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Discussions on the final report of the Group of Experts

Implication for transport from climate variability and change[*]

Submitted by a consultant

I. Introduction

1. This document provides a brief summary information on implication for transport from climate variability and change. It should serve as introduction in the final report. The Group of Experts requested at its sixteenth session that this document is tabled as official document at the seventeenth session.

II. Implications for Transport: A short review

2. With regard to the sensitivity of transport networks to Climate Variability and Change (CV & C), a previous review (ECE, 2013) has found that: (a) transportation assets tend to be sensitive to both incremental changes in the mean of climatic factors and extreme events (e.g. heat waves, heavy downpours and high winds and extreme sea levels and waves); (b) maintenance, traffic conveyance and safety are generally more sensitive to climate forcing than physical assets, as thresholds for e.g. delaying/cancelling transport services are generally lower than those for damages to infrastructure and (c) transport assets

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are sensitive to stressors whose occurrence is relatively unlikely in comparison to typical weather variability. For example, the superstructure of the US Gulf Coast bridges proved to be vulnerable to loading from direct wave impacts due to the unprecedented coastal sea levels induced by the storm surge of the Katrina (2005) hurricane (USDOT, 2012).

3. Hydro-meteorological extremes, such as heavy rainfall/floods and droughts are already causing substantial damages to transport infrastructure and services. Extreme precipitation may result in river floods that might be costly for inland transport networks (Hooper and Chapman, 2012), as major roadways and railways are located within and/or crossing flood plains; they can also have significant effects on bus/coach stations, train terminal facilities and inland waterway operations. There can be direct damages during, and immediately after, a heavy precipitation event that require emergency response as well as measures to support the structural integrity and maintenance of roads, bridges, drainage systems, and tunnels (USDOT, 2012).

4. Road and railway networks are projected to face significant risks of flooding as well as bridge scouring, whereas the projected increases in downpours/floods will also cause more rain-related road accidents (due to vehicle and road damages and poor visibility), delays, and traffic disruptions (e.g. Hambly et al., 2012). Road networks are expected to be severely affected by the projected increases in heavy downpours and flooding, through diverse impacts on the different types of pavement, asphalt and concrete; these would require adaptive maintenance practices such as construction of adequate drainage and the use of permeable pavements and polymer modified binders (e.g. Willway et al., 2008). Regions where flooding is already common will face more frequent and severe problems. Standing flood waters could have severe impacts and high costs; for example, the costs due to long-term road submersion in Louisiana have been estimated as US$ 50 million for 200 miles of the state highways (Karl et al., 2009). In the United States of America (USA), adaptation costs for (road and rail) bridges vulnerable to river flooding have been estimated as $140 – $250 billion through the twenty-first century (Wright et al., 2012). For the European Union 27 cost estimations are lower: future costs for bridge protection against flooding have been estimated as up to € 0.54 billion per year (EC, 2012; ECE, 2015).

5. Railway infrastructure could be also impacted severely, with impacts including track and line side equipment failure, flood scours at bridges and embankments due to high river levels and culvert washouts, landslides, as well as problems associated with personnel safety and the accessibility of fleet and maintenance depots. In the UK, costs related to extreme precipitation/floods and other extreme events, which are already estimated as £ 50 million a year, might increase to up to £ 500 million a year by the 2040s (Rona, 2011). Extreme winds are also projected to be more catastrophic in the future (e.g. Rahmstorf, 2012), particularly at coastal areas where they can cause coastal defense overtopping and flooding of coastal/estuarine railways. Extreme winds could also cause infrastructure failures and service interruptions though wind-generated debris (e.g. (PIARC, 2012; ECE, 2013; 2015).

6. Increases in the frequency/duration of heat waves may also pose substantial challenges in the railway, road (and airport) operations and services, due to rail buckling, road pavement damages and necessary reductions on aircraft payloads. The projected increases in the number of days with temperatures above about 38 0C (Vogel et al., 2017) can lead to increasing road infrastructure failures. Drier and hotter summers will cause pavement deterioration and/or subsidence, affecting performance and resilience (PIARC, 2012). Model projections (EC, 2012) have estimated the additional annual costs for the upgrade of asphalt binder for the European Union 27 under the SRES scenario A1B[1] as €

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[1] This scenario is roughly equivalent to the IPCC AR5 scenario RCP6.0.

38.5–135 million in the period 2040 - 2070 and € 65-210 million in 2070 - 2100. Nevertheless, it should be noted that as road surfaces are typically replaced every 20 years, such climatic impacts could be considered at the time of replacement. It should be also noted that heat waves could affect very significantly the transport personnel, passengers and freight, particularly when combined with high relative humidity (Mora et al., 2017; Monioudi et al., 2018).

7. Arctic warming may lengthen the arctic shipping season and introduce new shipping routes. There may be new economic opportunities for Arctic communities, as reduced sea ice extent (SIE) can facilitate access to the substantial hydrocarbon deposits (at Beaufort and Chukchi Seas) and increase international trade. At the same time, Arctic warming will result in: (I) greater coastal erosion due to increased coastal wave activity (e.g. Lantuit and Pollard, 2008) and extreme sea levels (Vousdoukas et al., 2018) at the polar shorelines of Canada, the Russian Federation and the USA; and (ii) increasing costs in the development and maintenance of transport infrastructure due to thawing permafrost (ECE, 2015). Permafrost thawing (e.g. Streletskiy et al., 2012; Schuur et al. 2015) presents serious challenges for transportation, such as settling and/or frost heaves that can affect the road structural integrity and load-carrying capacity (ECE, 2013). In Arctic areas many highways are located in areas with already discontinuous, patchy permafrost, requiring substantial maintenance costs as well as usage restrictions (Karl et al., 2009). Such disruptions are projected to increase substantially under the predicted increases in the extent/depth of permafrost thaw (EEA, 2015a).

8. Inland waterways[2] can also be affected by both floods and droughts. Floods can have major impacts such as suspension of navigation, silting, changes in the river morphology and damage of banks and flood protection works (ECE, 2013). Inland waterways can also be affected by low water levels during droughts, which are considered a greater hazard for inland waterways than floods (Christodoulou and Demirel, 2018). A case study[3] on the Rhine–Main–Danube (RMD) corridor has found that average annual losses due to low water levels were about € 28 million over a period of 20 years (see also Jonkeren et al., 2007). Projections from different climate models, however, did not show significant impacts on the RMD corridor by low flow conditions until 2050; nevertheless, ‘dry’ years might lead to a 6 - 7 per cent increase in total transport costs compared to ″wet″ years.

9. Impacts of CV & C on the European transport systems were studied in some European projects.[4] It was found that there is a lack of reliable information relevant to the vulnerability of the different transport modes. Direct costs borne by the transport sector, such as those from infrastructure repair/maintenance and vehicle damage and increased operational costs, have been estimated for the period 1998 - 2010 as € 2.5 billion annually, and indirect costs from transport disruptions as €1 billion annually. Rail has been the most affected transport mode, with ‘hot spots’ in E. Europe and Scandinavia, whereas the effects on roads (mainly from weather related road accidents) have been found to be more evenly distributed.

10. Coastal transport infrastructure (coastal roads, railways, seaports and airports) will be dis-proportionally impacted by the CV & C as, in addition to the above challenges, they will have to adapt to increasing marine coastal flooding. A recent study focusing on climate

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[2] According to the TRANSTOOLS8 reference scenario, in 2005 approximately 293 million tons of freight were transported within the EU countries (excluding national trade) using IWWs, a tonnage slightly less than the tonnage transported by rail and about one third of tonnage hauled by road

[3] EU FP7-ECCONET Project, www.tmleuven.be/project/ecconet/home.htm

[4] The EU-FP7 WEATHER www.weather-project.eu and EWENT Projects (www.weather-project.eu/weather/inhalte/research-network/ewent.php).

risks for seaports and coastal airports in the Caribbean region has found a significant and increasing risk of marine coastal flooding as early as in the 2030s, which will require significant technical adaptation measures (Monioudi et. al., 2018). In the ECE region, mean SLR and increasing storm surges and waves, particularly along the NW Europe, the Baltic Sea and the NE Pacific coast the of US and Canada (e.g. Vousdoukas et al., 2016; 2018), may induce major impacts, including flooding of roads, rail lines and tunnels in coastal areas. Coastal inundation can render transportation systems unusable for the duration of the event and damage terminals, intermodal facilities, freight villages, storage areas and cargo and, thus, disrupt supply chains for longer periods (ECE, 2013; 2015). Pecherin et al. (2010) have estimated that 1 m increase in the extreme sea levels (ESLs) above the inundation level of the current 1-in 100 year-storm event[5], would result in damages and repair costs of up to € 2 billion for mainland French A-roads, excluding operational and connectivity costs.

11. Another study (EC, 2012) has provided an initial estimate of the future risk of the European coastal transport infrastructure due to mean sea level rise-SLR and storm surges on the basis of a comparison between the coastal infrastructure elevation and the combined level of 1 m mean SLR and the 100-year storm surge height; it was found that coastal transport infrastructure (e.g. coastal roads) at risk represents the 4.1 per cent of the total, with an asset value of about € 18.5 billion. As however, more detailed projections on future extreme sea levels-ESLs and coastal waves are starting to emerge (Vousdoukas et al., 2016; 2018; Camus et al., 2017) for the ECE region (and beyond), it is a worthwhile exercise to assess again the potential inundation impacts on the ECE coastal transport infrastructure under different CV & C scenarios.

12. A recent study focusing on ports (Christodoulou and Demirel, 2018) has found that 64 per cent of the European Union seaports could be inundated under the IPCC (2013) estimated SLR and the projected ESLs (e.g. Vousdoukas et al., 2018). Major impacts include disruptions of operations and damages of port infrastructure and vessels, whereas hinterland connections will also be affected. Seaports in Greece (169), the UK (165) and Denmark (90) will be the worst affected by 2080, when the number of European Union seaports facing the risk of inundation is expected to increase by 50per cent relative to 2030 (to 852 ports). This trend is particularly strong along the North Sea coast, where according to the GISCO database over 500 ports are located with traffic accounting for up to 15 per cent of the worlds cargo transport (EUCC-D, 2013). A recent global port industry survey carried out by United Nations Conference on Trade and Development (UNCTAD) has indicated, however, a lack of information and data required for effective adaptation and low levels of preparedness across global ports (Asariotis et al., 2017).

13. Finally, it should be noted that the transport industry is a demand-driven industry. Climate Variability and Change can have significant effects in, almost all, sectors of economy, and thus affect indirectly transport services through e.g. changes in commodity demand and tourism transportation (ECE, 2015).

14. Generally, it appears that the effects of extreme events on the coastal transportation infrastructure (and related supply chains) should be urgently assessed in more detail. It should be also noted that as the current trend in climatic research is to assess impacts in relation to temperature thresholds (e.g. IPCC, 2018), it would be very useful to understand/communicate the CV & C implications on the infrastructure and activities for given global temperature targets (Seneviratne et al., 2016).

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[5] Costs assumed in the study: average linear property cost at €10 million/km of road surface; repair costs at about €250 thousands/km)

Table 1

Summary table of CV & C impacts on transportation infrastructure and operations. Note: List is not exhaustive

Factor/hazard	*Impacts*		
	Road	*Rail*	*IWWs ports, and airports*
Temperature			
Higher mean temperatures; heat waves/droughts; changes in the numbers of warm and cool days	Thermal pavement loading and degradation; asphalt rutting; thermal damage of bridges; increased landslides in mountainous roads; asset lifetime reduction; increased needs for cooling (passenger and freight); shorter maintenance windows; increased construction and maintenance costs; potential changes in demand	Track buckling; infrastructure and rolling stock overheating/failure; slope failures; signalling problems; speed restrictions; asset lifetime reduction; higher needs for cooling; shorter maintenance windows; higher construction and /maintenance costs; demand changes	Damage to infrastructure, equipment and cargo; higher energy consumption for cooling; air transport payload restrictions and runway extensions required; potential reductions in snow/ice removal costs; extension of the construction season
Reduced snow cover and arctic land and sea ice; permafrost degradation and thawing	Road buckling; decreases in travelling days; slope instability and embankment failures; coastal erosion affecting coastal roads; problems for ice roads	Rail track damages; slope instability and embankment failures; freight and passenger restrictions	Damages in port and airport infrastructure; longer shipping seasons and shorter routes in the Arctic (NEP)- less fuel costs, but higher support service costs
Precipitation			
Changes in the mean values; changes in intensity and/or frequency of extremes (floods and draughts)	Inundation; increased landslides; slope, earthwork and equipment failures; impacts on vital nodes e.g. bridges; poor visibility that increases accidents; more frequent slush flows; delays; changes in demand	Submersion, bridge scouring; problems with drainage systems and tunnels; landslides; underground flooding; embankment and earthwork damages; operational problems; delays; changes in demand	Port infrastructure inundation; direct damage to cargo and equipment; under extreme low rainfalls, navigation restrictions in IWWs due to droughts/diminished river water levels
Windstorms			
Changes in frequency and intensity of events	Damages to fences; diminished road safety-road accidents	Damages to installations and catenary; overvoltage; disruption to operations	Problems in vessel navigation and berthing with ports; cancellations/delays at airports
Sea levels/storms			
Mean sea level rise (SLR)	Increased risks of permanent inundation/erosion of coastal roads	Bridge scour, installation and catenary damage at coastal assets	Infrastructure damages from inundation of coastal assets; increased costs of port protection; effects on key transit points (e.g. the Kiel Canal)
Increased extreme sea levels (ESLs); changes in wave energy and direction	Structural damages to coastal roads; temporary inundation rendering the roads unusable; delays/diversions of traffic	Structural damages to coastal railways, embankments and earthworks; restrictions and disruption of coastal train operations	Asset inundation; higher port construction/maintenance costs; navigation channel sedimentation; people/business relocation, insurance issues

III. References

Asariotis R., Mohos-Naray V., Benamara H., 2017. Port Industry Survey on Climate Change Impacts and Adaptation. UNCTAD Research Paper No. 18, UNCTAD/SER.RP/2017/18. 37 pp plus Appendices.

unctad.org/en/PublicationsLibrary/ser-rp-2017d18_en.pdf

Christodoulou A., Demirel H., 2018. Impacts of climate change on Transport. A focus on airports, seaports and inland waterways. EUR 28896 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-97039-9, doi:10.2760/378464, JRC108865,

EC, 2012. Impacts of Climate Change on Transport: A focus on road and rail transport infrastructures, (F. Nemry and H. Demirel), JRC Scientific and Policy Reports. Publications Office of the European Union, Luxembourg, ISBN 978-92-79-27037-6.

ECE, 2013. Climate Change Impacts and Adaptation for International Transport Networks, United Nations Economic Commission for Europe, New York and Geneva, 2013, 248 pp. www.unece.org/fileadmin/DAM/trans/main/wp5/publications/climate_change_2014.pdf

ECE, 2015. Transport for Sustainable Development: The case of Inland Transport. United Nations Economic Commission for Europe, Transport Trends and Economics Series ECE/TRANS/251. www.unece.org/fileadmin/DAM/trans/publications/Transport_for_Sustainable_Development_UNECE_2015.pdf

GISTEMP, 2016. NASA Goddard Institute for Space Studies - GISS Surface Temperature Analysis (GISTEMP). Available from: data.giss.nasa.gov/gistemp/.

Hambly, D., J. Andrey, B. Mills and C. Fletcher, 2012. Projected implications of climate change for road safety in Greater Vancouver, Canada. Climatic Change. (doi: 10.1007/s10584-012-0499-0.

Hooper, E. and L. Chapman, 2012. Chapter 5 - The Impacts of Climate Change on National Road and Rail Networks. In Transport and Climate Change, Transport and Sustainability, Vol. 2., T. Ryley and L. Chapman, eds., Emerald Group Publishing Ltd, pp. 105–136. Available from dx.doi.org/10.1108/S2044-9941(2012)0000002008

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2018: Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner et al. (eds.)]. World Meteorological Organization, Geneva, Switzerland 32 pp. www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_High_Res.pdf

Jonkeren O., P. Rietveldand J. van Ommeren, 2007. Climate Change and Inland Waterway Transport: Welfare effects of low water levels on the river Rhine. Journal of Transport Economics and Policy 41 (3), 387–411.

Karl, T.R., Melillo, J. T. and Peterson, T. C. 2009. Global Climate Change Impacts in the United States. Cambridge University Press, 189 pp.

Lantuit, H. and W.H. Pollard, 2008. Fifty years of coastal erosion and retrogressive thaw slump activity

Monioudi I., N., Asariotis R., Becker A. et al., 2018. Climate change impacts on critical international transportation assets of Caribbean Small Island Developing States (SIDS): The case of Jamaica and Saint Lucia. Regional Environmental Change, 18 (8), 2211–2225.

Mora, C., Dousset, B., Caldwell, I.R. et al., 2017. Global risk of deadly heat. Nature Climate Change 7, 501-507. DOI: 10.1038/NCLIMATE3322

NSIDC, 2012. Rapid sea ice retreat in June [WWW] National Snow & Ice Data Center. Available from: nsidc.org/arcticseaicenews/2012/07/rapid-sea-ice-retreat-in-june/ [accessed 15/02/2016]

Perherin, C., A. Roche, F. Pons, I. Roux, G. Desire, and C. Boura (2010). Vulnérabilité du territoire national aux risques littoraux. XIèmes Journées Nationales Génie Côtier – Génie Civil Les Sables d'Olonne, 22-25 June 2010. (doi: 10.5150/jngcgc.2010.072-P).

PIARC, 2012. Dealing with the effects of climate change on road pavements. World Road Association (PIARC) Technical Committee D.2 Road Pavements, 146 pp. (ISBN: 2-84060-247-4).

Rona, J., 2011. Climate Change Adaptation and Transport – UK and Rail. Presentation at the second session of the Group of Experts on Climate change impacts and adaptation for international transport networks, UNECE, Geneva, 8 November 2011.

Schuur EAG, McGuire A.D., Schädel C., et al., 2015. Climate change and the permafrost carbon feedback. Nature 520, 171–179. 10.1038/nature14338

Seneviratne S. I., et al., 2016. Allowable CO2 emissions based on regional and impact-related climate targets. Nature 529, 477–483. doi:10.1038/nature16542.

Streletskiy D.A., N.I. Shiklomanov and F.E. Nelson (2012). Spatial variability of permafrost active-layer thickness under contemporary and projected climate in Northern Alaska. Polar Geography 35 (2) 95-116.

USDOT, 2012. Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: The Gulf Coast Study, Phase II. A report by the US Department of Transportation, Center for Climate Change and Environmental Forecasting [Choate A, W Jaglom, R Miller, B Rodehorst, P Schultz and C Snow (eds.)]. Department of Transportation, Washington, DC, USA, 470 pp.

Vogel M.M., Orth R., Cheruy F. et al., 2017. Regional amplification of projected changes in extreme temperatures strongly controlled by soil moisture temperature feedbacks. Geophys. Res. Letters, 44, 1511–1519. doi:10.1002/ 2016GL071235.

Vousdoukas M.I., Voukouvalas E., Annunziato A., Giardino A. and Feyen, L., 2016a. Projections of extreme storm surge levels along Europe. Climate Dynamics doi: 10.1007/s00382-016-3019-5.

Vousdoukas M.I., Mentaschi L., Voukouvalas E., Verlaan M., Jevrejeva S., Jackson L.P., Feyen L., 2018. Global probabilistic projections of extreme sea levels show intensification of coastal flood hazard. Nat. Commun. 9, 2360. doi.org/10.1038/s41467-018-04692-w.

Willway, T., Baldachin L., Reeves S. et al., 2008. The effects of climate change on highway pavements and how to minimise them: Technical report. PPR184, TRL Limited. ISBN 978-1-84608-734-9. United Kingdom

Wright L., Chinowsky P., Strzepek K. et al., 2012. Estimated effects of climate change on flood vulnerability of U.S. bridges. Mitigation and Adaptation Strategies for Global Change 17, 939-955 (doi: 10.1007/s11027-011-9354-2).