk near Rail Baltica railway near city of Pärnu in South-West Estonia.

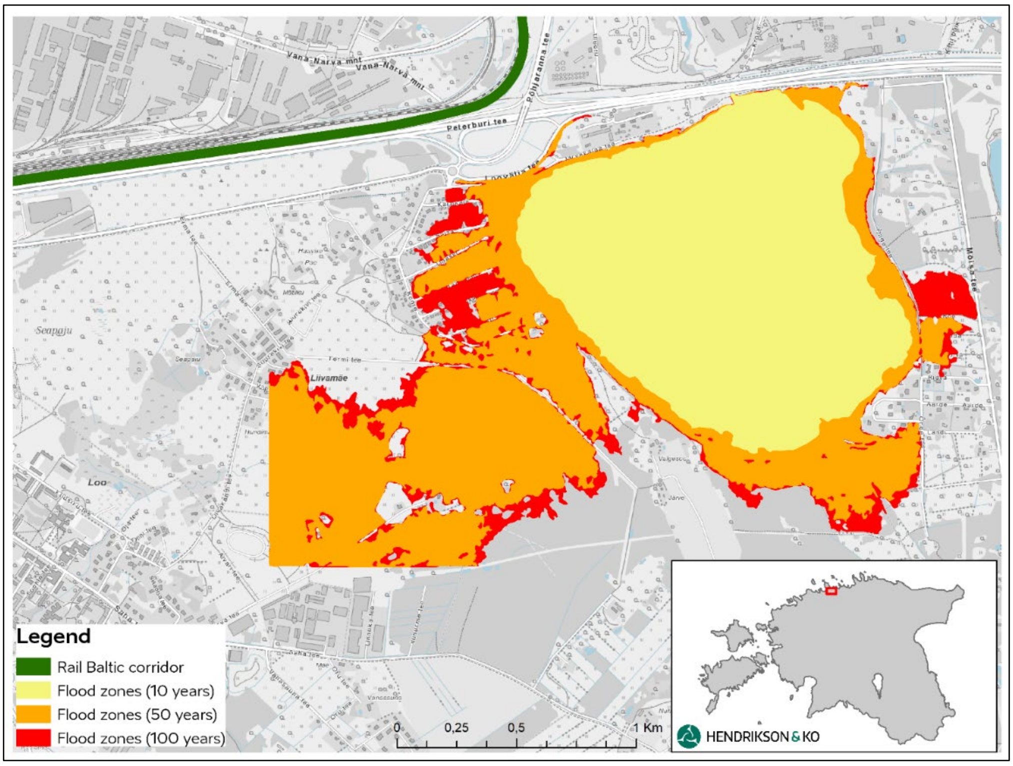


Figure 4.22 Maardu flood zones near Rail Baltica railway (N: 59°26'58.7" E:24°58'46.3")

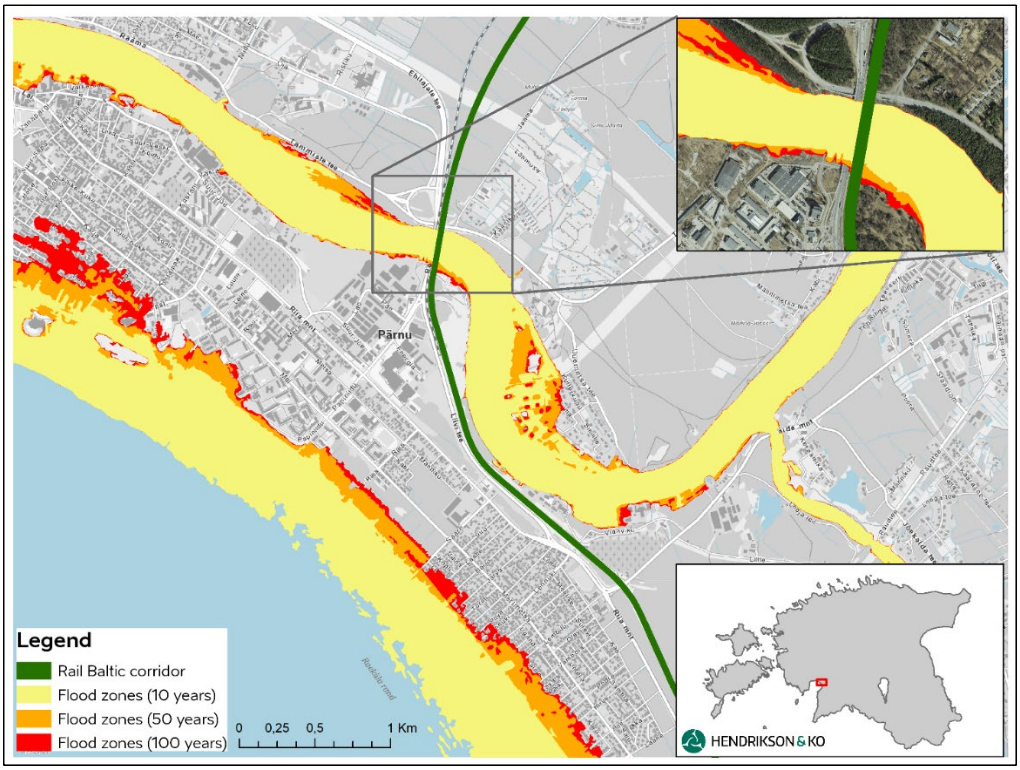


Figure 4.23 Pärnu flood zones near Rail Baltica railway (N: 58°22'40.8" E:24°33'21.5")

Latvia

Initial Latvian flood risk assessment was finished on 2011, being updated regularly. Areas with 100-year flood risk near Rail Baltica railway are presented on Figures 4.24-4.29.

Historic hydrometric and hydrological data over a period of 44 years were used for flood estimation calculations. Flow rates were calculated for each watercourse with a catchment area not less than 25 km^2. Analysis of data using static parameters calculated flow rates for probabilities of recurrence (p), where p = 0.5%; 1%; and 10%. The hydrodynamic mathematical model for Daugava river bed district was developed (on the basis of the DHI (Danish Hydrology Institute)'s hydrodynamic mathematical modelling program MIKE11. The hydrodynamic mathematical modelling was done for all three flood scenarios: floods with a high, medium and low probability.(Latvian flood assessment, 2014). Riga region was modelled within separate project (Rīga pret plūdiem – „Rīgas pilsētas virszemes ūdeņu ietekmju novērtēšana, novēršana un ekoloģiskā stāvokļa uzlabošana") and these risk estimates also include climate change factors.

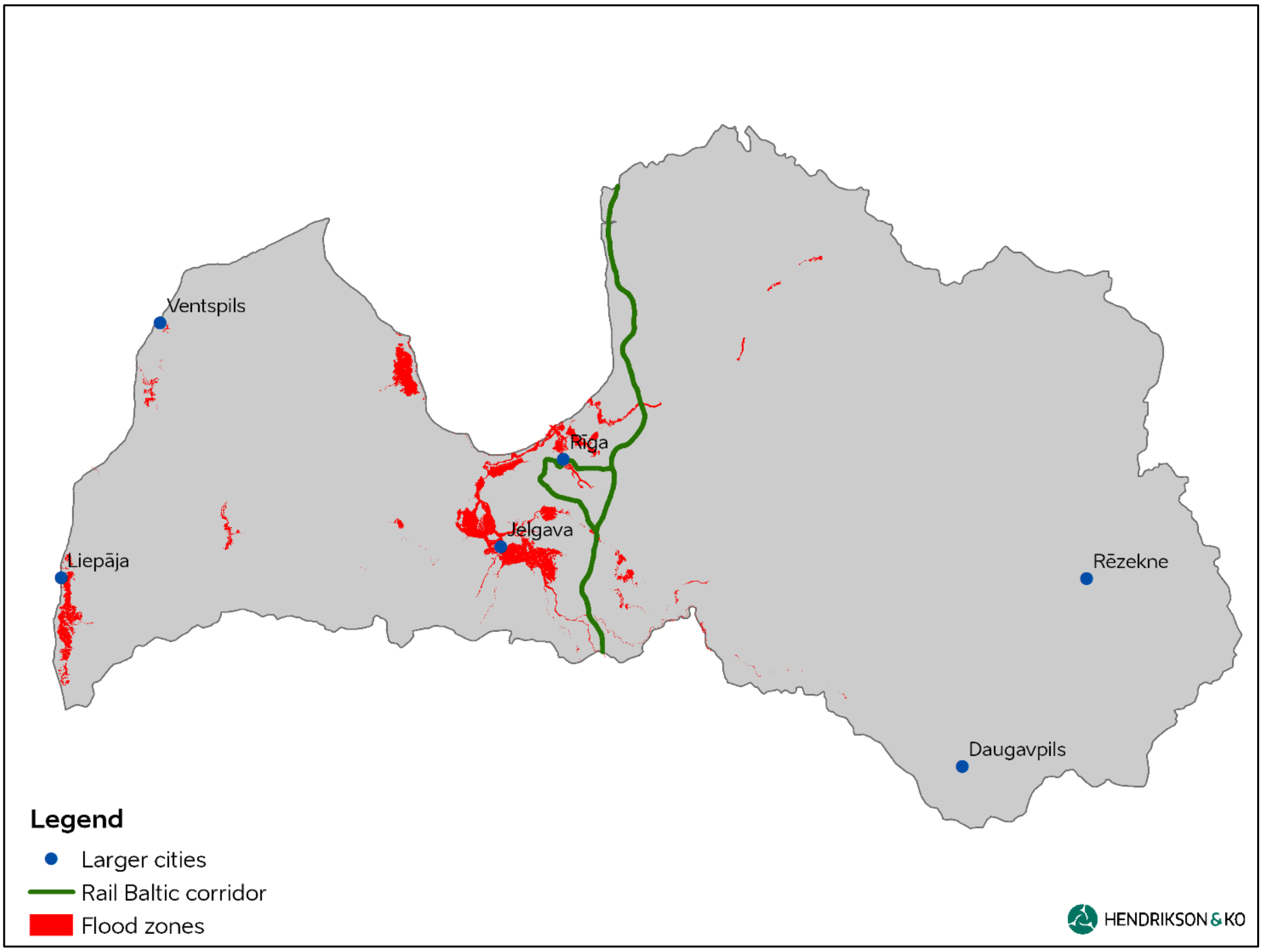


Figure 4.24 Areas with 100-year flood risk near Rail Baltica railway in Latvia

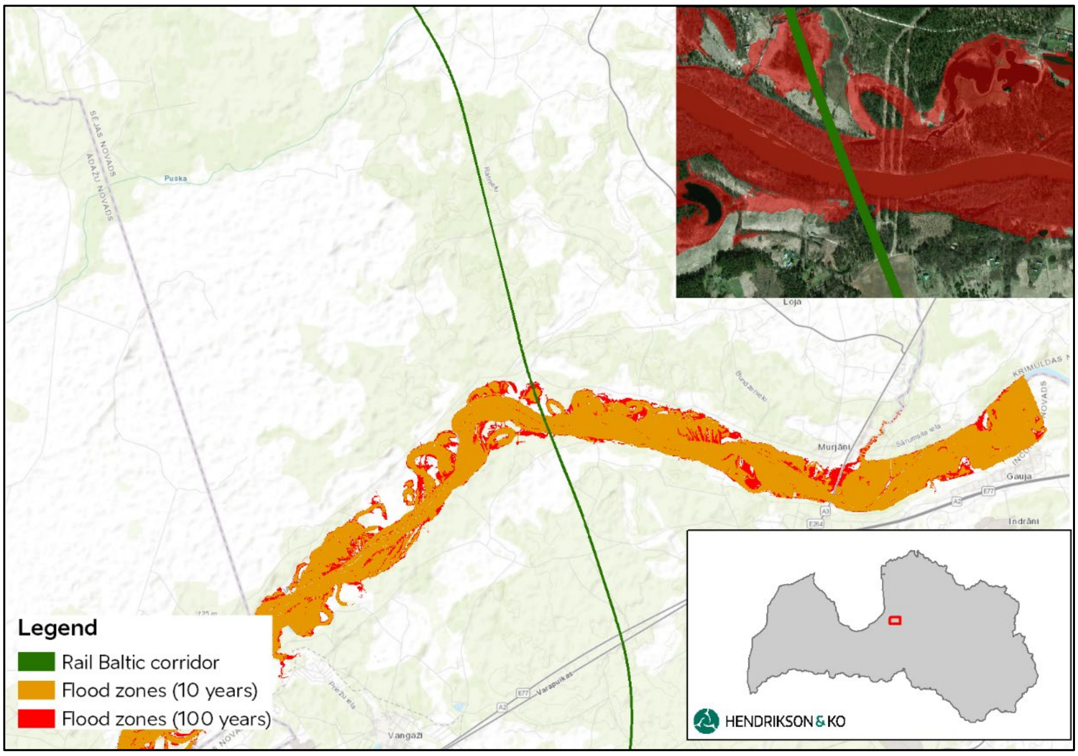


Figure 4.25 100-year flood risk area near Rail Baltica railway before city of Riga (N 57°08'10.8" E24°35'07.9")

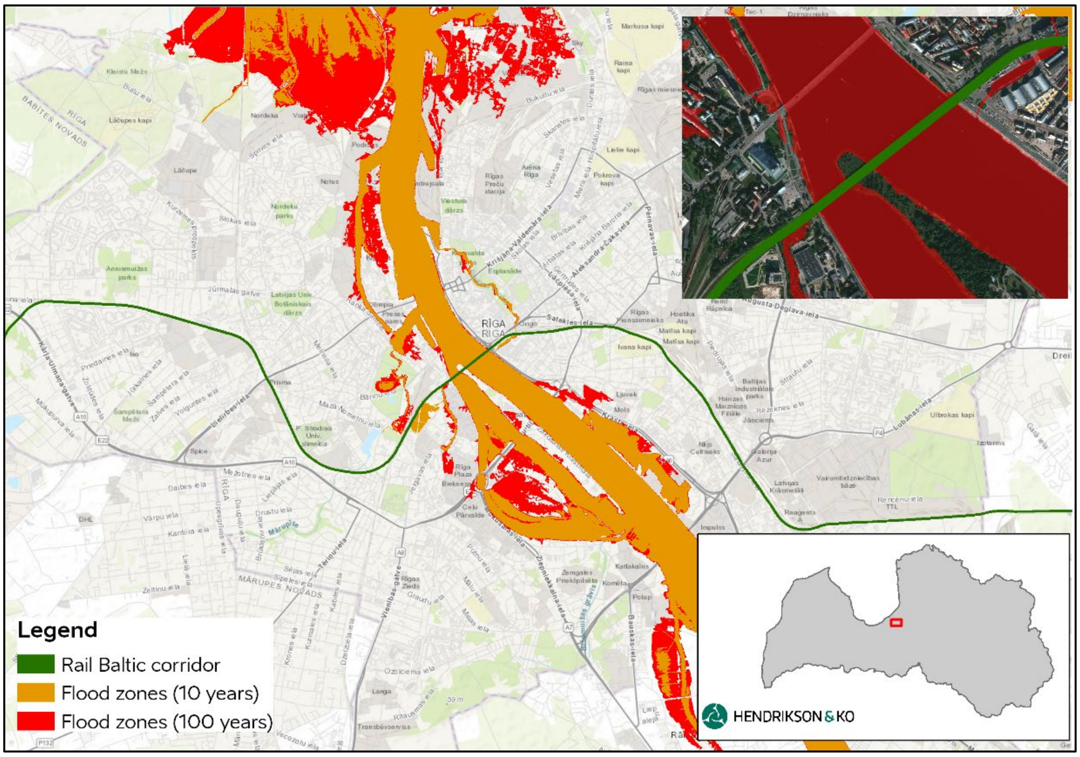


Figure 4.26 100-year flood risk area near Rail Baltica railway in the city of Riga (N 56°56'29.2" E 24°06'17.0")

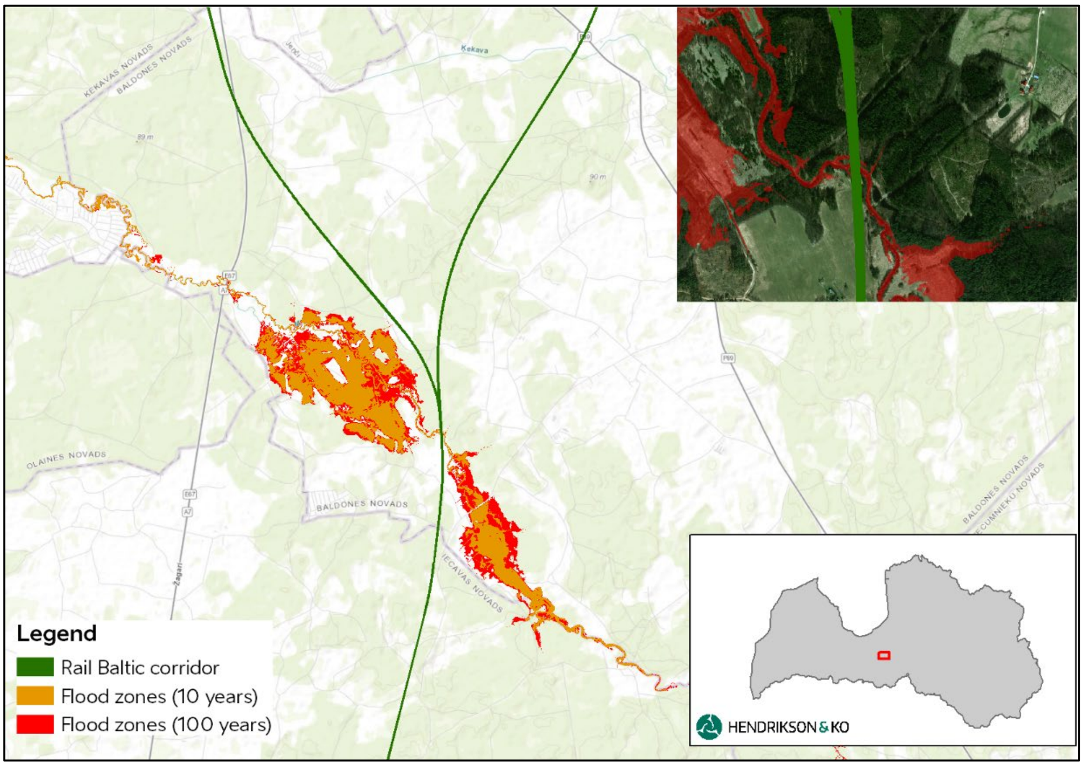


Figure 4.27 100-year flood risk area near Rail Baltica railway in Central Latvia (N 56°41'42.2" E 24°18'16.4")

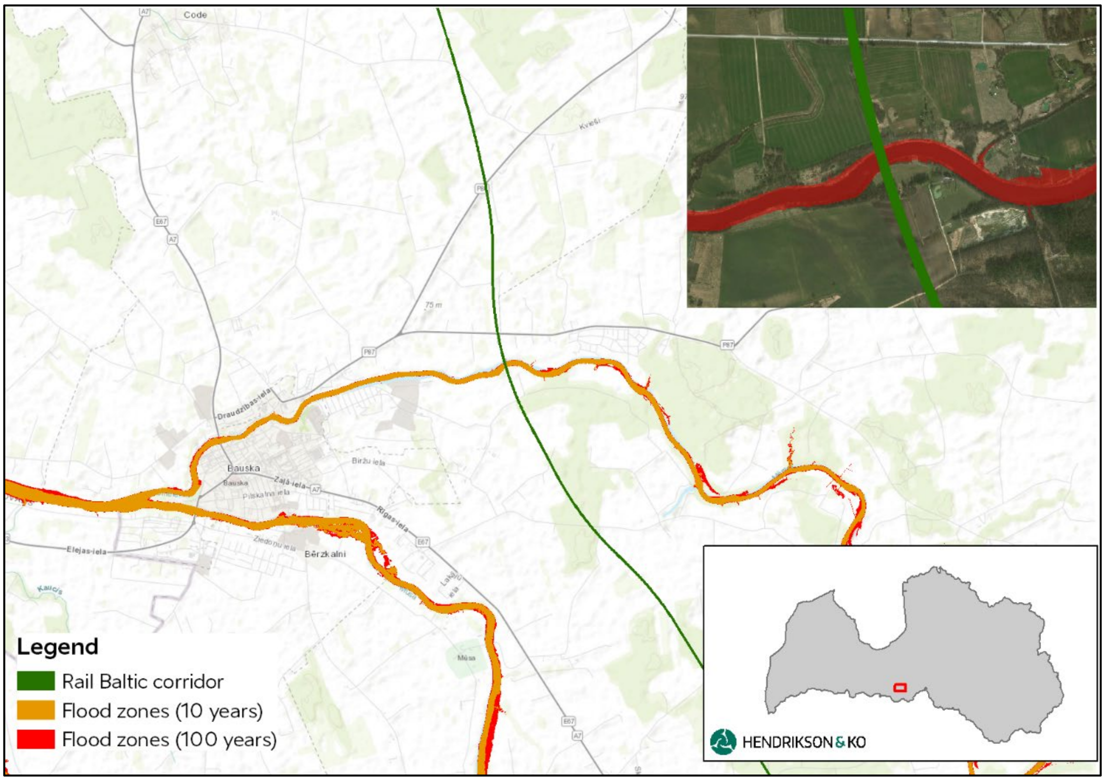


Figure 4.28 100-year flood risk area near Rail Baltica railway in Southern Latvia (N 56°25'18.1" E 24°15'14.8")

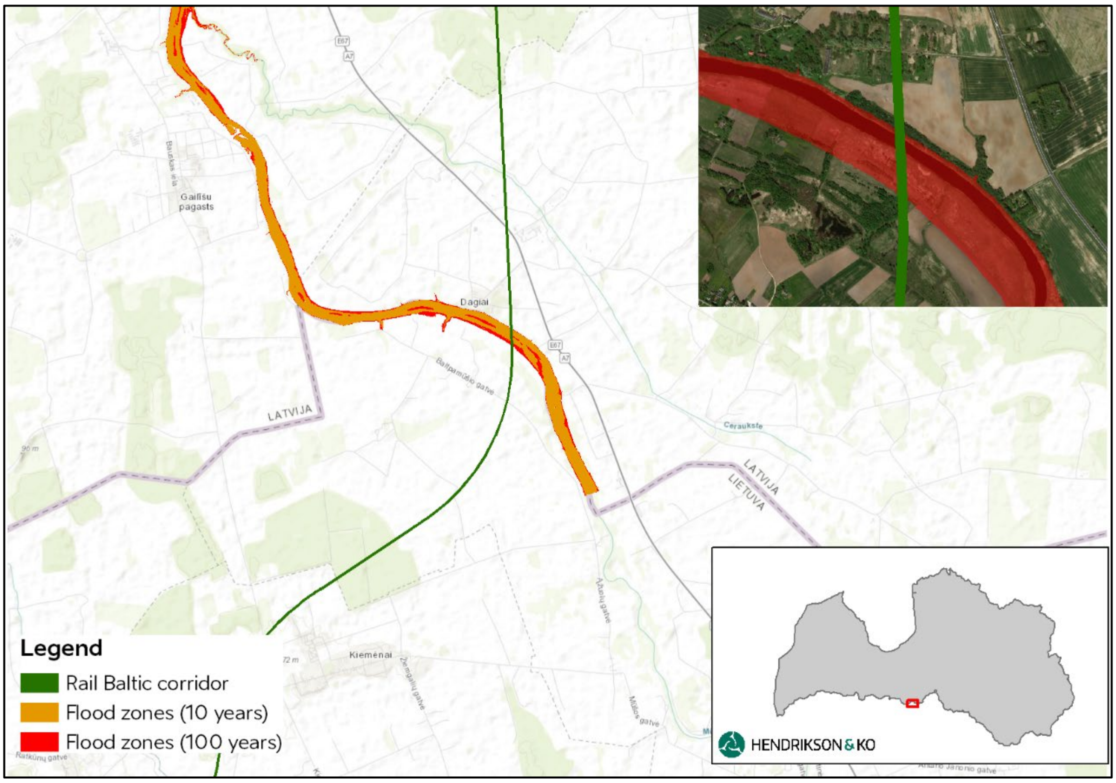


Figure 4.29 100-year flood risk area near Rail Baltica railway in border of Latvia and Lithuania (N 56°17'49.8" E24°20'11.4")

Lithuania

The first round of Lithuanian flood risk assessment was finished in 2011, being updated regularly. Areas with 100-year flood risk near Rail Baltica railway are presented on Figures 4.30-4.37.

All available data from the water gauging stations were used for the calculation of probabilities of flooding. The length of the measurement series was different at each station (longest time series in 1812-2010, shortest in 1986-2010). Flood mapping was made using 1D and 2D hydrodynamic modelling with probabilistic discharge as boundary conditions for the models. The models were calibrated and validated using 10-year time series. The uncertainties of the results maps (water level) are as following: 10% probability flood – 35cm, 1% probability flood – 50cm, 0.1% probability flood – 60cm. (Lithuanian flood assessment, 2014)

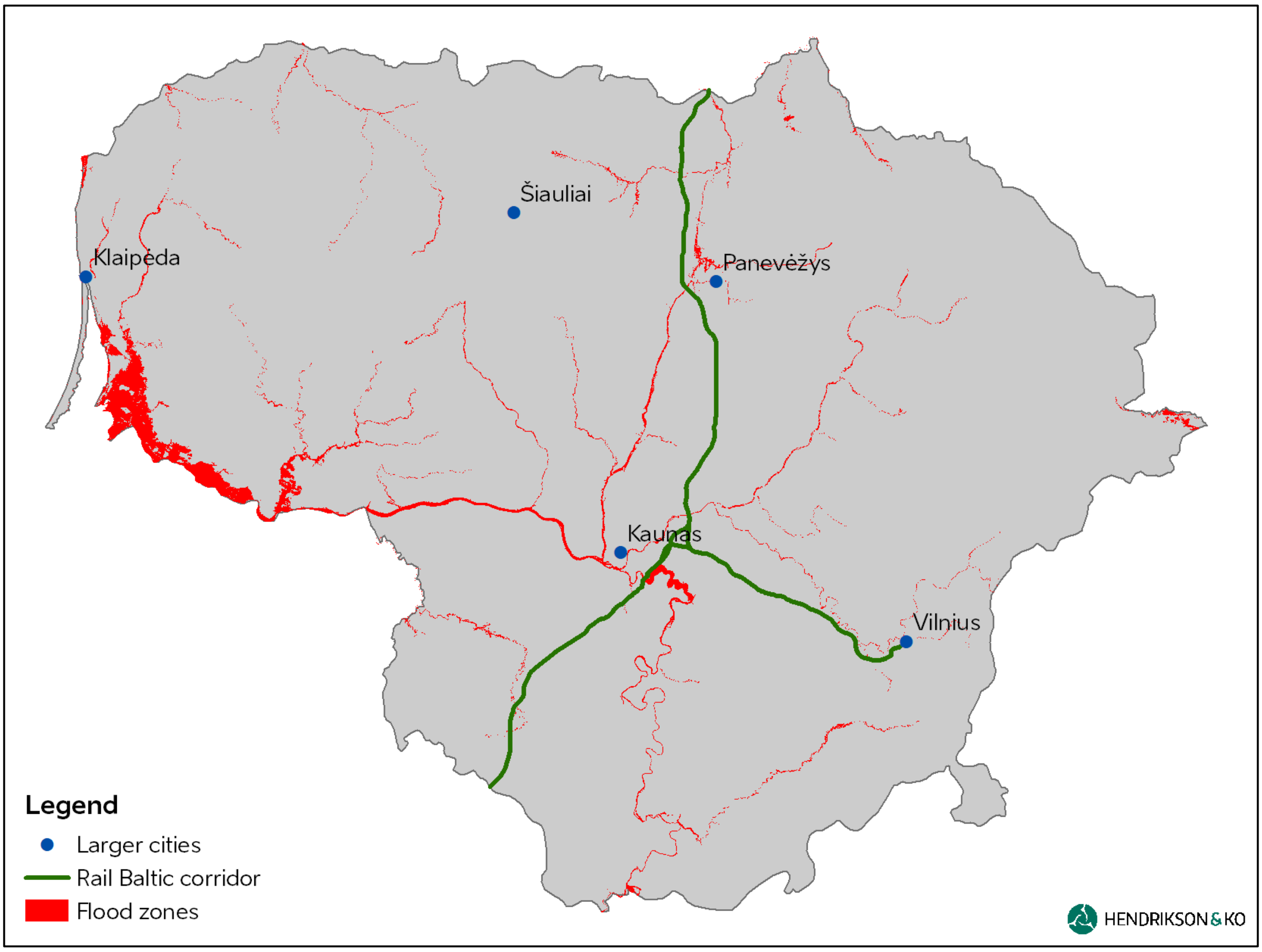


Figure 4.30 Areas with 100-year flood risk near Rail Baltica railway in Lithuania

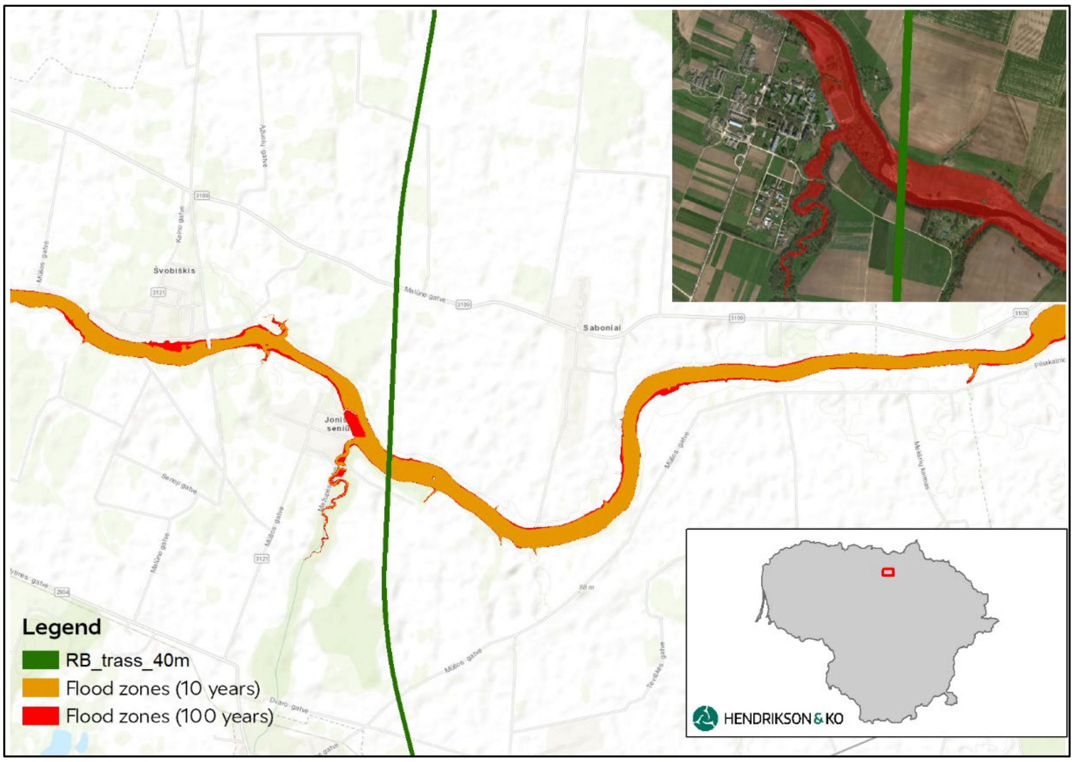


Figure 4.31 100-year flood risk area near Rail Baltica railway in Northern Lithuania (N 56°02'34.8" E 24°12'15.5")

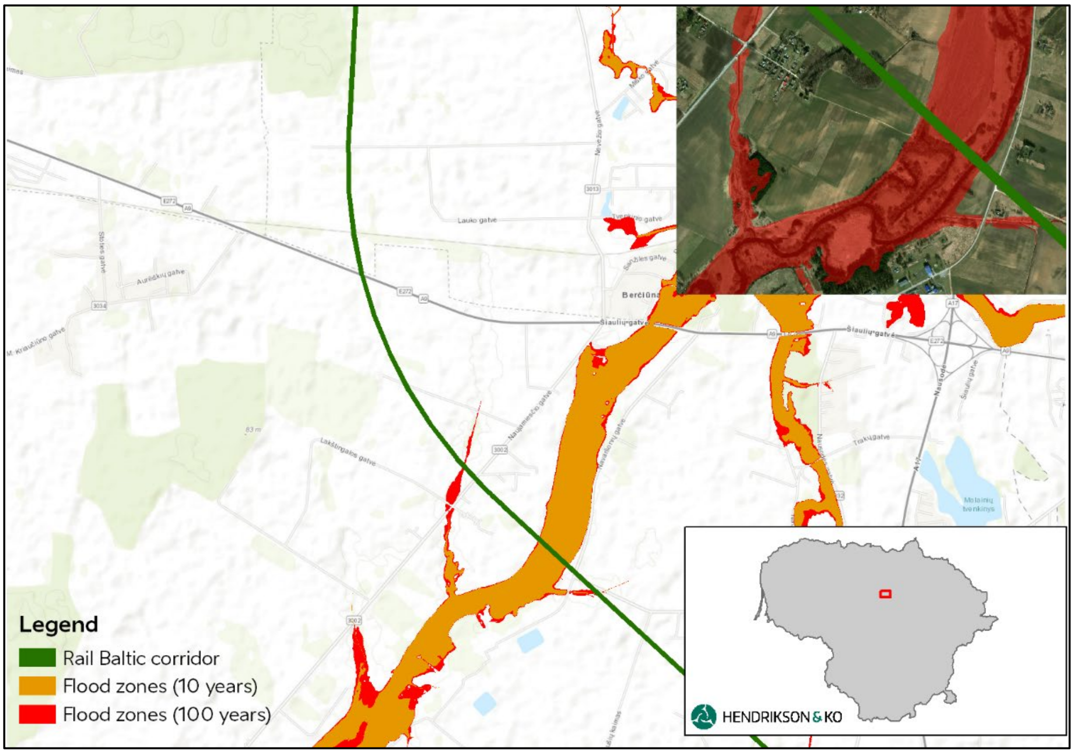


Figure 4.32 100-year flood risk area near Rail Baltica railway in Northern Lithuania (N55°43'02.7" E 24°13'22.0")

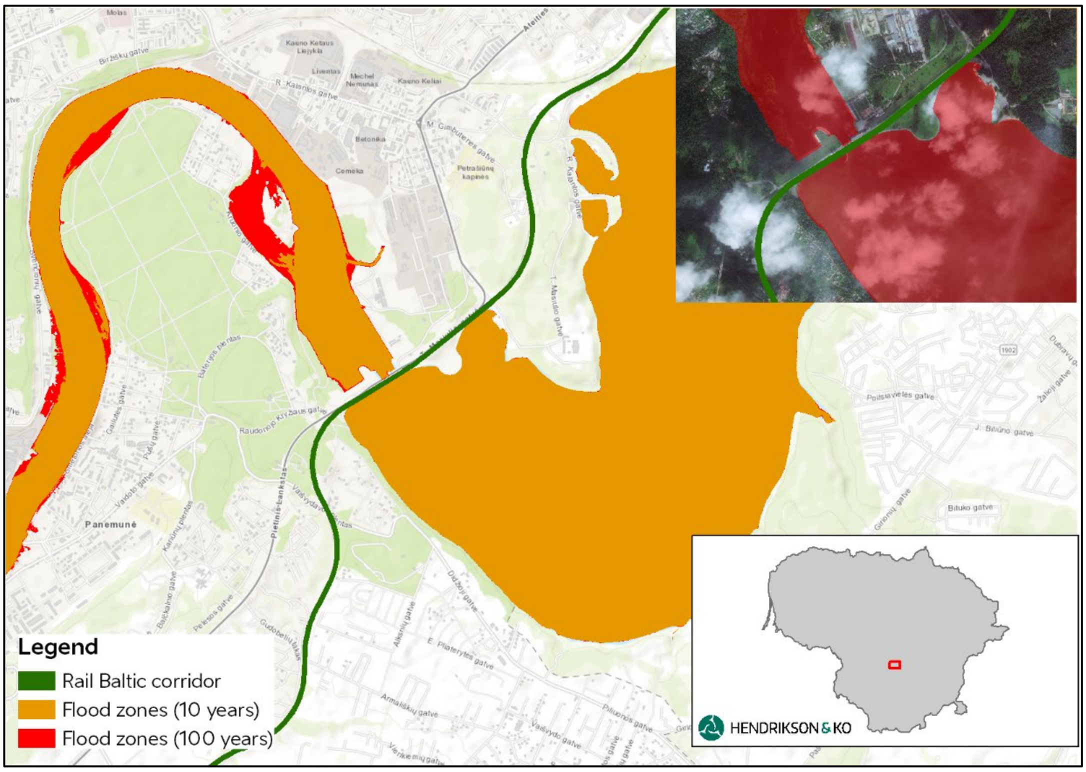


Figure 4.33 100-year flood risk area near Rail Baltica railway in city of Kaunas (N 54°52'25.4" E23°59'54.3")

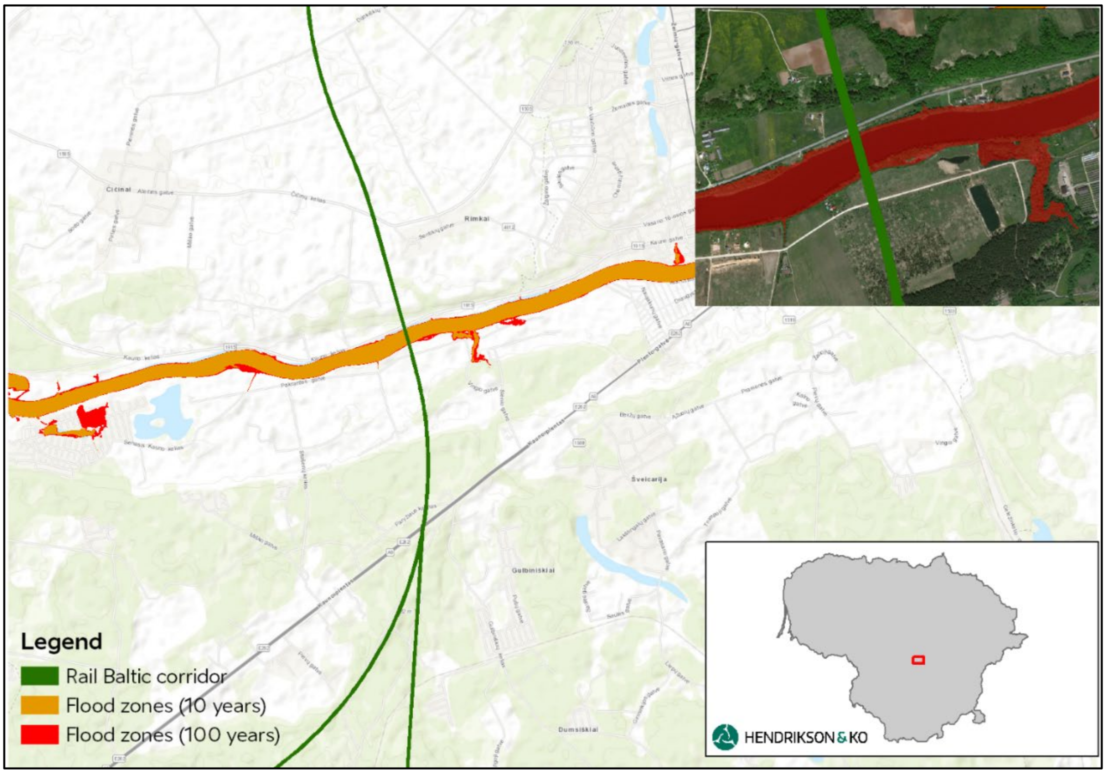


Figure 4.34 100-year flood risk area near Rail Baltica railway in city of Kaunas (N 55°03'38.4" E 24°13'33.9")

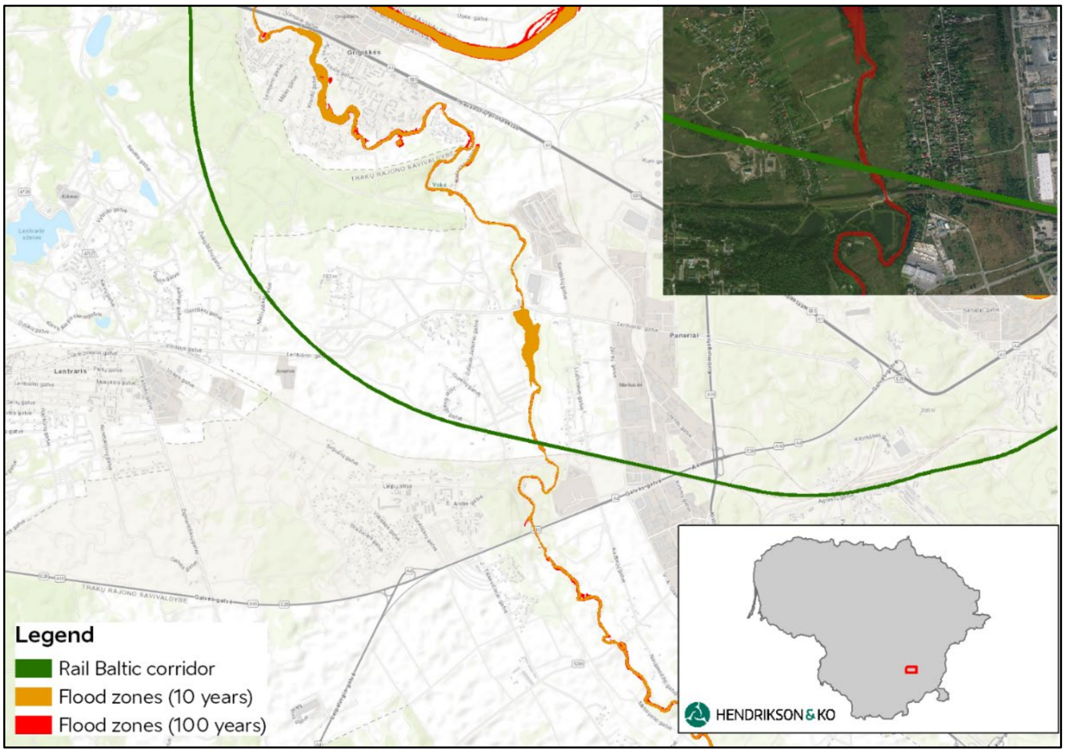


Figure 4.35 100-year flood risk area near Rail Baltica railway in city of Vilnius (N 54°38'05.9" E 25°07'17.7")

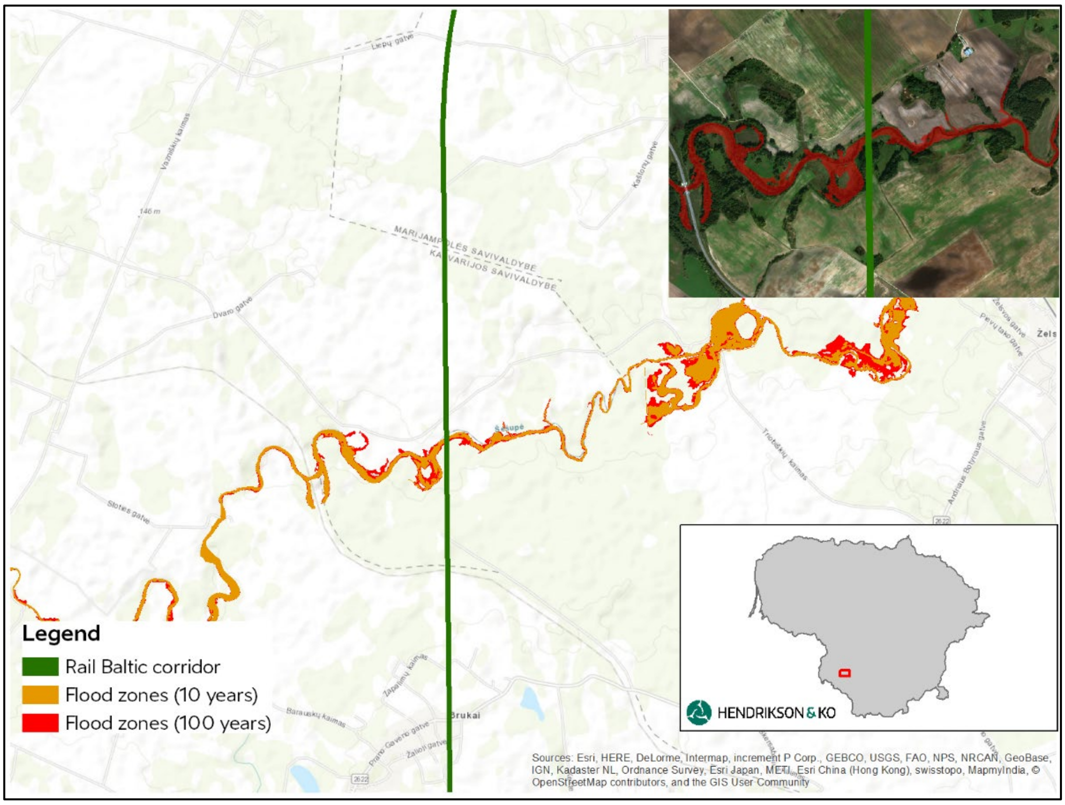


Figure 4.36 100-year flood risk area near Rail Baltica railway in South-West Lithuania (N 54°25'35.7" E23°19'43.9")

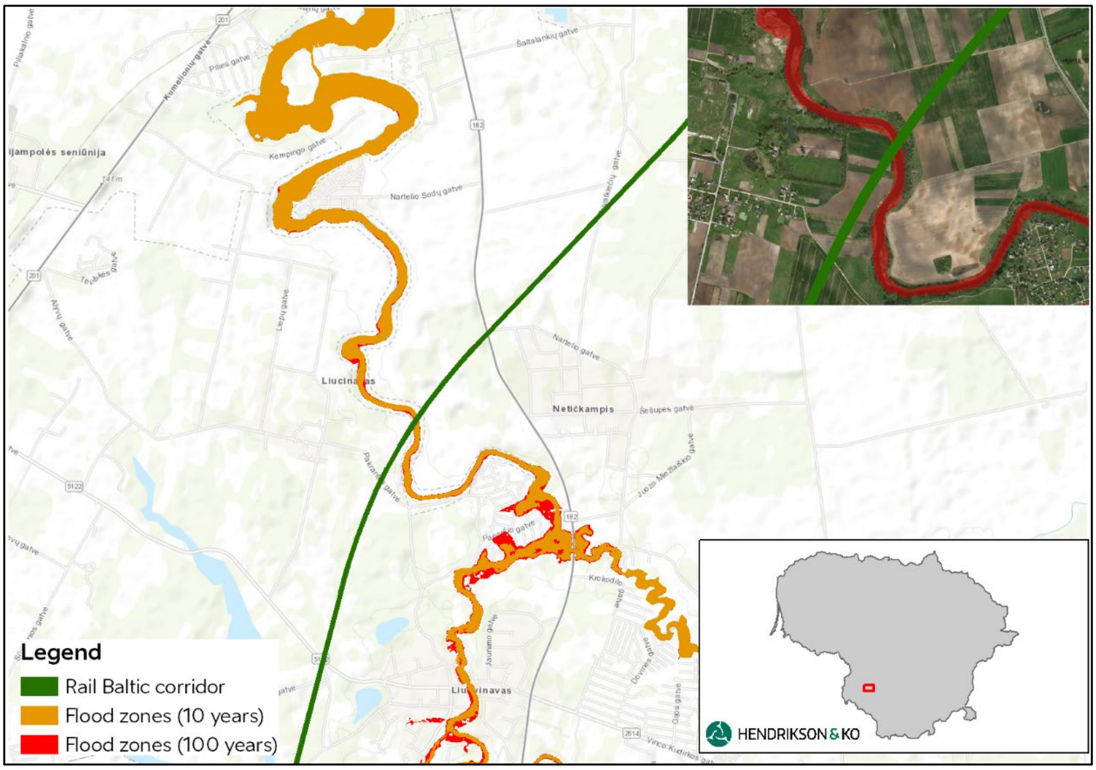


Figure 4.37 100-year flood risk area near Rail Baltica railway in South-West Lithuania (N 54°30'01.5" E 23°21'04.1").

4.1.5. Landslides

Estonia

Only registered location with landslide risk near Rail Baltica route in Estonia is the crossing of Pärnu river in city of Pärnu.

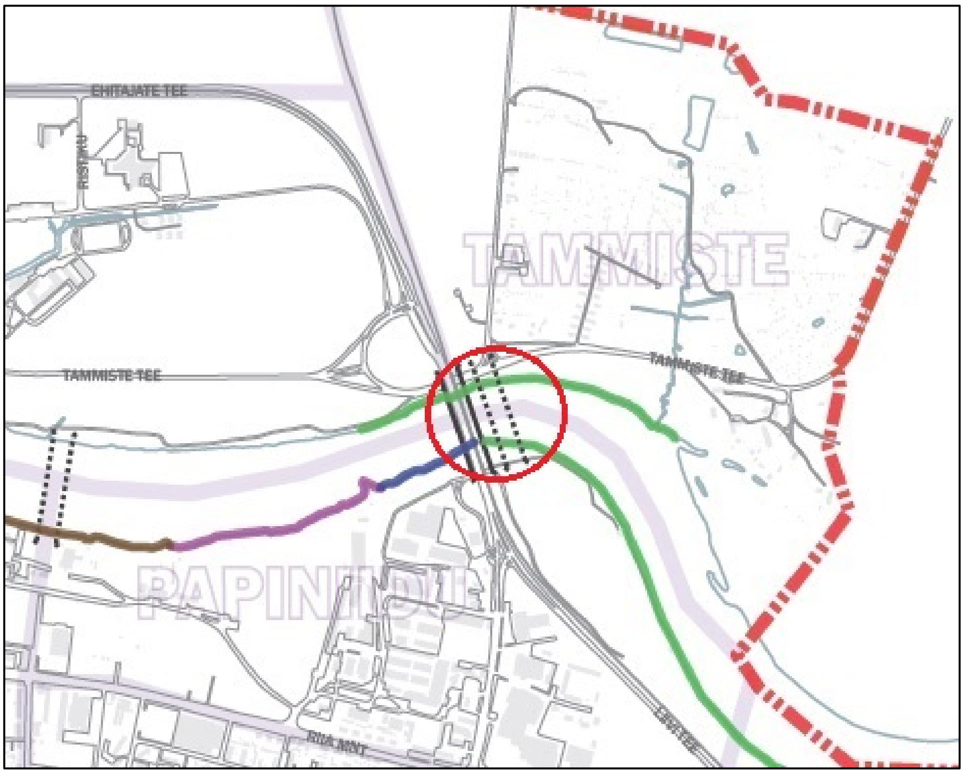


Figure 4.38 Extract from Pärnu city comprehensive plan until 2025. Dotted lines inside the red circle indicate Rail Baltica bridge location and green lines represent unstable slopes, where measures and special project is necessary for increasing the stability of the slopes.

Latvia

Landslide risk is considered very unlikely and is not relevant in Latvia routing (medium confidence). Will be investigated in detail design stage.

Lithuania

The Lithuanian Geological Survey has produced a map with registered landslide events – see Figures 4.39 – 4.41. These areas could also pose increased landslide risks to Rail Baltica.

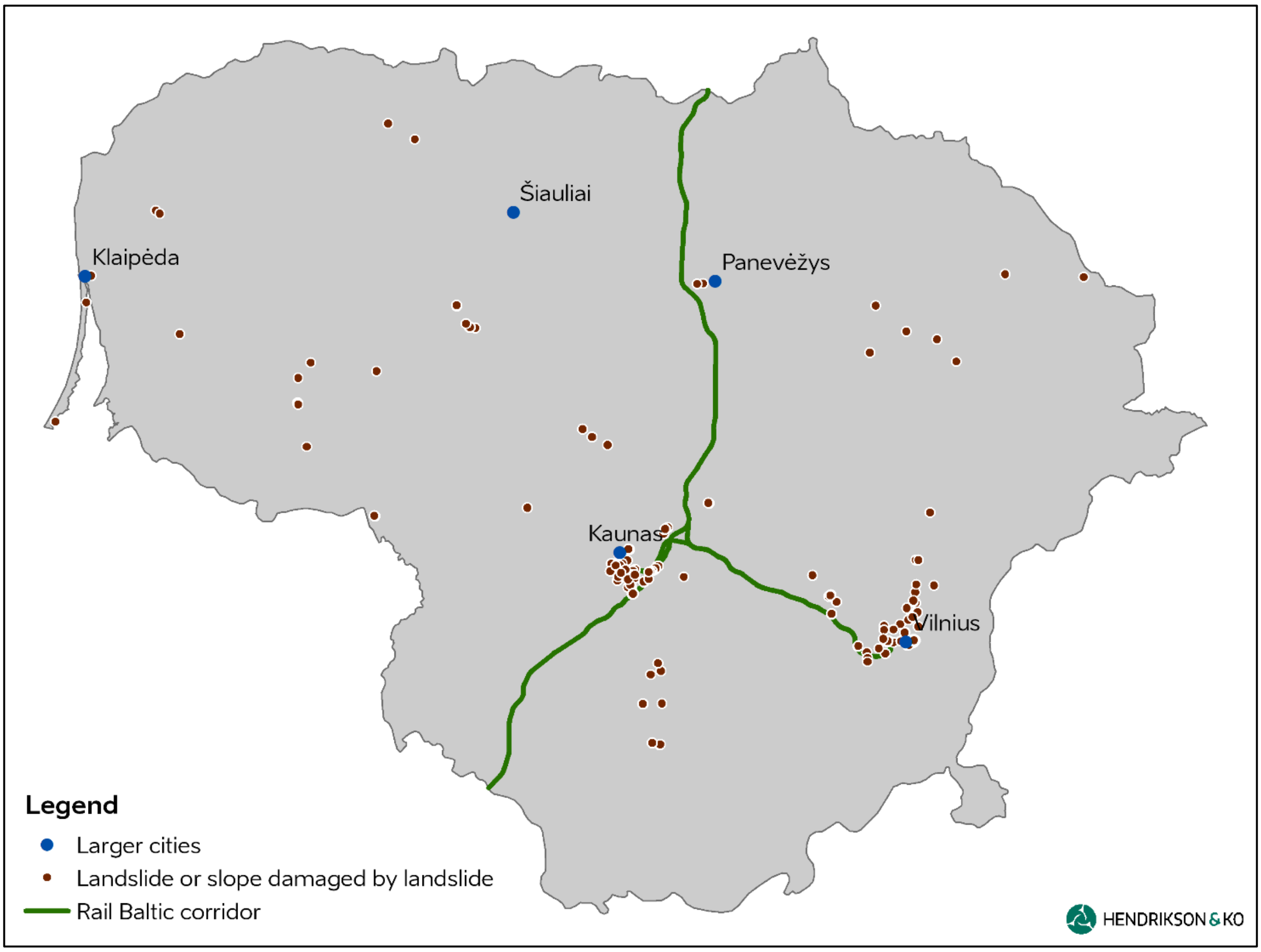


Figure 4.39 Registered landslide or slope damage by landslides events in Lithuania

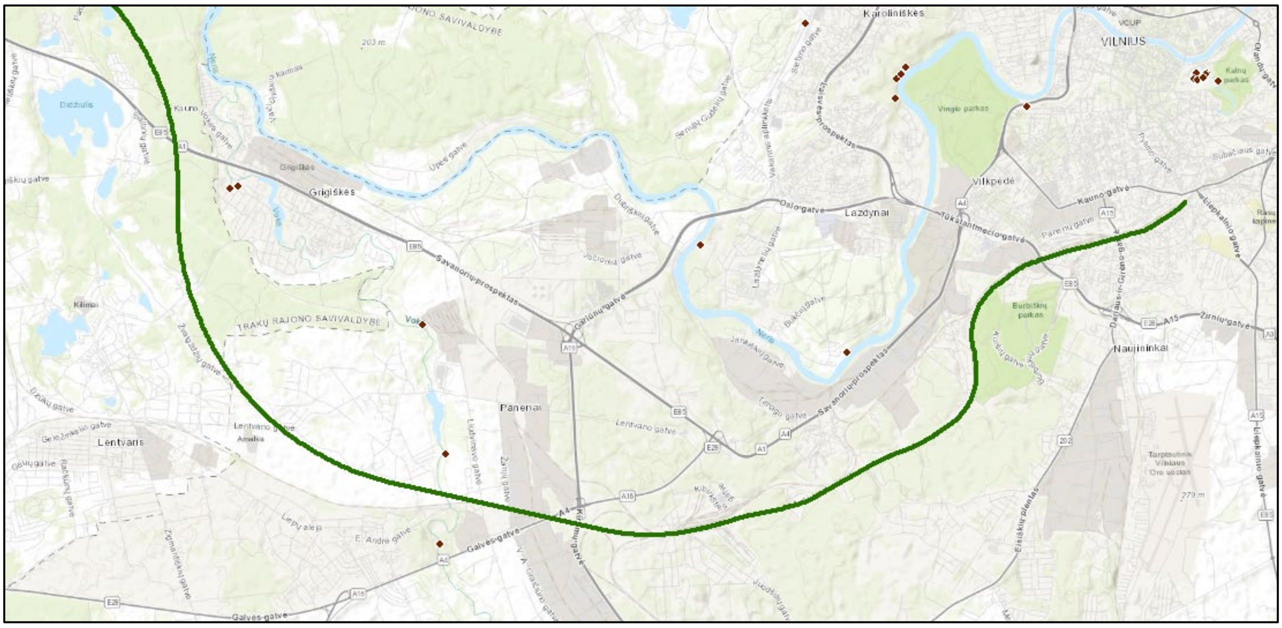


Figure 4.40 Registered landslide or slope damage by landslides events in city of Vilnius

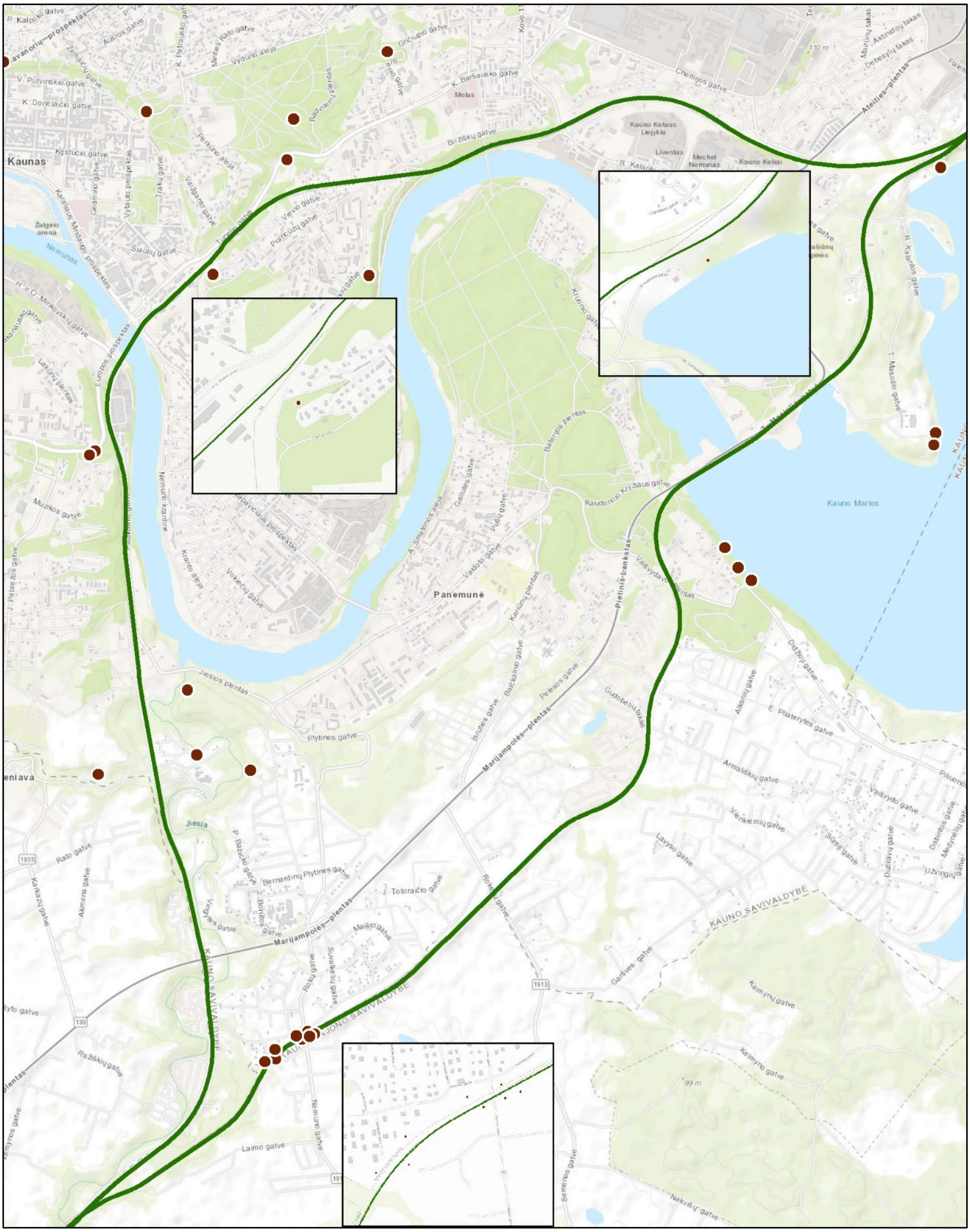


Figure 4.41 Registered landslide or slope damage by landslides events in city of Kaunas

4.1.6. Wind

The variation in monthly mean speeds (average of a continuous record) and highest gusts ('instantaneous' speed averaged over about 3 seconds) is shown below. In regard designing, maintenance and operating, the primary focus should be given to maximum wind speed (wind direction, frequency and magnitude).

The wind conditions vary along Rail Baltica corridor depending on seacoast proximity, landscape openness and other roughness factors. The annual average wind speed varies from 2,6 m/s in inland (Kuusiku) to 3,8 m/s in coastal zone (Pärnu) or open landscape (Kaunas). According to the Estonian wind atlas and modelling results (Kull 2003), the annual average wind speed at 10 m varies between 2 and 3,5 m/s in inland routing and raises up to 5 m/s near Tallinn. The routing between Pärnu and Riga falls to moderate wind speed zone, just at the edge of coastal wind zone where the wind speed depends rather on landscape openness, how forested the area along the routing is.

The risk rises significantly from winds at an average speed of 21 m/s, which can be accompanied by a break of the trees as well as the destruction of buildings. The strongest winds are associated with the passage of deep areas of low pressure. The frequency and strength of these depressions is greatest in the winter half of the year, especially from late September to February, and this is when mean speeds and gusts (short duration peak values) are strongest. Maximum average wind speed (m/s) in meteorological stations during period 1981-2017 varies from 13,7 to 20 m/s, being in average 14-15 m/s. Wind speed in Estonia is rising above 21 m/s on average 1.7 days a year. Between 1981-2017, such strong wind was registered only in Estonian islands, not in Rail Baltica routing.

The dangerous impact of gusts increases significantly from 25 m/s which can happen in inland territories almost everywhere. The western cyclones dominate with 83% of all year's storms (Eesti ilma riskid 2012). Maximum wind gust speed (m/s) in meteorological stations during period 1981-2017 varies between 26 and 40 m/s, with the maximum gusts registered in Ainaži and Bauska stations in Latvia. Gusts occur during winter storms in December-January. Also, gusts coincident with thunderstorms during summer (specially August). The so-called Storm of the 20th Century in Estonia occurred on the 6th-7th August, 1967, when the highest outbreak gust wind was recorded 35 m/s.

Summary of the most relevant wind related variables is presented in the figure 4.42.

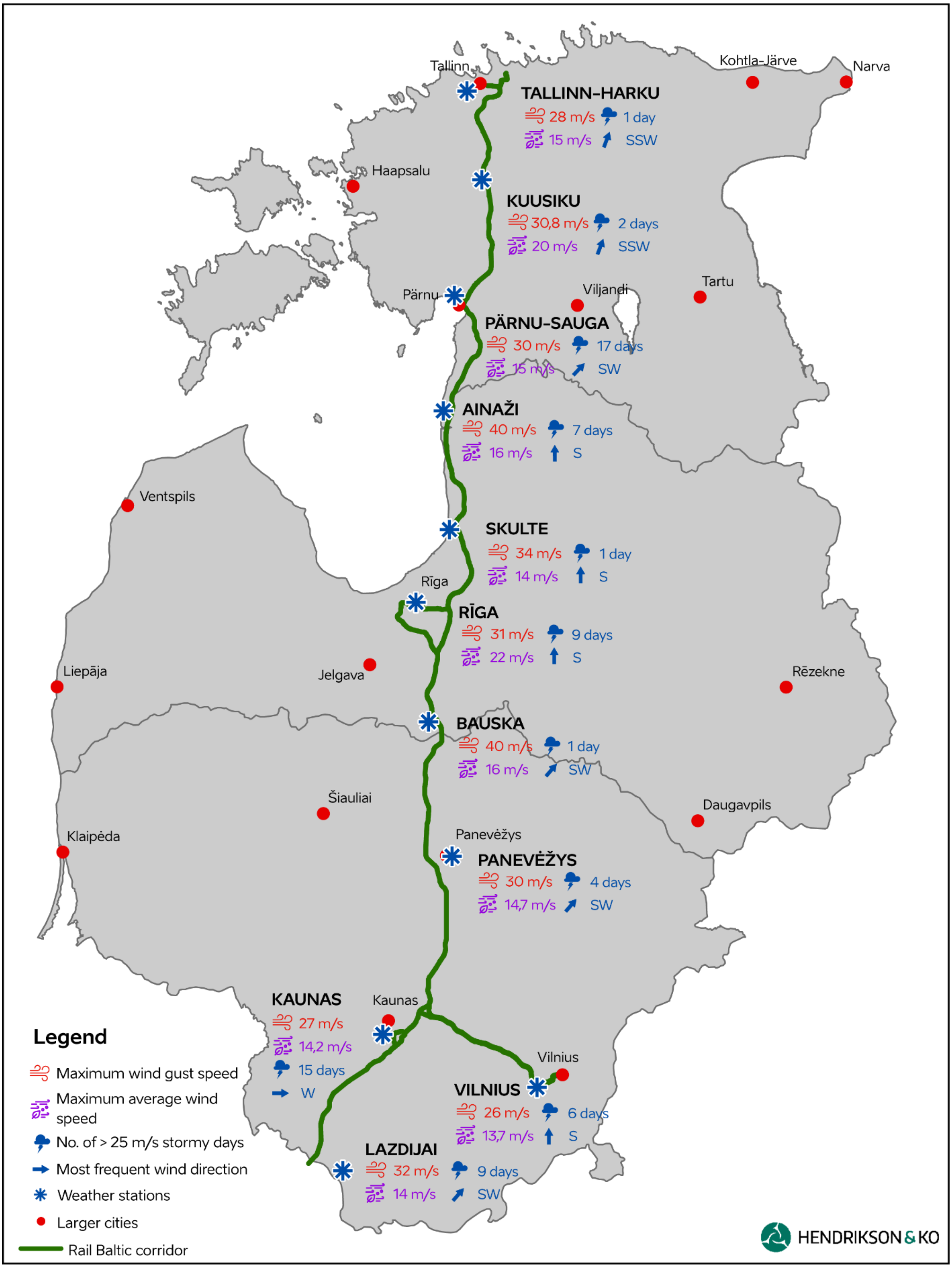


Figure 4.42 Most relevant wind related variables during period 1981-2017 in 11 stations along Rail Baltica

Estonia

Average wind speeds (m/s) during period 1981-2010 in Estonian and Lithuanian meteorological stations are presented in Table 4.10 and Figure 4.43.

Table 4.10 Monthly average wind speed (m/s) in meteorological stations during period 1981-2010

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	4,1	3,8	3,5	3,5	3,3	3,1	2,9	2,9	3,2	3,6	3,9	3,9	**3,5**
KUUSIKU	3,1	2,9	2,8	2,8	2,6	2,3	2,1	2,1	2,3	2,7	2,9	3	**2,6**
PÄRNU	4,5	4	3,7	3,5	3,5	3,5	3,4	3,5	3,7	4,2	4,3	4,3	**3,8**
PANEVĖŽYS	3,9	3,6	3,5	3,3	3,1	3,0	2,8	2,7	2,9	3,4	3,6	3,6	**3,3**
KAUNAS	4,7	4,3	4,1	3,7	3,4	3,2	3,0	3,0	3,4	4,0	4,3	4,4	**3,8**
VILNIUS	4,0	3,7	3,5	3,2	3,0	2,9	2,7	2,7	2,9	3,5	3,7	3,8	**3,3**
LAZDIJAI	4,0	3,6	3,4	3,1	2,9	2,9	2,7	2,6	2,9	3,3	3,7	3,7	**3,2**

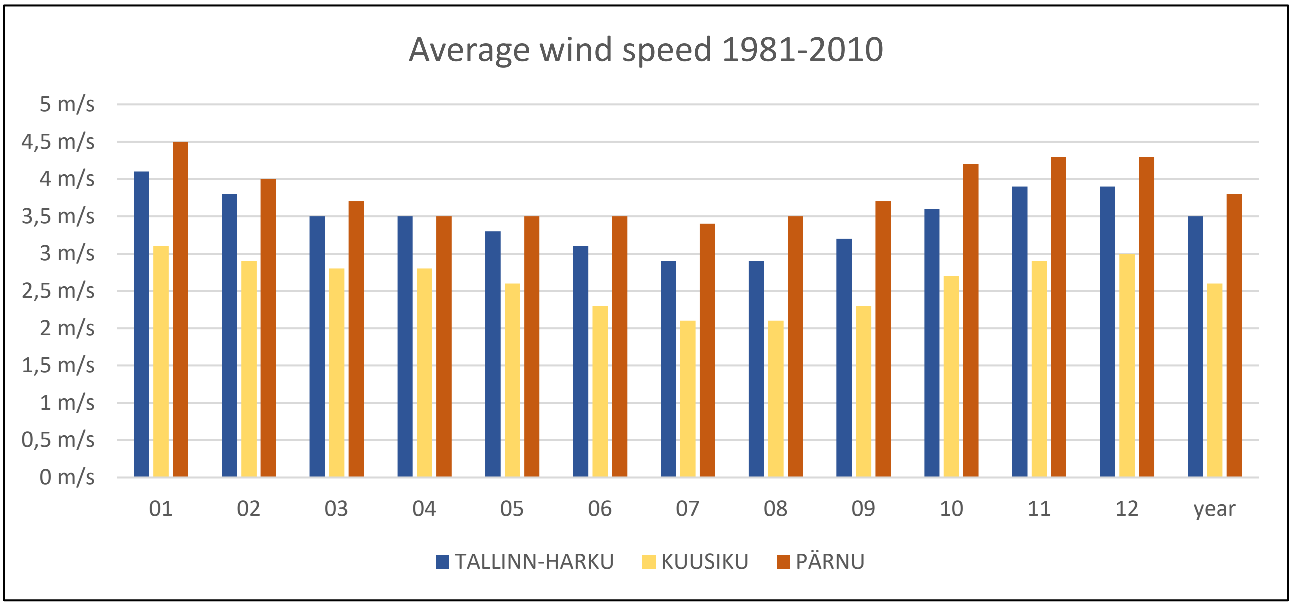


Figure 4.43 Monthly average wind speed in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2010

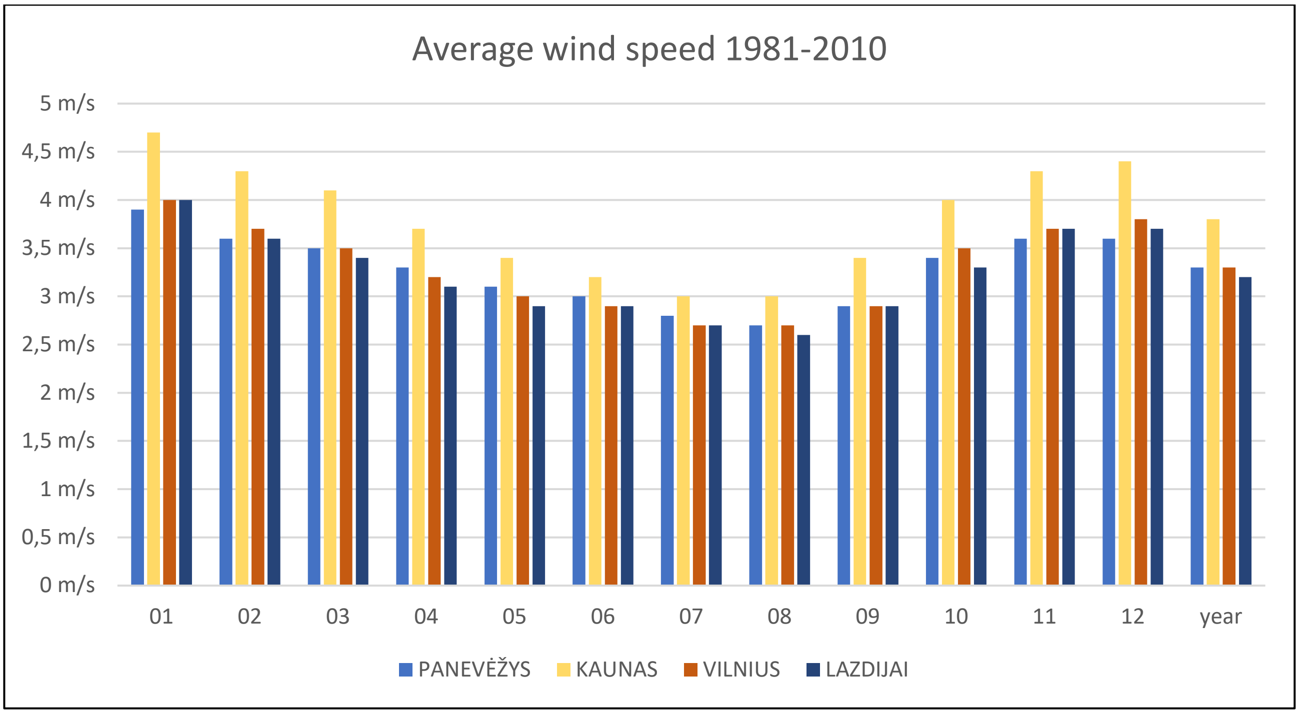


Figure 4.44 Monthly average wind speed in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010

Maximum average wind speed (m/s) in each month during period 1981-2017 in Tallinn-Harku, Kuusiku and Pärnu meteorological stations is presented in Table 4.11 and Figure 4.45.

Table 4.11 Maximum average wind speed (m/s) in each month in meteorological stations during period 1981-2017

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	13,0	13,0	13,0	15,0	11,0	12,0	10,0	10,0	11,0	12,0	12,0	15,0	**15,0**
KUUSIKU	19,0	20,0	18,0	15,1	15,0	16,0	15,0	18,0	19,0	19,0	17,0	20,0	**20,0**
PÄRNU	14,0	13,0	15,0	13,0	11,0	11,0	10,6	9,4	11,0	12,3	15,0	15,0	**15,0**
AINAŽI	16	13	14	12	14	12	15	12	12	15	15	16	**16**
SKULTE	13	11	14	8	10	9	10	11	10	14	13	12	**14**
RĪGA	22	16	19	13	13	14	15	15	15	17	17	20	**22**
BAUSKA	14	12	13	11	11	12	14	11	10	12	16	14	**16**
PANEVĖŽYS	14,7	12,3	13,5	12,7	12,9	12,1	11,7	12,6	12,5	13,3	13,3	12,8	**14,7**
KAUNAS	14,2	12,9	13,8	13,0	11,8	12,0	11,0	11,0	11,9	11,7	12,2	12,4	**14,2**
VILNIUS	13,3	11,8	13,7	13,0	11,5	11,7	11,1	11,0	10,8	11,3	11,6	11,7	**13,7**
LAZDIJAI	14,0	12,6	13,8	13,1	11,5	12,2	11,7	11,0	11,3	12,2	12,4	12,4	**14,0**

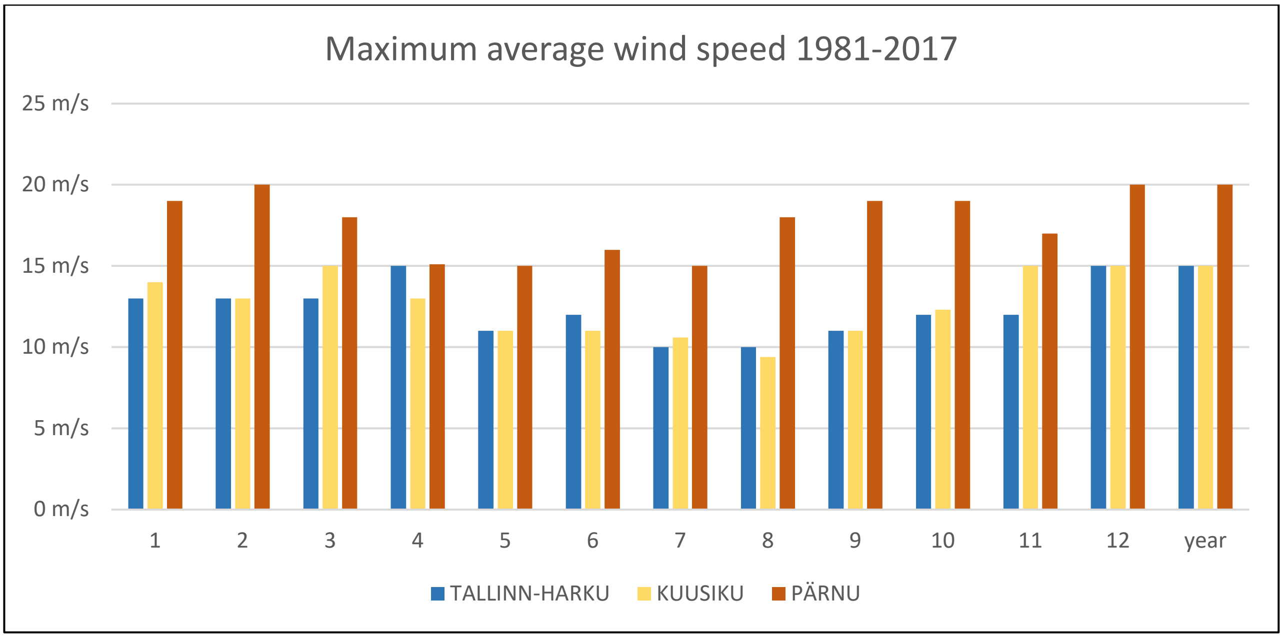


Figure 4.45 Maximum average wind speed in each month in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2017

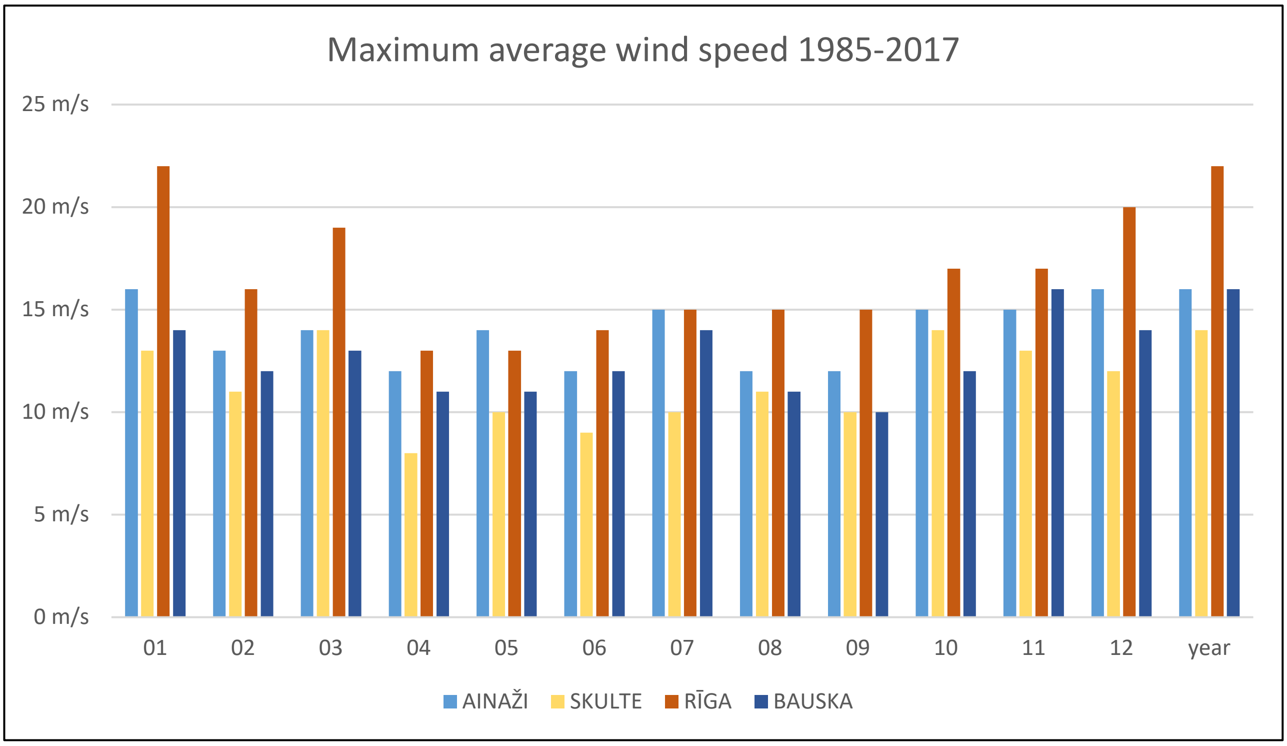


Figure 4.46 Maximum average wind speed in Ainaži, Skulte, Riga and Bauska meteorological stations during period 1985-2017

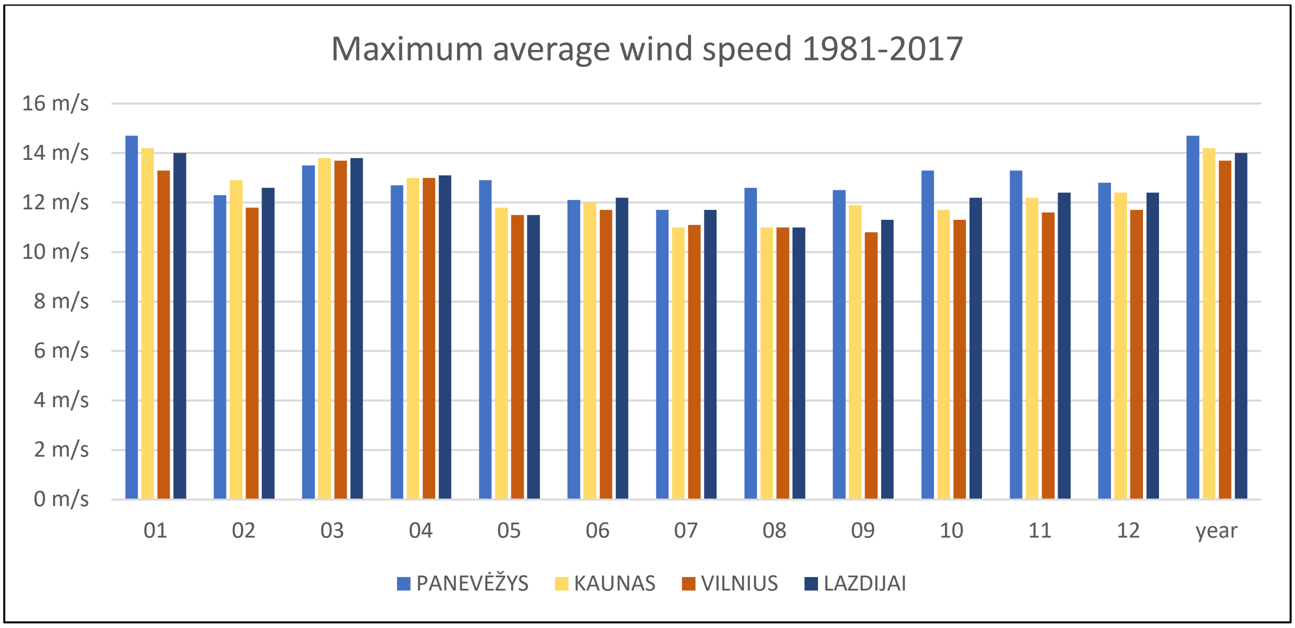


Figure 4.47 Maximum average wind speed in each month in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2017

Maximum wind gust speed (m/s) in each month during period 1981-2017 in meteorological stations is presented in table 4.12 and figure 4.48.

Table 4.12 Maximum wind gust speed (m/s) in each month in meteorological stations during period 1981-2017

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	24	23	24	23	22	21	21	22	21	22	24	28	**28**
KUUSIKU	31	26	25	24	26	24	23	24	26	29	26	29	**31**
PÄRNU	23	24	23	21	20	21	30	22	18	24	23	26	**30**
AINAŽI	32	22	23	20	21	20	21	27	26	26	40	26	**40**
SKULTE	27	24	21	20	23	20	21	21	24	34	34	24	**34**
RĪGA	30	28	25	24	23	26	23	23	25	24	31	27	**31**
BAUSKA	40	23	24	26	20	21	20	23	24	30	28	25	**40**
PANEVĖŽYS	30	27	23	22	22	24	20	22	23	25	24	25	**30**
KAUNAS	27	25	25	24	24	23	27	26	23	24	26	25	**27**
VILNIUS	25	22	22	23	25	25	24	20	19	22	22	26	**26**
LAZDIJAI	28	24	27	22	21	22	24	22	20	22	25	32	**32**

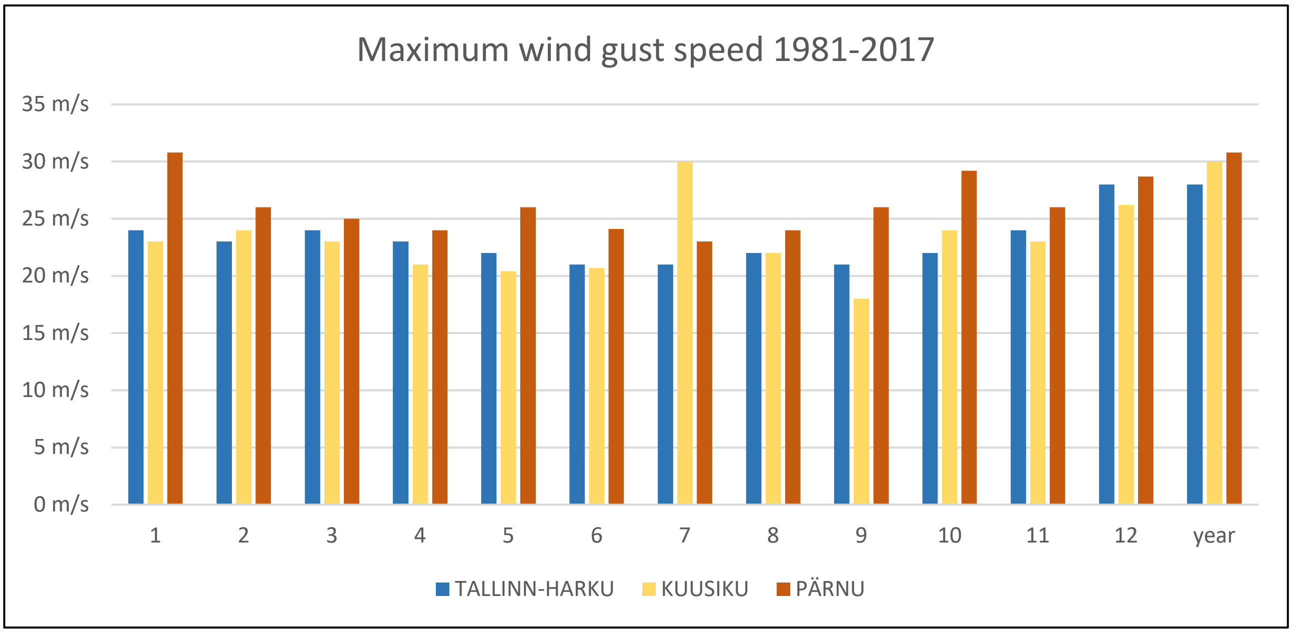


Figure 4.48 Maximum wind gust speed in each month in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2017

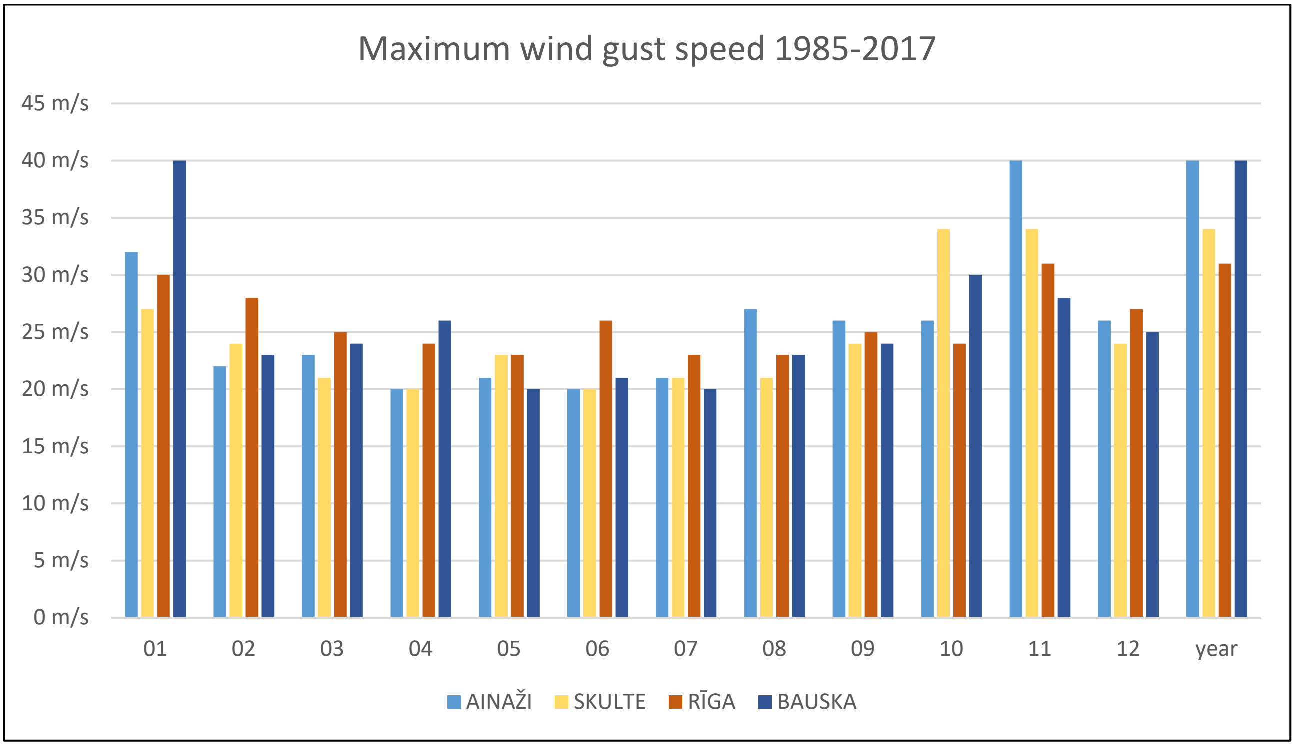


Figure 4.49 Maximum wind gust speed in Ainaži, Skulte, Riga and Bauska meteorological stations during period 1985-2017

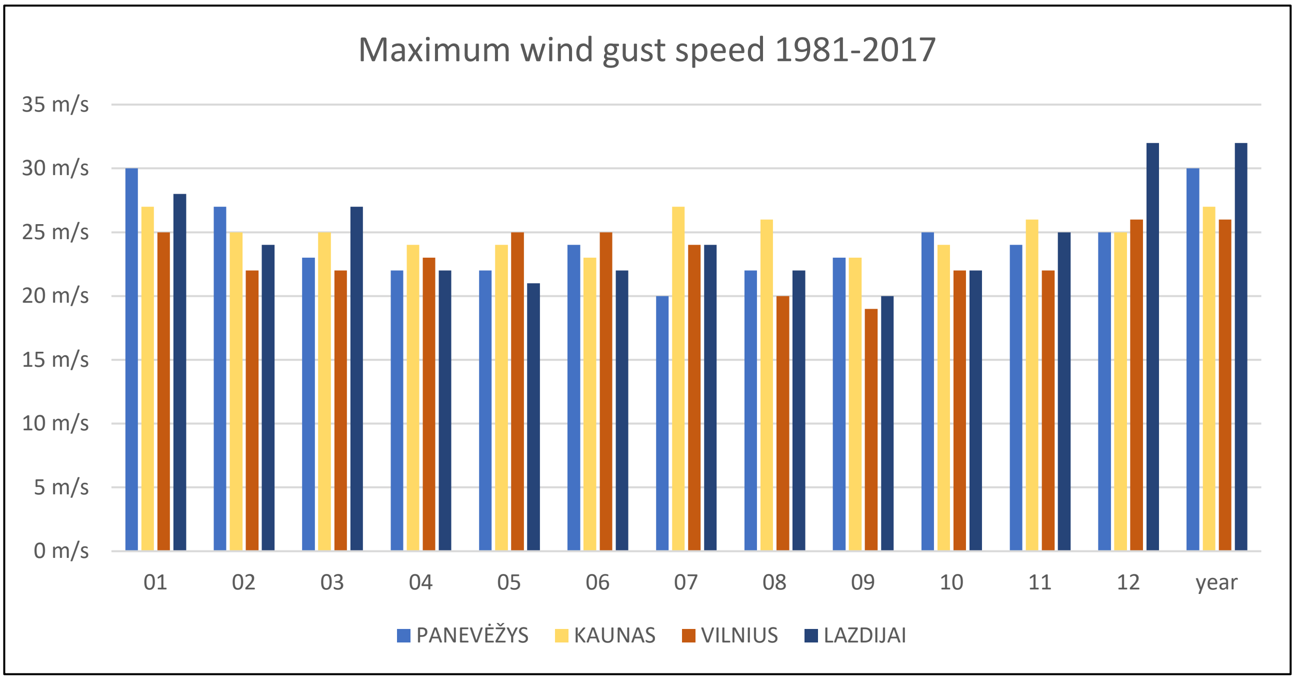


Figure 4.50 Maximum wind gust speed in each month in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2017

Number of >25 m/s stormy days during period 1981-2017 in each month in Tallinn-Harku, Kuusiku and Pärnu meteorological stations is presented on Figure 4.51, Ainaži, Skulte, Riga and Bauska (1985-2017)on Figure and in Panevėžys, Kaunas, Vilnius and Lazdijai (1981-2017) on Figure 4.45.

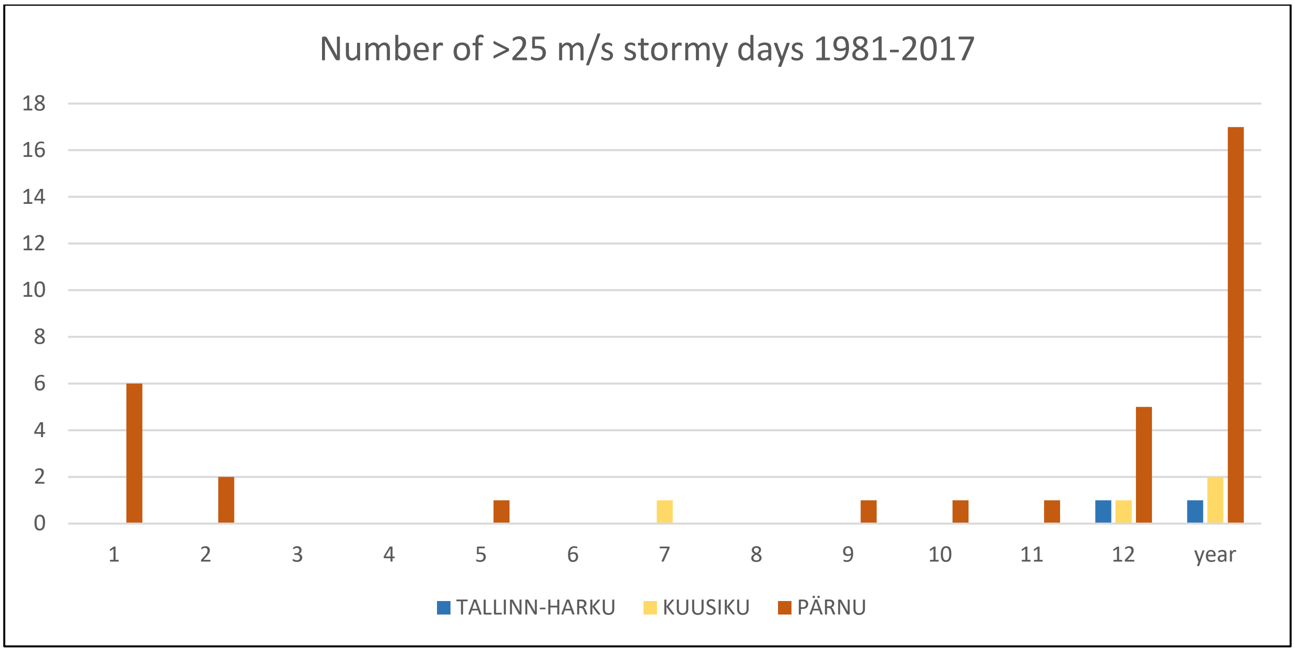


Figure 4.51 Number of >25 m/s stormy days in each month in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2017

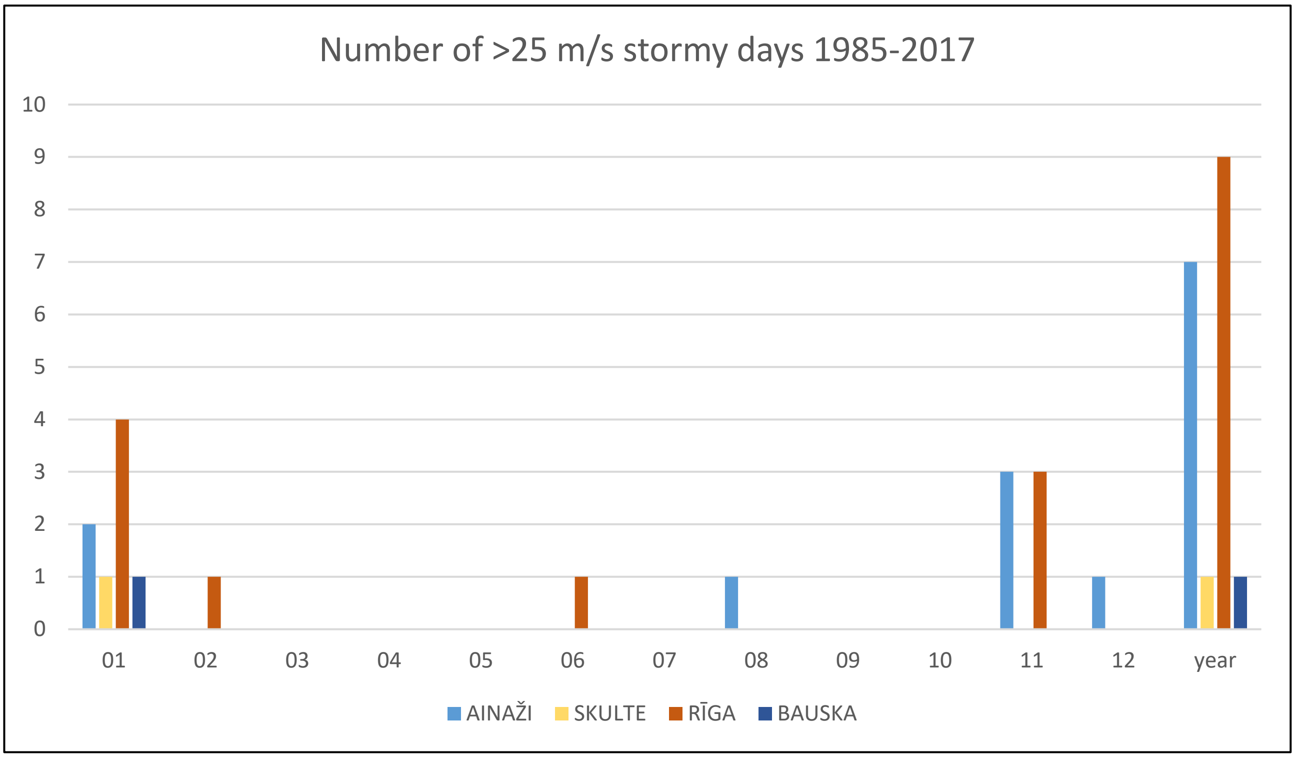


Figure 4.52 Number of >25 m/s stormy days in each month in Ainaži, Skulte, Riga and Bauska meteorological stations during period 1985-2017

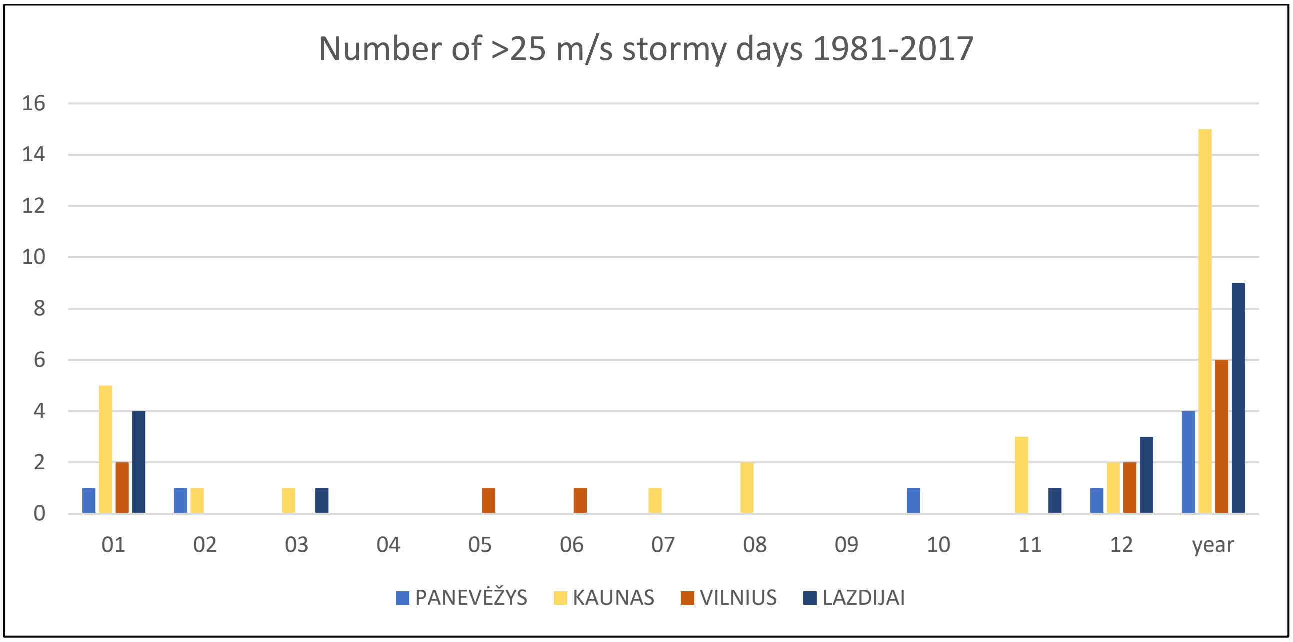
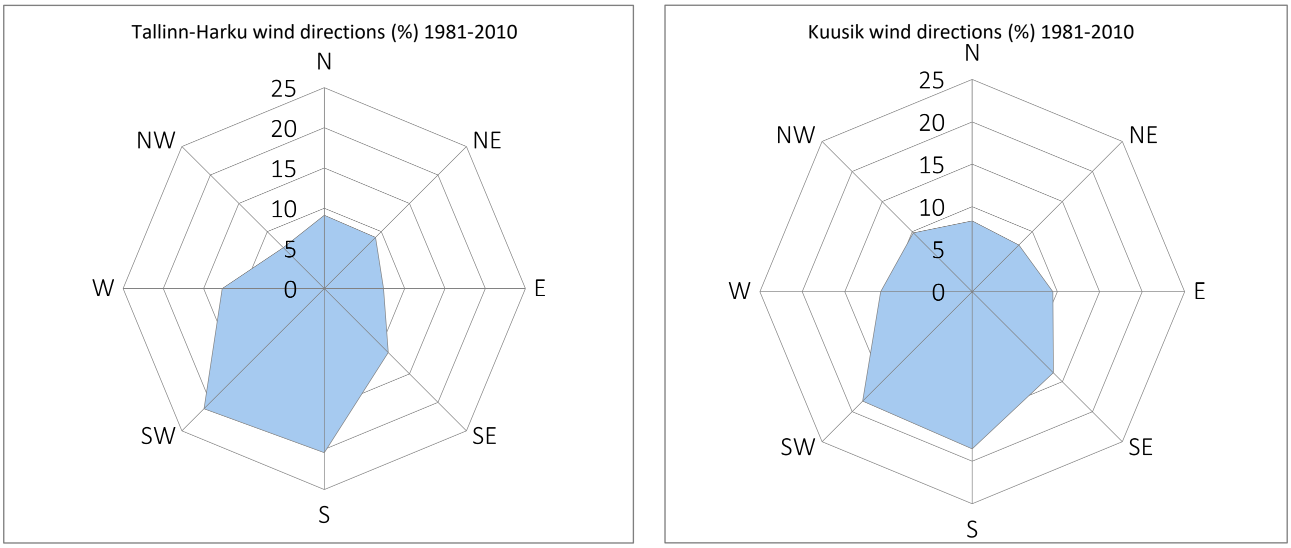
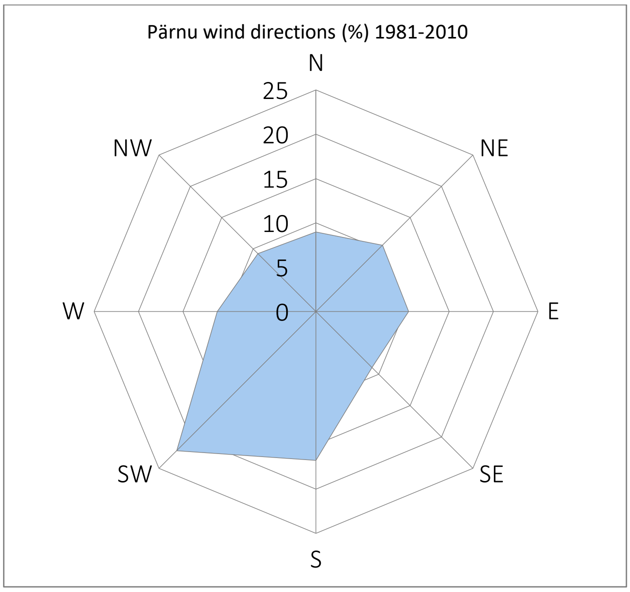


Figure 4.53 Number of >25 m/s stormy days in each month in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2017

Average wind directions (%) in the meteorological stations near Rail Baltica are presented in the Figures 4.54-4.60.

Figure 4.54 Average wind directions (%) in Tallinn-Harku and Kuusiku station during period 1981-2010





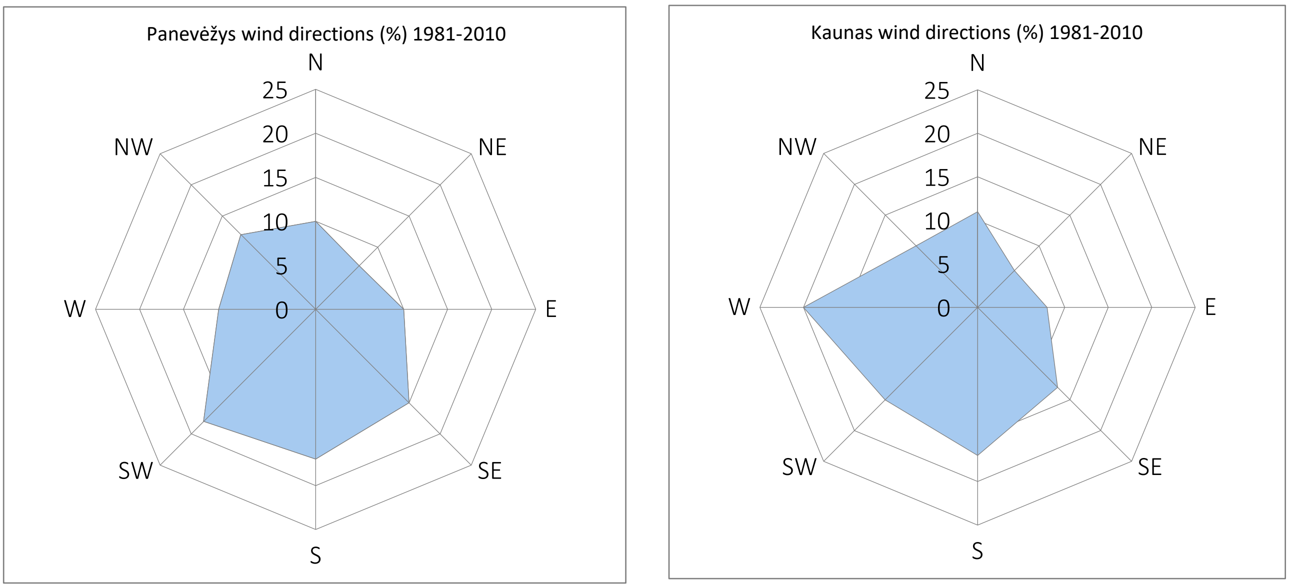


Figure 4.55 Average wind directions (%) in Pärnu, Panevėžys and Kaunas stations during period 1981-2010

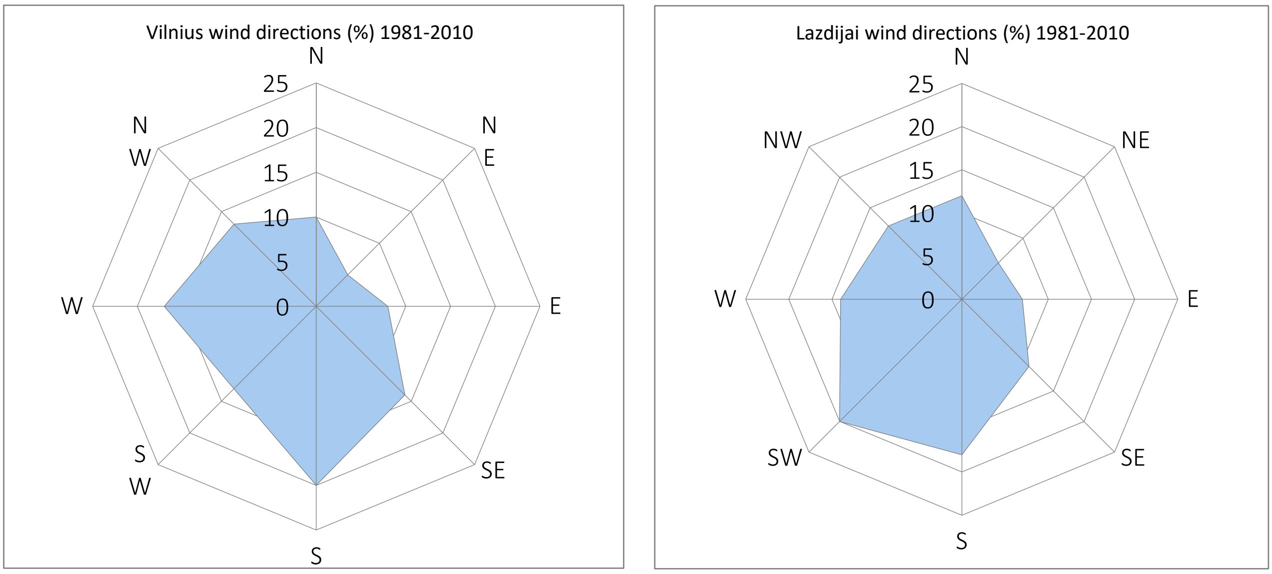


Figure 4.56 Average wind directions (%) in Vilnius and Lazdijai stations during period 1981-2010

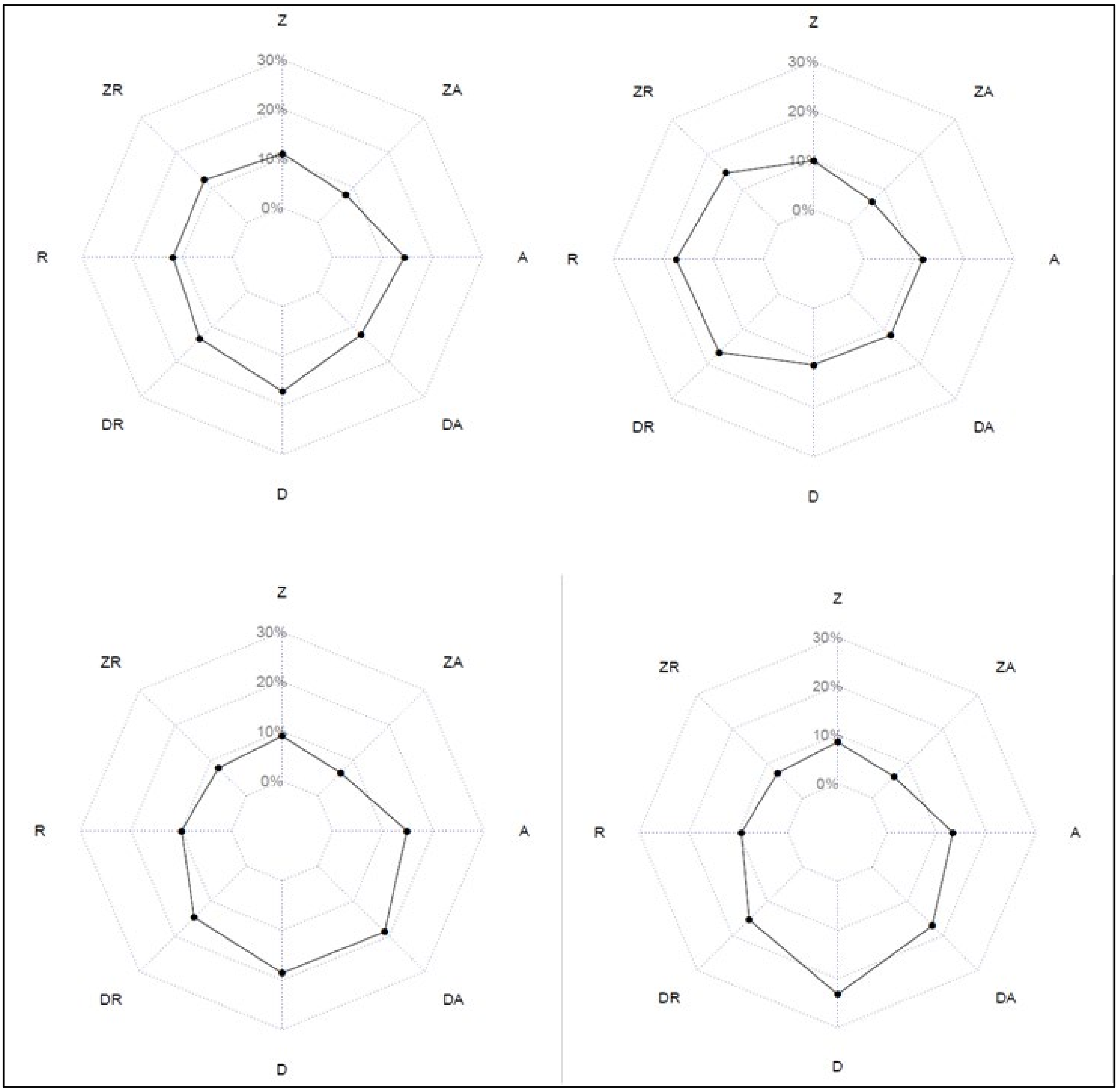


Figure 4.57 Average wind directions (%) in Ainaži station during period 1985-2017 (top row from left: spring, summer; bottom line from left: autumn, winter)

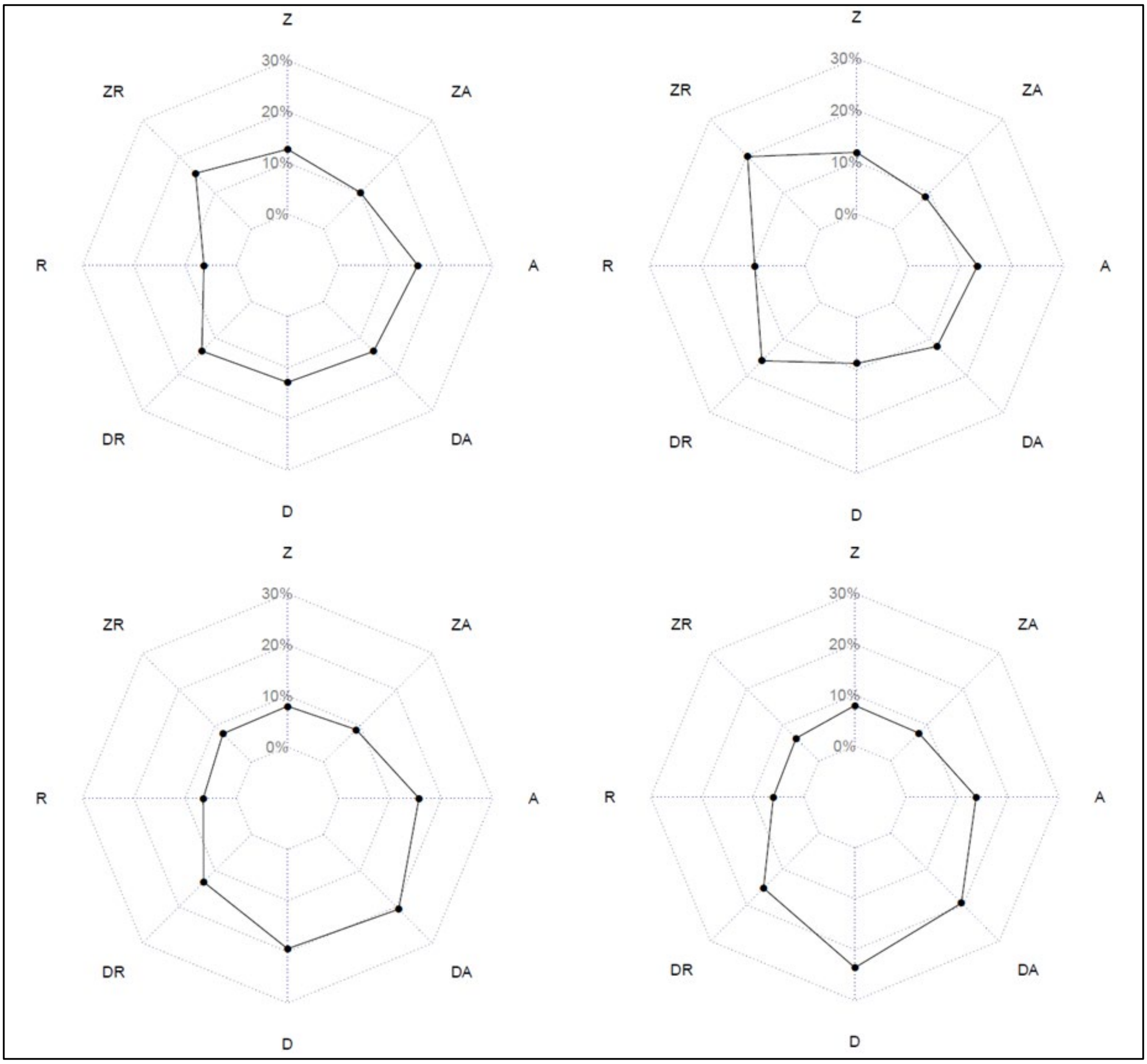


Figure 4.58 Average wind directions (%) in Skulte station during period 1985-2017 (top row from left: spring, summer; bottom line from left: autumn, winter)

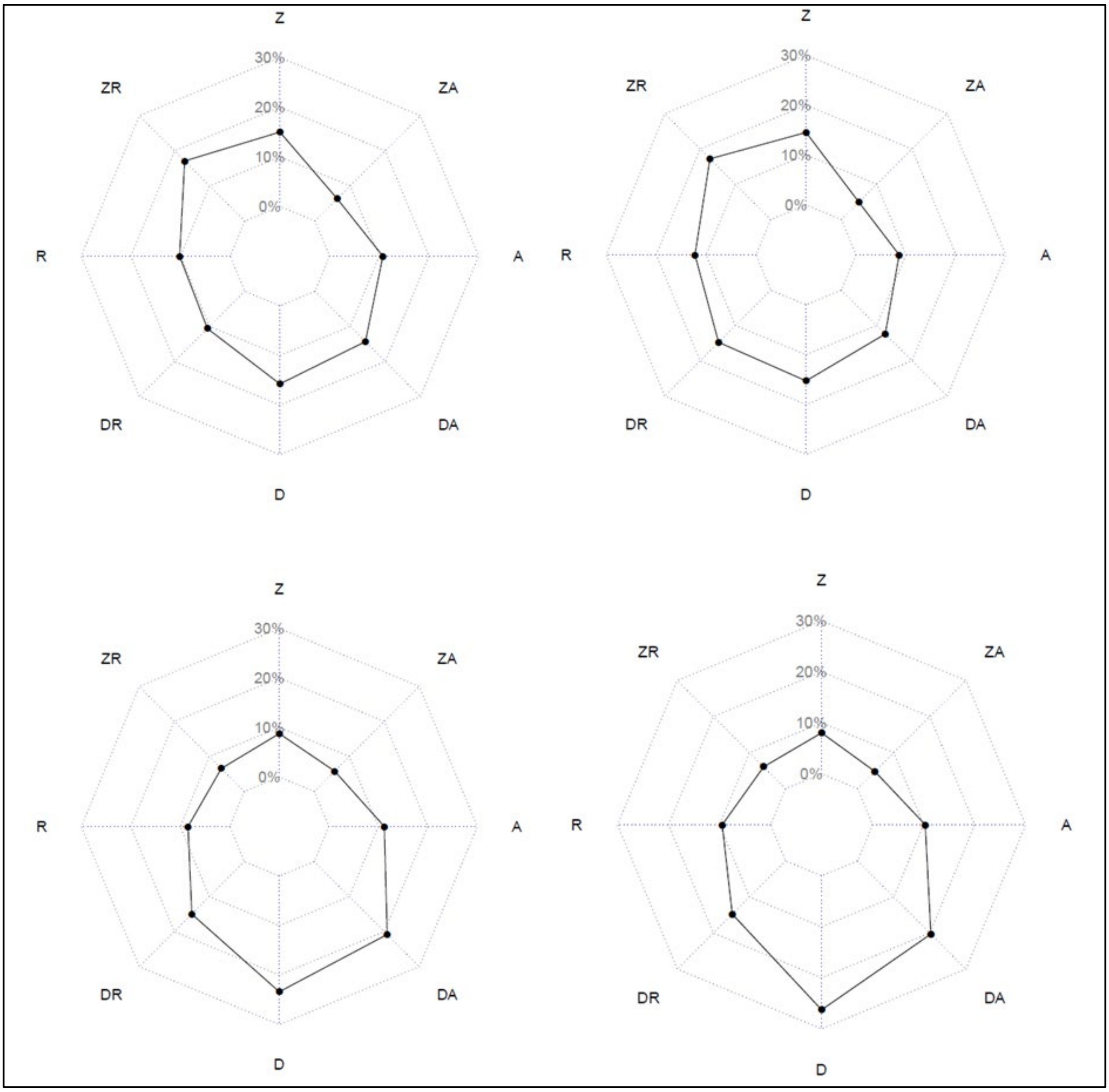


Figure 4.59 Average wind directions (%) in Riga station during period 1985-2017 (top row from left: spring, summer; bottom line from left: autumn, winter)

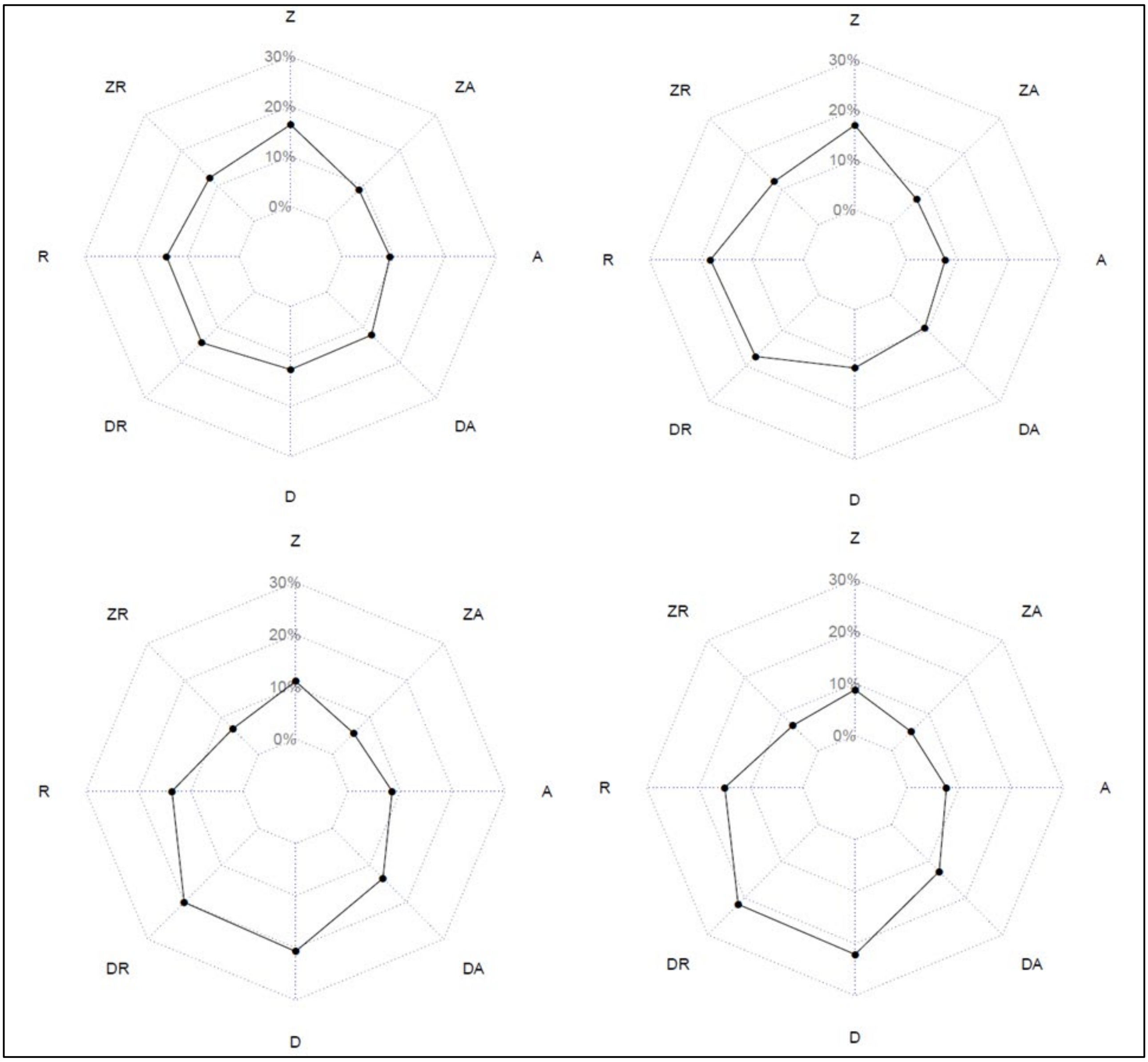


Figure 4.60 Average wind directions (%) in Bauska station during period 1985-2017 (top row from left: spring, summer; bottom line from left: autumn, winter)

4.1.7. Thunder

Rail infrastructure can also suffer severe damage from lighting strikes and the associated electrical discharge.

Estonia

Table 4.13 Mean days with thunder in in each month Tallinn-Harku (1981-2017), Kuusiku (1981-2007) and Pärnu (1981-2015) meteorological stations

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	0,03	0,00	0,00	0,08	1,78	3,03	4,24	3,86	1,38	0,41	0,11	0,00	**14,92**
KUUSIKU	0,04	0,00	0,04	0,15	2,04	3,33	4,15	3,89	1,33	0,11	0,00	0,00	**15,07**
PÄRNU	0,03	0,00	0,03	0,14	2,26	3,17	4,57	4,20	1,34	0,51	0,03	0,00	**16,29**

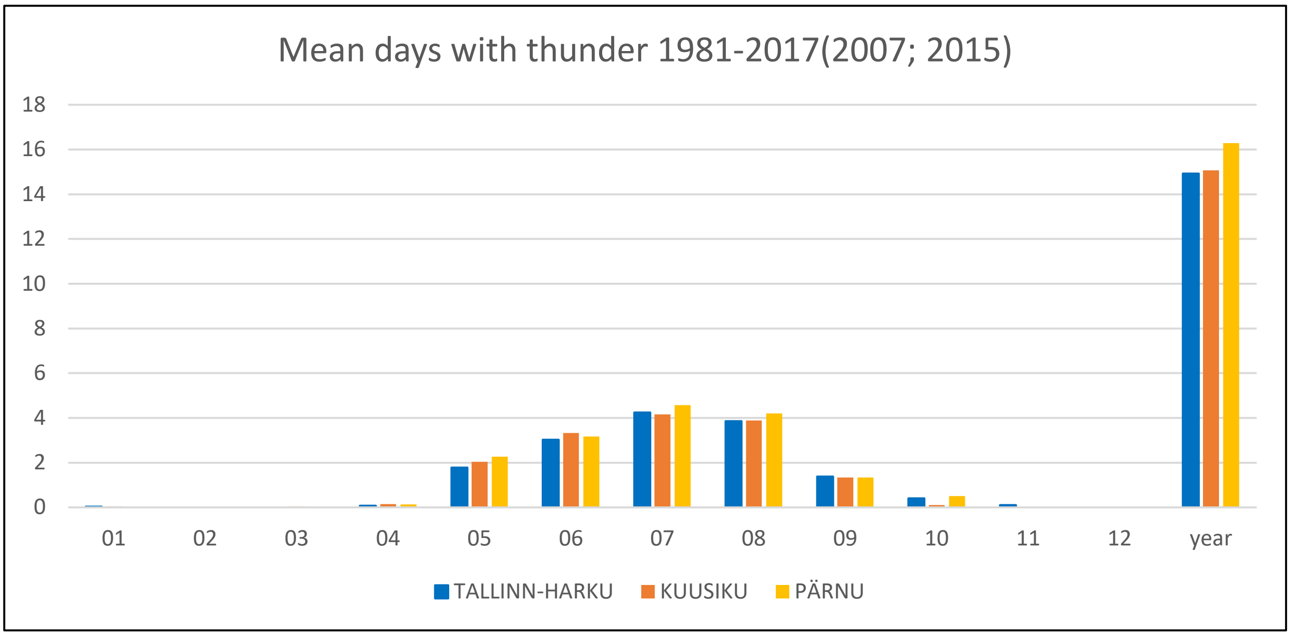


Figure 4.61 Mean days with thunder in each month in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2017 in Tallinn-Harku station. 1981-2007 in Kuusiku station and 1981-2015 in Pärnu station

Latvia

The average thunderstorm day frequency in Latvia over the period of 1960–2015 has been between 14.5 days in the coastal areas of the Baltic Sea and 23 days in the upland areas of the eastern part of the country, highlighting the role of orography in the spatial distribution of convective phenomena in the country. In comparison with the reference period 1961–1990, during the recent 30-year (1981–2010) normal period the number of thunderstorm events per year decreased by about 2, with the smallest and greatest changes taking place in the western part and the eastern parts of the country, respectively. (Zanita Avotniece, et al, 2017)

The lack of firm conclusions regarding the past and future behaviour of thunderstorm events is highly associated with the aforementioned observational limitations, and therefore the development of effective national warning systems is essential for mitigation of adverse effects of any possible changes to come. (Zanita Avotniece, et al, 2017)

Table 4.14 Mean days with thunder in in each month in Ainaži (1986-2009), Skulte (1986-2011), Riga (1986-2017) and Bauska (1986-2008) meteorological stations

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
AINAŽI	0,0	0,0	0,0	0,4	2,1	3,2	4,2	2,6	1,6	0,7	0,0	0,0	**14,8**
SKULTE	0,0	0,0	0,0	0,3	2,5	3,2	3,3	1,8	0,8	0,1	0,0	0,0	**12,0**
RĪGA	0,1	0,0	0,1	0,3	2,4	3,6	4,7	4,1	1,3	0,4	0,1	0,1	**17,2**
BAUSKA	0,0	0,0	0,0	0,6	2,7	4,0	4,7	3,0	1,2	0,1	0,0	0,0	**16,3**

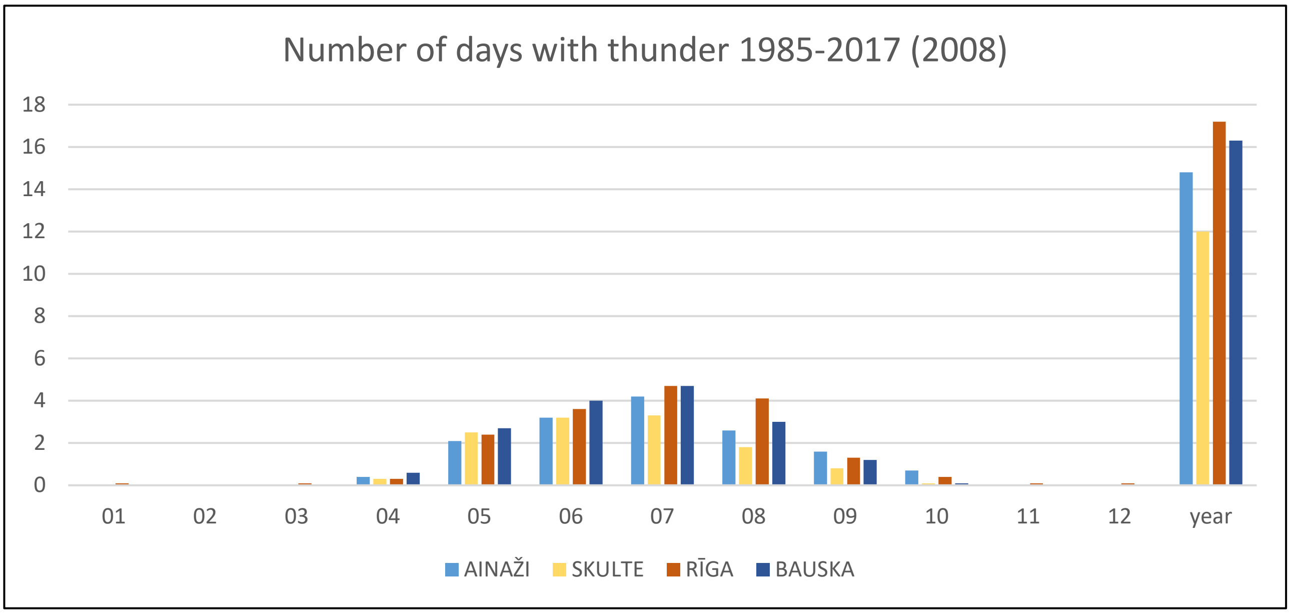


Figure 4.62 Mean days with thunder in in each month in Ainaži (1986-2009), Skulte (1986-2011), Riga (1986-2017) and Bauska (1986-2008) meteorological stations

Lithuania

There are 19-30 days with thunderstorm per year, on average (in some years, 40-45 days). The majority of such days occur in the southern regions, as they are dominated by the harsh, forested bed surface and sandy soils encouraging the mixing of air turbulence and thermal convection. The total annual duration of thunderstorms varies from 60 hours in the southern regions to 20 hours in the Central Lithuania. Usually, thunderstorms occur in June-July (in seaside areas - in August). (Lithuania's 7th UNFCCC report, 2017)

Average annual number days with thunder in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010 is presented in the Figure 4.63.

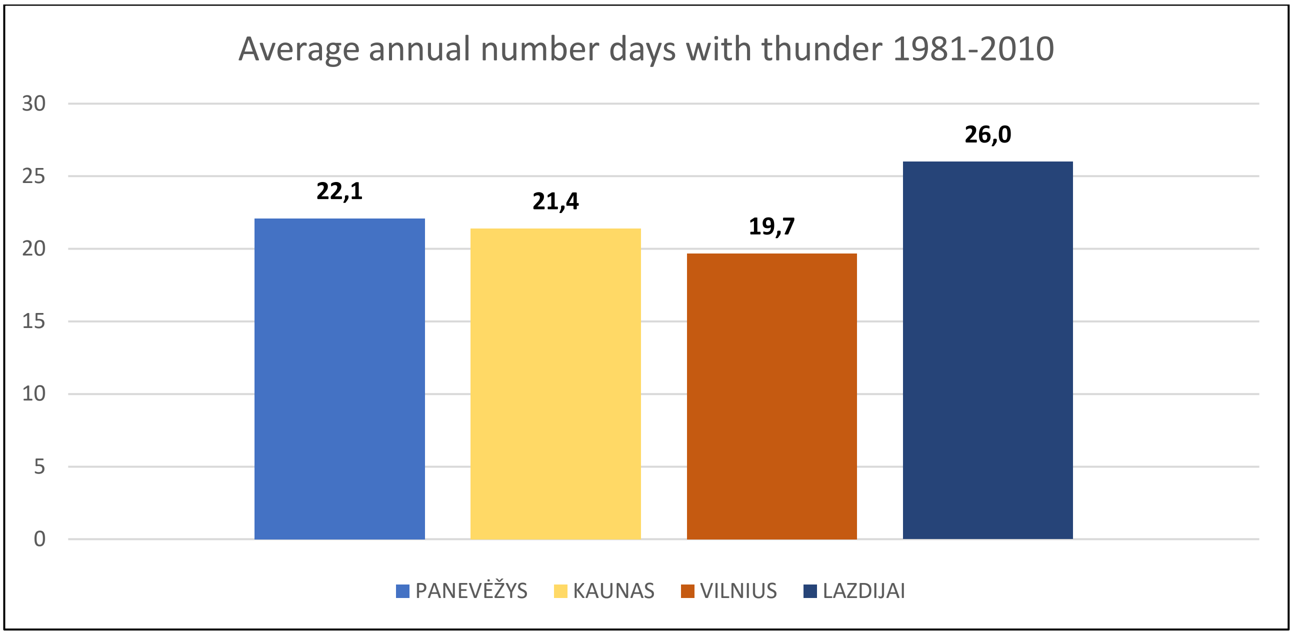


Figure 4.63 Average annual number days with thunder in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010

4.1.8. Freezing rain, glaze and hail

Annual average total days with freezing rain occurred 0,59 events in Tallinn and 0,83 events in Pärnu during period 1981-2017, with higher probability in late autumn-early winter, in November and December.

Annual average total days of glaze occurred 6,51 events in Tallinn and 6,86 events in Pärnu during period 1981-2017, with normal distribution throughout winter season, in November and December

Mean days with hail occurred from May until October 1,24 times in Tallinn-Harku, 2,30 times in Kuusiku and 1,63 times in Pärnu

Table 4.15 Mean days with freezing rain in each month in Tallinn-Harku (1981-2017),Pärnu (1981-2015), Ainaži (1986-2002; 2006-2009), Skulte (1986-2002; 2006-2012; 2016-2017), Riga (1986-2017) and Bauska (1986-2017) meteorological stations

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	0,03	0,05	0,03	0,05	0,03	0,00	0,00	0,00	0,00	0,05	0,16	0,16	0,59
PÄRNU	0,17	0,06	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,26	0,29	0,83
AINAŽI	0,2	0,1	0	0	0	0	0	0	0	0	0,1	0,4	0,8
SKULTE	0,6	0,2	0,1	0	0	0	0	0	0	0	0,2	0,4	1,5
RĪGA	0,4	0,3	0,1	0	0	0	0	0	0	0	0,1	0,7	1,6
BAUSKA	0,7	0,2	0,1	0	0	0	0	0	0	0	0,2	0,7	1,9

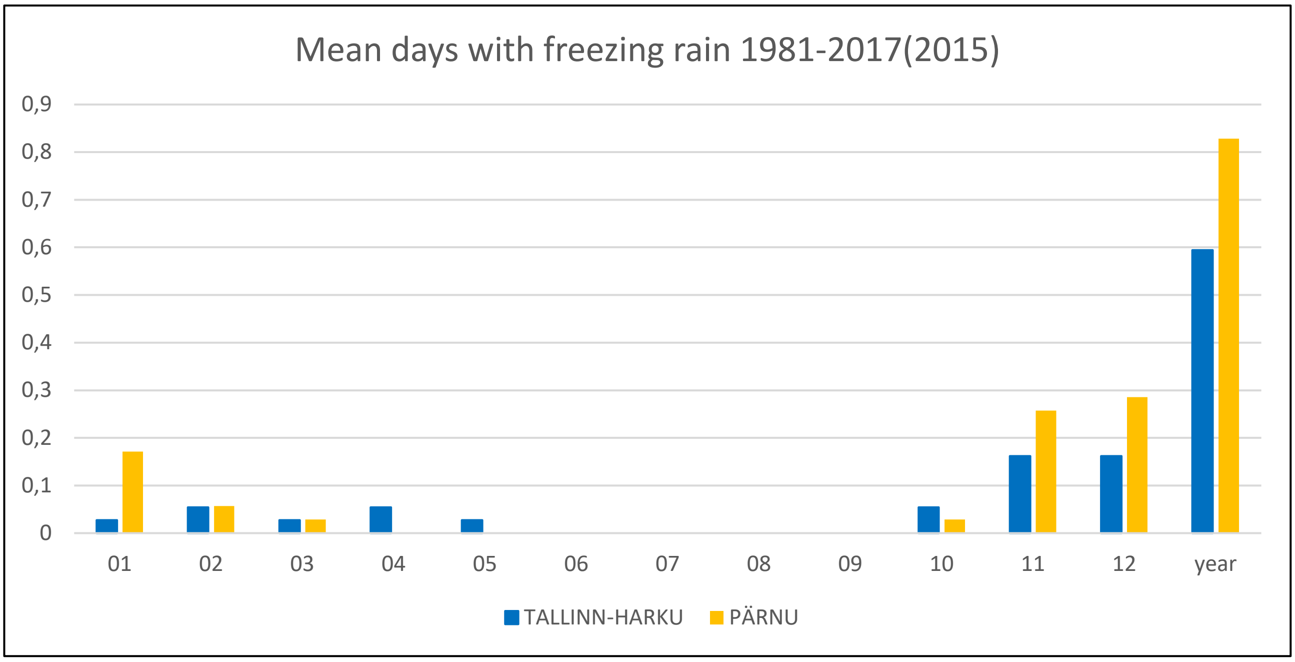


Figure 4.64 Mean days with freezing rain in each month in Tallinn-Harku and Pärnu meteorological stations during period 1981-2017 in Tallinn-Harku station and 1981-2015 in Pärnu station

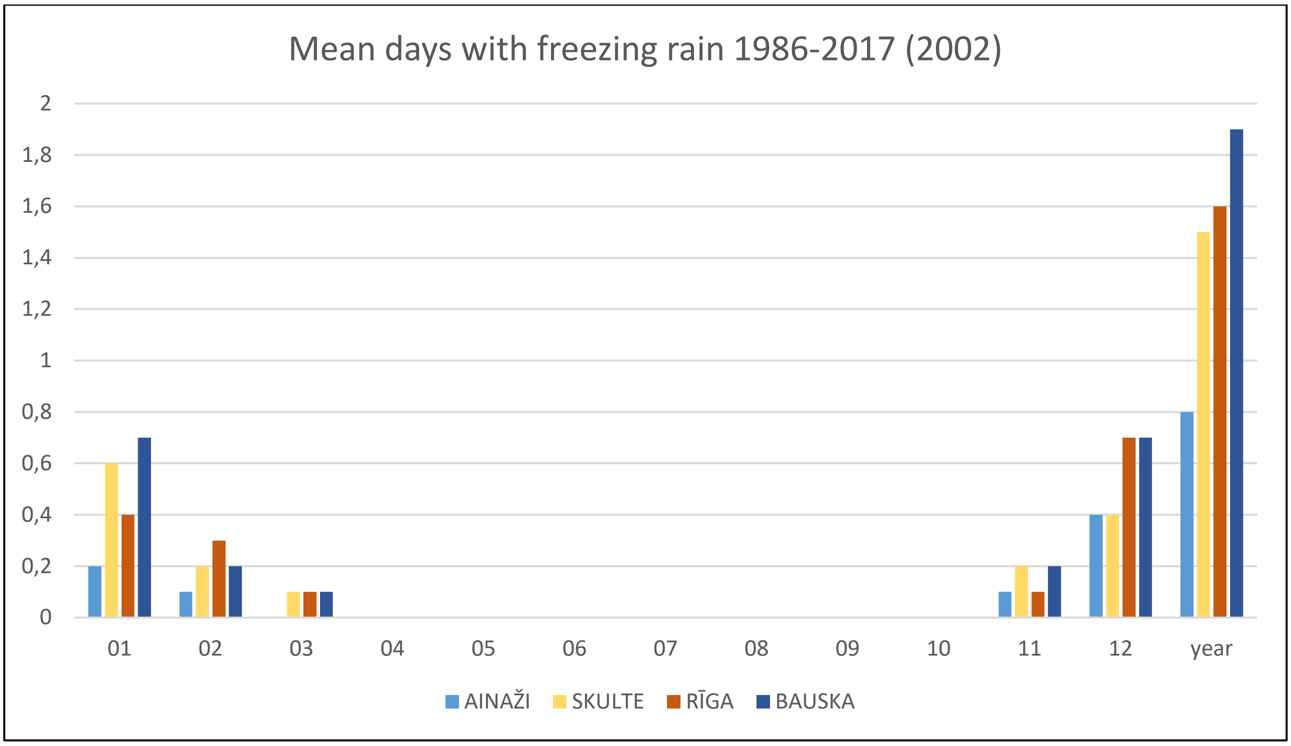


Figure 4.65 Mean days with freezing rain in each month in Ainaži (1986-2002; 2006-2009), Skulte (1986-2002; 2006-2012; 2016-2017), Riga (1986-2017) and Bauska (1986-2017) meteorological stations

Average annual number days with freezing rain in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010 is presented in the Figure 4.66.

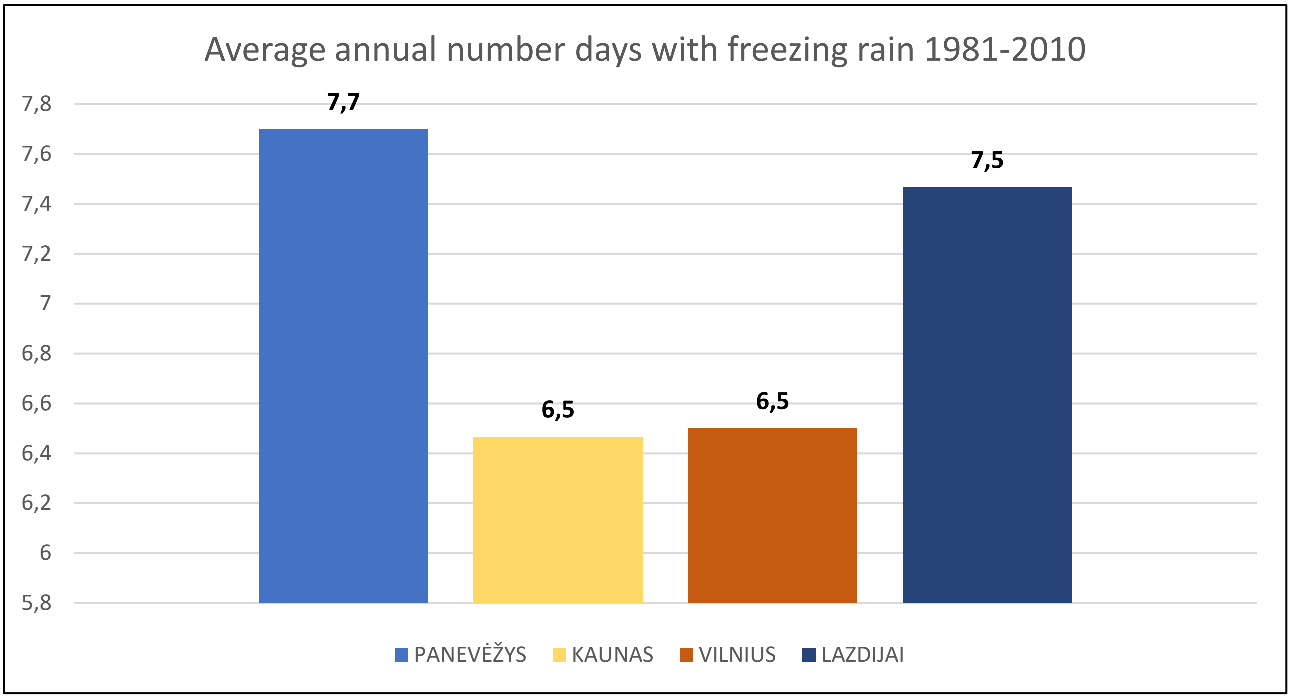


Figure 4.66 Average annual number days with freezing rain in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010

Table 4.16 Mean days with glaze in each month in Tallinn-Harku (1981-2017),Pärnu (1981-2015), Ainaži (1986-2002; 2006-2009), Skulte (1986-2011), Riga (1986-2017) and Bauska (1986-2008) meteorological stations

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	1,65	1,27	0,73	0,19	0,00	0,00	0,00	0,00	0,00	0,19	1,22	1,27	**6,51**
PÄRNU	2,06	1,43	0,63	0,34	0,00	0,00	0,00	0,00	0,00	0,06	0,77	1,57	**6,86**
AINAŽI	0,3	0,5	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,6	1,0	**2,5**
SKULTE	0,4	0,6	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,4	1,1	**2,6**
RĪGA	1,1	0,3	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,6	1,0	**3,1**
BAUSKA	1,8	0,9	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,3	0,9	2,7	**7,1**

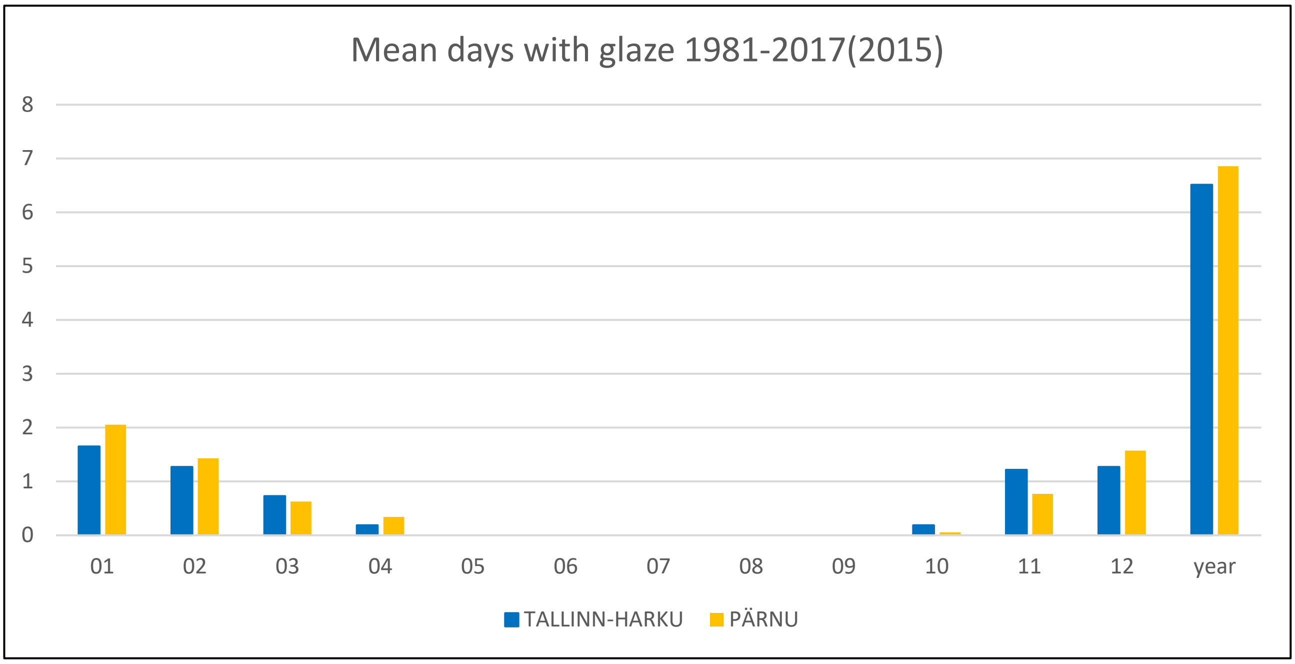


Figure 4.67 Mean days with glaze in each month in Tallinn-Harku and Pärnu meteorological stations during period 1981-2017 in Tallinn-Harku station and 1981-2015 in Pärnu station

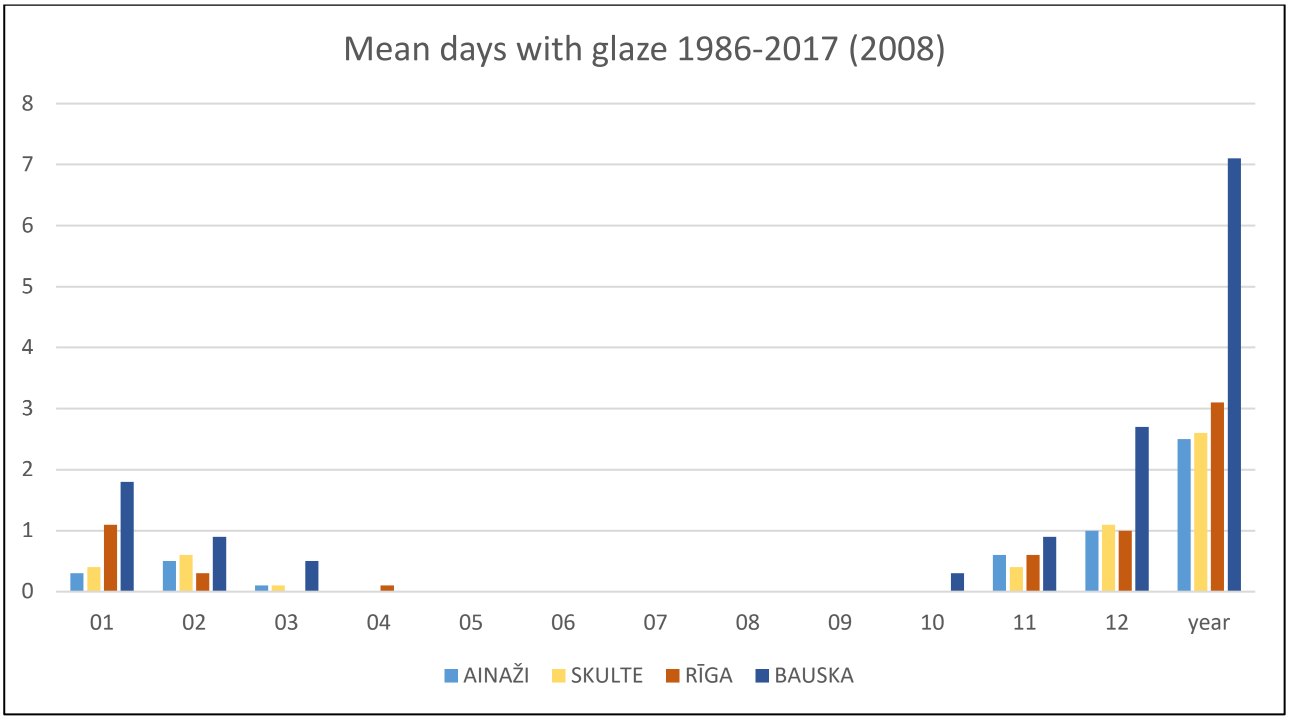


Figure 4.68 Mean days with glaze in each month in Tallinn-Harku (1981-2017),Pärnu (1981-2015), Ainaži (1986-2002; 2006-2009), Skulte (1986-2011), Riga (1986-2017) and Bauska (1986-2008) meteorological stations

Average annual number days with glazed frost in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010 is presented in the figure 4.69.

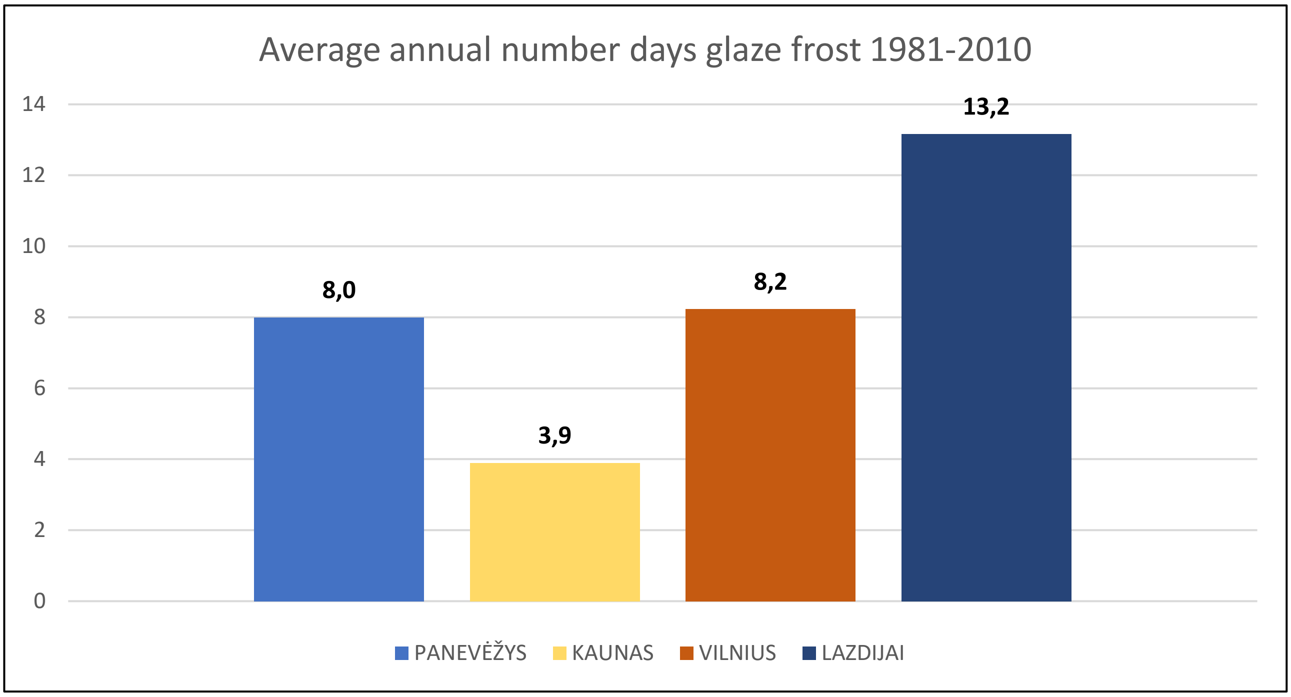


Figure 4.69 Average annual number days with glazed frost in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010

Table 4.17 Mean days with hail in each month in Tallinn-Harku (1981-2017), Kuusiku (1981-2007), Pärnu (1981-2017), Ainaži (1986-2009), Skulte (1986-2011), Riga (1986-2017) and Bauska (1986-2008) meteorological stations

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	0,00	0,00	0,00	0,03	0,22	0,24	0,08	0,14	0,16	0,35	0,00	0,03	**1,24**
KUUSIKU	0,00	0,00	0,00	0,07	0,41	0,37	0,33	0,26	0,63	0,22	0,00	0,00	**2,30**
PÄRNU	0,00	0,00	0,00	0,03	0,34	0,20	0,26	0,11	0,46	0,14	0,09	0,00	**1,63**
AINAŽI	0,00	0,00	0,00	0,00	0,10	0,00	0,00	0,00	0,10	0,10	0,00	0,00	**0,30**
SKULTE	0,00	0,00	0,00	0,00	0,10	0,10	0,10	0,20	0,30	0,00	0,00	0,00	**0,80**
RĪGA	0,00	0,00	0,00	0,00	0,10	0,10	0,10	0,20	0,20	0,00	0,00	0,00	**0,70**
BAUSKA	0,00	0,00	0,00	0,10	0,30	0,10	0,10	0,00	0,10	0,00	0,00	0,00	**0,70**

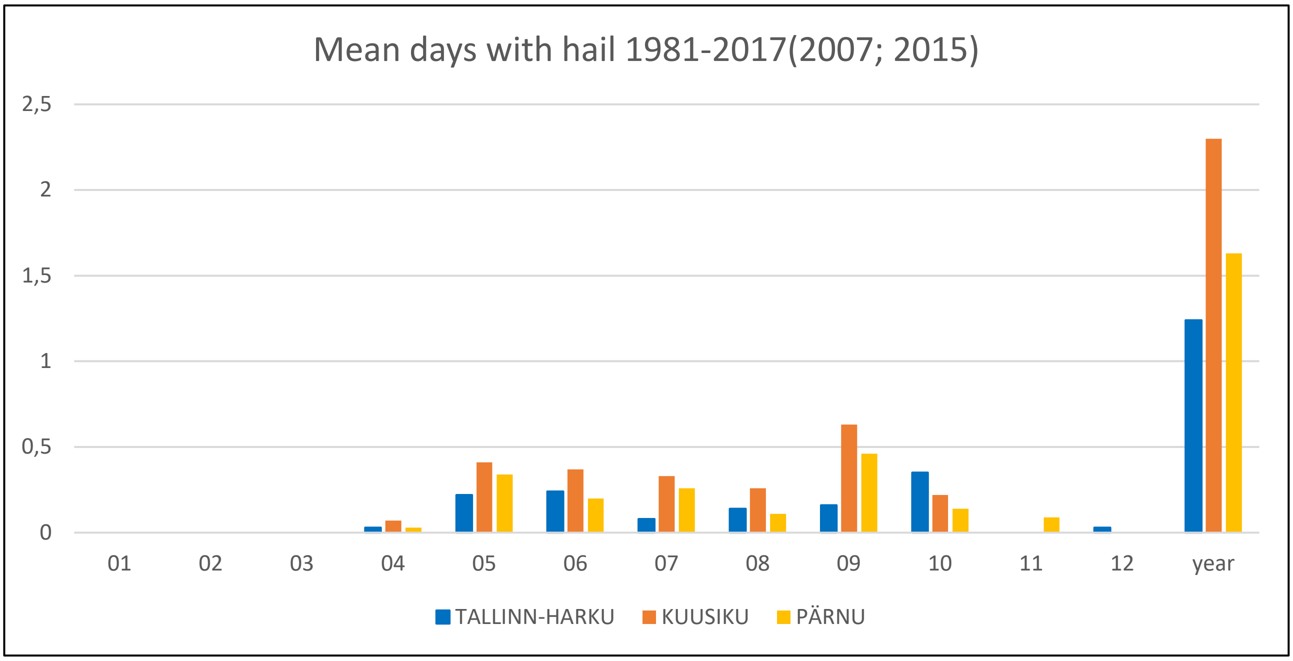


Figure 4.70 Mean days with hail in each month in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2017 in Tallinn-Harku station. 1981-2007 in Kuusiku station and 1981-2015 in Pärnu station

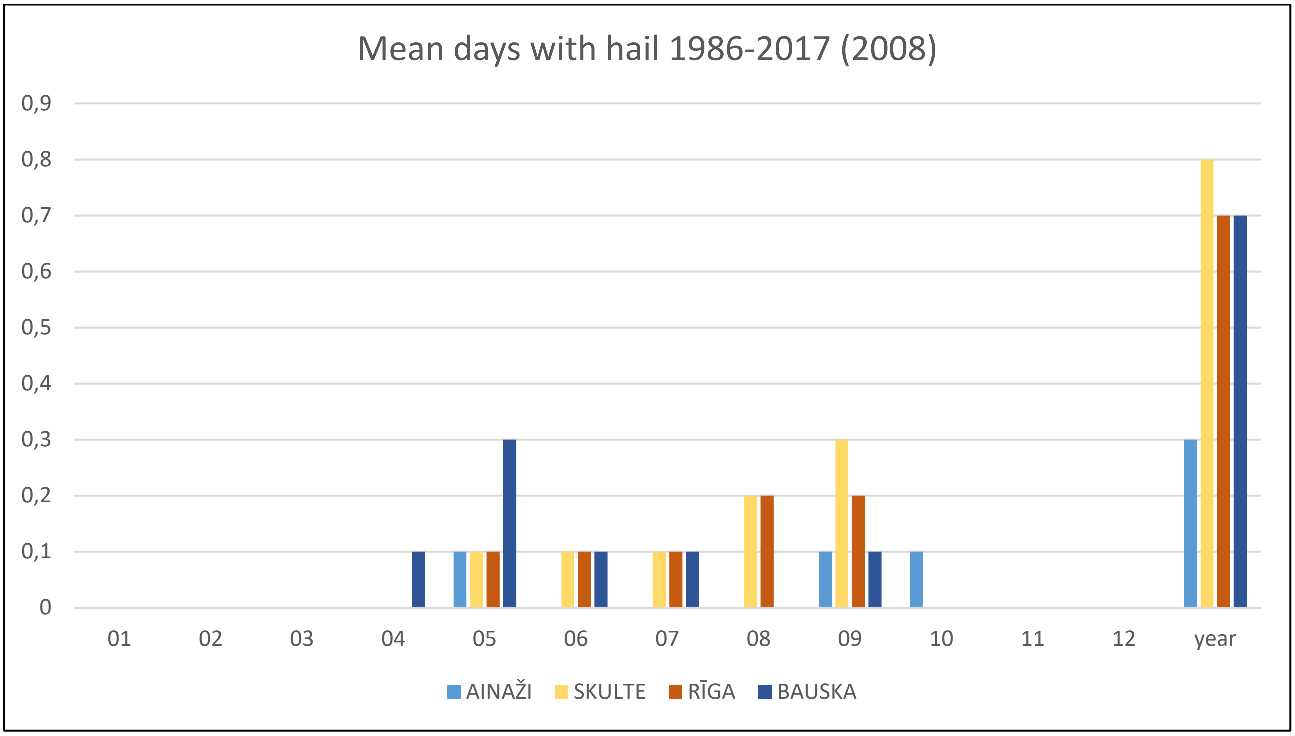


Figure 4.71 Mean days with hail in each month in Ainaži (1986-2009), Skulte (1986-2011), Riga (1986-2017) and Bauska (1986-2008) meteorological stations

Average annual number days with hail in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010 is presented in the Figure 4.72.

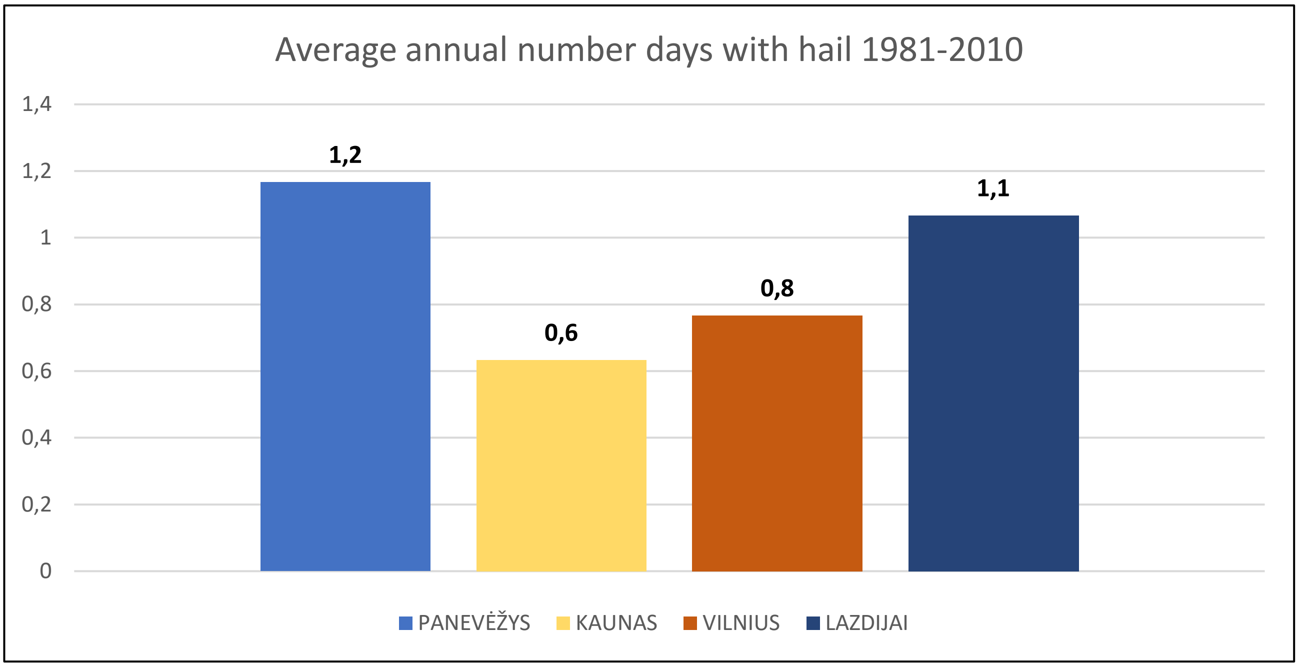


Figure 4.72 Average annual number days with hail in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010

4.1.9. Frost penetration of soil

Frost penetration depth of soil is presented by average duration, average and maximum frost penetration depth.)

Ground frost occurs on average on less than 80 days each year in southern route and over 115 days in northern route.

Estonia

Estonian Weather Authority do not monitor frost penetration of soils and they are not able to calculate it based on air temperatures. Therefore, data ordered by Estonian Road Administration from a private company Teede Tehnokeskus Ltd was collected. Acquired maximum frost penetration data and number of freezing cycles is from years 2013 to 2018 (until mid-November 2018) from 6 measure point nearest to the Rail Baltica route (Figure 4.73 and Table 4.18).

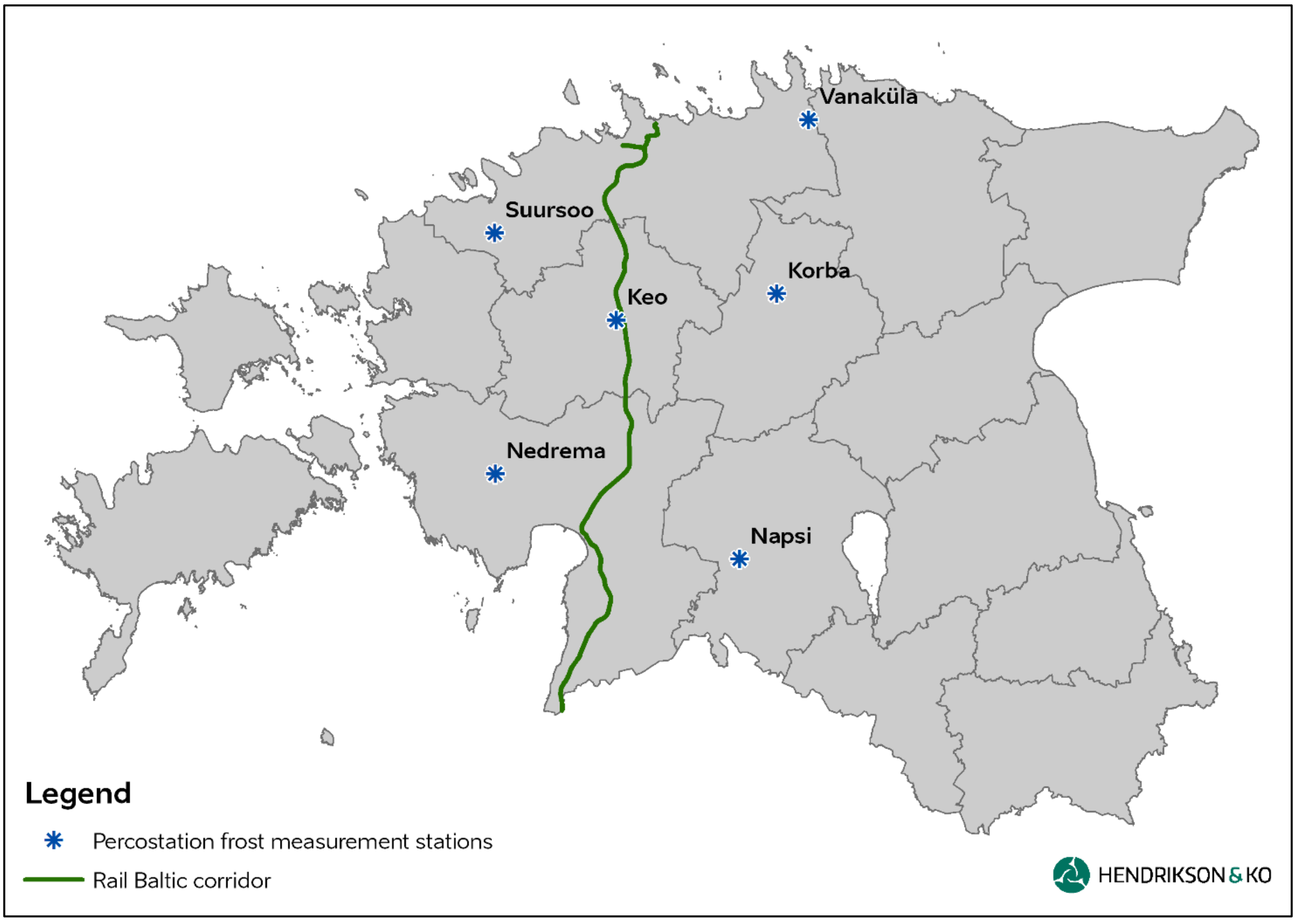


Figure 4.73 Percostation frost measurement station locations

Table 4.18 Maximum frost penetration data and number of freezing cycles in Keo, Korba, Napsi, Nedrema, Suursoo and Vanaküla Percostation frost measurement stations during period 2013-2018 (until mid-November 2018)

STATION	Max frost penetration and year	Max freezing cycles and year
Keo	190 cm (2013)	40 (2014)
Korba	170 cm (2013)	28 (2017)
Napsi	160 cm (2013)	27 (2016)
Nedrema	130 cm (2013, 2014 and 2018)	28 (2013)
Suursoo	160 cm (2013)	27 (2014)
Vanaküla	130 cm (2013 and 2018)	31 (2015)

Latvia

Latvian frost penetration of soil estimations are calculated by the Latvian Environment, Geology and Meteorology Centre (LVĢMC) based on the average recorded soil surface temperatures and ECMWF reanalysis data.

Table 4.19 Maximum estimated frost penetration of soil in Ainaži, Skulte, Riga and Bauska meteorological stations during period 1985-2017

STATION	January	February	March	December
AINAŽI	101	79	77	98
SKULTE	111	87	84	108
RĪGA	126	100	97	124
BAUSKA	54	48	42	59

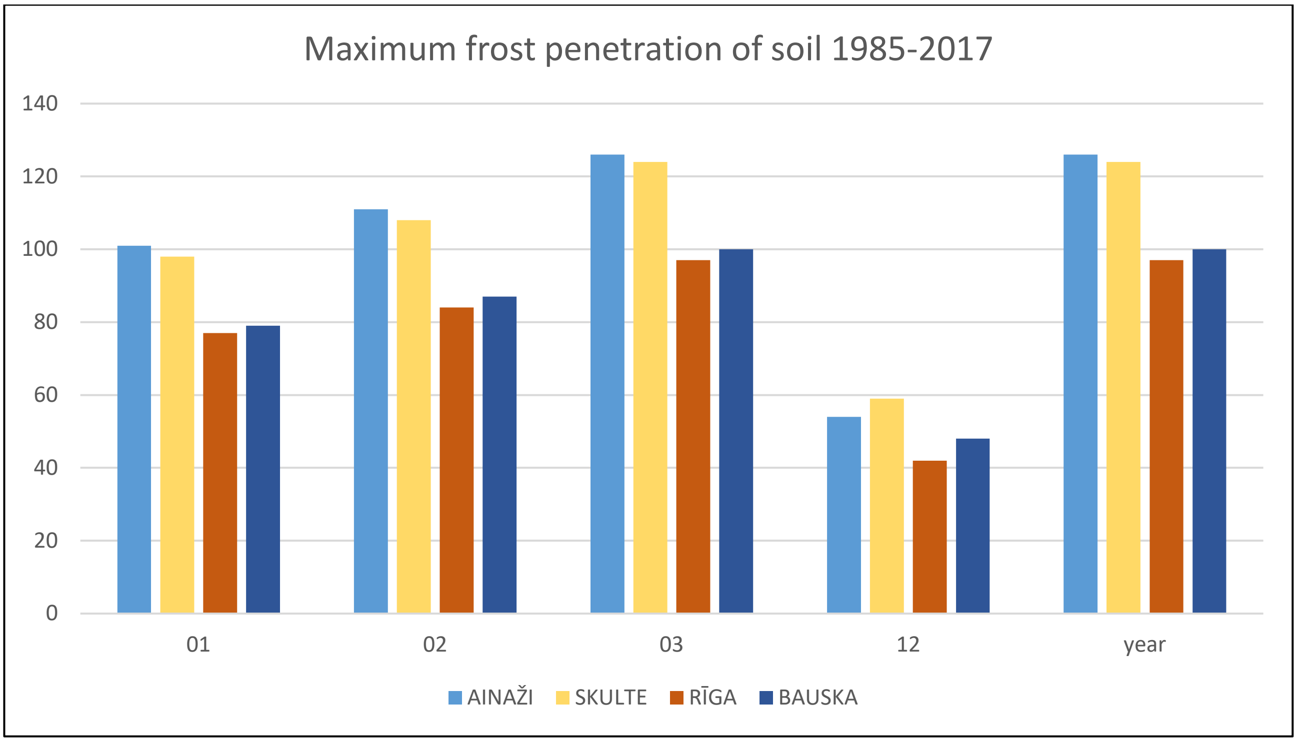


Figure 4.74 Maximum estimated frost penetration of soil in Ainaži, Skulte, Riga and Bauska meteorological stations during period 1985-2017

Table 4.20 Average frost permeability (days) in Ainaži, Skulte, Riga and Bauska meteorological stations during period 1985-2017

STATION	January	February	March	October	November	December
AINAŽI	19	20	15	1	3	12
SKULTE	19	19	14	1	3	12
RĪGA	18	18	13	0	3	11
BAUSKA	21	19	12	1	8	17

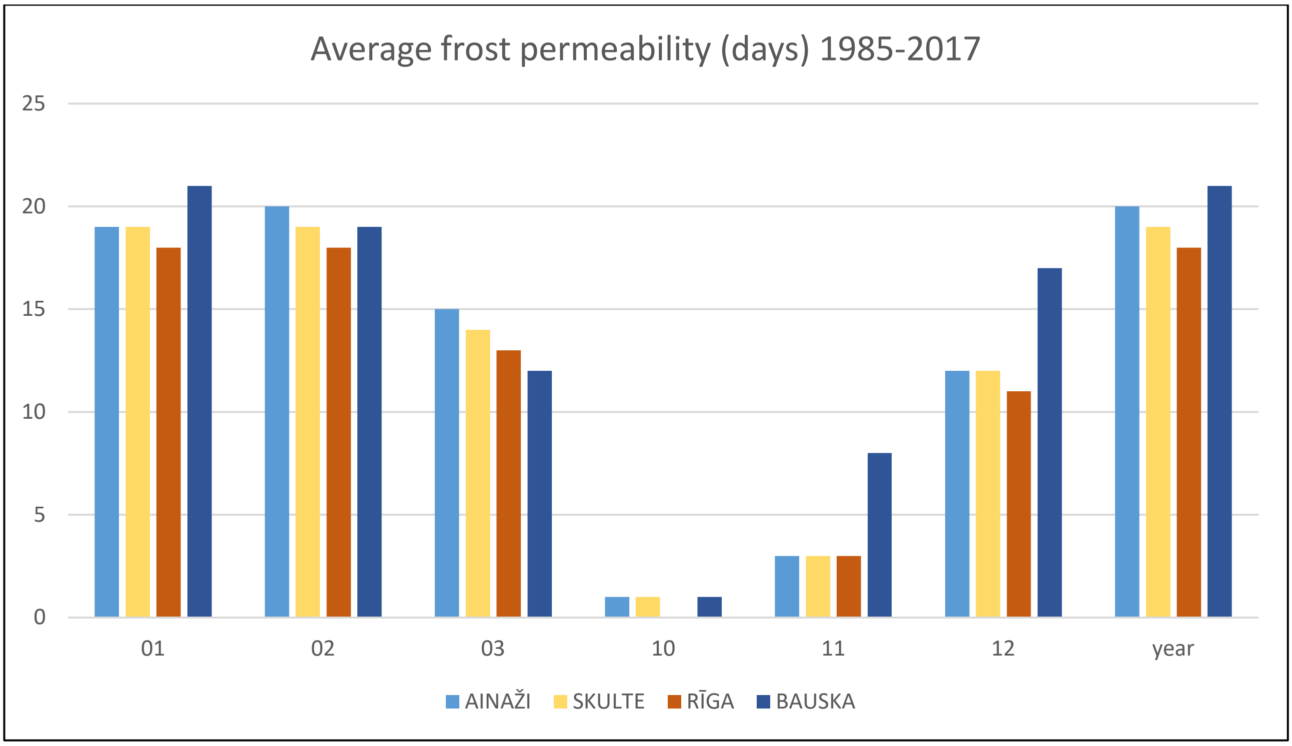


Figure 4.75 Average frost permeability (days) in Ainaži, Skulte, Riga and Bauska meteorological stations during period 1985-2017

Lithuania

In Lithuania, the duration of seasonal frost varies from 24 days (in warm winters) to 171 days (in cold winters) and the usual duration of frost is 123 days. The average maximum soil frost (down to 55-64 cm) is usually recorded in north-east, east, south-east and south, where dry sandy soils prevail, groundwater stratifies in great depths and the lowest temperature is recorded in winters. The deepest frost is reached in February. In cold winters, it penetrates down to the depth of 130-145 cm. Since the midst of the 20th century, the duration of soil frost decreased by two weeks, on average, and increased the likelihood of its full melting and refreezing. (Lithuania's 7th UNFCCC report, 2017)

Maximum frost penetration depth in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2017 is presented in the figure 4.76.

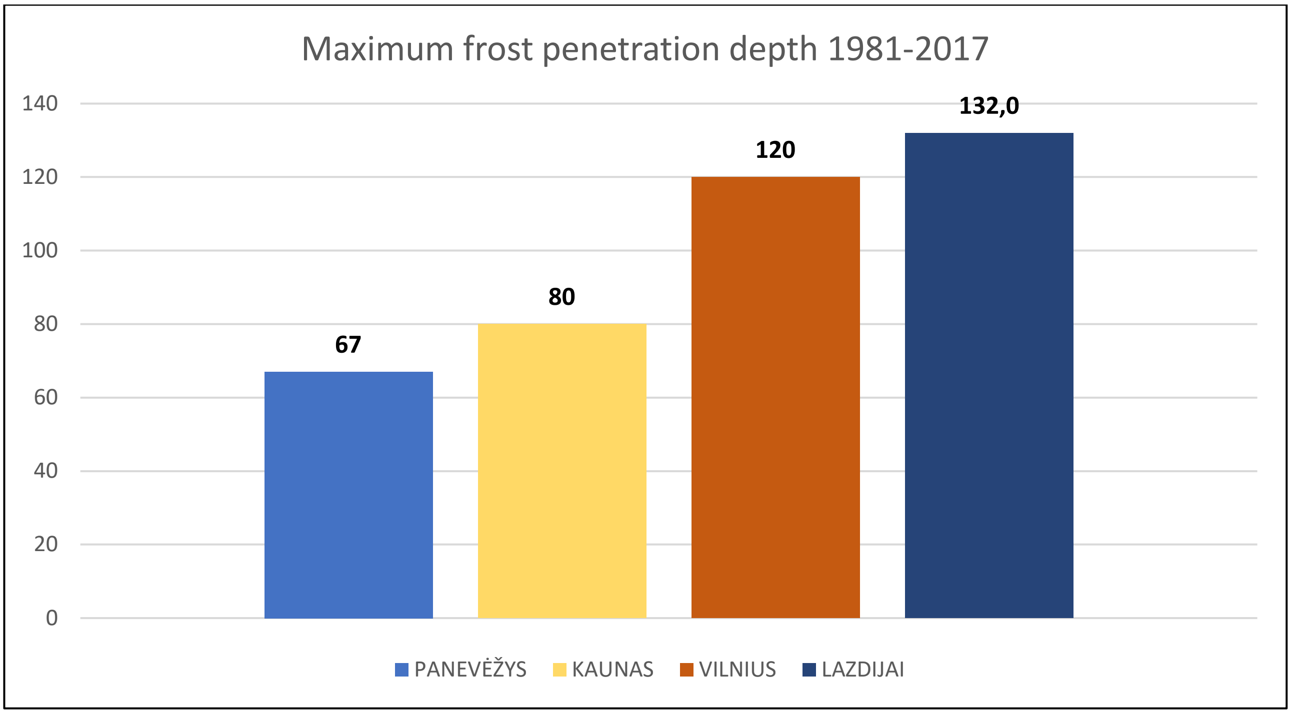


Figure 4.76 Maximum frost penetration depth in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2017

4.1.10. Fog

Fog hazard is featured by max number of days with dangerous fog, number of incidents with fog lasting over 12 and 24 h.

Events with medium fog (visibility under 500 m) occurred 16 times in Tallinn and twice more, 33 times in Pärnu. The foggiest months are March and April, though foggy days occurred in late autumn and during winter in Pärnu.

Estonia

Table 4.21 Number of events with medium fog (visibility under 500 m) in each month in Tallinn-Harku and Pärnu meteorological stations during period 1981-2017 (Tallinn-Harku) and 1981-2015 (Pärnu)

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	0	1	6	3	3	0	0	0	2	0	1	0	16
PÄRNU	2	4	6	8	1	0	0	0	0	5	3	4	33

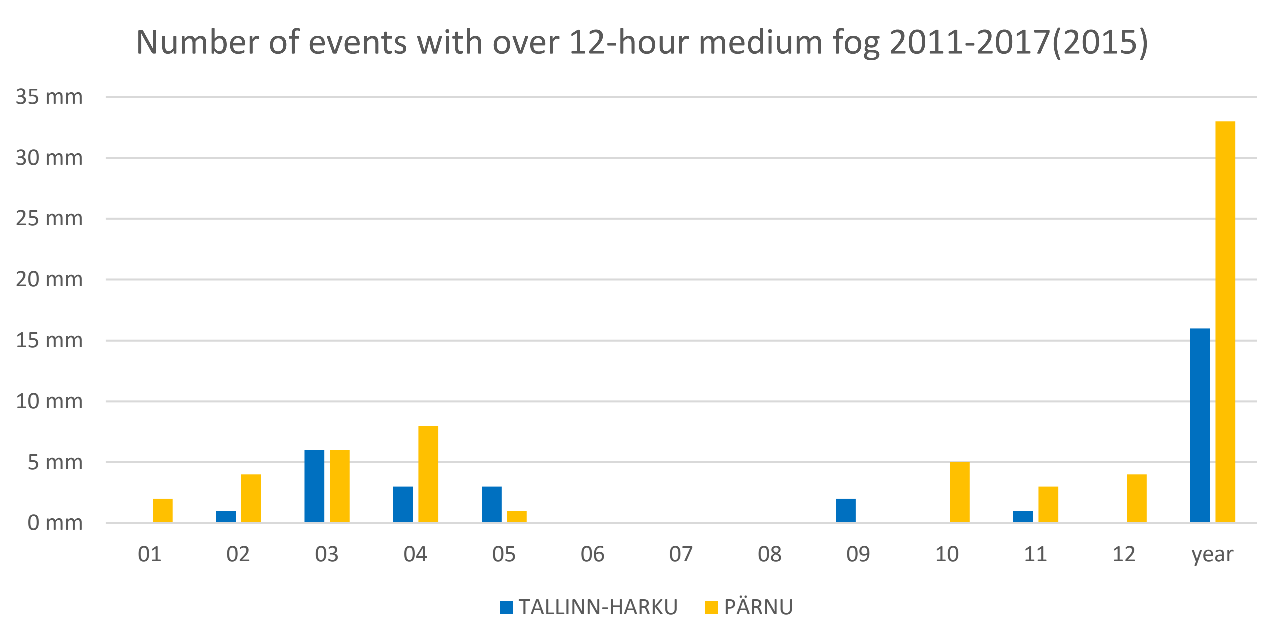


Figure 4.77 Number of events with medium fog (visibility under 500 m) in each month in Tallinn-Harku and Pärnu meteorological stations during period 1981-2017 (Tallinn-Harku) and 1981-2015 (Pärnu)

Latvia

Since the middle of the past century, the annual mean number of days with fog has decreased significantly; this could be associated with both the gradual decrease in industrial activities and the resultant improvements of air quality and the observed increase in air temperature. (Fog climatology in Latvia, 2014)

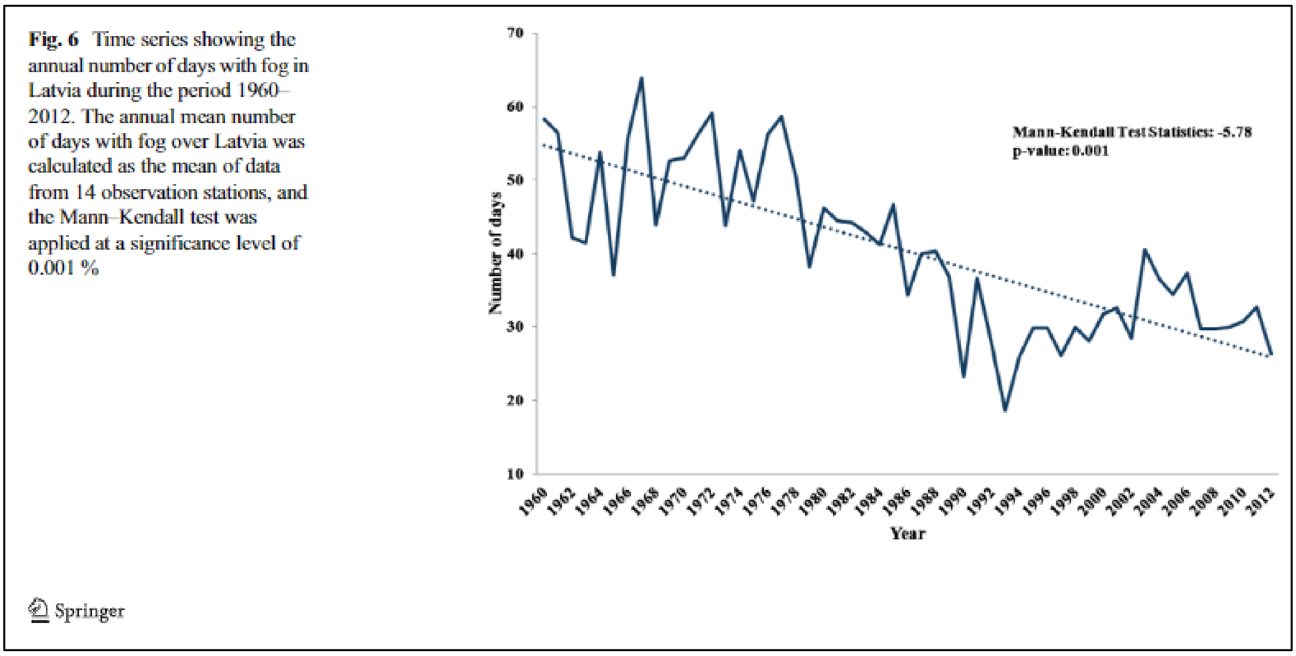


Figure 4.78 Number of days with fog during period 1960-2012 (Fog climatology in Latvia, 2014)

Recorded events with dangerous fog (visibility under 100 m) are presented in the Table 4.22 and figure 4.79.

Table 4.22 Average number of events with dangerous fog (visibility under 100 m) in Ainaži, Skulte, Riga and Bauska meteorological stations during period 1985-2017

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
AINAŽI	0,1	0	0,1	0,3	0,3	0,2	0	0,1	0,2	0,2	0,2	0	**1,7**
SKULTE	0	0,1	0,1	0,1	0	0	0	0	0	0	0,2	0,1	**0,6**
RĪGA	0,1	0,1	0,1	0,2	0	0,1	0	0,2	0,1	0,3	0,3	0,2	**1,7**
BAUSKA	0,3	0	0,2	0,2	0	0	0	0,1	0,1	0,1	0,3	0,1	**1,4**

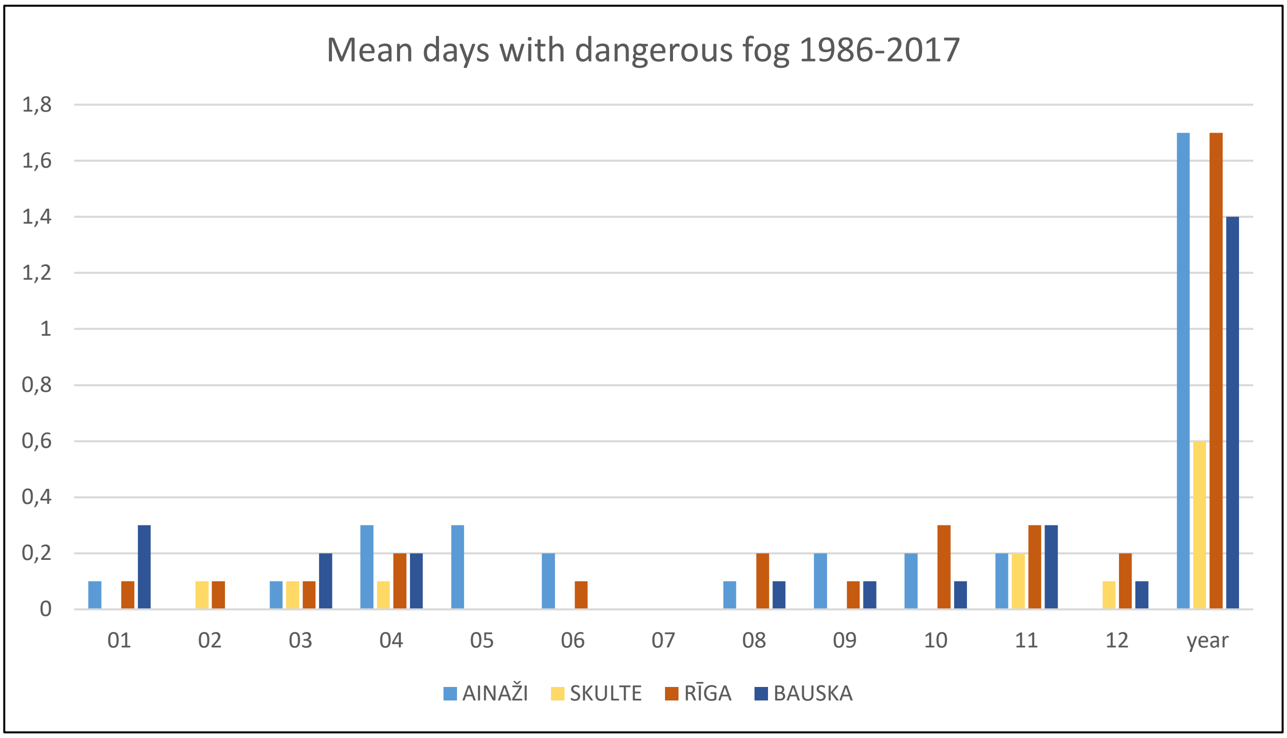


Figure 4.79 Average number of events with dangerous fog (visibility under 100 m) in Ainaži, Skulte, Riga and Bauska meteorological stations during period 1985-2017

Lithuania

Annual maximum number of days with dangerous fog (visibility under 100 m) in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010 is presented in the Figure 4.80.

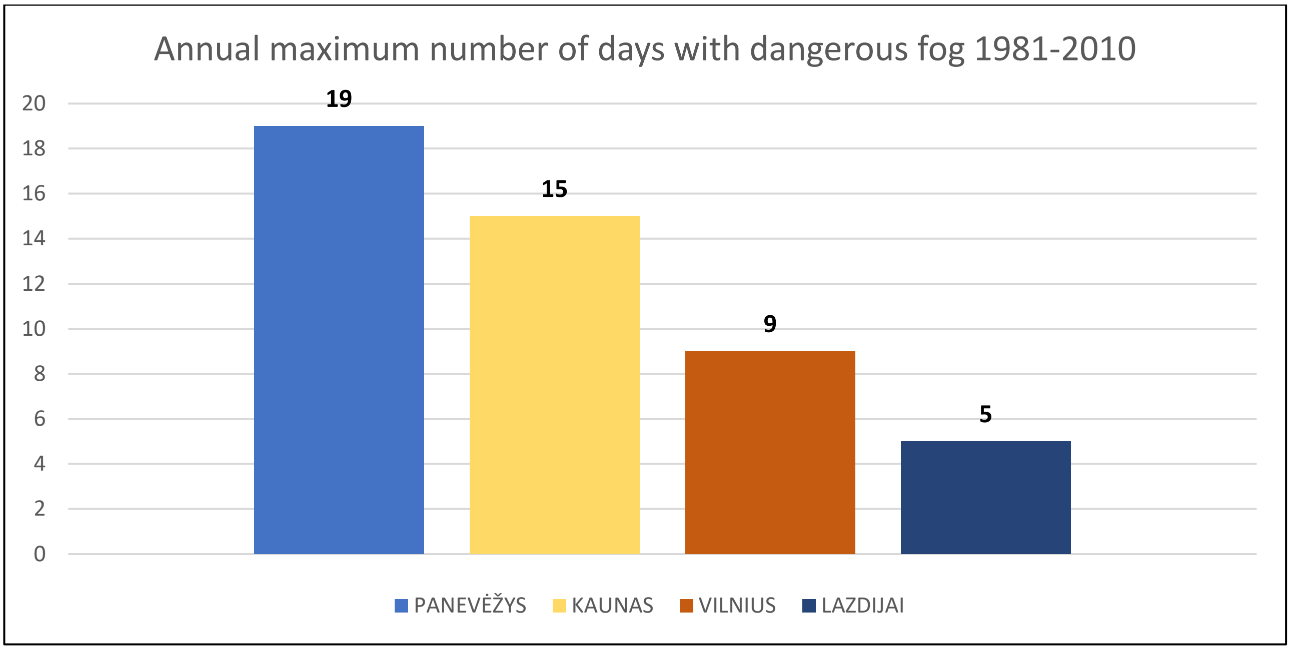


Figure 4.80 Annual maximum number of days with dangerous fog (visibility under 100 m) in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010

4.1.11. Humidity

Average relative humidity differs insignificantly along Rail Baltica routing from 79% southwards to 83% in Kuusiku, inland Estonia. The relative humidity is higher during autumn and winter.

Average relative humidity (%) during period 1981-2010 in Tallinn-Harku, Kuusiku and Pärnu meteorological stations is presented in Table 4.23 and Figure 4.81.

Table 4.23 Average relative humidity (%) in each month in meteorological stations during period 1981-2010 (1985-2017 for Latvian stations)

STATION	01	02	03	04	05	06	07	08	09	10	11	12	year
TALLINN-HARKU	88	85	81	73	69	74	76	79	82	85	88	88	**81**
KUUSIKU	90	87	82	74	69	74	77	81	85	88	91	91	**83**
PÄRNU	88	86	82	75	70	74	76	79	83	86	89	89	**81**
AINAŽI	87	86	82	75	74	78	79	80	82	84	87	88	**82**
SKULTE	86	83	77	70	67	71	73	75	80	83	87	88	**78**
RĪGA	86	85	80	75	74	77	77	78	81	83	87	87	**81**
BAUSKA	87	85	79	72	69	73	75	77	82	86	89	89	**80**
PANEVĖŽYS	87	84	80	72	69	74	75	77	83	86	88	89	**80**
KAUNAS	87	85	81	72	69	74	76	76	81	85	88	89	**80**

VILNIUS	87	84	78	69	68	72	74	74	80	84	89	89	**79**
LAZDIJAI	87	84	79	69	68	73	74	75	80	84	88	89	**79**

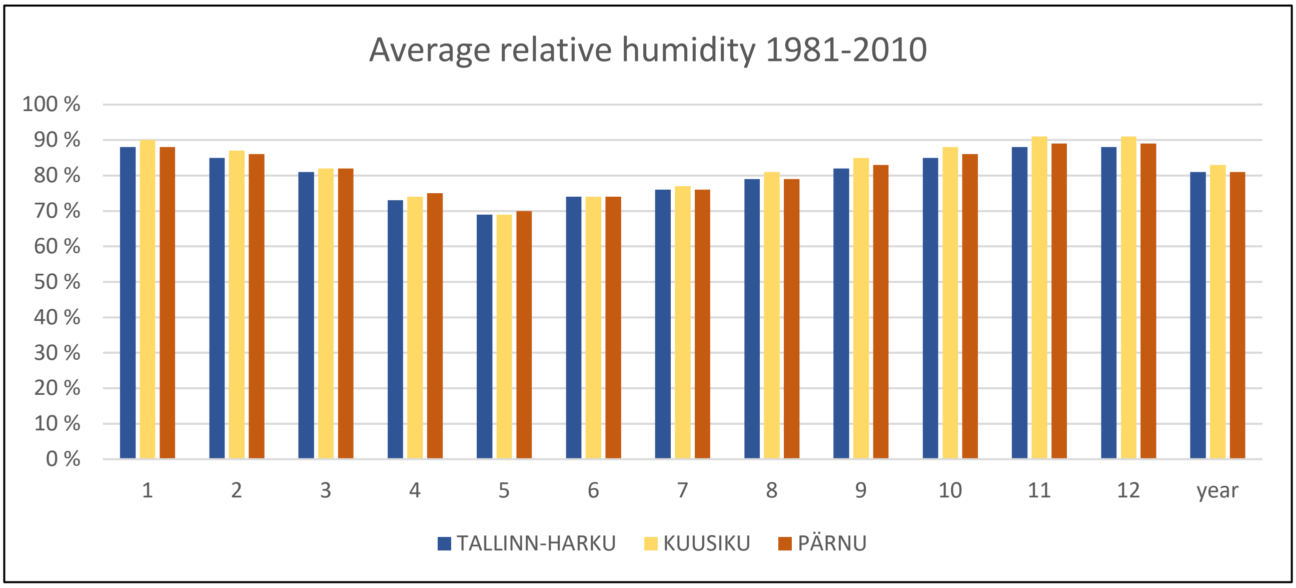


Figure 4.81 Average relative humidity (%) in each month in Tallinn-Harku, Kuusiku and Pärnu meteorological stations during period 1981-2010

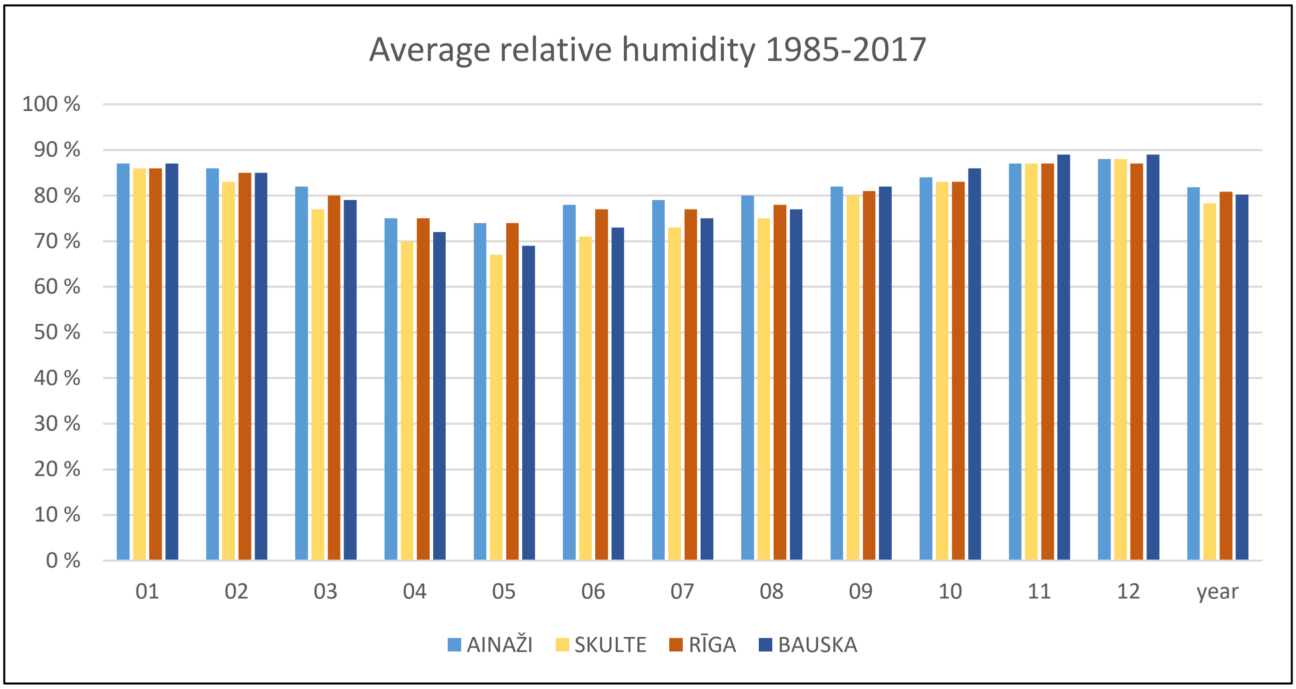


Figure 4.82 Average relative humidity (%) in each month in Ainaži, Skulte, Riga and Bauska meteorological stations during period 1985-2017

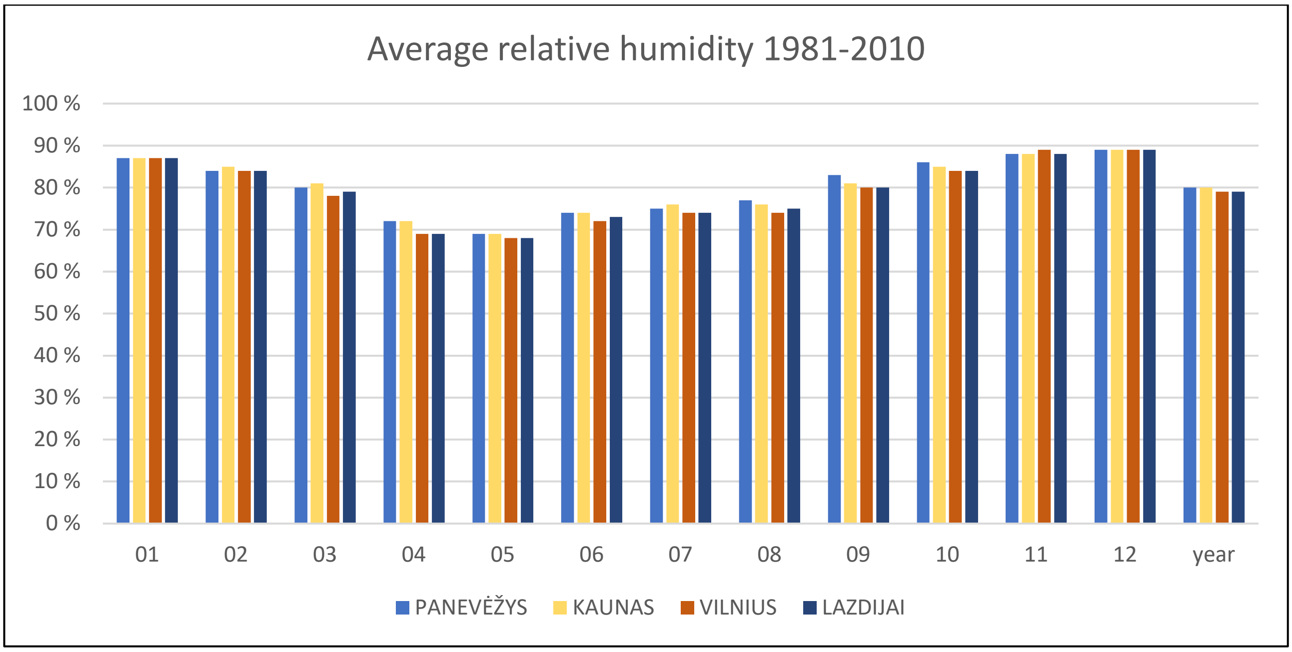


Figure 4.83 Average relative humidity (%) in each month in Panevėžys, Kaunas, Vilnius and Lazdijai meteorological stations during period 1981-2010

4.1.12. Wildfire

Estonia

Number of wildfires during period 1981-2010 in Harju, Rapla and Pärnu county is presented in Table 4.24 and Figure 4.84.

Table 4.24 Number of wildfires in Harju, Rapla and Pärnu counties during period 2010-2017

COUNTY	2010	2011	2012	2013	2014	2015	2016	2017
HARJU COUNTY	432	418	222	394	687	718	438	472
RAPLA COUNTY	37	25	11	24	101	56	61	60
PÄRNU COUNTY	69	47	24	81	37	47	35	37

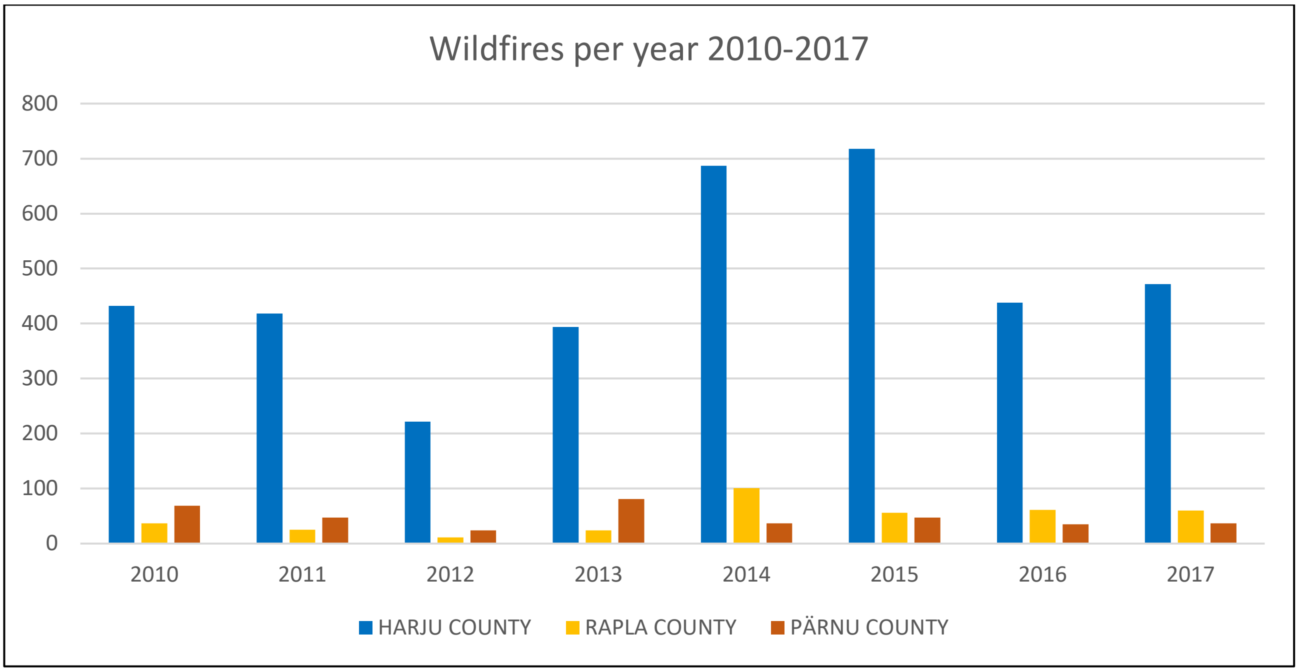


Figure 4.84 Number of wildfires in Harju, Rapla and Pärnu county during period 2010-2017

Latvia

Number or fires in the municipalities (counties and city of Riga) that Rail Baltica crosses during period 2009-2017 are presented in the table 4.25.

Table 4.25 Number or fires in the municipalities (counties and city of Riga) that Rail Baltica crosses during period 2009-2017

Year / Municipality	2009	2010	2011	2012	2013	2014	2015	2016	2017
Rīga city	2970	2467	2702	2607	2819	3004	2656	2299	2261
Baldones county	26	31	28	26	20	38	35	39	25
Bauskas county	101	115	95	125	136	156	155	1335	123
Garkalnes county	28	30	22	32	27	37	26	26	39
Iecavas county	44	49	43	34	56	51	76	61	59

Inčukalna county	40	21	33	24	34	43	44	27	22
Ķekavas county	89	69	85	86	99	82	33	118	75
Limbažu county	90	73	81	93	98	128	115	106	113
Mārupes county	68	43	62	44	47	54	59	51	47
Olaines county	152	148	143	112	145	156	158	128	138
Ropažu county	16	19	29	21	25	29	28	35	30
Salacgrīvas county	45	43	33	39	41	69	60	48	59
Salaspils county	107	96	96	87	123	152	141	132	118
Sējas county	11	14	10	9	13	12	15	20	10
Stopiņu county	57	52	45	48	62	73	65	65	54

Lithuania

Number or fires in the municipalities (and cities) that Rail Baltica crosses during period 1998-2017 are presented in the table 4.26.

Table 4.26 Number or fires in the municipalities (and cities) that Rail Baltica crosses during period 1998-2017

Municipality or city	Total number of fires
Lazdijų	2645
Kalvarijų	1354
Marijampolės	4402
Kazlų Rūdos	941
Kaunas city	21280
Kauno	7214
Jonavos	4888
Kėdainių	4521
Kaišiadorių	4016
Panevėžys city	9073
Panevėžio	6616
Pasvalio	3002
Vilnius city	34919
Vilniaus	10410
Trakų	5476
Elektrėnų	3511

4.2. Future projections of relevant climate variables and hazards

Table 4.27 Previous and future changes in climate variables (adopted from Latvia's 7th UNFCCC report, 2017)

Climate variables	Previous changes in present climate (1981-2010 with respect to 1961-1990	Future climate 2017-2100 (RCP4.5) with respect to 1961-1990
Mean air temperature	+0,7°C	>+3,5°C
Maximum air temperature	+0,7°C	>+3,4°C
Minimum air temperature	+0,8°C	>+9,5°C
Summer days	+3 days	+31 days
Frost days	—9days	—52days
Precipitation totals	+6% 39 mm	+13% 80 mm
Heavy precipitation days	+2 days	+ 3 days
Annual mean wind speed	—8%	—3% (uncertain)
Stormy days	— 1 day	0 days

In short, winters are becoming warmer and the probability of heat waves increases during summer in future climate. The length of summer increases dramatically, in contrary winter may shorten more than 1,5 months. There will be more rain, in particular during winter. Storms occur more often in future climate despite decreasing mean wind velocity.

Following chapters describing future climatic trends and predictions for individual climatic variables are generally based on the latest national level reports on climate change (KATI, 2015; Climate change scenarios for Latvia, 2017; Bukantis, A. et al, 2015). Methodology and level of detail of these reports are different for each country and this inevitably present in the current report. In regard the future climate and climate projections until the end of 21 century, changes in extremes can be linked to changes in the mean, variance, or shape of probability distributions which cannot predicted with high confidence. Many extreme weather events continue to be the result of natural climate variability (IPCC 2014). Global-scale trends in weather extremes are more reliable than regional-scale trends, depending on the geographical uniformity. World Climate Research Program Coordinated Regional Downscaling Experiment (EURO-CORDEX) initiative provides a horizontal resolution of 12.5 km for the emission scenarios RCP4.5 and RCP8.5.

4.2.1. Climate change trends in Estonia

The following summery is mainly based on Estonia's 7th UNFCCC report (2017). The average annual temperature has increased slightly faster in Estonia compared to the world as a whole since the middle of the last century. The trend has been 0.2–0.3 °C per decade since 1960-s. The warming trend of the winter is the clearest. The highest average increase in the temperature by months is observed in March with less snow, due to the faster warming of the ground. Higher increases in the temperature are also observed in other winter and spring months.

The majority of the sources are referring to an increase in the average wind velocity in winter and partly in spring. The increase is likely to range between 3–18% and is related to the increase in the number of cyclones moving to the Estonian territory from the Atlantic Ocean.

The increase in the average annual precipitation in the second half of the 20th century has been significant in Estonia, up to 15%, observed strongly during the period from October to March. The highest increase in precipitation in the RCP8.5 scenario can be observed in spring, and in the RCP4.5 scenario, however, in summer. An increase in the number of occurrences of extreme precipitation (more than 30 mm of precipitation over 24 hours) is forecasted, but taking into consideration the very low likelihood thereof in the majority of the year, these occurrences are only significant in summer (Estonia's 7th UNFCCC report, 2017).

The impacts of climate change on runoff are not as clear or clearly targeted as the observed long-term increase in precipitation. The runoff maximum of the rivers has moved to an earlier springtime and the peak runoffs are less steep. The likelihood of high runoffs in spring decreased during the period of 1922–2010. Jaagus et al. 2017 concluded that winter runoff values have increased, while stronger changes are typical for western Estonia. At the same time, specific runoff in April and May have notably decreased indicating the shift of the runoff maximum to the earlier time. The extremely high sea-level events tend to occur during the meteorologically more variable winter months, the so-called storm season, from September to March (Post and Kõuts 2014). Jaagus et al 2017 confirm the detection of coherent regime shifts in many climatic and hydrological parameters in Estonia that mainly occurred starting from the winter of 1988/89.

According to the RCP4.5 scenario, the number of days of snow in March will decrease by more than 10 days compared to the control period and, according to the RCP8.5 scenario, by up to 15 days, rarely exceeding 5 days. In January-February, according to the RCP4.5 scenario, snow cover will also decrease by at least 10 days, reaching the average of 15 days, which means that permanent snow cover will not form.

The average global rising of the sea on the coasts of Estonia by 20–40 cm based on the RCP4.5 future scenario and by approximately 40–60 cm based on the RCP8.5 future scenario by the end of the 21st century. The crustal uplift in the Estonian coastal areas continues up to-1.5 mm/year in Tallinn, being 0 near Pärnu (Rosenthau et al 2017). The storm surges caused by the long-lasting westerly winds and the following heavy westerly storm can be pronounced in Pärnu (max 275 cm in Pärnu Bay, January 9, 2005) though the probability of the coincidence of the mentioned events is relatively low: once in 20–40 years (Suursaar et al. 2006). As only cyclones with the specific trajectory can cause extreme storm surges, it is unclear whether further northward shifting of cyclone trajectories will increase the number of floods.

There is a very high peak of around 0 °C in the distribution of the frequencies of daily temperatures in the cold half of the year. This means that in the control period, in almost a fourth of the days of the cold half of the year the air temperature ranged from -1 to +1 °C.

4.2.2. Climate change trends in Latvia

The following summery is mainly based on Latvia's 7th UNFCCC report (2017). Mean, minimum and maximum air temperature values have been increased under the impact of recent climate change. Most changes have been observed in winter and spring seasons. The length of growing season and the number of summer days and tropical nights has increased while the number of frost days and ice days has decreased.

It is expected that by the end of the century the annual-mean air temperature will increase by an average of 3.5ºC in RCP 4.5 scenario and by 5.5ºC in RCP 8.5 scenario. The increase of air temperatures will affect the duration of the growing season – the scenarios project an extension of the growing season by 27 to 49 days, or by about 1 to 2 months. Changes are also observed in the climate index values characterizing extreme hot weather conditions. In Latvia the number of summer days is in average from 4 to 26 days a year, and as a result of the past climate change their number has increased by an average of 1-5 days per year.

The number of frost days will reduce by an average of 52 to 81 days per year and according to RCP 8.5 scenario in the most part of Latvia the reduction is projected at over 80 days per year. By 2100 the number of ice days will decrease by 32 to 46 days, in some locations in the Eastern regions by as much as 50 to 54 days per year. Decrease in snow cover depth and the number of days with snow cover will also be anticipated due to this.

Precipitation totals has been increased, especially in winter and spring seasons. The largest amount of precipitation has been observed in the Western area of Kurzeme and Vidzeme uplands, which is attributable to the topography of the area and the distance to the Baltic Sea and the Gulf of Rīga. Also, precipitation intensity has increased, which in turn has increased both the intensity and frequency of extreme precipitation events. By the end of the century, an increase of the total annual precipitation by 13 to 16% (about 80-100 mm) according to RCP4.5 and RCP 8.5 scenarios respectively is projected. The most significant precipitation increase is expected in winter season in which, along with temperature increase, comparing to recent period, one may expect larger percent of rain precipitation.

In the long-term period, average wind speed curve is trending slightly downwards and this tendency continues up to the end of the 21st century. The future the most radical decrease of mean wind speed (4-13%) can be expected in a moderate climate change scenario while in the significant climate change scenario a decrease of 0-6% is projected.

4.2.3. Climate change trends in Lithuania

The following summery is mainly based on Lithuania's 7th UNFCCC report (2017). According to RCP scenarios during 21st century in Lithuania daily air temperature fluctuations and the number of hot days (>30°C) and warm nights (>15 and >18°C) will increase. Thus, possibly heat waves will increase in frequency and intensity (they will last longer and will reach higher air temperatures). Number of extremely cold days will decrease more slowly. Average annual temperature may increase by 1.5-5.1°C. Increase in temperature will be larger in wintertime.

The average annual precipitation rate in the 21st century should increase by 3.7-13.5%. The highest precipitation growth is expected in October-April. Extensive rainfall increases in number of heavy rainfall (> 10 mm) and annual daily amount of maximum precipitation.

Relative air humidity during the cold season will unlikely to change much, but during the summer season will decrease significantly, especially in the second half of summer and at the beginning of autumn. The number of droughts in the summer (especially during the second half of vegetation period) is expected to increase.

The average wind speed will vary slightly, but wind speed fluctuations due to more frequent storm recurrence may increase, but wind gusts may increase, especially during the summer period.

The snow cover depth and the number of days with snow cover will decrease, especially in the western part of Lithuania, but the maximum snow cover thickness will not likely to change much. The number of thunderstorms will grow. The increase in the number of dangerous meteorological phenomena (such as freezing rain, hail, hurricane winds, etc.) is possible.

Based on the results of previous studies in Lithuania the Baltic Sea coast region is mostly vulnerable to climate change. Coast, coastal ecosystems, as well as local population are mostly affected by sea level rise, storm and hurricane winds, sea and Curonian Lagoon water warming and salinity changes. In 2081-2100 compared to 1986-2005 the global ocean level is likely to rise to 26-98 cm, Thermal water expansion contribution to the level rise will constitute 30-55%, glaciers 15-35%. It is estimated that the water level in the Baltic Sea in the 21st century will rise as well. However, changes in wind patterns and vertical tectonic movements will lead to a significant variation in water levels in different parts of the Baltic Sea. The water level will rise highest on the south-eastern coast, where Klaipėda city is situated

4.2.4. Temperatures

Estonia

The average annual temperature has increased slightly faster in Estonia compared to the world as a whole since the middle of the last century. The trend has been 0.2–0.3 °C per decade. The warming trend of the winter is the clearest. The highest average increase in the temperature by months is observed in March with less snow, due to the faster warming of the ground. Higher increases in the temperature are also observed in other winter and spring months. (KATI, 2015)

Average temperature projections in the RCP4.5 and RCP8.5 scenarios are presented in the Figure 4.85.

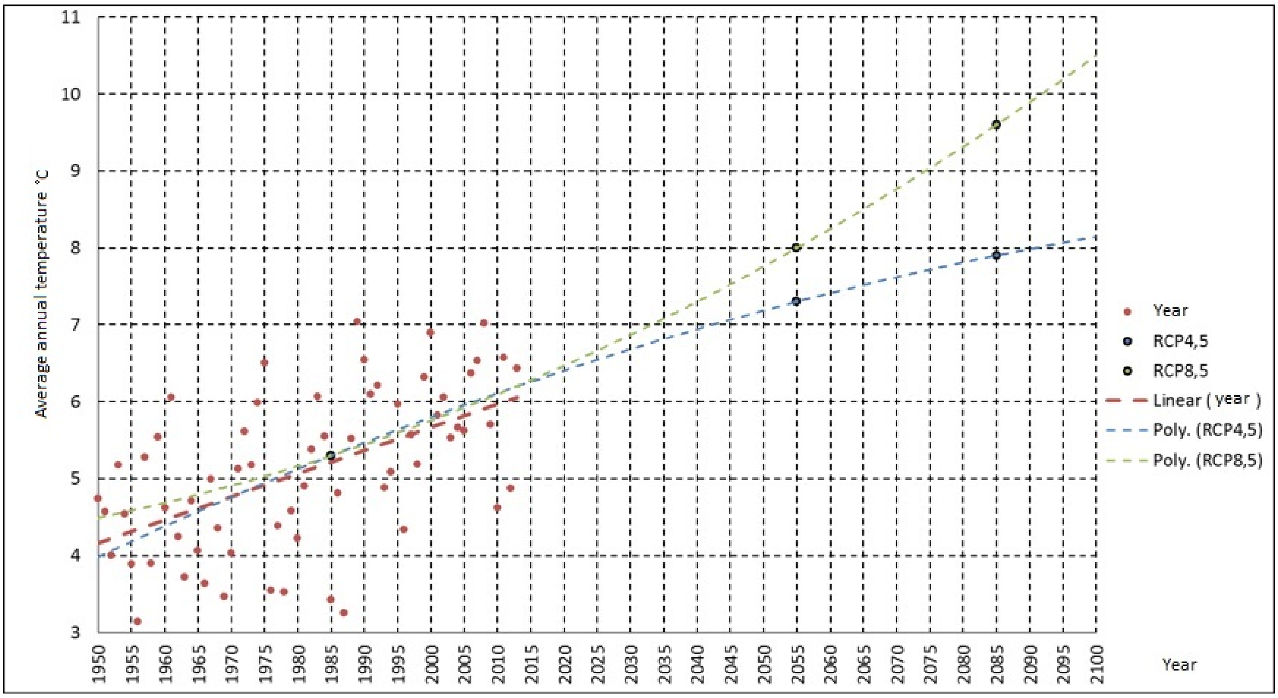


Figure 4.85 Average temperature projections in the RCP4.5 and RCP8.5 scenarios calculated based on data from Türi meteorological station. (KATI, 2015)

Latvia

Latvian future air temperature projections are presented in the Table 4.28.

Table 4.28 Latvian future air temperature projections (Climate change scenarios for Latvia, 2017)

Climate variable	Previous climatological value (1961-1990)	Previous changes (1981-2010 in relation to 1961-1990)	Future changes (2071-2100 in relation to 1961-1990)	
			RCP4.5	RCP8.5

Maximum temperature	Annual maximum value	+29.3 °C	↑ +0.7 °C	↑ +3.5 °C	↑ +5.7 °C
	Annual-mean value	+9.5 °C	↑ +0.7 °C	↑ +3.4 °C	↑ +5.4 °C
	Annual minimum value	-14.4 °C	↑ +1.4 °C	↑ +6.5 °C	↑ +9.5 °C
Mean temperature	Annual maximum value	+22.4 °C	↑ +0.7 °C	↑ +3.2 °C	↑ +5.4 °C
	Annual-mean value	+5.7 °C	↑ +0.7 °C	↑ +3.5 °C	↑ +5.5 °C
	Annual minimum value	-18.6 °C	↑ +1.7 °C	↑ +7.5 °C	↑ +11.0 °C
Minimum temperature	Annual maximum value	+17.6 °C	↑ +0.8 °C	↑ +3.1 °C	↑ +5.6 °C
	Annual-mean value	+2.0 °C	↑ +0.7 °C	↑ +3.6 °C	↑ +5.6 °C
	Annual minimum value	-24.1 °C	↑ +1.9 °C	↑ +9.3 °C	↑ +13.5 °C

Average temperatures

Until the end of century, annual mean air temperature can increase by 3.5- 5.5°C, while annual maximum value – by 3.2-5.4°C. Annual minimum value of mean air temperature is projected to increase by 7.5-11°C

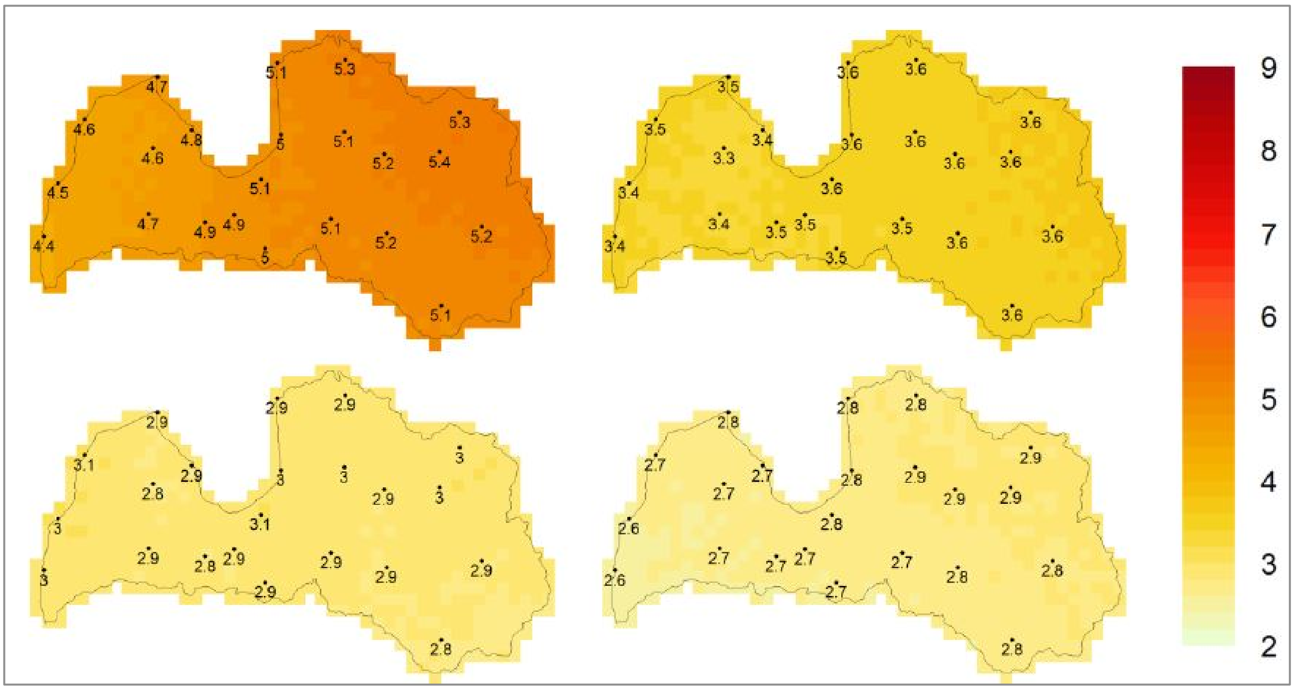


Figure 4.86 The forecast of global climate models for the seasonal average (from the left in the upper row in winter, spring, in the bottom line - summer, autumn) changes in the air temperature values (°C change 2071 - 2100 in relation to the values of 1961-1990) in the territory of Latvia following the RCP 4.5 climate change scenario

Minimum temperatures

During the summer season, the minimum temperature increase is expected in the territory of Latvia - the summer nights will become warmer and there will be a marked rise in the air temperature in the southern coast of the Rīga bay, in the area of Rīga. The annual-mean minimum air temperature rises similarly to the mean and maximum air temperature values, i.e. by 3.6ºC to 5.6ºC, however the annual minimum air temperature will increase by an average of 9.3ºC to 13.5ºC.

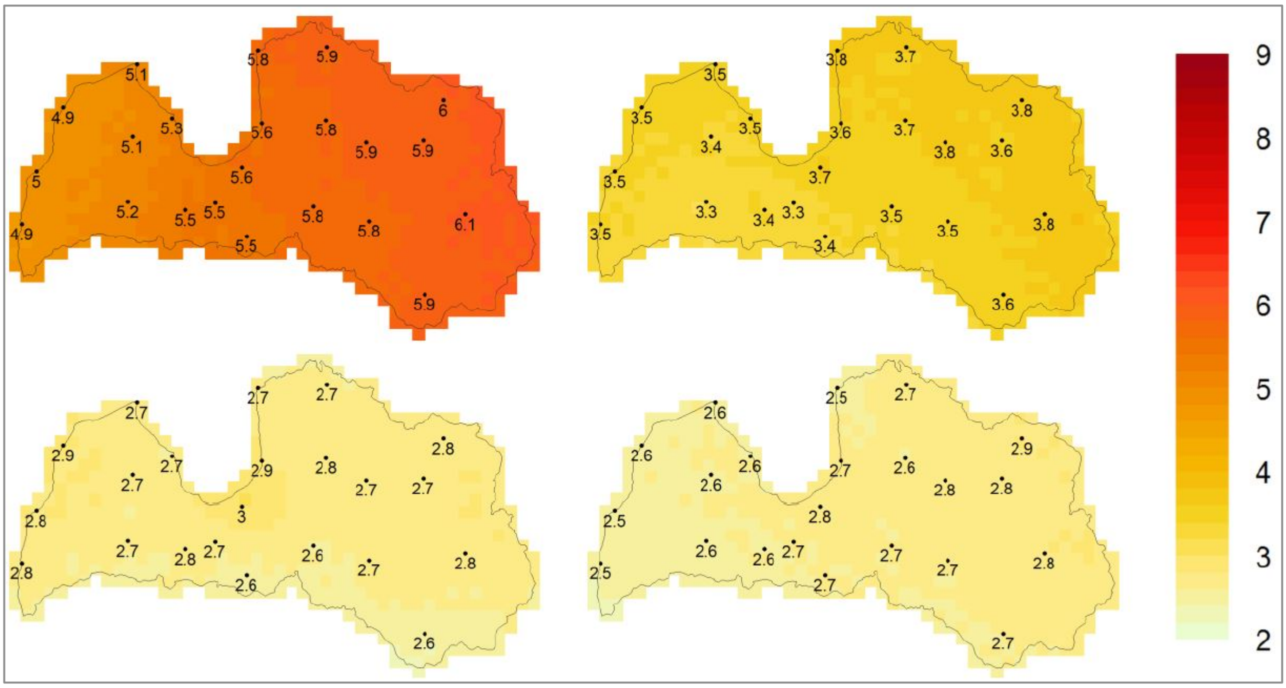


Figure 4.87 The forecast of global climate models for the seasonal minimum (from the left in the upper row in winter, spring, in the bottom line - summer, autumn) changes in the air temperature values (°C change 2071 - 2100 in relation to the values of 1961-1990) in the territory of Latvia following the RCP 4.5 climate change scenario

Maximum temperatures

Annual mean maximum air temperature, according to moderate and significant climate change scenarios, can increase by 3.4 - 5.4 °C, while a more rapid increase for extreme values is projected – annual maximum temperature by 3.6 - 5.7 °C. Annual minimum value of maximum air temperature can increase by 6.5 - 9.5 °C. 2071 - 2100 in relation to the values of 1961-1990) in the territory of Latvia following the RCP 4.5 climate change scenario

By the end of 21st century, the projected increase of summer days on average is 31 to 53 days.

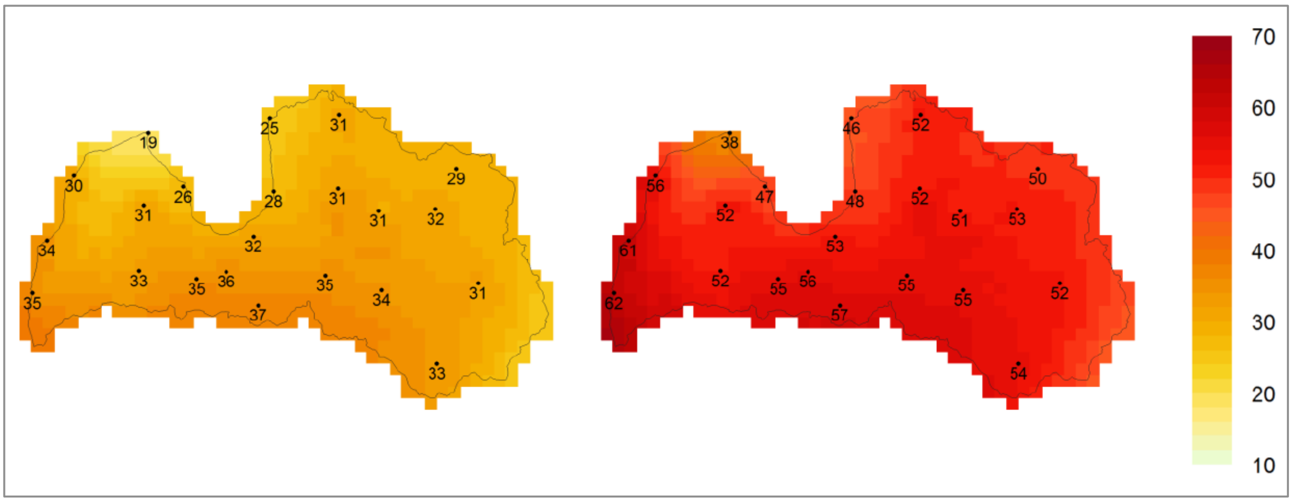


Figure 4.88 The forecast of global climate models for the number of summer days (the number of days change 2071 - 2100 in relation to the values of 1961-1990) Latvian territory along the RCP 4.5 (left) and RCP 8.5 (right) climate change scenarios

Historically, Latvia has always had a small number of tropical nights - in average from 0.1 to 0.7 nights a year, so no valid conclusions about the trends of change in the number of such nights can be made, however, an increase in the frequency of such nights has been observed during the last couple of decades. The number of tropical nights by year 2100 can increase by 4 to 14 nights.

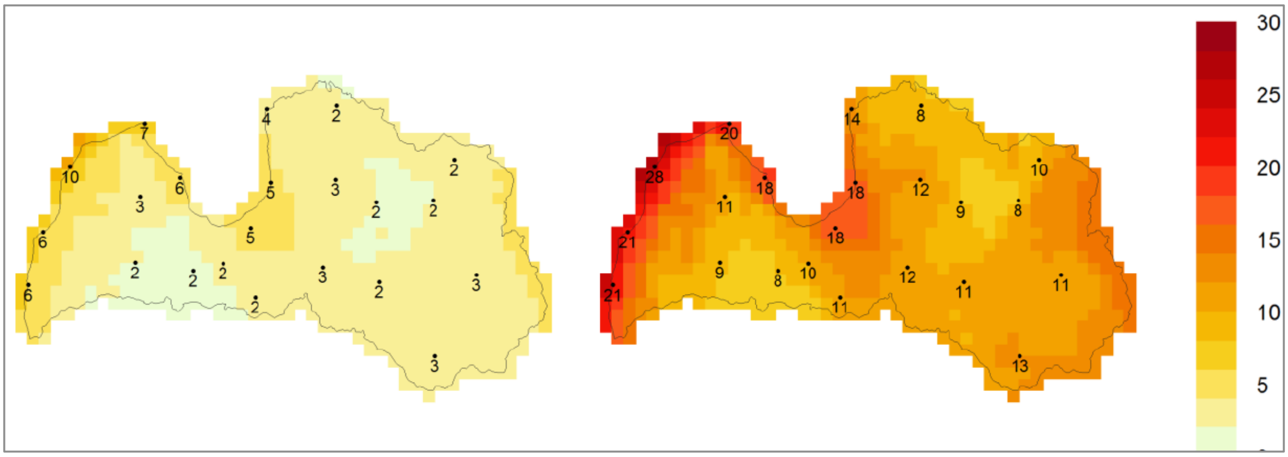


Figure 4.89 The forecast of global climate models for the number of tropic nights (the number of days change 2071 - 2100 in relation to the values of 1961-1990) Latvian territory along the RCP 4.5 (left) and RCP 8.5 (right) climate change scenarios

Lithuania

In Lithuania expected the highest increase in air temperature is projected according to RCP8.5 scenario and lowest increase according to RCP2.6 scenario. According to RCP4.5 and RCP6.0 scenarios the average annual temperature will increase at a similar pace as until the end of the 1980s, and only later according to RCP4.5 the air temperature will stabilize and based on RCP6.0 will continue to rise (Figure 4.90).

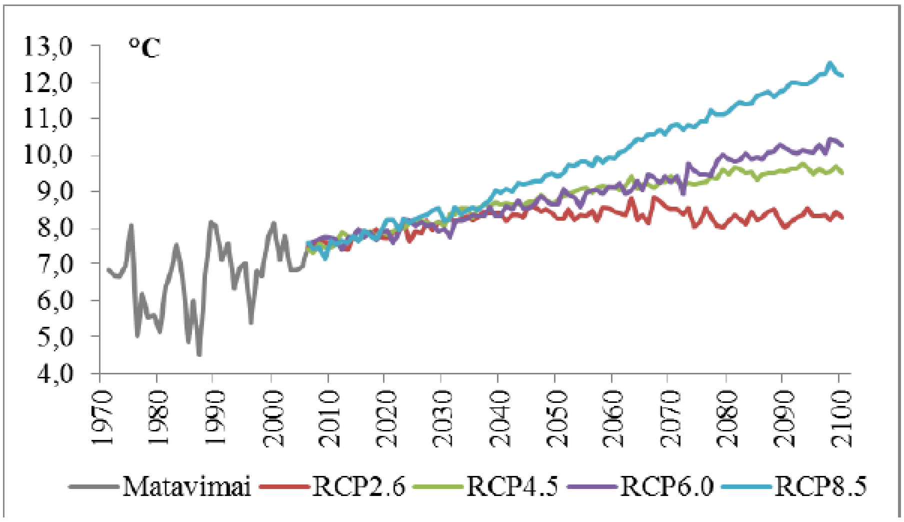


Figure 4.90 *Projections of the average annual air temperature change for Lithuania by 2100 according to different RCP scenarios*

Based on the study results it is projected, that by 2035 the air temperature will grow throughout all Lithuania. The average annual temperature will increase by 1.1-1.4°C compared to the 1986-2005 period. Major changes in air temperature during 2016-2035 are projected according to RCP4.5 and RCP8.5 scenarios. By 2035 the temperatures of the cold season in Lithuania will rise mostly. Major changes of air temperature are expected in February and March. By 2035 the most increase of air temperature is projected in February. These changes are projected according to RCP4.5 scenario.

In the West part of Lithuania, air temperature in the cold season will rise slower. In this part of Lithuania, the fastest growth of air temperature according to RCP8.5 scenario is also expected in February and March (up to 1.4 °C). The rapid growth of air temperature according to RCP 8.5 scenario is projected in July. In the West and South-West part of Lithuania, air temperature of this month will rise up to 1.5-1.6 °C.

Lowest air temperature changes are projected according to RCP6.0 scenario. Almost in all Lithuania, air temperature of June will rise at least (changes should not exceed 0.7-0.8°C), while in South-West part of Lithuania the lowest temperature increase is projected in December (0.6 °C).

It is forecasted that in the late 21st century the air temperature in Lithuania will continue to rise. The average annual temperature can increase by 1.5-5.1°C. The major changes in the late 21st century are projected according to RCP8.5 scenario, the lowest – according to RCP2.6 scenario.

In the late 21st century the air temperature in Lithuania will be fastest growing in the cold season. Based on RCP8.5 scenario the average temperature in January will rise mostly. In the North-East part of Lithuania, the air temperature this month is expected to rise by 6.3 °C. The lowest temperature change in January is projected in West part of Lithuania (5.3 °C). Projected growth of temperature is also expected in August. According to RCP8.5 scenario air temperature variations in this month vary from 4.7 to 5.4 °C in different parts of Lithuania. In the end of 21st century, the average air temperature should change at least in May. Even according to RCP8.5 scenario, air temperature changes in this month will not exceed 3.9 °C.

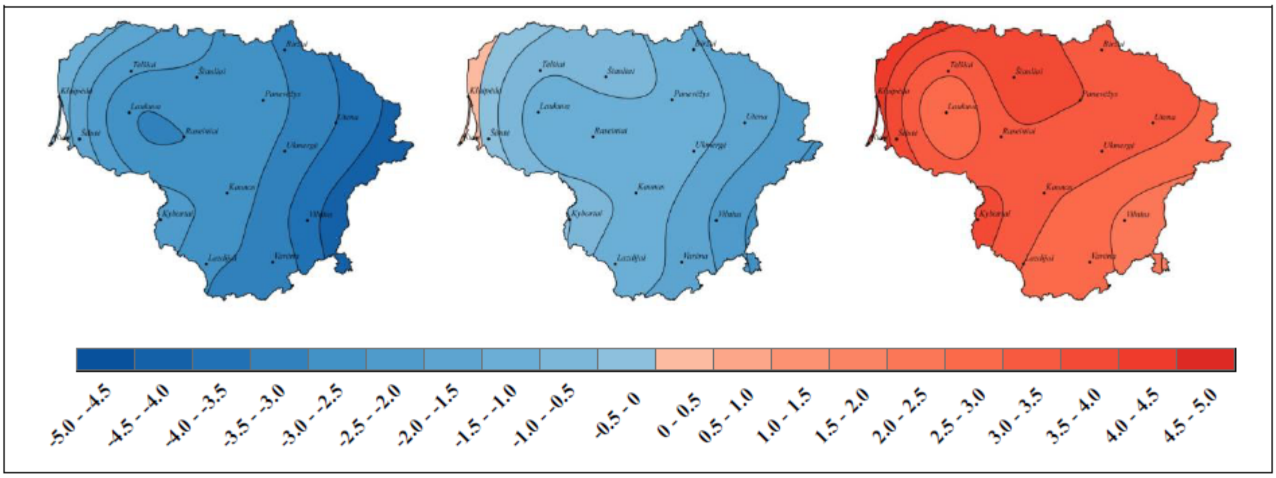


Figure 4.91 *Average annual January air temperature in Lithuania 1986-2005 m. (left) and predicted 2081-2100 period in accordance of RCP2.6 (middle) and RCP8.5 (right) scenarios, °C.*

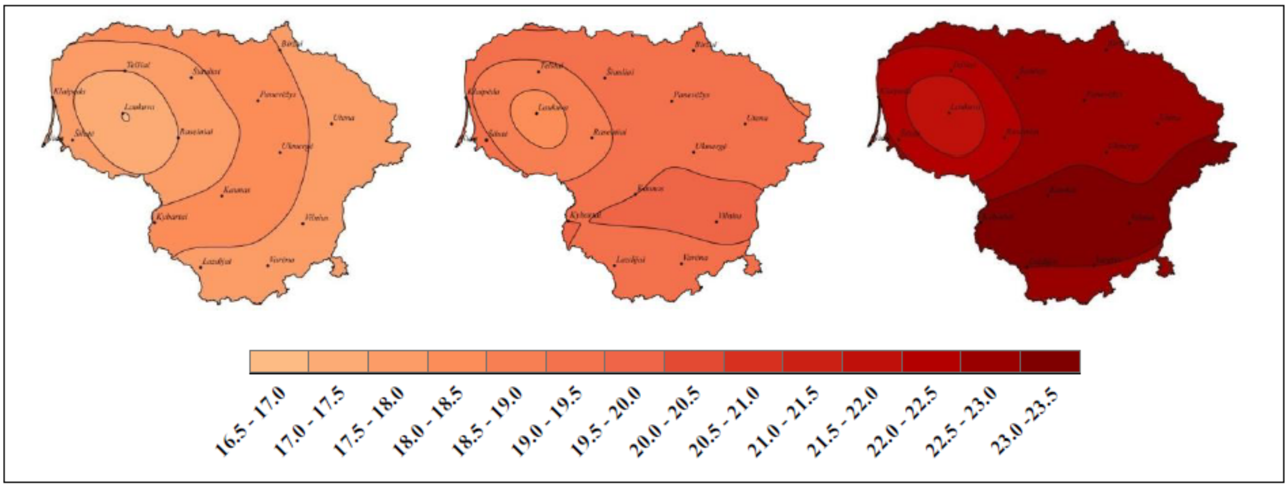


Figure 4.92 *Average annual July air temperature in Lithuania 1986-2005 m. (left) and predicted 2081-2100 period in accordance of RCP2.6 (middle) and RCP8.5 (right) scenarios, °C.*

During 2016-2035 period biggest changes of average annual minimum air temperature in Lithuania are projected according to RCP8.5 scenario. Mostly it will grow in the North-East and South-East part of Lithuania. Changes can reach 3.1 °C. In the rest part of Lithuania until 2035 it will rise up to 2.5-2.8°C. Least changes of minimum air temperatures are expected in West part of Lithuania (2.3°C).

The pace of changes will grow at the end of the 21st century. The average annual minimum air temperature mostly will increase in the North-East part of Lithuania according to RCP8.5 scenario (12.1 °C). In the rest part of Lithuania changes will be 9.4-11.6 °C. The lowest changes according to RCP2.6 scenario is projected in the West part of Lithuania (3.5 °C).)

The changes of the annual maximum air temperature will be much lower than the annual minimum. In the 21st century annual maximum air temperature mostly will rise in the South-East and South-West part of Lithuania, while lowest rise is projected in the West part of Lithuania. During the 2016-2035 period, changes will be very similar all over in Lithuania. According to RCP8.5 scenario changes should not exceed 1.6 °C in the South-West and South-East part of Lithuania, elsewhere 1.4-1.5 °C.

During 2081-2100 period the annual maximum air temperature rise will be faster. It is forecasted that by the end of the century, according to RCP8.5 the average annual maximum air temperature in the South-West and South-East part of Lithuania will be 6.7 °C, elsewhere 5.5-6.3 °C higher than the average of 1986-2005 period. According to the RCP2.6 scenario, changes at the end of this century in different parts of Lithuania should not exceed 1.5-1.8 °C. According to RCP8.5 scenario, at the end of the century the average annual maximum air temperature in the South-East part of Lithuania can reach almost 40 °C (Figure 4.93). (Bukantis, A. et al, 2015)

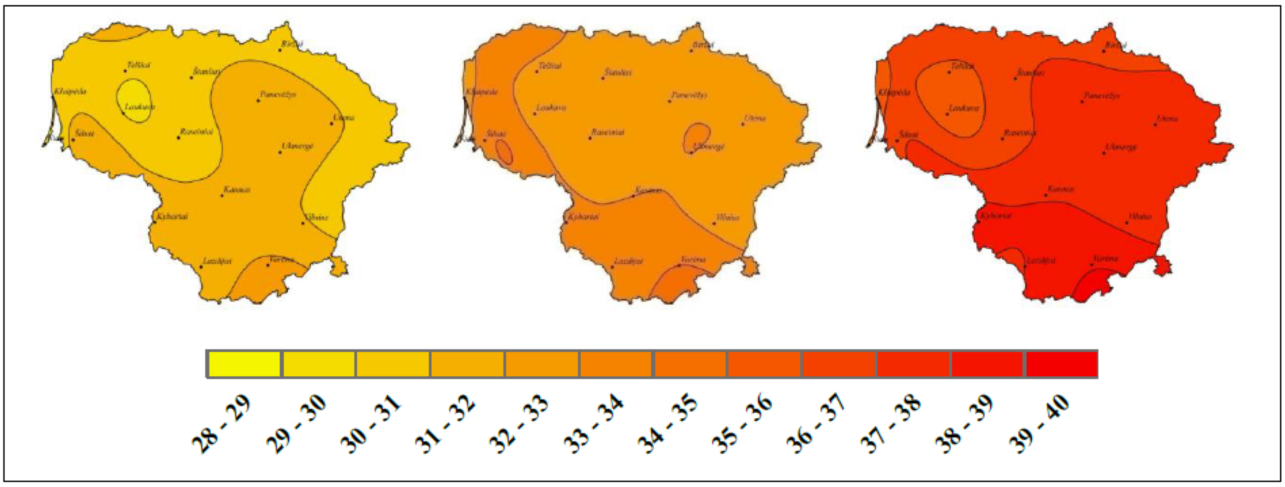


Figure 4.93 *The average annual maximum air temperature in Lithuania1986-2005 (left) and predicted 2081-2100 in accordance of RCP2.6 (middle) and RCP8.5 (right) scenarios, °C.*

4.2.5. Precipitation

Rainfall (monthly average and annual average values)

Extreme rainfall (frequency and magnitude, as example maximum daily precipitation, maximum monthly precipitation, frequency and duration of such situations)

Estonia

The increase in the average annual precipitation in the second half of the 20th century has been significant in Estonia, up to 15%, observed strongly during the period from October to March. The highest increase in precipitation in the RCP8.5 scenario can be observed in spring, and in the RCP4.5 scenario, however, in summer. An increase in the number of occurrences of extreme precipitation (more than 30 mm of precipitation over 24 hours) is forecasted, but taking into consideration the very low likelihood thereof in the majority of the year, these occurrences are only significant in summer. Precipitations will increase is predicted to be 19% by the end of the century in the RCP8.5 scenario (Table 4.29 and Figure 4.94). (Keskkonnaministeerium, 2018)

Table 4.29 Changes in average precipitation amounts in Estonia in periods 2041-2070 and 2071-2100 compared to control period of 1971-2000 (Keskkonnaministeerium, 2018)

Period	2041-2070		2041-2070	
Scenario	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Winter (DJF)	9%	15%	16%	22%

Spring (MAM)	10%	16%	21%	24%
Summer (JJA)	11%	18%	15%	19%
Autumn (SON)	10%	8%	11%	12%
Yearly average	10%	14%	16%	19%

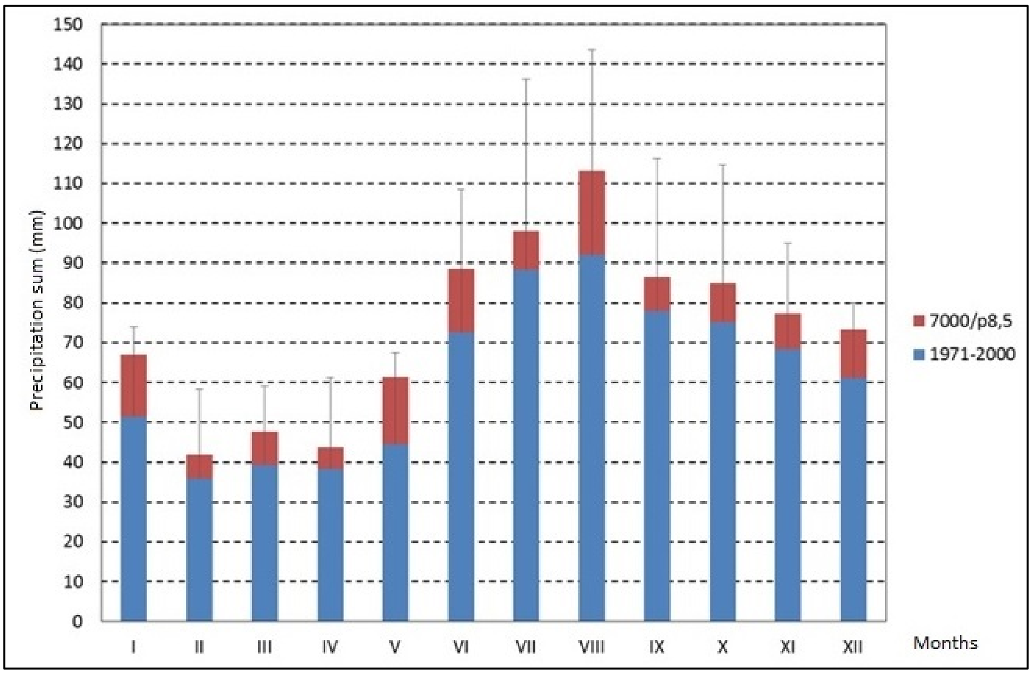


Figure 4.94 Monthly precipitations in Türi for control period and in the RCP8.5 scenario in on period 2071–2100.

Likelihood of extreme precipitation (over 30 mm per day) will increase in average (Table 4.30) and the likelihood increase can be up to 4 times in winter period in the RCP8.5 scenario. Registered extreme precipitation event locations are very random and no clear spatial pattern cannot be established.

Table 4.30 Projected changes in precipitation likelihoods of over 30 mm precipitations per day for different periods of year, scenarios and projection periods. (KAUR, 2014)

Period	2041-2070	2071-2100	2041-2070	2071-2100
Scenario	RCP4.5		RCP8.5	
Autumn (SON)	188%	184%	174%	245%
Winter (DJF)	201%	141%	231%	435%
Spring (MAM)	158%	207%	209%	244%
Summer (JJA)	124%	137%	139%	165%

Latvia

The scenarios project also an increase of the intensity of precipitation – by about 0.1 - 1 mm / day to 0.5 - 1.3 mm / day according to the scenarios (Table 4.31). The highest precipitation intensity increase is expected in the coastal area of the Baltic Sea and in Vidzeme as we can see in Figure 4.95.

Table 4.31 Latvian future precipitation projections (Climate change scenarios for Latvia, 2017)

Climate variable	Previous climatological value (1961-1990)	Previous changes (1981-2010 in relation to 1961-1990)	Future changes (2071-2100 in relation to 1961-1990)	
			RCP4.5	RCP8.5
Precipitation totals	651 mm	↑ +6%	↑ +6%	↑ +6%
Highest 1-day precipitation amount	33 mm	↑ +1 mm	↑ +3 mm	↑ +6 mm
Highest 5-day precipitation amount	58 mm	↑ +2 mm	↑ +9 mm	↑ +12 mm
Heavy precipitation days	15 days	↑ +2 days	↑ +3 days	↑ +5 days
Very heavy precipitation days	3 days	↑ +1 days	↑ +1 days	↑ +2 days
Simple daily intensity index	5.1 mm/per day	↕ 0 mm/per day	↕ 0 mm/per day	↑ +1 mm/per day

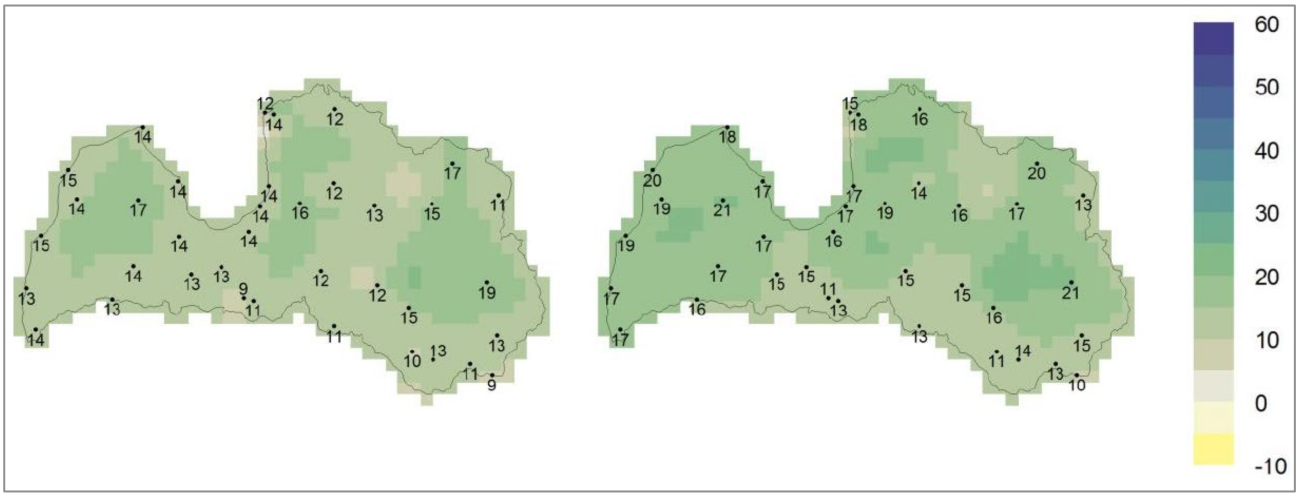


Figure 4.95 The forecast of global climate models for precipitation (% change 2071 - 2100 in relation to the values of 1961-1990) Latvian territory along the RCP 4.5 (left) and RCP 8.5 (right) climate change scenarios

Lithuania

The projections for annual precipitation rates up to 21st century middle under various RCP scenarios for Lithuania almost not differ (Figure 4.96). Only later projected higher changes appear according to RCP8.5 scenario and average annual precipitation rate stabilization is observed according to RCP2.6 scenario. Estimated changes in precipitation rates according to RCP4.5 and RCP6.0 are very similar.

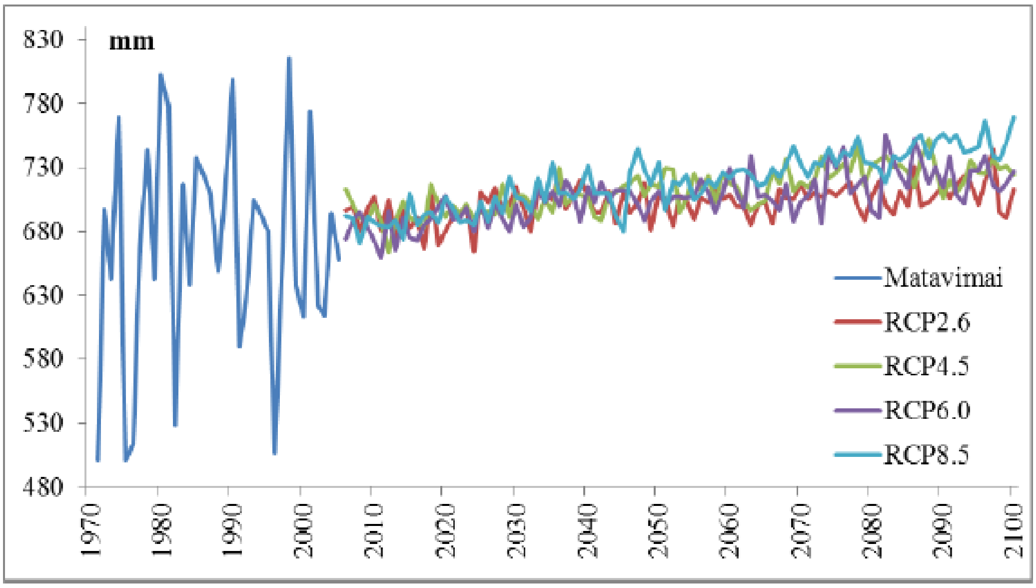


Figure 4.96 *Projected annual precipitation in Lithuania up to 2100 according to different RCP scenarios*

By 2035 the average annual precipitation rate should increase by 1.4-4.0 %. Major changes are projected according to RCP4.5 scenario and the lowest in RCP6.0 scenario. Model output results for all four RCP scenarios for the beginning of 21st century anticipate increase of the total amount of precipitation from October to April and in June. In September the decrease of precipitation is projected according to all RCP scenarios, with the exception of Lithuania's West part.

By 2035 in the territory of Lithuania, the amount of precipitation will mostly grow in the first half of the year. The largest changes in precipitation are expected in West part of Lithuania, and the smallest in the South-East part. In the North-East part of Lithuania, the fastest increase in precipitation is expected in February - 8.3%, while in the South-West part - in June (8.0%).

Model output data shows the largest negative changes of precipitation in July. The most decrease of precipitation is projected in South-East part of Lithuania (4-2 %), while in North-East only 2.6 %.

Even more significant changes in precipitation is projected in the late 21st century. The average annual precipitation may increase by 3.7-13.5 %. More changes are expected in the North part of the country than in South. According to RCP2.6 scenario annual average precipitation rate will unlikely to change significantly, most changes are projected according to RCP8.5 scenario.

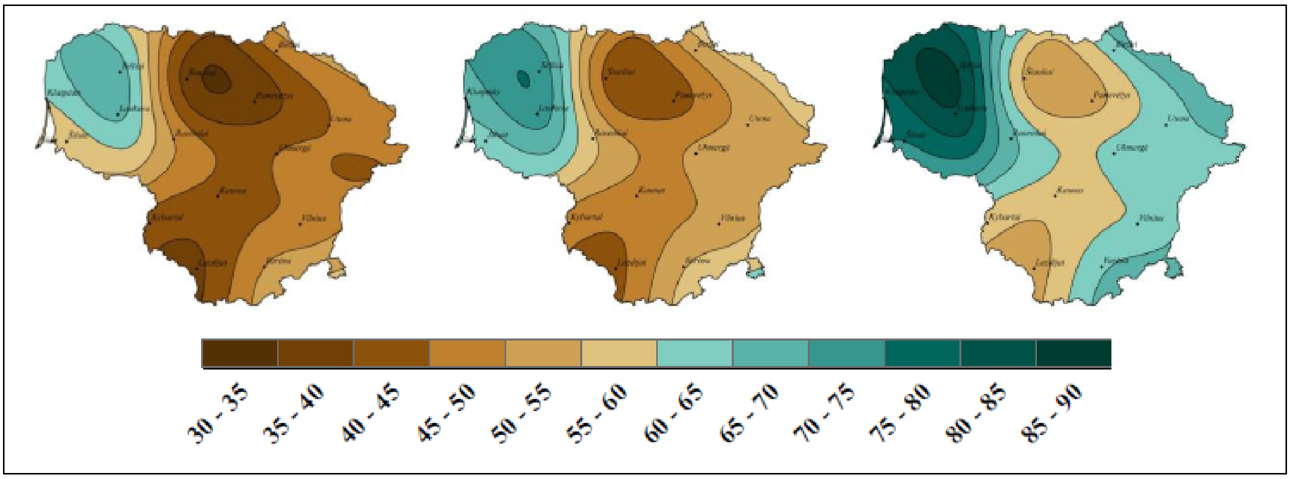


Figure 4.97 *Average annual January precipitation rate in Lithuania 1986-2005 m. (left) and projected 2081-2100 according to RCP2.6 (middle) and RCP8.5 (right) scenarios, mm.*

In the late 21st century, precipitation rate will mostly increase during cold season. In the West and South-East part of Lithuania, the fastest rise will be in January, respectively 26.5 % and 15.3 %, while in the middle of Lithuania and in the North-East part – in December. Expected changes in these parts of the country respectively will be 26.6 % and 27.5 %. These changes in the territory of Lithuania are projected according to RCP8.5. It is forecasted that precipitation rate changes in the future will be higher in the North part of Lithuania.

Precipitation rate decrease is expected in July-September. Precipitation rate mostly should decrease in the South-East of the country, and at least in the West. In the central, North-East and South-East regions of Lithuania, precipitation most likely will decrease in July. In the West part of Lithuania - in August and in South-West – in September. Although this indicator should increase in the future, but the spatial distribution of precipitation will remain close to the current one (Figures 4.98-4.100).

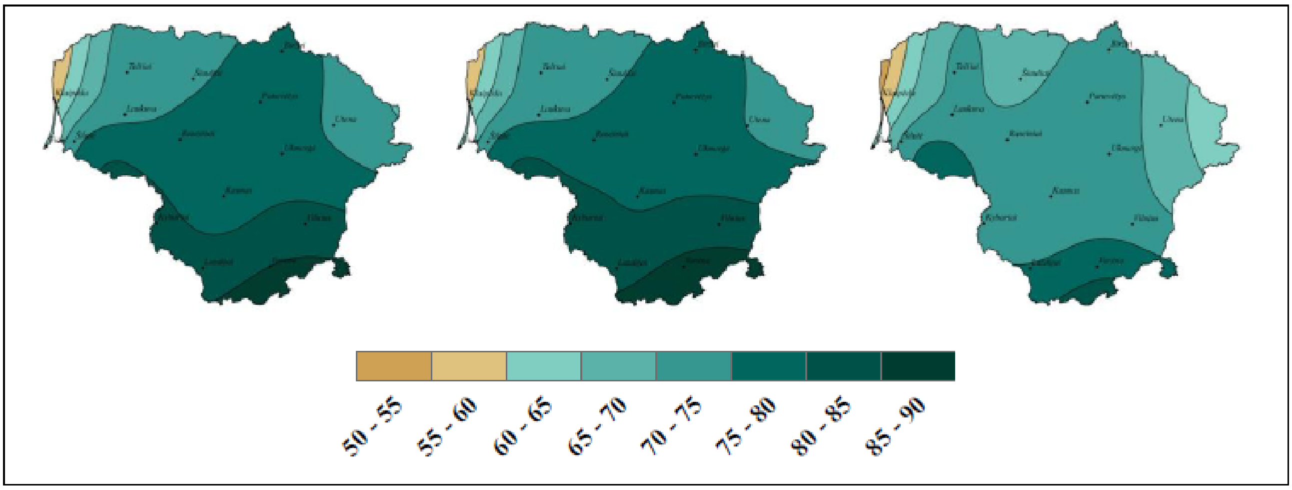


Figure 4.98 *Average annual July precipitation rate in Lithuania 1986-2005 m. (left) and projected 2081-2100 according to RCP2.6 (middle) and RCP8.5 (right) scenarios, mm.*

During 2016-2035 period, climate models do not foresee any significant changes in the number of days when precipitation rate is >1 mm per day. The results of modelling show that in most parts of Lithuania the number of such days will remain unchanged up to 2035, and regional variations in change should be minimal (no more than 1-2 days). According to RCP2.6 scenario, in 2081-2100 period it is expected that days number of precipitation (> 1 mm) should increase throughout all Lithuania, and according to RCP8.5 scenario in the South part of Lithuania such days should decrease by 3 days, elsewhere increase by 1-3 days.

The analysis of the number of days with precipitation rate (> 10 mm) shows that intensive precipitation in the territory of Lithuania will be more and more frequent. In the basic period, the average number of days, when precipitation rate is > 10 mm, in Lithuania ranged from 13 days a year. In this century, the increase in such days is projected by all scenarios. It is expected, that in 2016-2035 period, the number of days (> 10 mm) most likely should increase in the North part of Lithuania (up to 2 days), and in the remaining parts of Lithuania the changes should not exceed 1 day. According to RCP8.5 scenario, in 2081-2100 period, in the central, West and North-East parts of Lithuania such days will increase by 6, and in the South of the country – by 5. Model output results for the RCP2.6 scenario predict similar changes throughout all Lithuania (up to 2 days). At the end of this century, the average number of days (> 10 mm) of precipitation, can increase up to 18-28 days per year.

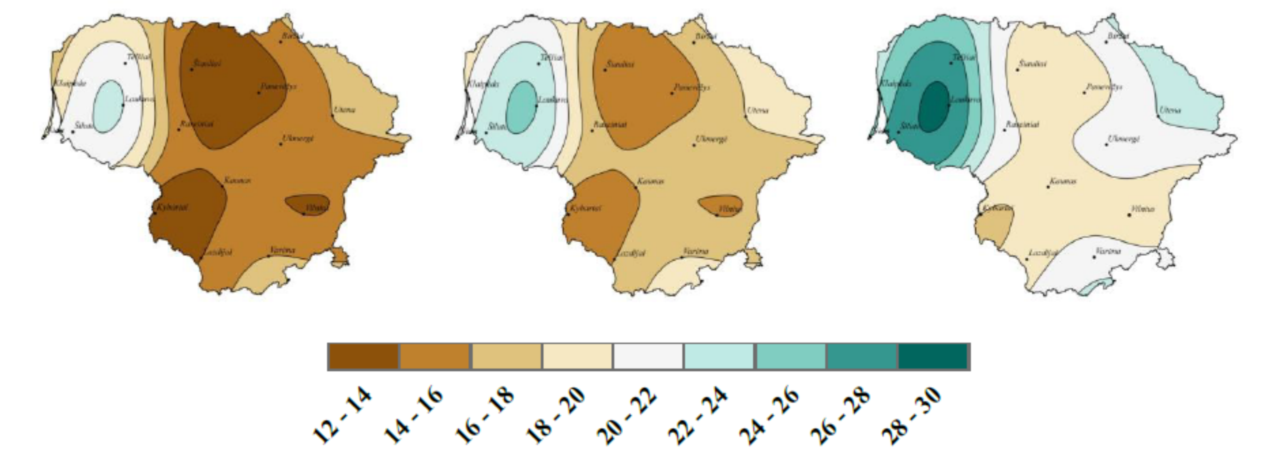


Figure 4.99 *The average annual number of days when precipitation rate is >10 mm per day 1986-2005 m. (left) and projected in 2081-2100 according to RCP2.6 (middle) and RCP8.5 (right) scenarios.*

In the future, the annual maximum amount of precipitation in Lithuania will grow. According to RCP2.6 scenario, only in North-East of Lithuania annual maximum amount of precipitation should slightly decrease, but in the rest parts of Lithuania according to all scenarios increase by 1.9-4.6 %. At the end of the century, the maximum daily precipitation rate will increase faster and, according to RCP8.5 scenario, in the central part of the country should increase by 17.4 %. In the future, the value of this indicator should increase but the distribution of isolines will remain similar. (Bukantis, A. et al, 2015)

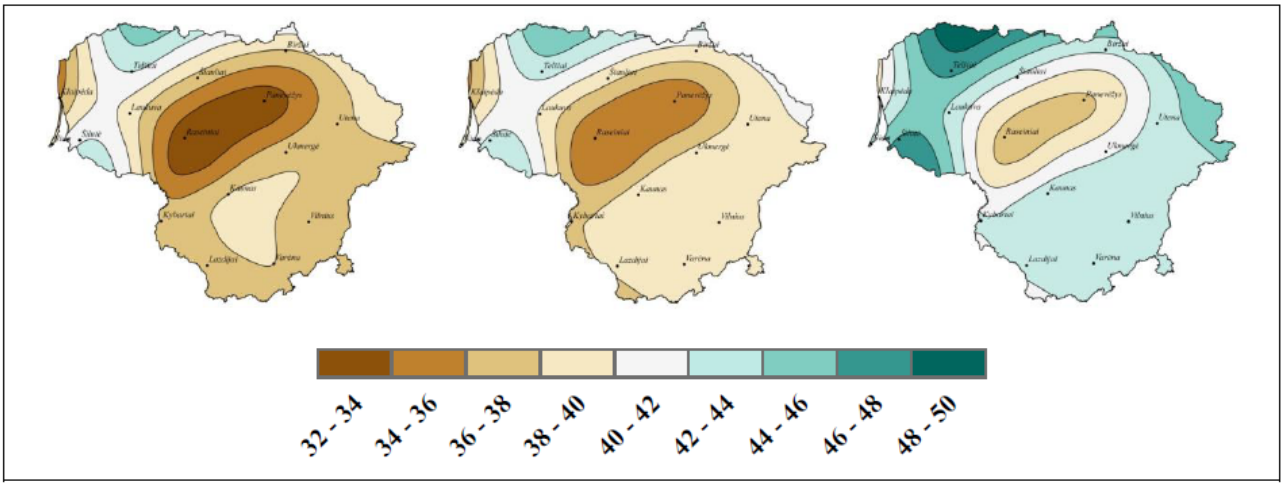


Figure 4.100 *The maximum daily precipitation rate 1986-2005 m. (left) and projected in 2081-2100 according to RCP2.6 (middle) and RCP8.5 (right) scenarios.*

4.2.6. Snowfall and snow cover

Snowfall (monthly average and annual average values, snow coverage duration)

Extreme snowfall (frequency and magnitude, as example maximum daily precipitation, maximum monthly precipitation, frequency and duration of such situations)

Estonia

Majority of the precipitation in winter will be in the form of rain, considering drastic temperature increase in the winter based on the RCP8.5 scenario. This water quickly reaches rivers, which means there will not be spring flooding in most of the years.

Projections for the end of 21th century show significant decrease of snow cover. Snow is very unlikely in April and average duration of snow cover will be reduced by more than 10 days in March and only some part of North-East Estonia will have snow cover for over half of the days in January and February in the RCP4.5 scenario. Snow cover periods will be decreased further in the RCP8.5 scenario – maximum of 10 days per month in North-East and South-East Estonia. Average snow cover duration for control period and RCP4.5 and RCP8.5 scenarios is presented in Figure 4.101. (KAUR, 2014)

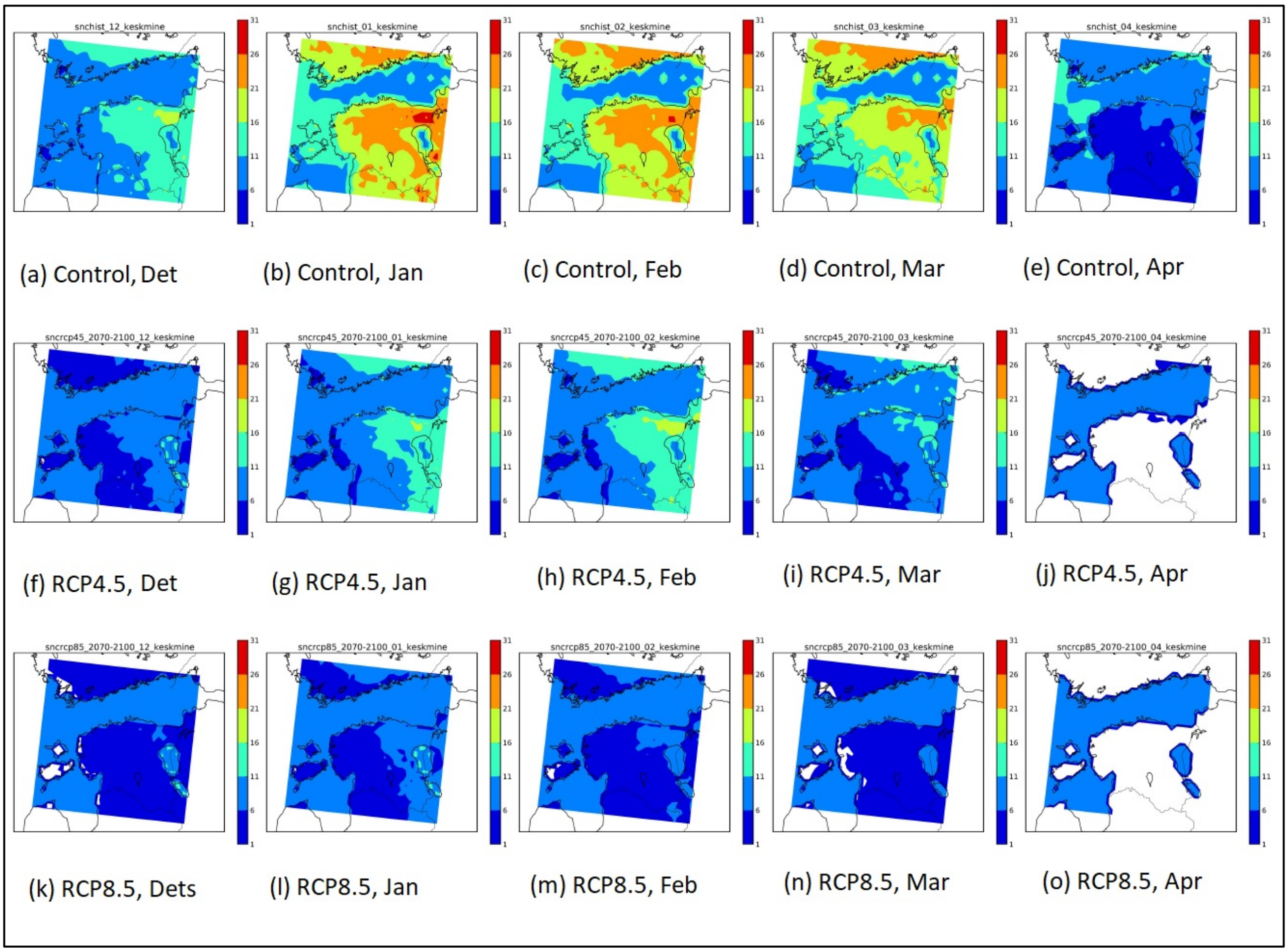


Figure 4.101 Average snow cover duration (days) for control period 1971-2000 and RCP4.5 and RCP8.5 scenarios for period 2071-2100. (KAUR, 2014)

Latvia

The maximum increase in one day's precipitation in winter leads to a sharp increase in snow precipitation above the norm. The increase in the number of days with very high precipitation and the decrease in the number of days without a thaw, which in general characterizes more frequent wet snow manifestations). (Latvia's 7th UNFCCC report, 2017)

Table 4.32 Latvian future snowfall projections (Climate change scenarios for Latvia, 2017)

Climate variable	Previous climatological value (1961-1990)	Previous changes (1981-2010 in relation to 1961-1990)	Future changes (2071-2100 in relation to 1961-1990)	
			RCP4.5	RCP8.5
Annual-mean temperature	+29.3 °C	↑ +0.7 °C	↑ +3.5 °C	↑ +5.5 °C
Annual-mean minimum temperature	+2.0 °C	↑ +0.7 °C	↑ +3.6 °C	↑ +5.6 °C
Highest 1-day precipitation amount	33 mm	↑ +1 mm	↑ +3 mm	↑ +6 mm
Very heavy precipitation days	3 days	↑ +1 days	↑ +1 days	↑ +2 days
Days without a thaw	62 days	↓ -9 days	↓ -32 days	↓ -46 days
Frost days	134 days	↓ -9 days	↓ -52 days	↓ -81 days
Ice days	62 days	↓ -9 days	↓ -32 days	↓ -46 days

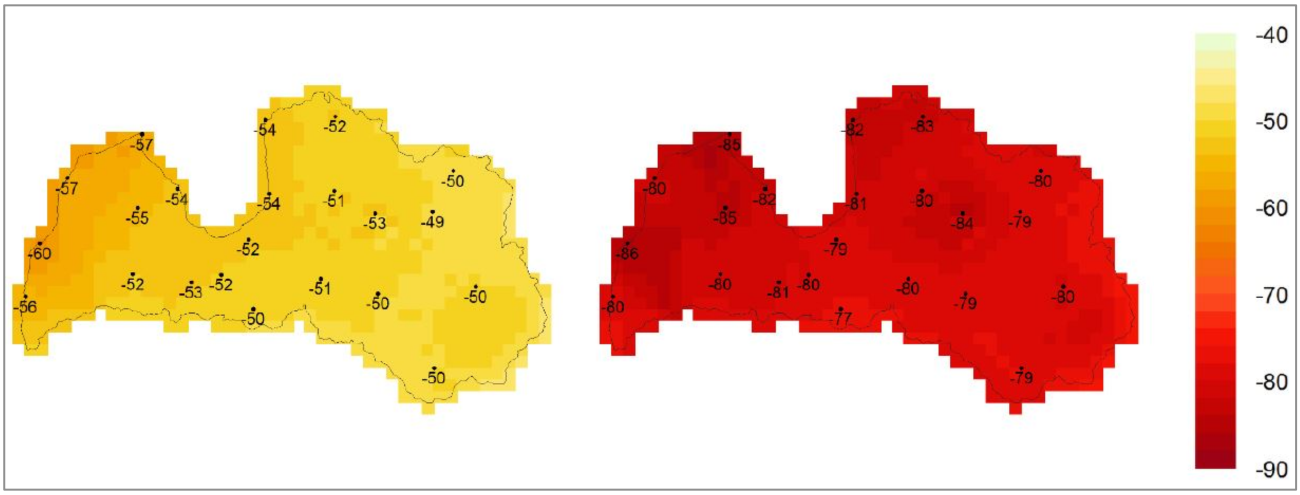


Figure 4.102 The forecast of global climate models for frost days (number of days change 2071 - 2100 in relation to the values of 1961-1990) Latvian territory along the RCP 4.5 (left) and RCP 8.5 (right) climate change scenarios

Consequently, due to the fact, that the most rapid air temperature rise will be experienced during the winter season, it is expected that the number of frost days and ice days will reduce significantly. The number of frost days will reduce by an average of 52 to 81 days per year and according to RCP 8.5 scenario in the most part of Latvia the reduction is projected at over 80 days per year. By 2100 the number of ice days will decrease by 32 to 46 days, in some locations in the Eastern regions by as much as 50 to 54 days per year. Decrease in snow cover depth and the number of days with snow cover will also be anticipated due to this.

Lithuania

According to all climate change scenarios, the number of days with snow cover in Lithuania will decrease. According to the predictions that until 2035 the number of days with snow cover will decrease by 14-15, until 2065 - by 13-34, and until 2100 - by 17-56 days to corn pare with reference period of 1986-2005.

The annual maximum snow cover thickness in Lithuania was also mostly influenced by air temperature in December (in 88 % of cases the mean average, maximum or minimum temperature of this month was included in multiple regression equations) and February (81 %). Unlike days with snow cover, the amount of precipitation influences the maximum snow cover. The precipitation values in different months were independent variables in multiple regression equations in 38 % of cases. It was estimated that the maximum snow cover thickness in Lithuania in 21st century will decrease. It is predicted that until 2035 the maximum snow cover thickness will decrease by 4-5 cm, until 2065 - by 5-9 cm, and until 2100 - by 5-14 cm.

The smallest changes in snow cover indices are predicted according to RCP2.6, while the largest ones are predicted according to RCP8.5 scenario. The largest negative changes in number of days with snow cover are expected in the western part of the country, and the smallest in the East. On the coastal area the largest decrease of snow cover depth is also very likely. (Rimkus, E.; Pasiskeviciute, R. 2017)

4.2.7. Floods

Majority of the precipitation in winter will be in the form of rain, considering drastic temperature increase in the winter based on the RCP8.5 scenario. This water quickly reaches rivers, which means there will not be spring flooding in most of the years. Spring floods (main flood risk) will be less severe due to milder winters and inconsistent snow coverage. Maximum discharges of spring floods have decreased in the Baltics over the period 1922-2010 (Sarauskiene et al 2015).

Due to changes in the trajectories of cyclones and the resulting higher frequency of western storms, Estonian coastal areas may be at a risk of increasingly frequent rises in the water level and floods, the extent of which in the future will probably exceed what has been experienced so far. The flood risk in inland waters is assessed as considerably lower compared to that in coastal areas. (Estonia's 7th UNFCCC report, 2017)

4.2.8. Landslides

Precipitation is a common trigger of landslides and probability of landslides will increase due to increased precipitation and flooding events, although no future projections are available for landslides in Baltic States.

4.2.9. Wind

Estonia

The majority of the sources are referring to an increase in the average wind velocity in winter and partly in spring. The increase is likely to range between 3–18% and is related to the increase in the number of cyclones moving to our territories from the Atlantic Ocean.

Likelihood of severe storms (21 m/s or more) might increase, but there is much uncertainty in long-term predictions. (KAUR 2014)

Latvia

Stormy days in Latvia are observed very rarely: from 0-1 day per year in most parts of the territory up to 6.9 and 7.9 days on the average in Liepāja and Ventspils; up to recently, the number of such days on the average in Latvia has decreased by 1 day.

Table 4.33 Latvian future wind speed projections (Climate change scenarios for Latvia, 2017)

Climate variable	Previous climatological value (1961-1990)	Previous changes (1981-2010 in relation to 1961-1990)	Future changes (2071-2100 in relation to 1961-1990)	
			RCP4.5	RCP8.5
Annual-mean wind speed	3.6 m/s	↓ -8%	↓ -7%	↓ -3%
Stormy days	1 day	↓ -1 day	↕ 0 days	↕ 0 days
Calm days	75 days	↑ +13 days	↑ +13 days	↑ +13 days

In the future the most radical decrease of mean wind speed (4-13%) can be expected in a moderate climate change scenario while in the significant climate change scenario a decrease of 0-6% is projected.

Lithuania

The average wind speed is unlikely to change much, but wind gusts may increase, especially during the summer period. It is likely that the recurrence of storms and hurricane winds will increase, especially during the cold season. (Lithuania's 7th UNFCCC report, 2017)

The comparison of the average annual wind speeds in 1971-1990 and 1991-2010 revealed the tendency of wind weakening by 03-05 m/s (i.e., 7-10 %). However, a chance exists that these changes of wind speed could have been influence by the changes of environment of the meteorology stations (overdevelopment, planting, etc), rather than by the particularities of atmospheric circulation. The winds mostly weakened (by 0.5-1.1 m/s) in Klaipėda at the end of summer and autumn.

The wind increasing up to 15 m/s in gusts becomes a dangerous meteorological phenomenon. The wind speed of 15 m/s and more is typical to the seaside areas 60 days per year, on average, in central Lithuania - 20-25 days, and in the east and south east - only 6-10 days. The average number of annual days, when the speed of wind gust reaches 15 m/s and more, decreased by 1-10 days in Lithuania, as compared with 1971-1990 and 1991-2010.

The maximum speed of wind in gusts can reach up to 35-40 m/s near the Baltic Sea, and in other regions of Lithuania - 25-28 m/s. In case of tornadoes, the speed of wind can reach even more than 50 m/s. When analysing the maximum wind speeds in 1971-2010, no significant long-term tendency of their change has been observed. During this period, the wind speed of 30 m/s and stronger was recorded in meteorological stations eight times in total. Pursuant to the data of the forecast climate models, the climate warming is accompanied with the likely increase in the incidence of winds gaining the strength of a tornado, especially during the local squalls.

In autumn and winter, usually the south, south-west and west winds are blowing, in summer, the west and north-west winds are dominating. When comparing the repetition of the average wind direction in 1961-1990 and 1991-2010, more changes that are significant were established in the seaside areas only. Here, the incidence of south-east winds decreased even by 9 percentage points, whereas the incidence of south, west and north winds increased by 2-4 percentage points. In the Eastern Lithuania, the south-east winds decreased by 4 % and south winds increased as well. The incidence of doldrums (calm) increased by 1-2 percentage points in the seaside areas and Central Lithuania and their current annual likelihood became similar in the entire Lithuania – 2.4-3.1 %. (Bukantis, A. et al, 2015).

4.2.10. Thunder

Higher air temperature causes more intense formation of typical summer thunder clouds. Natural phenomena associated with thunder clouds will be more likely and with more severe consequences, but more detailed projections are not possible due to uncertainty and random spatial nature of the thunder events. (KAUR 2014) The impacts of climate change that may be at risk include increase in the likelihood of sudden and strong thunderstorms in summer, although no detailed future projections are available for Baltic countries.

4.2.11. Frost penetration of soil

No clear projections available about frost penetration of soil for Estonia, Latvia and Lithuania, though the soil frosting would be affected by much warmer winters.

The more frequent incidence of defrosting of soil in the entire country shows that, in the past 50 years, not only have the winters become warmer, but also the infiltration conditions of the cold season water, minimum outflow of rivers and nature of spring flood hydrogram have likely suffered significant changes. (Lithuania's 7th UNFCCC report, 2017)

4.2.12. Fog

No future projections available about fog for the Baltic states.

4.2.13. Humidity

No future climate projections available for humidity in Estonia, Latvia and Lithuania. Climate projections are available for the precipitations. During the cold season relative humidity is unlikely to change much and during warm season will decrease (mostly in July-September). (Lithuania's 7th UNFCCC report, 2017)

4.2.14. Wildfires

No future projections available for wildfires in the Baltic states though the occurrence of wildfires increases very likely as summer temperatures increase, drought periods occur.

5. Sensitivity assessment

Initial scoping of railway related hazards and variables and identification of geographical conditions of Rail Baltica railway corridor were carried out and some of the potential hazards excluded from the sensitivity assessment as a result:

- ✓ **Seal level rise** – Rail Baltica railway is in the safe distance from the Baltic sea – sea line is about 400 m from the railway in the nearest point (in Muuga terminal in Estonia) and therefore is not in the risk zone of sea level rise, which is estimated to be approximately 40-60 cm in the Estonian coastline (compensated by the rising surface). (TÜ geograafia osakond 2015)

- ✓ **Sea water temperature change** – sea water temperature change has an effect on various future climatic conditions like coastal air temperature, humidity, precipitation, fog, etc, which themselves could have negative impacts- These hazards are analysed as individual risks. Sea water temperature change it self do not oppose direct risks to the railway

- ✓ **Urban heat island effect** – this hazard is incorporated to the high temperatures hazard.

- ✓ **Solar radiation** – does not impose direct, significant risk itself. Incorporated to the high temperatures hazard.

- ✓ **Coastal erosion** - Rail Baltica railway is in the safe distance from the Baltic sea – s sea line is about 400 m from the railway in the nearest point (in Muuga terminal in Estonia) and therefore is not in the risk zone coastal erosions.

- ✓ **Vegetation season length** – does not have direct and significant impact. Indirectly analysed under hazard storms (trees and other vegetation on tracks) and adhesion (leaves on the tracks).

Sensitivity assessment of railway assets and services to various climatic variables or hazards was carried out based on the literature reviews and interviews with various relevant parties - railway infrastructure managers, train traffic operators, road administrations and high voltage transmission grid operators in all three Baltic States.

Assets or services of the analysed companies or organizations were defined having medium to high sensitivity against the following climatic hazards and variables:

- ✓ **Snow**
- ✓ **Wind**
- ✓ **Thunder**
- ✓ **Heat waves**
- ✓ **Cold waves**
- ✓ **Frost penetration of soil**
- ✓ **Fog**
- ✓ **Flooding**

- ✓ **Ground instability and land slides**
- ✓ **Adhesion**
- ✓ **Wild fires**
- ✓ **Freezing rain**
- ✓ **Glazed frost**

Hail and karst were excluded from following assessment, as low risk hazards, and draught incorporated to the hazard wildfire in the vulnerability assessment, as they are closely tied and draught by itself was not defined as high risk, based on the sensitivity assessment. Summary results of the sensitivity analysis are presented in the Table 5.1.

Table 5.1. Sensitivity analysis results. I - Estonian Railway (infrastructure manager), II - Elron (Estonian passenger operator), III - Latvian Railway infrastructure department, IV - Latvian Railway passenger operation department, V - Lithuanian Railways prevention/safety department, VI - Lithuanian Railways cargo department, VII – Lithuanian Railways passenger operation department, VIII – Lithuanian Railways infrastructure operation and maintenance department reply No. 1, IX – Lithuanian Railways infrastructure operation and maintenance department reply No. 2, X – Network Rail study, XI - Riksdagstryckeriet study, XII – Banedanmark study, XIII - Elering (high voltage lines operator in Estonia), XIV - Estonian Road Administration, XV - Augstsprieguma tikls (Latian high voltage lines operator), XVI – Latvian Road Administration, XVII - Lithuanian high voltage line operator, XVIII - Lithuanian Road Administration. Red colour – high sensitivity, yellow colour – low to medium sensitivity, white colour – no significant sensitivity

Climatic variable/hazard	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII
Snow																		
Wind																		
Thunder																		
Heat waves																		
Cold waves																		
Frost penetration of soil																		
Fog																		
Flooding																		
Ground instability and land slides																		
Hail storms																		
Adhesion																		
Wild fires																		
Freezing rain																		
Draught																		
Glazed frost																		
Karst																		

6. Vulnerability assessment

Vulnerability assessment was carried out considering hazards and climatic variables defined as having medium to high impact (services or assets are sensitive to them) in the sensitivity assessment. Hail and karst were excluded based on the sensitivity assessment (Chapter 5) and draught incorporated to the hazard wildfire, as they are closely tied and draught by itself was not defined having significant impact.

Vulnerability of assets or services against the following climatic hazards and variables was assessed:

- ✓ **Flooding and heavy rains**
- ✓ **Wind and storms**
- ✓ **Ground instability and land slides**
- ✓ **Lightning**
- ✓ **Snow**
- ✓ **Low temperatures**
- ✓ **Frost penetration of soil**
- ✓ **Freezing rain**
- ✓ **Glazed frost**
- ✓ **Leaf fall (adhesion)**
- ✓ **High temperatures**
- ✓ **Draught and wild fires**
- ✓ **Fog**

Purpose of the vulnerability assessment is to analyse historic climate data and relevant extreme values together with future climate trends to identify, if they are exposed to historic climatic events or potential events in the future. Key aspect is to understand, if future climatic trends could enhance the vulnerability or not. Historic values and future climatic trends are then benchmarked considering exiting design standards, principles of Rail Baltica and other relevant aspects, which could decrease service or asset exposure, to produce the final vulnerability level rating.

Results of the vulnerability assessment are presented in the Tables 6.1-6.13.

Table 6.1 Vulnerability assessment - Flooding and heavy rains

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
FLOODING AND HEAVY RAINS						
Rail Baltica crosses or is located near **14 national level flood risk zones** (13 rivers and one lake) **Maximum sum of 24-hour precipitation – 86,8 mm** (Pärnu in June) **Maximum sum of one-minute precipitation – 6,6 mm** (one-minute data only available for Lithuania) - Panevėžys in July 2010	Increased annual precipitation (especially in winter) and in the number of occurrences with extreme precipitation.	Construction site flooding during construction phase due to increased surface or ground water levels. Significant factors are the condition of drainage systems and water regime of water bodies in the neighbouring areas. Construction stage will be likely completed within 10 years so long-term climate change trends are not so relevant.	Construction	Flooding risks are mitigated by contractors taking appropriate measures to manage extreme weather events (incl. heavy rains and flooding) and adhere to health and safety standards. Contractors will be required to have a risk management system.	**Low**	Undertaker needs to monitor extreme weather events.
		Fluvial and pluvial flooding of track or embankment resulting in instability problems in cutting areas, tunnels and lowlands with unfavourable runoff and drainage conditions (incl. problems with culverts). Significant factors are the condition of drainage systems and water regime of water bodies in the neighbouring areas. During operation, flooding and heavy rains can reduce structures' stability and bearing capacity	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to withstand a rain intensity of 6mm/minute as stated in EN50125-2, chapter 4.5. Rail Baltica DG-s (RBDG-MAN-016-0101): Where the railway runs in cuttings, the studies of the water catchment areas crossed lead the design of the hydraulic drainage system. Peak flow calculation methods are specified in a separate chapter. If required by local administration, peak flow calculation should take into consideration the effects of climate change.	**High**	More detailed measures will be proposed after risk assessment.

				Specification of pumps, that are required in some circumstances, will be specified upon consultants' hydrological calculations. Eurocodes are also followed in the design stage.		
		Damage to the access roads or road infrastructure and/or possible access restrictions to stations, track, substations, etc. due to general flooding of nearby areas. Significant factors are the condition of drainage systems and water regime of water bodies in the neighbouring areas. During operation, flooding and heavy rains can reduce structures' stability and bearing capacity.	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to withstand a rain intensity of 6mm/minute as stated in EN50125-2, chapter 4.5. Eurocodes are also followed in the design stage. Roads are designed according to the national level standards.	**High**	More detailed measures will be proposed after risk assessment.
		Fluvial flooding damage to bridge structures and embankment crossing rivers and streams and ditches.	Operation	Bridges are designed against 1% annual flooding probabilities of rivers. DG-s (RBDG-MAN-016-0101): Embankment construction technical solutions in flood zones shall be insensitive to water but also unaffected by water circulation (mitigate risk of infill material washout). These materials are called "flood zone" materials. The height of the submerged section is that of the "Highest Water Level" (HWL), determined by a specific hydraulic study with a probability of once in 100 years and shall be designed with a safety margin of HWL + 0.5m. DG-s (RBDG-MAN-016-0101): In flood plain, top of sub ballast layer shall be place 1,50 m	**Medium**	More detailed measures will be proposed after risk assessment.

				over HWL. Slopes are protected against risk of erosion in the event of water circulation along the embankment. Eurocodes are also followed in the design stage.		
		Water ingress to critical equipment, including traction power distribution sites, leading to signalling or other electronic equipment failures, requiring switch off or, possibly causing damage. Significant factors are the condition of drainage systems and water regime of water bodies in the neighbouring areas.	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to withstand a rain intensity of 6mm/minute as stated in EN50125-2, chapter 4.5. DG-s (RBDG-MAN-016-0101): In flood plain, top of sub ballast layer shall be place 1,50 m over HWL. Slopes are protected against risk of erosion in the event of water circulation along the embankment. Eurocodes are also followed in the design stage.	**Low**	Substations and autotransformers are essential in delivering traction power supply to the route and should be located outside of flood risk zones. Need to be considered in design stage.

Table 6.2. Vulnerability assessment - Wind and storms

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
WIND AND STORMS						
Maximum average wind speed – 20 m/s (Riga in January) **Maximum wind gust speed – 40 m/s** (Ainaži in November and Bauska in January)	Likely increase in the frequency and intensity of high wind events (with some uncertainty). Significant increase in mean wind speed is not expected.	Wind interference with construction equipment and workers, particularly with temporary equipment. Construction stage will be likely completed within 10 years so long-term climate change trends are not so relevant.	Construction	Extreme wind risks are mitigated by contractors taking appropriate measures to manage extreme weather events and adhere to health and safety standards.	**Low**	Undertaker needs to monitor extreme weather events.
		Failure of or direct damage to parts of structure or infrastructure as a result of changes in extreme winds and gustiness. Noise barriers, OLE and fencing are likely to be most at risk.	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to withstand wind according to EN 50125-3, chapter 4.5 and EN 50125-2, chapter 4.4.1 with a maximum wind flow velocity of $v = 24m/s$ (W1). Maximum wind speed according to the standard EN 50125-3, chapter 4.5 is conventionally taken as 35 m/s. Eurocode - EN 1991-1-4: Eurocode 1: Actions on structures shall be followed in the design stage.	**High**	More detailed measures will be proposed after risk assessment.

		Possible blockage of railway drainage systems due to obstructions and windborne debris from domestic or third-party objects, as well as potentially trees landing on track and causing damage to overhead line equipment (OLE).	Operation	Vegetation near track (inside the area between fences) is managed and no trees are allowed inside that area. Tree free buffer zone is 40 m from the outside track. Fences act as partial barriers for debris outside of the Railway area.	**Medium**	More detailed measures will be proposed after risk assessment.
		Speed restrictions to trains due to high wind events.	Operation	Traffic is regulated according to the wind conditions. Detailed restrictions will be defined during future design stages.	**Medium**	More detailed measures will be proposed after risk assessment.

Table 6.3. Vulnerability assessment - Ground instability and landslides

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
GROUND INSTABILITY AND LANDSLIDES						
Maximum sum of 24-hour precipitation – 86,8 mm (Pärnu in June) **Maximum sum of one-minute precipitation – 6,6 mm** (one-minute data only available for Lithuania) - Panevėžys in July 2010	Increased annual precipitation (especially in winter) and in the number of occurrences of extreme precipitation. Warmer winters and decreased snow cover duration.	Increased precipitation and warmer winters will increase the problems with ground instability in the construction areas and make deforestation more difficult and expensive in wet areas. This is multi-hazard type exposure, which is also affected by other climatic hazards like flooding, saturation of soil, frost penetration of soil and groundwater levels and technical aspects like drainage systems. Construction stage will be likely completed within 10 years so long-term climate change trends are not so relevant.	Construction	Ground instability risks are mitigated by contractors taking appropriate measures and planning construction periods. Risk areas are determined during geotechnical and hydrological studies prior to the construction stage.	**Low**	Undertaker needs to monitor extreme weather events. Potential risks of construction delays due to ground instability, should be considered when compiling project time schedules. Need to be considered in project management/design stage.
		Increased instability can lead to landslides, earthworks failures and damage to structures (mainly bridges, catenaries, noise walls, passenger stations, signs, safety barriers and cables). This is multi-hazard type exposure, which is also affected by other climatic hazards like flooding, saturation of earthworks and groundwater levels	Operation	Rail Baltica DG-s (RBDG-MAN-015-0101): Principles of slope protection and different types of embankments, e.g. in damp areas, underwater, flooding zones etc and slope types. Eurocodes are also followed in the design stage.	**High**	More detailed measures will be proposed after risk assessment.

		and technical aspects like drainage systems.				

Table 6.4 Vulnerability assessment - Lightning

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
LIGHTNING						
Highest average annual number days with thunder – 26 days (Lazdijai)	Lightning events could be more likely and with more severe consequences in summer period, but this projection is with great uncertainty.	Safety risk to construction equipment and workers. Construction stage will be likely completed within 10 years so long-term climate change trends are not so relevant.	Construction	Lightning risks are mitigated by contractors taking appropriate measures to manage extreme weather events and adhere to health and safety standards.	**Low**	Undertaker needs to monitor extreme weather events.
		Direct damage to buildings, structures and lineside equipment (signalling and track circuit).	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be designed for the effects of lightning according to the Standards EN50124-1. An assessment of the risks presented by lightning shall be carried out in accordance with the standards of series EN-62305. If	**Medium**	More detailed measures will be proposed after risk assessment.

				necessary, a lightning protection system shall be erected. Eurocodes are also followed in the design stage.		
		Indirect damage to buildings, structures, line side equipment and equipment and cabling traction power distribution sites from lightning strikes damaging trees.	Operation	Vegetation near track (inside the area between fences) is managed and no trees are allowed inside that area. Tree free buffer zone is 40 m from the outside track. Measures for mitigation wind hazard, will also mitigate risk associated with lightning strikes damaging trees.	**Low**	No additional adaption measures required.

Table 6.5 Vulnerability assessment - Snow

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
SNOW						
Highest average annual number days with thunder – 26 days (Lazdijai)	The snow cover depth and the number of days with snow cover will decrease. Increased precipitation could lead to more extreme snowfall events.	Points operating equipment (POE) failures due to snow accretion. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, temperature, freezing rain and glazed frost.	Operation	Points operating equipment (POE) will be automatically monitored and electric heating is used to clear the snow/ice.	**Medium**	More detailed measures will be proposed after risk assessment.
		Accidents due to slippery surfaces in station platforms, footways, stairs, etc.	Operation	Existing national level standards and design practices.	**Medium**	More detailed measures will be proposed after risk assessment.
		Overhead line equipment may fail due to snow/ice overloading. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, temperature, freezing rain and glazed frost.	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to fulfil requirements as stated in EN 50125-2, chapter 4.6 and EN 50125-3, chapter 4.7. Rail Baltica DG-s (RBDG-MAN-012-0101): The Catenary System shall be designed considering snow and ice load to a temperature up to +5°C.	**Low**	No additional resilience measures required.

				Rail Baltica DG-s (RBDG-MAN-012-0101): The Catenary System shall be designed for an ice load of class I3 (heavy 15N/m) on conductors. Eurocodes are also followed in the design stage.		
		Problems when ice or thick snow forms on the contact lines and inhibits contact between train and contact lines. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, temperature, freezing rain and glazed frost.	Operation	Rail Baltica DG-s (RBDG-MAN-018-0101): Methods used for de-icing OCS systems are specified in detail. Eurocodes are also followed in the design stage.	**Low**	No additional adaption measures required.
		Reliability of trains may reduce at low temperatures due to: failure of train horns due to ice/snow accretion; failure of sliding doors, couplers, pneumatic devices and reduced effectiveness of brakes due to ice/snow accretion; traction motor failures due to snow and/or water ingress, and damage from snow and/or ice accretions dislodged at speed. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, temperature, freezing rain and glazed frost.	Operation	Train operators are aware of the climatic conditions (including heavy snowfall and ice/snow accretion possibility) in Baltic States and take appropriate measures.	**Low**	No additional adaption measures by infrastructure manager required.

Table 6.6 Vulnerability assessment - Low temperatures

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
LOW TEMPERATURES						
Minimum recorded air temperature – -35.7 °C (Ainaži 2003)	Clear warming trend for winter periods reduces likelihood and severity of extremely low temperatures and cold waves.	Possible negative health implications for staff, disruption to construction. Construction stage will be likely completed within 10 years so long-term climate change trends are not so relevant.	Construction	Cold weather risk to staff and equipment during construction is mitigated by contractors being aware of and taking appropriate measures during extreme weather events and adhere to health and safety standards.	**Low**	Undertaker needs to monitor extreme weather events.
		General risk of freezing of mechanical and electrical equipment.	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to withstand temperatures equivalent Class T2 (external ambient temperature: -40° C to +35° C) as defined in EN 50125-3, chapter 4.3. Eurocodes are also followed in the design stage.	**Low**	No additional adaption measures required.
		Increase risk of rail and weld breaks due to extreme cold conditions due to bad quality rail or rollingstock. Cable breaks due to embankment processes.	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to withstand temperatures equivalent Class T2 (external ambient temperature: -40° C to +35° C) as defined in EN 50125-3, chapter 4.3. Eurocodes are also followed in the design stage.	**Medium**	More detailed measures will be proposed after risk assessment.

				Train operators are responsible for the technical conditions of their rolling stock. Detailed specifications for rails and welds will be defined during future design stages.		
		Potential increase in number of days outside normally acceptable range of conditions for heating systems on trains and affect efficiency of auxiliary power supply.	Operation	Train operators are responsible for the technical conditions of their rolling stock.	**Low**	No additional adaption measures by infrastructure manager required.
		Possible negative health implications for passengers and staff.	Operation	Passenger stations include heated waiting areas for passengers. Passenger train operators are aware of the potential climatic conditions, including extreme cold waves and take appropriate measures.	**Low**	Appropriate instructions and equipment suitable for various weather conditions (including temperature up to -35° C) should be given to the staff. Need to be considered in operation/ maintenance stage

Table 6.7 Vulnerability assessment - Frost penetration of soil

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
FROST PENETRATION OF SOIL						
Maximum frost penetration of soil – 190 cm (Keo measure point, located near Kuusiku station, in 2014)	Clear warming trend for winter periods reduces likelihood and average depth of frost penetration of soil.	Complications in the construction process due to soft ground soil in winter periods. This is multi-hazard type exposure, which is also affected by other climatic conditions like flooding, saturation of soil, ground instability/landslides and groundwater levels and technical aspects like drainage systems. Construction stage will be likely completed within 10 years so long-term climate change trends are not so relevant.	Construction	Ground instability risks in warm winter periods are mitigated by contractors taking appropriate measures and planning construction periods.	**Low**	Potential risks of construction delays due to ground instability in warm winter periods should be considered when compiling project time schedules. Need to be considered in project management/design stage.
		Potential damage to the railway and maintenance road embankments through frost heave.	Operation	DG-s (RBDG-MAN-016-0101) suggest following frost penetration depths: Estonia: 2,05 m; Latvia: 1,74 m; Lithuania: 1.7 m. Detailed technical requirements will be updated during future design stages. Roads are designed according to the national level standards.	**Medium**	More detailed measures will be proposed after risk assessment.

Table 6.8 Vulnerability assessment - Freezing rain

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
FREEZING RAIN						
Highest average annual number days with freezing rain – 7,7 days (Panevėžys)	Winter periods will get warmer, which decreases likelihood, but increased precipitation could lead to more extreme freezing rain events.	Possible disruption of construction process. Construction stage will be likely completed within 10 years so long-term climate change trends are not so relevant.	Construction	Freezing rail risk to construction process is mitigated by contractors being aware of and taking appropriate measures during extreme weather events.	**Low**	Undertaker needs to monitor extreme weather events.
		Points operating equipment (POE) failures due snow and ice formation. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, temperature, snow and glazed frost.	Operation	Points operating equipment (POE) will be automatically monitored and electric heating is used to clear the snow/ice.	**Medium**	More detailed measures will be proposed after risk assessment.
		Overhead line equipment (OLE) may fail due to ice overloading. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, temperature, snow and glazed frost.	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to fulfil requirements as stated in EN 50125-2, chapter 4.6 and EN 50125-3, chapter 4.7. Rail Baltica DG-s (RBDG-MAN-012-0101): The Catenary System shall be designed considering snow and ice load to a temperature up to +5°C.	**Low**	No additional adaption measures required.

				RB DG-s (RBDG-MAN-012-0101): The Catenary System shall be designed for an ice load of class I3 (heavy 15N/m) on conductors.		
		Problems when ice or thick snow forms on the contact lines and inhibits contact between train and contact lines. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, temperature, freezing rain and glazed frost.	Operation	Rail Baltica DG-s (RBDG-MAN-018-0101): Methods used for de-icing OCS systems are specified in detail.	**Low**	No additional adaption measures required.

Table 6.9 Vulnerability assessment - Glazed frost

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
GLAZED FROST						
Highest average annual number days glaze frost – 13,2 days (Lazdijai)	Clear warming trend for winter periods, which decreases likelihood, but increased precipitation could lead to more extreme glazed frost events.	Points operating equipment (POE) failures due snow and ice formation. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, temperature, snow and glazed frost.	Operation	Points operating equipment (POE) will be automatically monitored and electric heating is used to clear the snow/ice.	**Medium**	More detailed measures will be proposed after risk assessment.
		Overhead line equipment (OLE) may fail due to ice overloading. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, temperature, snow and glazed frost.	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to fulfil requirements as stated in EN 50125-2, chapter 4.6 and EN 50125-3, chapter 4.7. Rail Baltica DG-s (RBDG-MAN-012-0101): The Catenary System shall be designed considering snow and ice load to a temperature up to +5°C. Rail Baltica DG-s (RBDG-MAN-012-0101): The Catenary System shall be designed for an ice load of class I3 (heavy 15N/m) on conductors.	**Low**	No additional adaption measures required.

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
		Problems when ice or thick snow forms on the contact lines and inhibits contact between train and contact lines. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, temperature, snow and glazed frost.	Operation	Rail Baltica DG-s (RBDG-MAN-018-0101): Methods used for de-icing OCS systems are specified in detail.	**Low**	No additional adaption measures required.

Table 6.10 Vulnerability assessment - Leaf fall (adhesion)

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
LEAF FALL (ADHESION)						
Maximum average wind speed (June-September) – 19 m/s (Kuusiku in September) **Maximum wind gust speed (June-September) – 30 m/s** (Pärnu in July) **Maximum sum of one-minute precipitation – 6,6 mm** (one-minute data only available for	Vegetation period will be longer, weather events like wind and precipitations have the potential to be more extreme	Increased disruption from autumn leaf fall or changed temporal patterns of leaf fall. This is multi-hazard type exposure, which is affected by various climatic hazards like wind, temperature and precipitation.	Operation	Vegetation near track (inside the area between fences) is managed and no trees are allowed inside that area. Tree free buffer zone is 40 m from the outside track. Fences and noise barriers also provide barrier against leaves.	**Low**	Maintenance and monitoring systems for adhesion (including leaf fall) required. Need to be considered in operation/ maintenance stage

Lithuania) - Panevėžys in July 2010						

Table 6.11 Vulnerability assessment - High temperatures

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
HIGH TEMPERATURES						
Maximum recorded air temperature – 35.5 °C (Panevėžys in August 1992)	Increase in summer average and maximum temperature and number of hot days. .	Increased heat stress for staff, particularly outdoor construction workers. Construction stage will be likely completed within 10 years so long-term climate change trends are not so relevant.	Construction	Risk of heat stress to staff during construction is mitigated by contractors required to be aware of and take appropriate measures during extreme weather events and adhere to health and safety standards.	**Low**	Undertaker needs to monitor extreme weather events. Potential risks of construction delays due to heat waves should be considered when compiling project time schedules. Need to be considered in project management/design stage.

		Rail buckling and/or associated misalignment problems.	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to withstand temperatures equivalent Class T2 (external ambient temperature: -40° C to +35° C) as defined in EN 50125-3, chapter 4.3. Eurocodes are also followed in the design stage. Detailed specifications for rail will be defined during future design stages. Maintenance and monitoring measures will also be put in place.	**Medium**	More detailed measures will be proposed after risk assessment.
		Overhead line equipment (OLE), may fail to operate properly under extreme heat resulting in a reduction in electrical loading capability, fail to operate properly or be damaged.	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to withstand temperatures equivalent Class T2 (external ambient temperature: -40° C to +35° C) as defined in EN 50125-3, chapter 4.3. Eurocodes are also followed in the design stage. Modern OLE equipment is designed for higher standards and there are no heat related problems according to the experts interviewed during sensitivity assessment.	**Low**	No additional adaption measures required.
		Planting failures may occur, which could have detrimental impact in stability of embankments. This is multi-hazard type exposure, which is mostly affected by temperature and precipitation.	Operation	Rail Baltica DG-s (RBDG-MAN-015-0101): Principles of slope protection and different types of embankments, e.g. in damp areas, underwater, flooding zones etc and slope types. Eurocodes are also followed in the design stage.	**Low**	Slope design should consider increased probability of draughts and implement appropriate measures like use seed mixtures with

						draught resistant species. Need to be considered in design stage.
		Increased risk of thermal expansion joints being pushed beyond their design capability, presenting a direct risk of damage to bridges structures and indirect of damage of other assets dependent upon bridge.	Operation	Rail Baltica DG-s (RBDG-MAN-012-0101): All system shall be constructed to withstand temperatures equivalent Class T2 (external ambient temperature: -40° C to +35° C) as defined in EN 50125-3, chapter 4.3. Eurocodes are also followed in the design stage.	**Medium**	More detailed measures will be proposed after risk assessment.
		Increased heat stress for passengers and staff on trains due to cooling systems inefficiency.	Operation	Train operators are aware of the potential climatic conditions, including extreme heat waves and take appropriate measures.	**Low**	No additional adaption measures by infrastructure manager required.

Table 6.12 Vulnerability assessment - Draught and wildfires

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures

DRAUGHT AND WILDFIRES						
Highest number of extreme heat waves (3 days + 30 °C) -19 events (Kaunas)	Increase in summer average and maximum temperature and number of hot days, which could lead to increased drying out of soils and vegetation and increased fire hazards.	Extended periods of hot days may lead to a risk of fires in vicinity of construction zones and disruption of construction process. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, humidity and precipitation. Construction stage will be likely completed within 10 years so long-term climate change trends are not so relevant.	Construction	Fire hazard risk to construction workers and equipment is mitigated by contractors being aware of and taking appropriate measures during extreme events, like fires, and adhere to health and safety standards.	**Low**	No additional adaption measures by infrastructure manager required.
		Extended periods of hot days may lead to a risk of fires in vicinity of the route can cause direct damage, disruptions due to flying ash and implementation of precautionary measures. This is multi-hazard type exposure, which is also affected by other climatic hazards like wind, humidity and precipitation.	Operation	Vegetation near track (inside the area between fences) is managed and no trees are allowed inside that area. Tree free buffer zone is 40 m from the outside track. Ditches alongside the railway will restrict fire spreading to some extent. Existing fire safety and emergency standards and procedures.	**Medium**	More detailed measures will be proposed after risk assessment.

		Planting failures may occur due to draught, which could have detrimental impact in stability of embankments. This is multi-hazard type exposure, which is mostly affected by temperature and precipitation.	Operation	Rail Baltica DG-s (RBDG-MAN-015-0101): Principles of slope protection and different types of embankments, e.g. in damp areas, underwater, flooding zones etc and slope types.	**Low**	Slope design should consider increased probability of draughts and implement appropriate measures like use seed mixtures with draught resistant species. Need to be considered in design stage.

Table 6.13 Vulnerability assessment - Fog

Registered climatic extremes or events	Trend and likelihood of climate hazard	Exposure and consequences	Construction or Operation Stage	Existing / embedded mitigation measures	Vulnerability level	Proposed additional adaptation measures
FOG						
Highest annual maximum number of days with dangerous fog (visibility under 100 m) - 19 (Panevėžys)	No clear projections about fog available. Since the middle of the past century, the annual mean number of days with fog has decreased in Latvia significantly. This could be associated with both the gradual decrease in industrial activities and the resultant improvements of air quality and the observed increase in air temperature.	Construction process might be disturbed due to decreased visibility. Construction stage will be likely completed within 10 years so long-term climate change trends are not so relevant.	Construction	Extreme fog events during construction are mitigated by contractors being aware of, taking appropriate measures during and adhere to health and safety standards during extreme weather events.	**Low**	Undertaker needs to monitor extreme weather events.
		Traffic can be disrupted due to decreased visibility.	Operation	Train traffic of Rail Baltica is not dependent on train driver visibility, because of ERTMS 2 signalling system.	**Low**	No additional adaption measures required.
		Operations (e.g. shunting), maintenance could be disrupted and passengers and staff risks increased.	Operation	Existing national level health and safety standards.	**Medium**	More detailed measures will be proposed after risk assessment.

7. Risk assessment

Risk assessment was carried out for exposure and consequences defined having medium or high vulnerability to the future climatic conditions and hazards in the vulnerability assessment (Chapter 6).

Purpose of the risk assessment was to define likelihood and magnitude of a certain consequence to produce a risk rating for each consequence. Qualitative likelihood levels and consequence magnitude levels, used in the risk assessment, are described respectively in Tables 7.1 and 7.2.

Historic values and future climatic trends were benchmarked considering exiting design standards, principles of Rail Baltica and other relevant aspects, which could decrease service or asset exposure, to produce the consequence likelihood assessment. It is imperative to understand, in detail, potential consequences of climatic hazards and variables and cause-effect chains to the assets and services of Rail Baltica. For this purpose, a risk assessment workshop, with the technical experts of various fields, was organized to discuss all the technical aspects relevant to the risk assessment. Risk rating was then defined based on the agreed consequence likelihood and magnitude assessments. Confidence level for each risk rating, was defined as a last step, to validate the results based on the type, amount, quality and consistency of evidence.

Table 7.1 Risk rating matrix

RISK RATING MATRIX					
LIKELIHOOD	CONSEQUENCES/IMPACT				
	Insignificant	Minor	Moderate	Major	Catastrophic
Very likely	Medium	High	High	Extreme	Extreme
Likely	Medium	Medium	High	High	Extreme
Unlikely	Low	Medium	Medium	High	High
Very unlikely	Low	Low	Medium	Medium	Medium
Extremely unlikely	Low	Low	Medium	Medium	Medium

Table 7.2 Likelihood levels

Likelihood level	Likelihood description
Very likely	Event is expected to occur often during the 100-year design life of the infrastructure or 50 years for systems or 10 years for construction, due to clear and significant adverse changes in the relevant climatic variables and hazards.
Likely	Event is expected to occur several times during the 100-year design life of the infrastructure or 50 years for systems or 10 years for construction, due to clear or significant adverse changes in the relevant climatic variables and hazards.
Unlikely	Event is expected to occur at least once, few times during the 100-year design life of the infrastructure or 50 years for systems or 10 years for construction, due to clear or meaningful adverse changes in the relevant climatic variables and hazards.
Very unlikely	Event is not expected to occur more than once during the 100-year design life of the infrastructure or 50 years for systems or 10 years for construction, due to unclear or minor adverse changes in the relevant climatic variables and hazards.
Extremely unlikely	Event only occurs in exceptional circumstances and would not be expected to occur during the 100-year design life of the infrastructure or 50 years for systems or 10 years for construction, due to positive changes in the relevant climatic variables and hazards.

Table 7.3 Consequence magnitude levels

Consequence level	Consequence on human health and infrastructure	Consequence on environment and reputation
Catastrophic	Fatalities and/or extensive damage to critical infrastructure	Significant and irreversible adverse environmental impacts and/or significant long-term impact to reputation
Major	Multiple serious injuries and/or major damage to critical infrastructure	Major and long-term adverse environmental impacts and/or major long-term impact to reputation
Moderate	Non-permanent injuries, but hospitalization is needed and/or moderate damage or significant degradation of infrastructure	Moderate adverse environmental impacts and/or moderate impact to reputation
Minor	Some medical treatment at a hospital needed, minor damage or degradation of infrastructure	Minor short-term adverse environmental impacts and/or minor short-term impact to reputation
Insignificant	Only minor first aid treatment may be required and /or slight degradation of infrastructure	Insignificant short-term impact to environment and/or insignificant short-term impact to reputation.

Table 7.4 Risk assessment - **Flooding and heavy rain**

Asset or service associated with the risk	Consequences	Existing / embedded mitigation measures	Consequence likelihood	Consequence magnitude	Risk rating[3]	Confidence[4] level
FLOODING AND HEAVY RAINS						
Track and embankment, catenaries	Fluvial and pluvial flooding of track or embankment resulting in instability problems in cutting areas, tunnels and lowlands with unfavourable runoff and drainage conditions (incl. problems with culverts).	All system shall be constructed to withstand a rain intensity of 6mm/minute as stated in EN50125-2, chapter 4.5. DG-s (RBDG-MAN-016-0101): Where the railway runs in cuttings, the studies of the water catchment areas crossed lead the design of the hydraulic drainage system. Peak flow calculation methods are specified in a separate chapter. If required by local administration, peak flow calculation should take into consideration the effects of climate change. Eurocodes are also followed in the design stage. Specification of pumps, that are required in some circumstances, will	**Likely** – Several times heavy rains have occurred. Design solutions consider 1% of annual flooding probabilities of rivers. In long term prospect, precipitations will increase, which is currently not considered in Latvian (except Riga region) and Estonian national level flood and water flow predictions. Most incidents might not be tied to flooding zones and determined by very specific local conditions, hydraulic modelling and design solutions.	**Minor** – minor damage or degradation to embankment and other track related infrastructure, short-term traffic disruption.	**Medium**	**Medium** – historic data on 6 mm per minute precipitation is missing, detailed correlation between flood probabilities and future increased precipitation has not been modelled in Estonia and Latvia. In addition, the conditions of amelioration systems and channels in nearby areas is not known currently.

[3] Consequence likelihood x consequence magnitude

[4] IPCC - Confidence in the validity of a finding, based on the type, amount, quality and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgement) and the degree of agreement. Confidence is expressed qualitatively.

		be specified upon consultants' hydrological calculations.				
Bridges and culverts	Fluvial flooding damage to bridge structures and embankment crossing rivers and streams and ditches.	Bridges are designed against 1% annual flooding probabilities of rivers. Embankment construction technical solutions in flood zones shall be insensitive to water but also unaffected by water circulation (mitigate risk of infill material washout). These materials are called "flood zone" materials. The height of the submerged section is that of the "Highest Water Level" (HWL), determined by a specific hydraulic study with a probability of once in 100 years and shall be designed with a safety margin of HWL + 0.5m. In flood plain, top of sub ballast layer shall be place 1,50 m over HWL. Slopes are protected against risk of erosion in the event of water circulation along the embankment.	**Extremely unlikely** – Probability considerably lowered by measures set in the Rail Baltica DG-s for larger rivers with national flooding zoning. Spring floods will be less severe due to inconsistent snow coverage. Likely - probability is higher for smaller rivers, streams and ditches due to heavy rain and flash flooding events and affected by very specific local conditions (third party risk).	**Minor** - scouring of bridge piers and abutments during periods of peak river flow not likely to cause critical damage during one event, but may add up during multiple events and peaks. Temporary disruptions due to short-term flash flooding and minor damage or degradation of infrastructure can occur near smaller rivers, streams or ditches.	**Low** **(Larger rivers)** **Medium** **(Smaller rivers, streams and ditches)**	**Medium** – Detailed correlation between flood probabilities and future increased precipitation has not been modelled in Estonia and Latvia. In addition, the conditions of amelioration systems and channels in nearby areas is not known currently.
Access and maintenance roads and	Damage to the access roads or road infrastructure	All system shall be constructed to withstand a rain intensity of	**Likely** – Several times heavy rains have occurred. Design solutions for access roads consider national	**Minor** – access roads to stations are with hard surface and therefore no significant	**Medium**	**Medium** – 6 mm per minute precipitation historic data is missing, detailed

road infrastructure linked to Rail Baltica, such as access routes for Rail Baltica staff	and/or possible access restrictions to stations, track, substations, etc. due to general flooding of nearby areas.	6mm/minute as stated in EN50125-2, chapter 4.5. Eurocodes are also followed in the design stage. Roads are designed according to the national level standards.	standards and 2% or 5% flooding probabilities. Detailed correlation between flood probabilities and water levels and future increased precipitation has not been modelled in Estonia and Latvia.	damage and access restrictions are relatively short-term and secondary.		correlation between flood probabilities and future increased precipitation has not been modelled in Estonia and Latvia. In addition, the conditions of amelioration systems and channels in nearby areas is not considered.

Table 7.5 Risk assessment – **Wind and storms**

Asset or service associated with the risk	Consequences	Existing / embedded mitigation measures	Consequence likelihood	Consequence magnitude	Risk rating	Confidence level
WIND AND STORMS						
All infrastructure, but especially catenaries, noise barriers and fencing	Failure of or direct damage to parts of structure or infrastructure as a result of changes in extreme winds and gustiness. Noise barriers, OLE and fencing are likely to be most at risk.	All system shall be constructed to withstand wind according to EN 50125-3, chapter 4.5 and EN 50125-2, chapter 4.4.1 with a maximum wind flow velocity of $24 m/s$ (W1). Maximum wind speed according to the standard EN 50125-3, chapter 4.5 is conventionally taken as 35 m/s. Eurocode - EN 1991-1-4: Eurocode 1: Actions on structures shall be followed in the design stage.	**Unlikely** – no registered events in the weather stations over the maximum values stated in the standards. Likely increase in the frequency and intensity of storms (with some uncertainty) according to the future projections.	**Minor** – Only minor damage or degradation of infrastructure is expected, because wind events will be expected to exceed the standard values by a small proportion.	**Medium**	**Medium** – high wind event projections are with some uncertainty. Detailed technical requirements are not yet developed.

		Detailed technical requirements will be considered during future design stages with potential mitigation through design change or operational management.				
All infrastructure, but especially catenaries, drainage and fencing	Possible blockage of railway drainage systems due to obstructions and windborne debris from domestic or third-party objects, as well as potentially trees landing on track and causing damage to catenaries and fencing.	Vegetation near track (inside the area between fences) is managed and no trees are allowed inside that area. Tree free buffer zone is 40 m from the outside track. Fences act as partial barriers for debris outside of the Railway area.	**Very likely** – events with wind damaging trees are common in the current climate and the probability will likely increase due to increase in the frequency and intensity of high wind events (with some uncertainty) according to the future projections.	**Moderate** – damage to catenaries will cause disruption in the traffic. Any disruption to Rail Baltica operation is significant, as rerouting options are not available.	**High**	**Medium** – high wind event projections are with some uncertainty.
Train traffic	Speed restrictions to trains due to high wind events.	Traffic is regulated according to the wind conditions. Detailed restrictions will be defined during future design stages.	**Likely** - likely increase in the frequency and intensity of storms (with some uncertainty) according to the future projections.	**Minor** - minor short-term impact to reputation due to delays.	**Medium**	**Medium** – high wind event projections are with some uncertainty. Detailed restrictions are not defined.

Table 7.6 Risk assessment – **Ground instability and landslides**

Asset or service associated with the risk	Consequences	Existing / embedded mitigation measures	Consequence likelihood	Consequence magnitude	Risk rating	Confidence level
GROUND INSTABILITY AND LANDSLIDES						
Earthworks and structures (mainly bridges, OLE, access roads, noise walls, passenger stations, signs, safety barriers and cables)	Increased instability can lead to landslides, earthworks failures and damage to structures (mainly bridges, catenaries, noise walls, passenger stations, signs, safety barriers and cables).	Rail Baltica Design Guidelines-Railway substructure, Part 1 embankments and earthworks (RBDG-MAN-015-0101) states slope protection principles and different types of embankments in damp areas, underwater, flooding zones etc. Rail Baltica Design Guidelines RBDG-MAN-016-0101, Hydraulic Drainage and Culvert will be followed, which specifies peak flow calculation methods. If required by local administration, peak flow calculation should take into consideration the effects of climate change. Eurocodes are also followed in the design stage.	**Unlikely** – structure should be stable according to the Rail Baltica DG-s, but increased precipitation and potentially more extreme weather events could increase the likelihood. Also, drainage systems of nearby areas could have unexpected effects.	**Minor** - moderate damage or significant degradation of infrastructure.	**Medium**	**Medium** - multi-hazard type exposure, which is also affected by other climatic hazards like flooding, saturation of earthworks and groundwater levels and technical aspects like drainage systems, which makes it harder to predict.

Table 7.7 Risk assessment – **Lightning**

Asset or service associated with the risk	Consequences	Existing / embedded mitigation measures	Consequence likelihood	Consequence magnitude	Risk rating	Confidence level
LIGHTNING						
Buildings, structures and lineside equipment (signalling and track circuit) and traffic	Direct damage to buildings, structures and lineside equipment (signalling and track circuit) and indirect impacts (maintenance, traffic).	All system shall be designed for the effects of lightning according to the Standards EN50124-1. Eurocodes are also followed in the design stage. An assessment of the risks presented by lightning shall be carried out in accordance with the standards of series EN-62305. If necessary, a lightning protection system shall be erected.	**Likely** - Higher air temperature may cause more intense formation of typical summer thunder clouds. Natural phenomena associated with thunder clouds will be more likely and with more severe consequences, but more detailed projections are not possible due to uncertainty and random spatial nature of the thunder events.	**Minor** – disruption in some cases. Safety and engineering standards are mature for lightning protection.	**Medium**	**Medium** – lightning event projections are with some uncertainty. Detailed technical requirements are not yet developed.

Table 7.8 Risk assessment – **Low temperatures**

Asset or service associated with the risk	Consequences	Existing / embedded mitigation measures	Consequence likelihood	Consequence magnitude	Risk rating	Confidence level
LOW TEMPERATURES						
Rails, underground cables	Increase risk of rail and weld breaks due to extreme cold conditions due to bad quality rail or rollingstock. Cable breaks due to embankment processes.	Detailed specifications will be defined during future design stages.	**Very unlikely** – mostly determined by quality risk and specific design solutions. Climate risk will be less likely due to more mild winters in future.	**Major** – major interruptions.	**Medium**	**Low** - Detailed technical requirements are not yet developed. Uncertainty of quality factor. Clear trend on warmer future winters.

Table 7.9 Risk assessment – **Snow, freezing rain and glazed frost**

Asset or service associated with the risk	Consequences	Existing / embedded mitigation measures	Consequence likelihood	Consequence magnitude	Risk rating	Confidence level
SNOW, FREEZING RAIN AND GLAZED FROST						
Points operating equipment (POE) and catenaries	Points operating equipment (POE) failures due to snow and ice accretion. Damage to catenaries.	Points operating equipment (POE) will be automatically monitored and electric heating is used to clear the snow/ice. Detailed technical requirements for POE-s and catenaries will be considered during future design stages with potential mitigation	**Very likely** - Majority of the precipitation in winter will be in the form of rain, but extreme snowfalls would still occur and could be even more severe as average precipitation increases in winter periods. Wet snow events will be more likely. Measures of snow	**Minor** - minor short-term impact to reputation due to delays.	**High**	**Medium** – there is a clear consensus about the future projections of associated climatic variables and understanding of the consequence mechanisms. Detailed technical requirements are not yet developed.

		through design change or operational management.	clearance of POE-s, could be dysfunctional.			
Station platforms, footways, stairs, etc	Accidents due to slippery surfaces in station platforms, passenger walks, stairs, etc.	Existing national level standards and design practices.	**Very likely** - Clear trend of increased temperatures in the winter periods with more precipitation and increased likelihood of wet snow, freezing rain, glazed frost and ice formation events.	**Major** – hospitalization could be needed in some cases as a result of accidents due to slippery surfaces.	**High**	**Medium** – there is a clear consensus about the future projections of associated climatic variables and understanding of the consequence mechanisms. Detailed technical requirements for surfaces in various areas are not yet developed.

Table 7.10 Risk assessment – **Frost penetration of soil**

Asset or service associated with the risk	Consequences	Existing / embedded mitigation measures	Consequence likelihood	Consequence magnitude	Risk rating	Confidence level
FROST PENETRATION OF SOIL						
Railway and maintenance road embankments	Potential damage to the railway and maintenance road embankments through frost heave.	DG-s (RBDG-MAN-016-0101) suggest following frost penetration depths: Estonia: 2,05 m; Latvia: 1,74 m; Lithuania: 1.7 m. Detailed technical requirements will be updated during future design stages. Roads are designed according to the national level standards.	**Very unlikely** - clear warming trend for winter periods reduces likelihood and average depth of frost penetration of soil.	**Moderate** - uneven longitude of track, bearing capacity decreased, speed reductions.	**Medium**	**Medium** – there is a clear consensus about the future projections of associated climatic variables and understanding of the consequence mechanisms. Final technical requirements are not yet fixed.

Table 7.11 Risk assessment – **High temperatures**

Asset or service associated with the risk	Consequences	Existing / embedded mitigation measures	Consequence likelihood	Consequence magnitude	Risk rating	Confidence level
HIGH TEMPERATURES						
Rails	Rail buckling and/or associated misalignment problems due to Critical Rail Temperature (CRT) .	All system shall be constructed to withstand temperatures equivalent Class T2 (external ambient temperature: -40° C to +35° C) as defined in EN 50125-3, chapter 4.3. Eurocodes are also followed in the design stage. Detailed specifications for rail will be defined during future design stages. Maintenance and monitoring measures will also be put in place.	**Very unlikely** – only mid-day maximum for few hours can exceed +35 ° C.	**Catastrophic** – consequence magnitude is expected to be minor – rail quality will be monitored and measures (e.g. speed restrictions) implemented, but possibility of train derailment, in worst case scenario, can´t be excluded.	**Medium**	**Medium** – there is a clear consensus about the future temperature projections and understanding of the consequence mechanisms. Detailed technical requirements are not yet developed.
Thermal joints	Increased risk of thermal expansion joints being pushed beyond their design capability, presenting a direct risk of damage to bridges structures and indirect of damage of other assets dependent upon bridge.	All system shall be constructed to withstand temperatures equivalent Class T2 (external ambient temperature: -40° C to +35° C) as defined in EN 50125-3, chapter 4.3. Eurocodes are also followed in the design stage. Detailed specifications for thermal joints will be defined during future design stages. Maintenance and monitoring	**Very unlikely** – only mid-day maximum for few hours can exceed +35 ° C.	**Major** – consequence magnitude is expected to be minor – bridges will be monitored and measures (e.g. traffic restrictions, repair actions) implemented, but possibility major damage to the bridge, in worst case scenario, can´t be excluded.	**Medium**	**Medium** – there is a clear consensus about the future temperature projections and understanding of the consequence mechanisms. Detailed technical requirements are not yet developed.

		measures will also be put in place.				

Table 7.12 Risk assessment - **Fog**

Asset or service associated with the risk	Consequences	Existing / embedded mitigation measures	Consequence likelihood	Consequence magnitude	Risk rating	Confidence level
FOG						
Operations, maintenance, staff and passengers	Operations (e.g. shunting), maintenance could be disrupted and passengers and staff risks increased.	Existing safety standards applied.	**Likely** – low visibility events are likely to occur with similar likelihood and severity as in the past.	**Minor** – some disruption to operations.	**Medium**	**Medium** – no clear future fog projections are available. Clear regulations and past experience in regard to fog events.

Table 7.13 Risk assessment – **Draught and wildfire**

Asset or service associated with the risk	Consequences	Existing / embedded mitigation measures	Consequence likelihood	Consequence magnitude	Risk rating	Confidence level
DRAUGHT AND WILDFIRE						
All infrastructure and services	Direct damage, disruptions due to flying ash and precautionary measures caused by wildfires.	Vegetation near track (inside the area between fences) is managed and no trees are allowed inside that area. Tree free buffer zone is 40 m from the outside track. Ditches alongside the railway will restrict fire spreading to some extent. Existing fire safety and emergency standards and procedures.	**Likely** – more extreme summer temperatures and draught events. Multi hazard risk – wild fire risk increases substantially in high wind conditions.	**Moderate** – moderate damage or significant degradation of infrastructure. Delays and disruptions operations.	**High**	**High** - there is a clear consensus that future wild fire risk increases. Clear regulations and past experience in regard to wildfires.

8. Adaptation options

Adaptation measures were developed for all the consequences and associated services or assets assessed during the risk assessment as all the analysed risks (except fluvial flooding on larger rivers) were ranked as medium or high risk. This clearly indicates that most of the consequences analysed in the vulnerability assessment have a considerable likelihood of manifesting during the life-cycle of Rail Baltica.

Measure type (avoidance, mitigation, optimization), development or implementation stage, responsible parties and cost estimate and efficiency was specified during this stage and presented in a summary Tables 8.1-8.10.

Relevant additional information for specific measure has been added after table of each hazard/climatic variable, if necessary.

Cost estimates were defined based on three categories: **Low cost** - 0 € to 20 000 €, **Medium cost -** 20 000 € to 200 000 €, **High cost:** over 200 000 €.

Weather resilience and climate change adaptation actions include a range of measures appropriate to the strength of evidence and level of risk which may include changes to processes, standards and specifications, increasing knowledge and skill base, measures that increase the resilience of the assets to current and future impacts, cost-efficient adaptations and investments. This should be considered in the ongoing and future studies, incl. utilities requirements study, weather service, maintenance and operation principles study, etc.

Workshop to discuss, validate and assess feasibility of each measure was carried out.

It is important to note that management of climate risks should be integrated into the general risk management, monitoring and control systems of Rail Baltica and not managed as a stand-alone subject.

Table 8.1 Climate change adaptation measures – **Flooding and heavy rain**

Asset or service associated with the risk	Consequences	Risk rating	Adaptation measures	Measure type	Measure development (D) or implementation (I) stage(s)	Responsible parties	Cost estimate	Cost efficiency
1. FLOODING AND HEAVY RAINS								
1.1 Track and embankment, catenaries, bridges and culverts	Fluvial and pluvial flooding of track or embankment in cutting areas, tunnels and low-lying locations with unfavourable runoff and drainage conditions (incl. culverts). Fluvial flooding (incl. ice) damage to bridge structures and embankment crossing rivers and streams and ditches.	**Medium**	1.1.1. Change in the DG-s document "Railway substructure, Part 2 hydraulic, drainage and culverts": Replace sentence "If required by local administration, peak flow calculation should take into consideration the effects of climate change" with "Peak flow calculations should take into consideration the effects of climate change".	Avoidance, Mitigation	DG-s (I)	Contracting Authority	**Low -** Minimal cost for Contracting Authority	**High** – cost optimal design solutions could be achieved with little additional cost to measure implementation
			1.1.2. Upgrading flood zone modelling and high-water level (HWL) and peak flow calculations with National Weather Authorities is required e to specify methodology which takes into account climate change allowance in the peak flow predictions.	Avoidance, Mitigation	DG-s (D)	Contracting Authority	**Low -** some communication and work required.	**High** – optimal design solutions could be achieved with medium additional costs.
			1.1.3. Design principles of stormwater systems in artificial environments, considering historic data and relevant climate change trends should be developed and implemented.	Avoidance, Mitigation	DG-s (D) Design (I)	Contracting Authority Designer	**Medium -** Separate study may be required.	**Medium** – optimal design solutions could be achieved with medium costs.
			1.1.4. Monitoring and alerting system of flooding and heavy rain needs to be developed and implemented within the Rail Baltica weather services. Sensitive	Mitigation	DG-s (D) Design (D)	Contracting Authority Designer	**Unknown -** Highly dependent on system specification.	**Unknown -** Highly dependent on system specification.

			areas are proposed by designer, if necessary.		Pre-operation (I)			
			1.1.5. Maintenance code for ditches, channels, streams and culverts (with third parties), including ice and snow clearance during winter and spring season peak flows. Third party risk assessment.	Avoidance, Mitigation	DG-s (D) Operation (I)	Contracting Authority Third parties (responsible for infrastructure outside of Rail Baltica area).	**Medium (uncertain) -** development incorporated into maintenance plan study. Regular maintenance is required. Costs will also be dependent on cooperation details with third parties.	**Medium (uncertain)–** some consequences could be avoided or mitigated with medium costs.
1.2 Access and maintenance roads and road infrastructure linked to Rail Baltica, such as access routes for Rail Baltica staff	Damage to the access roads or road infrastructure and/or possible access restrictions to stations, track, substations, etc. due to general flooding of nearby areas.	**Medium**	1.2.1. Climate change trends should be considered in the process of developing DG-s principles for roads.	Avoidance, Mitigation	DG-s (D)	Contracting, Authority	**Low - s**mall part incorporated into the road standard study.	**High** – significant consequences could be avoided or mitigated and optimal solutions developed with low costs.
			1.2.2. Frost index (more details under frost penetration of soil risk) should be also considered in the process of developing DG-s principles for roads.	Avoidance, Mitigation	DG-s (D)	Contracting, Authority	**Low - m**inimal cost for Contracting Authority.	**High** – significant consequences (frost heave problems) could be avoided or mitigated and optimal solutions developed with low costs.

1. Flooding and heavy rains - additional information

Relevant climate change trends

Precipitation will be increased, especially during winter period. Climatic projections estimate increased likelihood of more severe heavy rains and flash floods in the future, with likelihood of extreme precipitation (over 30 mm per day) can be increased up to 4 times and over 1.5 times in summer period according to the RCP8.5 scenario. (Keskkonnaagentuur, 2014). However, the distribution of precipitation by intensity is not modelled by climate scenarios and the uncertainty of statements and forecasted data is extremely high. Extreme precipitation events have become already more frequent and intense during 1957-2009 (Tammets and Jaagus 2012). Spring floods will be less severe due to milder winters and inconsistent snow coverage. Maximum discharges of spring floods decreased over the period 1922-2010 (Sarauskiene et al 2015).

Measure 1.1.2

Flood, HWL and peak flow modelling and calculations and technical solutions like drainage systems and pumping equipment (if required) should also consider potential increase of ground level levels in future winter period due to increased precipitation and minimal evaporation in the winter period.

Measures 1.1.1.; 1.1.2. and 1.3.2.

Climate change factor is not currently included in Estonian and Latvian (except Riga region) peak flow calculations. Latvia is expected to have new flood and peak flow estimations, which include climate change factor, by 2019. This study and other relevant latest studies on climate change on flood risk should be considered in the design process. Not considering climate change in peak flow calculations could lead to under and over estimations, which would increase flooding events risk in first case and cost inefficiency for the latter.

Biggest rivers – Daugava and Neris - are regulated, their runoff is controlled and risks mitigated as dams and other hydroengineering is designed and constructed by the highest standards.

The Pärnu River Case for declining flooding risk: Pärnu river 100-year maximum peak flow estimation from Estonian Weather Authority is based only on historic data and maximum peak flows registered in 1920s, 1930s, 1940s or 1950s are determining values for future predictions. Maximum flow rate of 798 m^3 was registered on 25.04.1931 in Oore station on Pärnu river downstream. 42 highest peak flows were all registered during period 1922-1956. Followed by 43rd maximum peak flow of 515 m^3 on 06.04.2010 (highest during period 1957-2017). If design uses similar peak flow estimation as 846 m^3, acquired on 13.08.2015 in Rail Baltica preliminary design stage from Estonian Weather Authority and adds additional 0,5 m to the HWL for safety then **over estimation of the risk is very probable**, considering the ongoing climatic trend.

Measure 1.1.3.

Currently, pluvial flooding caused by very heavy rain and flash floods is the most frequently exposed climate risk in the Baltic countries. So, it could be transferred to the Rail Baltica corridor, by third parties. There is one event with 6.6 mm of rain in one minute in Lithuania during period 1981-2017 (only Lithuania has precipitation data with 1-minute precision). DG-s currently state that all systems need to be designed against 6 mm per minute rain. It is advised to revise and potentially upgrade stormwater system design in the critical areas (e.g. cities and built-up areas).

Measure 1.1.4

Critical locations with potential flood risk (including due to third party risk) should be defined by geotechnical and hydrological studies and potential locations for remote condition monitoring systems, for operation stage, should be suggested during technical design stage, if necessary. Sensitive areas to consider (could be elaborated in further stages) – tunnels, cuttings, areas with extensive artificial surfaces (cities). Designer should propose a suitable location (including necessary connectivity solutions) to place the sensors[5]. It is advised to specify the sensor type and associated specific requirements prior to the design stage and not include this as a task for designer, because of the potential problems integrating different sensors (chosen by each designer for different sections of Rail Baltica) into centralized Rail Baltica systems. Special maintenance inspections routine should be developed and used after extreme weather events (specify thresholds and conditions). Incident data (incl. asset performance and asset degradation data) should be combined with meteorological data to able to determine cause-effect relations and develop risk management plans.

[5] Example of a potential sensor - http://www.bedia.com/index.php/en/products/group/cls/item/product-bedia-cls-2x

Table 8.2 Climate change adaptation measures – **Wind and storms**

Asset or service associated with the risk	Consequences	Risk rating	Adaptation measures	Measure type	Measure development (D) or implementation (I) stage(s)	Responsible parties	Cost estimate	Cost efficiency
2. WIND AND STORMS								
2.1 All infrastructure, but especially catenaries, noise barriers and fencing	Failure of or direct damage to parts of structure or infrastructure as a result of changes in extreme winds and gustiness.	**Medium**	2.1.1. Multi-hazard risk (high wind in combination with snow, freezing rain or glazed frost) need to be assessed during specification of catenaries and other sensitive systems. Improved design parameters for sensitive assets.	Avoidance, Mitigation,	DG-s (D)	Contracting, Authority	**Medium - s**eparate study could be required.	**Medium** – optimal design solutions would be achieved with medium costs.
			2.1.2. Identify potential wind corridor locations (coast, relief, open landscape, long bridges). Relevant infrastructure should be determined during design stage, measures implemented accordingly.	Avoidance, Mitigation	Design (D; I)	Designer	**Medium -** some extra work in design stage.	**Medium –** optimal design solutions would be achieved with medium costs.
			2.1.3. Monitoring and alerting system of wind and storms needs to be developed and implemented within the Rail Baltica weather services.	Mitigation	DG-s (D) Design (D) Pre-operation (I)	Contracting Authority	**Unknown** - highly dependent on system specification.	**Unknown** - highly dependent on system specification.
2.2 All infrastructure, but especially catenaries, drainage and fencing	Possible blockage of railway drainage systems due to obstructions and windborne debris from domestic or third-party objects, as well as potentially trees landing on track	**High**	2.2.1. Identification of areas where 40 m tree free zone is not allowed/possible during technical design and environmental assessment stages.	Avoidance	Design (D)	Designer	**Low -** small part incorporated into the design and environmental assessment process.	**High** – important information could be acquired with low costs.
			2.2.2. Special monitoring system and measures required for conservation areas or other areas where 40 m tree free zone is not allowed.	Mitigation	DG-s (D) Operation (I)	Contracting Authority Infrastructure manager	**Low -** periodical visual assessments with tree cutting are used. Tree related measures (cutting, trimming) are low cost.	**High** – risk is decreased significantly with low costs.

	and causing damage to catenaries and fencing.		2.2.3. Windproof/storm-proof environment programme (third party elements and flying objects).	Avoidance	DG-s (D) Operation (I)	Contracting Authority	**Medium -** development incorporated into maintenance plan study.	**Low** – some consequences could potentially be avoided with medium costs.
			2.2.4. Monitoring and alerting system of wind and storms needs to be developed and implemented within the Rail Baltica weather services.	Mitigation	DG-s (D) Pre-operation (I)	Contracting Authority	**Unknown -** highly dependent on system specification.	**Unknown -** highly dependent on system specification.
2.3 Train traffic	Speed restrictions to trains due to high wind events.	**Medium**	2.3.1. Monitoring and alerting system of wind and storms needs to be developed and implemented within the Rail Baltica weather services. Integration with traffic control system shall be considered.	Mitigation	DG-s (D) Pre-operation (I)	Contracting Authority	**Unknown -** highly dependent on system specification.	**Unknown -** highly dependent on system specification.
			2.3.2. Specific weather thresholds (incl. wind speeds) should be developed for safe operations of trains.	Avoidance, Mitigation	Pre-operation (D)	Contracting Authority	**Low -** separate study is probably not necessary.	**High** – risk is decreased significantly with low costs.

2. Wind and storms - additional information

Relevant climate change trends

Likely increase in the frequency and intensity of storms (with some uncertainty) according to the future projections. Milder winters could increase the risk on wet snow, freezing rain and glazed frost events (Keskkonnaagentuur, 2014; Latvijas Vides, ģeoloģijas un meteoroloģijas centrs 2017; Kilpys, J., Pauša, K., Jurkus, N., 2017).

Measures 2.2.1 and 2.2.2

Milder winters will increase winter storm damages - storms and wet snow loads may topple trees when roots rise easily from moist and soft ground.

Measure 2.2.2

Special maintenance inspections routine should be developed and used after extreme weather events. Incident data (incl. asset performance and asset degradation data) should be combine with meteorological data to able to determine cause-effect relations and develop more accurate risk management plans and actions.

Measure 2.2.3

Items with high risk (trampolines, signs, etc.) should be defined and appropriate measures (e.g. informing third parties about the potential risks, inspections in critical locations, cooperation principles with third parties to mitigate the risk) developed.

Table 8.3 Climate change adaptation measures – **Ground instability and landslides**

Asset or service associated with the risk	Consequences	Risk rating	Adaptation measures	Measure type	Measure development (D) or implementation (I) stage(s)	Responsible parties	Cost estimate	Cost efficiency
3. GROUND INSTABILITY AND LANDSLIDES								
3.1 Earthworks and structures (mainly bridges, OLE, access roads, noise walls, passenger stations, signs, safety barriers, utilities and cables)	Increased instability can lead to landslides, earthworks failures and damage to structures (mainly bridges, catenaries, noise walls, passenger stations, signs, safety barriers and cables).	**Medium**	3.1.1. Change in the DG-s document "Railway substructure, Part 2 hydraulic, drainage and culverts": Replace sentence "If required by local administration, peak flow calculation should take into consideration the effects of climate change" with "Peak flow calculations should take into consideration the effects of climate change".	Avoidance, Mitigation	DG-s (I)	Contracting Authority	**Low** - minimal cost for Contracting Authority.	**High** – cost optimal design solutions could be achieved with little additional cost to measure implementation
			3.1.2. Upgrading flood zone modelling and high-water level (HWL) and peak flow calculations with National Weather Authorities (is required to specify methodology which takes into account climate change allowance in the peak flow predictions.	Avoidance, Mitigation	DG-s (D)	Contracting Authority	**Medium** - some communication and work required.	**High** – optimal design solutions could be achieved with medium additional costs.
			3.1.3. Monitoring system needs to be developed and implemented in sensitive areas (suggested by designer if necessary).	Mitigation	DG-s (D) Design (D) Pre-operation (I)	Contracting Authority Designer	**Unknown** - highly dependent on system specification.	**Unknown** - highly dependent on system specification.
			3.1.4. Maintenance plan for ditches, channels, streams and culverts (with third parties) including ice and snow clearance	Avoidance, Mitigation	DG-s (D) Operation (I)	Contracting Authority	**Medium (uncertain)** – development incorporated into maintenance plan study.	**High** – significant consequences could be avoided or mitigated with medium costs.

			during winter and spring season peak flows. Third party risk assessment.			Third parties (responsible for infrastructure outside of Rail Baltica area).	Regular maintenance is required. Costs will also be dependent on cooperation details with third parties.	
			3.1.5. Need to add requirement to DG-s that underground buried utilities and structures of above ground utilities shall not be foreseen at the location of instable ground and/or landslides as they can cause extremely hazardous situations (e.g. breakage of gas pipeline).	Avoidance	DG-s (D) Design (I)	Contracting Authority Designer Third parties (responsible for infrastructure outside of Rail Baltica area).	**Low -** implemented through avoidance.	**High-** significant consequences could be avoided without additional cost.

3. Ground instability and landslides - additional information

Relevant climate change trends

Precipitation will be increased, especially during winter period. Climatic projections estimate increased likelihood of more severe heavy rains and flash floods in the future, with likelihood of extreme precipitation (over 30 mm per day) can be increased up to 4 times in winter period and over 1.5 times in summer period according to the RCP8.5 scenario. (Keskkonnaagentuur, 2014)

Spring floods will be less severe due to milder winters and inconsistent snow coverage.

Measures 3.1.2 and 3.2.2

Flood, HWL and peak flow modelling and calculations and technical solutions like drainage systems and pumping equipment (if required) should also consider potential increase of ground level levels in future winter period due to increased precipitation and minimal evaporation in the winter period.

Measures 3.1.1 and 3.1.2

Climate change factor is not currently included in Estonian and Latvian (except Riga region) peak flow calculations. Latvia is expected to have new flood and peak flow estimations, which include climate change factor, by 2019. This study and other relevant latest studies on climate change on flood risk should be considered in the design process. Not considering climate change in peak flow calculations could lead to under and over estimations, which would increase flooding events risk in first case and cost inefficiency for the latter.

The Pärnu River Case for declining flooding risk: Pärnu river 100-year maximum peak flow estimation from Estonian Weather Authority is based only on historic data and maximum peak flows registered in 1920s, 1930s, 1940s or 1950s are determining values for future predictions. Maximum flow rate of 798 m^3 was registered on 25.04.1931 in Oore station on Pärnu river downstream. 42 highest peak flows were all registered during period 1922-1956. Followed by 43rd maximum peak flow of 515 m^3 on 06.04.2010 (highest during period 1957-2017). If design uses similar peak flow estimation as 846 m^3, acquired on 13.08.2015 in Rail Baltica preliminary design stage from Estonian Weather Authority and adds additional 0,5 m to the HWL for safety then **over estimation of the risk is very probable**, considering the ongoing climatic trends.

Measure 3.1.3

Critical locations with potential landslides, ground instability (both railway embankment and slopes in wet cuts) and high ground water level risks should be defined by geotechnical and hydrological studies and potential locations for remote condition monitoring systems, for operation stage, should be suggested during technical design stage, if necessary. Sensitive areas to consider (could be elaborated in further stages) – slopes in cuttings and slopes of larger water bodies, which Rail Baltica crosses. Designer should propose a suitable location (including necessary connectivity solutions) to place the sensors, if justified. It is advised to specify the sensor type and associated specific requirements prior to the design stage and not include this as a task for designer, because of the potential problems integrating different sensors (chosen by each designer for different sections of Rail Baltica) into centralized Rail Baltica systems. Special maintenance inspections routine should be developed and used after extreme weather events. Incident data (incl. asset performance and asset degradation data) should be combine with meteorological data to able to determine cause-effect relations and develop more accurate risk management plans and actions.

Table 8.4 Climate change adaptation measures – **Lightning**

Asset or service associated with the risk	Consequences	Risk rating	Adaptation measures	Measure type	Measure development (D) or implementation (I) stage(s)	Responsible parties	Cost estimate	Cost efficiency
			4. LIGHTNING					
4.1 Buildings, structures and lineside equipment (signalling and track circuit) and traffic	Direct damage to buildings, structures and lineside equipment (signalling and track circuit) and indirect impacts (maintenance, traffic).	**Medium**	4.1.1. Lightning risk assessment should consider the possibility of more frequent thunder clouds with more severe consequences in the future. Adequate lightning protection measures for signalling, telecommunication and power supply equipment shall be considered.	Avoidance, Mitigation	DG-s (D)	Contracting, Authority	**Medium -** separate study could be required.	**Medium** – optimal design solutions would be achieved with medium costs.
			4.1.2 Monitoring and alerting system of thunder storms needs to be developed and implemented within the Rail Baltica weather services.	Mitigation	DG-s (D) Pre-operation (I)	Contracting Authority	**Unknown -** highly dependent on system specification.	**Unknown -** highly dependent on system specification.
			4.1.3. All third-party utilities shall be grounded for lighting near the railway to avoid EMD and electric surge to railway and its structures. Third-party utilities with potential EMD and electrical surge risk to Rail Baltica should be determined during the design stage.	Avoidance	Design (D) Pre-operation and Operation (I)	Contracting Authority Designer Third parties (responsible for infrastructure outside of Rail Baltica area). Infrastructure manager	**Medium** - third-parties shall be liable for most of the implementation. Contracting Authority shall implement when re-designing and constructing the existing utilities.	**High -** high risk avoidance will be achieved with medium cost

4. Lightning - additional information

Relevant climate change trends - Higher air temperature may cause more intense formation of typical summer thunder clouds. Natural phenomena associated with thunder clouds will be more likely and with more severe consequences, but **more detailed projections are not possible due to uncertainty and random spatial nature of the thunder events.**

Measure 4.1.1.

Lightning risk assessment should include principles of a suitable and efficient dissipation array system (DAS). Risk assessment should also consider third party (electricity sources, telecommunication systems) risks associated with lightning.

Measure 4.1.2.

Incident data (incl. asset performance and asset degradation data) should be combine with meteorological data to able to determine cause-effect relations and develop more accurate risk management plans and actions.

Table 8.5 Climate change adaptation measures – **Low temperatures**

Asset or service associated with the risk	Consequences	Risk rating	Adaptation measures	Measure type	Measure development (D) or implementation (I) stage(s)	Responsible parties	Cost estimate	Cost efficiency
5. LOW TEMPERATURES								
5.1 Rails, underground cables and utilities	Increase risk of rail and weld breaks due to extreme cold conditions due to bad quality rail or rollingstock. Cable breaks due to embankment processes. Utility failures and breakages due to movements in embankment and freezing of carried liquids.	**Medium**	5.1.1. Stability of the embankment should be achieved by developing and using frost index maps (more information under hazard frost penetration of soil).	Avoidance, Mitigation	DG-s (D)	Contracting Authority	**Low** - minimal cost for Contracting Authority	**High** – significant consequences (frost heave problems) could be avoided or mitigated and optimal solutions developed with low costs.
			5.1.2 Monitoring and alerting system for low temperatures to be developed and implemented within the Rail Baltica weather services.	Mitigation	DG-s (D) Pre-operation (I)	Contracting Authority	**Unknown** - highly dependent on system specification.	**Unknown** - highly dependent on system specification.
			5.1.3 Utilities must be foreseen located deep enough or insulated that freezing of carried liquid would be prevented. Casing pipes have to be foreseen to eliminate possibility for leakage into the soil/embankment when pipe breakage should take place. Monitoring system to be put in place to detect leakages.	Avoidance, Mitigation	Utilities requirements study (D) Design and Operation (I)	Contracting Authority Designer Third parties (responsible for infrastructure outside of Rail Baltica area).	**High** - investment and maintenance cost of detection systems are high.	**Medium** - even if the detection systems come with high cost then they can help to extensively reduce severe impact from leakages to railway.

5. Low temperatures **- additional information**

Relevant climate change trends

Clear trend of increased temperatures in the winter periods. However, the absolute minimum temperatures are modelled with very low certainty by current climate scenarios. Similar cold waves and absolute minimum temperatures as registered during the period 1981-2017 (Chapter 4.1 and Figure 4.1) may occur in nearest future, despite general climate warming trend.

Measure 5.1.2.
Incident data (incl. asset performance and asset degradation data) should be combine with meteorological data to able to determine cause-effect relations and develop more accurate risk management plans and actions.

Table 8.6 Climate change adaptation measures – **Snow, freezing rain and glazed frost**

Asset or service associated with the risk	Consequences	Risk rating	Adaptation measures	Measure type	Measure development (D) or implementation (I) stage(s)	Responsible parties	Cost estimate	Cost efficiency
6. SNOW, FREEZING RAIN AND GLAZED FROST								
6.1 Points operating equipment (POE), catenaries and overhead power lines	Points operating equipment (POE) failures due to snow and ice accretion. Damage to catenaries, overhead power lines.	**High**	6.1.1. Specification of technical requirements for POE-s, catenaries and overhead power lines should consider clear trend of milder winters with more precipitation and increased likelihood of wet snow, freezing rain and glazed frost events.	Avoidance, Mitigation,	DG-s (D)	Contracting, Authority	**Medium -** separate study could be required.	**Medium** – risk is reduced with medium costs.
			6.1.2. Development and implementation of maintenance system, including principles of systematic monitoring and forecast (could be incorporated into Rail Baltica weather service) and required tools and machinery - "Winter maintenance plan" - is required.	Avoidance, Mitigation	DG-s (D) Pre-operation (I)	Contracting Authority	**Unknown -** highly dependent on system specification.	**Unknown -** highly dependent on system specification.
6.2 Station platforms, footways, stairs, etc	Accidents due to slippery surfaces in station platforms, passenger walks, stairs, etc.	**High**	6.2.1. Technical solutions and materials, which will greatly decrease risk of slippery surfaces, shall be specified in the passenger areas, which are exposed to climatic variables like rain, snow, ice, freezing rain and glazed frost.	Avoidance, Mitigation	DG-s (D) Design (D; I)	Contracting, Authority Designer	**Medium -** solutions and materials with better quality could cost more.	**Medium –** some consequences could be avoided or mitigated with medium costs.
			6.2.2. Maintenance plan development and implementation in passenger areas.	Avoidance, Mitigation	DG-s (D) Operation (I)	Contracting Authority Infrastructure manager	**Medium -** Continuous maintenance costs. Development incorporated into maintenance plan study.	**High** – majority of the consequences could be avoided or mitigated with medium costs.

6. Snow, freezing rain and glazed frost - additional information

Relevant climate change trends

Clear trend of increased temperatures in the winter periods with more precipitation and increased likelihood of wet snow, freezing rain, glazed frost and ice forming events (Keskkonnaagentuur, 2014; Latvijas Vides, ģeoloģijas un meteoroloģijas centrs 2017; Kilpys, J., Pauša, K., Jurkus, N., 2017).

Measure 6.1.2

Special maintenance inspections routine should be developed and used after extreme weather events.

Incident data (incl. asset performance and asset degradation data) should be combine with meteorological data to able to determine cause-effect relations and develop more accurate risk management plans and actions.

Measure 6.2.1.

Main goal of the measure is to use solutions (roofs, heating, etc) and materials, which would minimize the risk of incidents with passengers due to slippery surfaces. Material with as high as possible slippery resistance should be used in passenger areas.

Measure 6.2.2. Suitable solutions and materials could avoid some of the incidents, but adequate maintenance is the main measure, which can reduce the risk significantly.

Table 8.7 Climate change adaptation measures – **Frost penetration of soil**

Asset or service associated with the risk	Consequences	Risk rating	Adaptation measures	Measure type	Measure development (D) or implementation (I) stage(s)	Responsible parties	Cost estimate	Cost efficiency
7. FROST PENETRATION OF SOIL								
7.1 Railway and maintenance road embankments	Potential damage to the railway and maintenance road embankments through frost heave during the winter and loss of bearing capacity during the thawing period, if soil underneath is frost susceptible.	**Medium**	7.1.1. Frost Index or Freezing Index (FI) and average annual air temperature data, covering the whole Rail Baltica corridor, should be developed (input for selecting appropriate countermeasures, e.g. necessary thickness of granular frost protection layer).	Avoidance, Optimization	Design(D; I)	Designer	**Medium –** some work and data acquisition are required.	**High** – optimal design solutions, with great impact to material quantities, would be achieved with medium costs.
			7.1.2. Design solutions should use the results of developed Frost Index and average annual air temperature.	Avoidance, Optimization	Design (I)	Designer	**Low -** Insignificant increase in work amount in the design stage.	**High** – optimal design solutions would be implemented with low costs.

7. Frost penetration of soil - additional information

Relevant climate change trends – Average annual temperature is expected to rise 1.5-5.5 °C by year 2100. Clear trend of increased temperatures in the winter periods, which would result in decrease of frost penetration depth (Keskkonnaagentuur, 2014; Latvijas Vides, ģeoloģijas un meteoroloģijas centrs 2017; Kilpys, J., Pauša, K., Jurkus, N., 2017). Similar frost penetration of soil depths registered (Estonia, Lithuania) or calculated (Latvia) (Chapter 4.1.9, Tables 4.18, 4.19 and Figure 4.76) may still occur in nearest future, despite general climate warming trend.

Measure 7.1.1.

The frost penetration depths indicated in the Rail Baltica Design Guidelines (RBDG-MAN-016-0101) - are currently as follows:

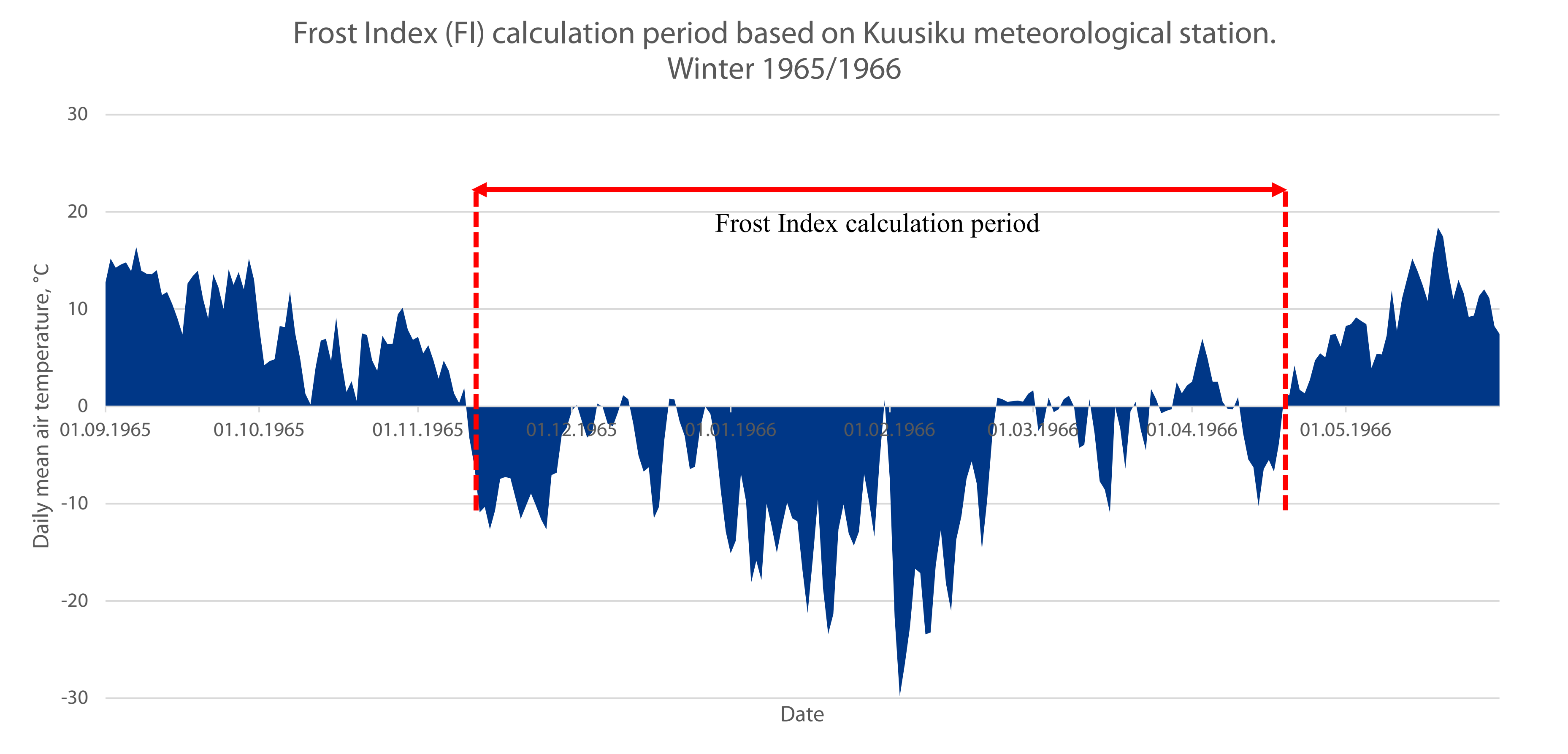
- Estonia: 2.05 m;
- Latvia: 1.74 m;
- Lithuania: 1.70 m.

Aforementioned values do not take into account different climatic zones within each county, which could lead to under or over estimations of frost penetration depths in specific regions (e.g. coastal areas, inland) In case frost penetration depth is underestimated, it could lead to problems related with frost heave during the freezing period (winter) and loss of bearing capacity during the thawing period (spring) which will increase track maintenance costs in the operating phase (OPEX). In case frost penetration depth is overestimated, it will increase construction costs without additional benefits to track performance during the construction phase (CAPEX). Currently selected approach by Systra is to follow UIC 719R for designing the track pavement and in order to select appropriate frost protection layer thickness, two input values must be determined – Frost Index (FI) and average annual air temperature. It must be taken into account that according to UIC 719R, FI and average annual air temperature must be selected based on the harshest winter experienced in specific location (i.e. meteorological station).

Frost Index (FI) or sometimes referred to as Freezing Index is combined measure of magnitude and duration of freezing temperatures (below 0°C) within given freezing season and it's used to express the severity of winter and estimate frost penetration depths for given location. FI is expressed by cumulative degree-days for one freezing season and total annual Frost Index is calculated by adding all the negative average daily temperatures for a specific location during the time period starting when freezing period's area under during the degree-days curve is larger than following short period of thawing in autumn (if there's such period) and ending when thawing period's area under the degree-days curve is larger than previous freezing period's area. See an example based on Kuusiku weather station data below (Total FI = 1068 °C x days).

$$FI = \sum (0°C - T_{d,i})$$

FI – freezing index (cumulative), degree-days (°C × days) for a given period of time
$T_{d,i}$ – average daily air temperature for a given day



NOTE: The start of the calculation period is 11.11.1965 and end is 18.04.1966. It can be observed from the graph that there was a short thawing period from 29.03.1966 to 06.04.1966. Due to the fact that the area under the date-temperature curve for period was smaller than the area of the following freezing period (from 07.04.1966 to 18.04.1966), the end of calculation period is 18.04.1966.

The Latvian State Roads has ordered a study “Frost Heave Properties Assessment of the Soils for the Road Pavement designs”, which will have an interim report completed in March 2019. It is advised to investigate the conclusions of that study to have more frost heave related information about Latvia.

Table 8.8 Climate change adaptation measures – **High temperatures**

Asset or service associated with the risk	Consequences	Risk rating	Adaptation measures	Measure type	Measure development (D) or implementation (I) stage(s)	Responsible parties	Cost estimate	Cost efficiency
8. HIGH TEMPERATURES								
8.1 Rails	Rail buckling and/or associated misalignment problems due to Critical Rail Temperature (CRT).	**Medium**	8.1.1. Multi hazard effect – it is also necessary to consider solar radiation factor during specification of temperature range values for rails (incl. sub-system compatibility). Investigate high temperature stressing regimes.	Avoidance, Mitigation	DG-s (D)	Contracting Authority	**Low** - minimal cost for Contracting Authority	**High** – optimal design solutions would be achieved with medium costs.
			8.1.2. Monitoring and alerting system for high temperatures to be developed and implemented within the Rail Baltica weather services.	Mitigation	DG-s (D) Pre-operation (I)	Contracting Authority	**Unknown** - Highly dependent on system specification.	**Unknown** - Highly dependent on system specification.
8.2 Expansion joints	Increased risk of thermal expansion joints being pushed beyond their design capability, presenting a direct risk of damage to bridges structures and indirect of damage of other assets dependent upon bridge.	**Medium**	8.2.1. Multi hazard effect – it is also necessary to consider solar radiation factor during specification of technical requirements for thermal expansion joints.	Avoidance, Mitigation	DG-s	Contracting, Authority	**Low** - minimal cost for Contracting Authority	**High** – optimal design solutions would be achieved with low costs.
			8.2.2 Monitoring and alerting system for high temperatures to be developed and implemented within the Rail Baltica weather services.	Mitigation	DG-s (D) Pre-operation (I)	Contracting Authority	**Unknown** - Highly dependent on system specification.	**Unknown** - Highly dependent on system specification.

8.3 Electrotechnical equipment	Outages of equipment due to high temperatures.	**Medium**	8.3.1. It is necessary to consider heat from direct solar radiation during specification of requirements on containers and design of its locations.	Avoidance, Mitigation	DG-s (D)	Contracting, Authority	**Low -** minimal cost for Contracting Authority	**High** – optimal design solutions would be achieved with low costs.

8. High temperatures - additional information

Relevant climate change trends – There is a clear consensus about the rise of future temperatures, including summer maximum temperatures up to approximately 5° C, which could lead to maximum temperatures around 40° C, according to worst case climate change scenarios (Keskkonnaagentuur, 2014; Latvijas Vides, ģeoloģijas un meteoroloģijas centrs 2017; Kilpys, J., Pauša, K., Jurkus, N., 2017).

Measure 8.1.1, 8.2.1 and 8.3.1

Technical requirements in urban areas for rails, expansion joints and electrotechnical equipment should also consider the heat island effect, which will further enhance the impact of rising summer maximum temperatures. Special requirements should be considered in urban areas because of this. In regard urban heat island (UHI) effect, the temperature is higher in urbanised Greater Tallinn that in the surroundings by 3-5 °C (Sagris and Sepp, 2017).

Significant changes in solar radiation during the warm season are not expected (KATI, 2015; Lithuania's 7th UNFCCC report, 2017) and existing solar radiation data could be used.

Multi-year (1991-2014) maximum direct normalized irradiance at surface (W/m^2) in May-July varies from 280 to 360 W/m^2 in the locations of Rail Baltica (Solar Atlas 2019). Greatest one hour direct solar radiation amounts in Estonia are recorded in mid-days in June on average – 1.18 MJ/m^2. Greatest recorded daily direct solar radiation amount is 27,7 MJ/m^2 (in Tõravere on 20th of June 1979).

Measure 8.2.1

Different technologies should be investigated and most appropriate implemented. Some example mitigation possibilities (WRWRP, 2016):

- strengthening plates could be installed at sites of tight curvature,
- glued ballast could be used on some embankments
- painting the rail white

Measures 8.1.2. and 8.2.2.

Potential locations for remote condition monitoring systems, where rail or thermal joints temperature is critical, should be suggested during technical design stage if necessary. Special maintenance inspections routine should be developed and used after extreme weather events, like heatwaves. Incident data (incl. asset performance and asset degradation data) should be combine with meteorological data to able to determine cause-effect relations and develop more accurate risk management plans and actions. Rolling stock could in the future include temperature monitoring equipment (https://www.rssb.co.uk/Library/research-development-and-innovation/2016-05-t1009-exec-report.pdf). Possibilities of rolling stock also monitoring rail temperature, could be investigated.

Table 8.9 Climate change adaptation measures – **Fog**

Asset or service associated with the risk	Consequences	Risk rating	Adaptation measures	Measure type	Measure development (D) or implementation (I) stage(s)	Responsible parties	Cost estimate	Cost efficiency
9. FOG								
9.1 Operations, maintenance, staff and passengers	Operations (e.g. shunting), maintenance could be disrupted and passengers and staff risks increased.	**Medium**	9.1.1. Elaborate and implement alerting and emergency notification systems for staff and passengers.	Avoidance	Pre-Operation (D; I)	Contracting Authority	**Unknown** - Highly dependent on system specification.	**Unknown** - Highly dependent on system specification.

9. Fog - additional information

Relevant climate change trends – No clear projections about future fog events.

Table 8.10 Climate change adaptation measures – **Draught and wildfire**

Asset or service associated with the risk	Consequences	Risk rating	Adaptation measures	Measure type	Measure development (D) or implementation (I) stage(s)	Responsible parties	Cost estimate	Cost efficiency
10. DRAUGHT AND WILDFIRE								
All infrastructure and services	Direct damage, disruptions due to flying ash and precautionary measures caused by wildfires.	**Medium**	10.1.1. Multi hazard effects of climate change (increased probability of high wind events, increased temperatures and more severe draughts) should be considered while developing risk assessments, safety standards and risk management plans.	Avoidance, Mitigation,	DG-s (D) Operation (I)	Contracting Authority Designers	**Low** - Results of current climate risks study could be considered with low additional costs.	**High** – important input could be acquired with low costs.
			10.1.2. Peat land fires near or under the railway and other wildfire sensitive areas – special and high impact risk enhanced by climate change, that needs special attention in design stage, and risk management plans.	Avoidance, Mitigation,	DG-s (D) Design (D; I)	Contracting Authority Designers	**Low** - Results of current climate risks study could be considered with low additional costs.	**High** – important input could be acquired with low costs.

10. Draught and wildfire - additional information

Relevant climate change trends

There is a clear consensus about the rise of future temperatures, including summer maximum temperatures up to approximately 5° C, according to worst case climate change scenarios. Likely increase in the frequency and intensity of storms (with some uncertainty) according to the future projections.

Measure 10.1.2

Technical solutions in peat land areas should be designed so embankment stability is preserved in case of a peat land fire.

8.1. Adaptation measures by implementation

A. Additional surveys and studies:

A1 (1.1.2; 3.1.2). Upgrading flood zone modelling and high-water level (HWL) and peak flow calculations with National Weather Authorities is required to specify methodology which takes into account climate change allowance in the peak flow predictions.

- Responsible party: Contracting Authority
- Stage: Before or during design stage
- Action description: Authorities responsible for flood and high-water level (HWL) predictions should be contacted by the Contracting Authority to specify if and in what extent climate change is being considered in the future predictions. Necessity and possibilities of updating the methodology to better address the specific railway related requirements and risks (more info and Pärnu river example under paragraph "1. Flooding and heavy rains - additional information") should be discussed with relevant authorities. Design Guidelines should be updated based on the results, if necessary.

A2 (1.2.1; 1.2.2) Climate change trends should be considered in the process of developing DG-s principles for roads. Frost index (more details under frost penetration of soil risk) should be also considered in the process of developing DG-s principles for roads.

- Responsible party: Contracting Authority
- Stage: Before or during design stage
- Action description: Investigate if current road design principles in DG-s are optimal considering additional information about the climate change and frost index calculations.

A3 (2.1.1; 6.1.1) Multi-hazard risk (high wind in combination with increased likelihood of wet snow, freezing rain or glazed frost) shall be considered during specification of POE-s, catenaries and overhead, ETCS markerboards and other sensitive systems. Improved design parameters for sensitive assets.

- Responsible party: Contracting Authority or study contractor
- Stage: Before or during design stage
- Action description: As described in the measure text

A4 (4.1.1.) Lightning risk assessment should consider the possibility of more frequent thunder clouds with more severe consequences in the future. Adequate lightning protection measures for signalling, telecommunication and power supply equipment shall be considered.

- Responsible party: Contracting Authority or study contractor
- Stage: Before or during design stage
- Action description: As described in the measure text (4.1.1)

B. Weather monitoring, forecasting and alerting – Rail Baltica Weather Service

B1 (1.1.4; 2.1.3; 2.2.4; 2.3.1; 3.1.3; 4.1.2; 5.1.2; 6.1.2; 8.1.2; 8.2.2) Monitoring, alerting and forecasting system for flooding and heavy rain, storms, thunder, ground instability and landslides, high temperatures, low temperatures and snow, freezing rain and glazed frost needs to be developed and implemented within the Rail Baltica weather services. Integration with traffic control system shall be considered.

- Responsible party: Contracting Authority
- Stage: Before or during design stage
- Action description: Rail Baltica Weather Service system (more info in paragraph 12) needs to be developed by Contracting Authority or by study contractor before technical design is completed, so the system requirements could be integrated into the design.

B2 (2.3.2.) Specific weather thresholds (incl. wind speeds) should be developed for safe operations of trains.

- Responsible party: Contracting Authority
- Stage: Before the operation
- Action description: Should be specified during development of Rail Baltica Weather Service and critical weather thresholds integrated into traffic control system, if possible.

C. Infrastructure maintenance and operational plan

C1 (1.1.5; 3.1.4) Maintenance code for ditches, channels, streams and culverts (with third parties), including ice and snow clearance during winter and spring season peak flows. Third party risk assessment.

- Responsible party: Infrastructure manager
- Stage: Pre-operation
- Action description: Third party risk significant and should be considered in the development of the maintenance code. Cooperation with third parties is necessary.

C2 (2.2.2.) Special monitoring system and measures required for conservation areas or other areas where 40 m tree free zone is not allowed.

- Responsible party: Infrastructure manager
- Stage: Pre-operation
- Action description: Periodical visual assessments with required measures (cutting, trimming) should be carried out.

C3 (2.2.3.) Windproof/storm-proof environment programme (third party elements and flying objects)

- Responsible party: Infrastructure manager
- Stage: Pre-operation
- Action description: Items with high risk (trampolines, signs, etc.) should be defined and appropriate measures (e.g. informing third parties about the potential risks, inspections in critical locations, cooperation principles with third parties to mitigate the risk) developed.

C4 (6.2.2) Maintenance plan development and implementation in passenger areas.

- Responsible party: Infrastructure manager
- Stage: Pre-operation
- Action description: As described in the measure text (6.2.2)

C5 (10.1.2.) Peat land fires near or under the railway – special and high impact risk enhanced by climate change, that needs special attention in design stage, and risk management plans.

- Responsible party: Infrastructure manager
- Stage: Pre-operation
- Action description: As described in the measure text (10.1.2).

8.2. Rail Baltica Weather Service principles

Rail Baltica Weather Services should be developed in three domains:

1. Weather Definitions and Thresholds
2. Weather Information and Support systems
3. Weather Event Response

1. Weather Definitions and Thresholds

The management should set weather thresholds and definitions which should follow, downscale and specify in detailed manner the meteorological alerting criteria according to railway engineering, operations, management standards and designated risk assessment. National meteorological services provide alert in the possible occurrence of severe weather, such as heavy rain with risk of flooding, severe thunderstorms, gale-force winds, heat waves, forest fires, fog, snow or extreme cold with blizzards, or severe coastal tides. The traffic lights colours (green – no dangers, yellow, orange, red) depending on dander levels are used to indicate the severity of the extreme weather and its possible impact. The three official danger levels (classic grading) declared by the national weather services as follows:

- First level warning / yellow: Weather can be dangerous in certain situations. Take into account when your activity is affected by the weather. Keep track of future weather forecasts.
- Second level warming / orange: The weather is dangerous. There are unusual weather events. Be very careful and keep an eye on the weather forecast. Be aware of the risks that may be unavoidable. Follow all recommendations given by the authorities.
- Third level warning /red- Extremely Dangerous Weather. High damage is likely. Long-term expose of extreme weather conditions can cause a natural disaster. Risks to life and health. Keep informed of future developments through television, radio, or the Internet. Follow all commands given by the authorities, ready for emergency measures.

This can respond to the RB case as follows: Normal conditions, Be aware, Challenging weather, Extreme weather (see below 8.2.3).

National weather service issues alert according to the criteria of weather data and processes, for example in Estonian case, wind speed 33 m/s and above (30% of territory) is declared the third level warning. The alerting system could be set and installed to the entire operations as automatic. Wind alert systems in France, Spain and Japan high speed railways automatically slow down of trains or even stop.

2. Weather Information and Support systems

This part of weather support systems provides measured, monitored and modelled, real-time and offline information for reporting, forecasting and alerting in daily operations of Rail Baltica.

Obtaining various types of weather information, forecasts and alerts, using original data obtained in the Rail Baltica infrastructure, incl. trains, through contracts with meteorological organisations and external service providers is an important sub-system of Rail Baltica.

A comprehensive range of services can comprise the following:

- High resolution weather forecast and live weather data.
- Regular weather reports and briefs on weather events;
- 24-hour availability of expert weather forecasters;
- Online monitoring in important and critical locations and at rail infrastructure elements;
- Flood forecasts.
- Early warnings that are triggered when forecast or live weather data increases the risk to vulnerable or critical assets.
- The system should be integrated to the other controlling systems, also available on a range of mobile and other devices to disseminate information and support the management of the operational response.

Rail Baltica should set own weather stations that provide local real-time information enables instant operational response, for example through better decisions on when to place speed restrictions in high wind conditions. The stations will also provide additional local observations that can be utilised within the national weather service's system.

Also, improving forecasting is needed to operate Rail Baltica as current 3 h radar and other forecasting methods to forecast heavy rainfall or thunderstorm in smaller grid at Rail Baltica routing as well improving the radar coverage so that it can predict the movement of heavy rain or thunderstorms more into future, as opposed to the three hours it can predict now. The more time there is to plan and prepare maintenance and repair actions, the better the efficiency.

Cooperation with third parties (National Weather Agencies, Road Administrators, Flight operators, etc) should be established to ensure effective use and sharing of weather data, and development of additional monitoring and prediction systems.

Integrating the Rail Baltica Weather Service with traffic control system should be considered.

Special maintenance inspections routine should be developed and used after extreme weather events (specify thresholds and conditions).

Incident data (incl. asset performance and asset degradation data) should be combined with meteorological data to able to determine cause-effect relations and develop risk management plans.

3. Weather Event Response

Management and operation code need weather resilience planning according to the following operating and altering statuses:

- Normal conditions
- Be aware
- Challenging weather
- Extreme weather

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Annex 1 – Glossary

The table blow provides a glossary of words, terms and acronyms used throughout the report.

Words term or acronym	Definition
Adaptation (climate change)	The term used to describe responses to the effects of climate change. The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.' Adaptation can also be thought of as learning how to live with the consequences of climate change.
Adaptive Capacity	The ability of a system to adjust to climate change(including climate variability and extremes),to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.
Baseline	The baseline (or reference) is any datum against which change is measured. It might be a "current baseline", in which case it represents observable, present-day conditions. It might also be a "future baseline", which is a projected future set of conditions excluding the driving factor of interest. Alternative interpretations of the reference conditions can give rise to multiple baselines.
Climate	Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.
Climate Change	IPCC defines climate change as '... any change in climate over time, whether due to natural variability or as a result of human activity.' The United Nations Framework Convention on Climate Change (UNFCCC) defines it specifically in relation to human influence, as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'.
Climate Model	A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHGs) and aerosols, generally derived using climate models.
Climate Projection	A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHGs) and aerosols, generally derived using climate models.
Exposure	The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

Words term or acronym	Definition
Extreme Weather Event	An extreme weather event is an event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations.
Flood	The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods and glacial lake outburst floods.
Hazard	The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts.
Impacts	The effects of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential and residual impacts. Potential impacts are all impacts that may occur given a projected climate, without considering adaptation. Residual impacts are the impacts that would occur after adaptation.
Intergovernmental Panel on Climate Change (IPCC)	The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change. The IPCC is an organization of governments that are members of the United Nations or WMO. The IPCC currently has 195 members. The IPCC provides regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation.
Mitigation	An anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhance greenhouse gas sinks.
Representative Concentration Pathways (RCPs)	Four RCPs (RCP2.6, RCP4.5, RCP6 and RCP8.5) were selected and defined by their total radiative forcing (cumulative measure of human emissions of GHGs from all sources expressed in W/m^2) pathway and level by 2100. The RCPs were chosen to represent a broad range of climate outcomes, based on a literature review, and are neither forecasts nor policy recommendations. Each RCP could result from different combinations of economic, technological, demographic, policy, and institutional futures. For example, the RCP4.5 could be considered as a moderate mitigation scenario and RCP8.5 as an extreme scenario.
Resilience	The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur.
Risk Management	The plans, actions or policies to reduce the likelihood and/or consequences of risks or to respond to consequences.

Words term or acronym	Definition
Sensitivity	The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g. a change in crop yield in response to a change in the temperature) or indirect (e.g. damages caused by more frequent coastal flooding due to rising sea levels).
Uncertainty	Uncertainty relates to a state of having limited knowledge which can result from a lack of information or over disagreement over what is known or even knowable. Uncertainty may arise from many sources, such as quantifiable errors in data, or uncertain projections of human behaviour. Uncertainty can be represented by quantitative measures or by qualitative statements.
Vulnerability	The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.