Impacts of climate change in Europe: A focus on road and rail transport infrastructures

Group of Experts on Climate Change impacts and adaptation for international transport networks - Fourth session

Geneva, 9 October 2012

Françoise Nemry

Joint Research Centre
The European Commission's in-house science service
One Directorate-General of the European Commission

7 institutes in 5 countries: Italy, Belgium, Germany, The Netherlands, Spain

**Mission:** to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies.

Unit on Economics of Climate Change, Energy and Transport
A JRC/IPTS research on transport and climate changes
Overview of future impacts for transport
Research focus
Vulnerability and cost assessment method
Current weather associated costs
Adaptation and future vulnerability:
  - Bridge scour
  - Rail buckling risk
  - Road pavement
  - Vulnerability to sea level rise
Indicative EU27-wide costs
Discussion
A JRC/IPTS research on transport and climate changes

JRC PESETAII project to analyse and quantify the future impacts and costs of climate changes on:

- Biophysical and sectoral impacts: agriculture, health, energy, river floods, forestry, energy, transport: future costs and adaptation
- EU economy as a whole (GEM-E3 macroeconomic model)

Scientific support to EU policy making on adaptation to climate change

Summary report on PESETAII in preparation

Detailed report on Transport study: F. Nemry and H. Demirel, 2012
<table>
<thead>
<tr>
<th>Climate Impact</th>
<th>Overview of Potential Impact on Transport System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased Summer Temperatures</td>
<td>Asphalt rutting, rail track buckling, Low river water levels for navigation, Thermal expansion of bridges, Overheating of diesel engine</td>
</tr>
<tr>
<td>Increased Winter Temperatures</td>
<td>Reduction in cold weather rail maintenance, Changed construction seasons</td>
</tr>
<tr>
<td>Increased Precipitation and floodings</td>
<td>Flooding of land transport infrastructures, Wet pavements and safety risks, Embankment disruption, Bridge scour, Flooding of underground transit systems, More frequent slushflow avalanches, Landslides and associated risks.</td>
</tr>
<tr>
<td>Increased and more frequent extreme winds</td>
<td>Damage and safety issue on roads, railways, pipelines, seaports, airports, Bridges, signs, overhead cables, railroad signals, tall structures at risk, Disturbance to transport electronic infrastructures, signaling, etc</td>
</tr>
<tr>
<td>Sea Level Rise and sea storm surges</td>
<td>Erosion of coastal highways, Higher tides at ports/harbor facilities, Low level aviation infrastructure at risk, Regular and permanent inundation, Corrosion, Bridge scour</td>
</tr>
<tr>
<td>Permafrost degradation and thawing</td>
<td>Road, rail, airport, pipeline embankments failures</td>
</tr>
<tr>
<td>Reduced Arctic Ice Cover</td>
<td>New northern shipping routes (summer), Reduced ice loading on structures, such as bridges or piers</td>
</tr>
<tr>
<td>Earlier River Ice Breakup</td>
<td>Ice-jam flooding risk</td>
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</tbody>
</table>
**Research focus**

**Focus on** road and rail transport infrastructures and assess:

1. Possible future trends in weather-induced deterioration and damages
2. Adaptation and vulnerability case studies

<table>
<thead>
<tr>
<th>Mode</th>
<th>Typical infrastructure life</th>
<th>Climate stressor</th>
<th>Adaptation measure</th>
<th>Avoided impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>road</td>
<td>7-10 years maintenance cycle</td>
<td>Heat</td>
<td>changing asphalt binder</td>
<td>- reduce road pavement degradation (road cracking) &lt;br&gt;- avoid accidents (vehicle damages, fatalities)</td>
</tr>
<tr>
<td>rail</td>
<td>50-100 years track life</td>
<td>Heat</td>
<td>speed limitations changing track conditions</td>
<td>- reduce rail track buckling damage &lt;br&gt;- avoid accidents (vehicle damages, injuries, fatalities)</td>
</tr>
<tr>
<td>road</td>
<td>&gt; 100 yr life</td>
<td>High river discharge</td>
<td>- rip rap, - strenghtening of bridge foundations with concrete</td>
<td>- mitigate bridges scour risk &lt;br&gt;- accidents, fatalities</td>
</tr>
<tr>
<td>road</td>
<td>&gt; 100 yr life</td>
<td>Sea level rise and sea storm surges (vulnerability of land transport network to permanent or episodic inundation)</td>
<td>(vulnerability of land transport network to permanent or episodic inundation)</td>
<td>-</td>
</tr>
</tbody>
</table>
Assessment method

Assessing future exposure to future climate stressor:

- IPCC A1B scenario, by 2040-2070 and 2070-2100 (also E1 and RCP8.5)
- FP7 ENSEMBLE: high resolution projected climate variable (T, p,…) – 25 km*25 km

<table>
<thead>
<tr>
<th>Global emission scenario</th>
<th>Abbreviation</th>
<th>Scenario</th>
<th>Institute</th>
<th>Regional climate model</th>
<th>Driving GCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1B</td>
<td>A1B-KNMI</td>
<td>A1B-KNMI-RACMO2-ECHAM5</td>
<td>KNMI</td>
<td>RACMO2</td>
<td>ECHAM5</td>
</tr>
<tr>
<td>A1B-METO</td>
<td>A1B-METO-HadRM3Q0-HadCM3Q0</td>
<td>METO</td>
<td></td>
<td>HadRM3Q0</td>
<td>HadCM3Q0</td>
</tr>
<tr>
<td>A1B-DMI</td>
<td>A1B-DMI-HIRHAM5-ECHAM5</td>
<td>DMI</td>
<td></td>
<td>HIRHAM5</td>
<td>ECHAM5</td>
</tr>
</tbody>
</table>

Engineer-based **technico-economic** analysis applied on combined geographical information:

- **Climate data and derived climate stress factors** for each assessed problem (e.g. rail track temperature, pavement temperature, extreme precipitations and thresholds…)
- **Transport** information for EU27 (transport network, transport activity): TRANSTOOLS, TELEATLAS, GISCO
- **Digital elevation model** (e.g. sea level rise)
- **Coastal information** (e.g. sea storm heights – DIVA database)
- **Hydrological data** (JRC/IES)
- **Engineering data sources**: EU data sources and US data sources (FHWA, EPA,..)
Climate resilience costs component in current construction designs

Weather-induced contribution to maintenance & repair costs:
~30%-50% of EU27 road maintenance costs
~10 billion €/yr

Of which extreme weather induced damages (FP7 WEATHER):
~1.8 billion €/yr for road transport (80% of all transport)
~0.9 billion €/yr for road infrastructures
~0.65 billion €/yr due to heavy rainfalls & floods

=> How will these cost change with climate change?
Future vulnerability – Road pavement degradation

Average precipitation (road rutting): extra 100 mm annually results in enhanced deterioration of road pavements

⇒ climate models do project such changes only in limited areas (to be assessed in a detailed study)

Summer conditions (road cracking):

⇒ need to adapt asphalt

Winter conditions: cracking and potholes (joint effect of deep frost and thaw-freezing cycle effects, also function of precipitation – FHWA, 2008)

⇒ ~-500 to -170 million €/yr

Change in Freezing days
(by 2070-2100 compared with 1990-2010, A1B- KNMI scenario)
1. **River floods**: Rainfall over an extended period and an extended area can cause major rivers to overflow their banks. Downstream areas may be affected, even when they didn’t receive much rain themselves => ~5-10% of total rainfall related impacts

2. **Prolonged intense rainfalls** (7-days heavy precipitation) : e.g. road, rail embankment

3. **Extreme precipitations** (>50 mm/day) and possibly induced flash floods or urban floods
   - **flash floods** in areas with steep slopes, where heavy rain water flows downhill gathering speed and all the water comes together in the river bed
   - **urban floods** : lack of drainage in an urban area

<table>
<thead>
<tr>
<th>Trigger Point</th>
<th>Consequences</th>
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</thead>
<tbody>
<tr>
<td>&gt;50 mm/24h</td>
<td>Flooded roads, reduced pavement fraction</td>
</tr>
<tr>
<td>&gt;100 mm/24h</td>
<td>- Sewer system fills up&lt;br&gt; - Water rises up the streets from manholes&lt;br&gt; - Rainwater fills the streets and overflows streets&lt;br&gt; - Drainage may be overloaded&lt;br&gt; - Causes decreased traffic&lt;br&gt; - Reduced visibility, flooded streets</td>
</tr>
<tr>
<td>&gt;150 mm/24h</td>
<td>- Roads may be washed out&lt;br&gt; - Bridges may be flooded&lt;br&gt; - Vehicles may be damaged&lt;br&gt; - Roads may be covered by water or transported debris</td>
</tr>
<tr>
<td>&gt;200 mm/24h</td>
<td>Landslide risk in mountainous regions</td>
</tr>
</tbody>
</table>
Future changes in intense precipitation
(2070-2100 compared with 1990-2010 - A1B-KNMI scenario)

Frequency of extreme precipitation

Maximum 7-day precipitation

Costs to increase from 630 million €/yr today to 712-832 million €/yr (+10% - 30%)
The problem: road cracking

Adaptation: modify the asphalt binder

(more costly: ~6000 to 10000 €/km lane for every 4 degree temperature increment)

Remark:

changes in asphalt also dictated by milder winter conditions (-), changing precipitation regimes (+).
Adaptation: Road pavement

Change in average maximum 7-day pavement temperature (2070-2100 compared with 1990-2010)

~ 52 – 180 million €/yr extra costs over 2040-2100
The problem:

Large lateral misalignments in continuous welded rail (CWR) under heat driven compressive forces, especially on tangent and curved tracks.

=> derailment risk (severe events in UK (2003), US, Australia)

Rail tracks anchored under a "stress-free" temperature (SFT; ~23 – 27 C over EU27).
Stress-free temperature reduced as a result of after winter season repairing operations, traffic load, weak track conditions (inadequate ballast e.g. missing ballast, deficient ties).

Adaptation measures involve

* Temperature monitoring and speed limits to prevent buckling and derailment risk (critical temperatures)
* Changing stress free temperature (but constraints by inter-season variability)
* Adjusting maintenance and de-stressing regime
Adaptation : Rail track buckling

Extra number of days per year with speed restriction in case of “inadequate ballast”

<5% tracks under “inadequate ballast condition, short distance trip lines, speed limits from ~12:00 – 20:00
=> affecting ~<2% of km trips affected during the estimated number of days

Current delays: ~0.012% trip time under free speed flow conditions;
Possibly doubling in the future; +25-48 million €/yr;
Only 50% if changed SFT (but what about feasibility and cost?)
**Adaptation**: Bridge scour

**The problem:**

Bridge scour: removal of river bed sediment from around bridge abutments or piers, potentially scooping out scour holes, and compromising the integrity of the structure.

Water normally flows faster around piers and abutments making them susceptible to local scour. Enhanced in case of high river flow discharge.

60% of all bridge failures result from scour and other hydraulic related causes.

**United States**: 46 of 86 major bridge failures resulted from scour near piers from 1961 to 1976. Bridge collapse over the River Towy, Wales (UK) in Oct. 1987 resulted in 4 deaths

**Adaptation:**

- **Riprap**: placing large blocks at the base of the bridge piers
- **Concrete reinforcement** of foundation: Beyond water velocities of 12 and 10 km/h for sand and non sandy material respectively
Adaptation: Bridge scour

Bridges exposed to a 100-yr return period river peak discharge as % of historical period (A1B-KNMI)

2040-2070 and 2070-2100

~20% of bridges vulnerable

325–475 million €/yr (2040-2100)
The problem

How much transport infrastructure at risk of permanent (1 meter sea level rise) or episodic inundation (sea storm surges) by 2010

Vermeer and Rahmstorf, 2009
Inundation map
Areas at risk of permanent or temporary inundation (example in Portugal)

a) baseline scenario
b) 1 m sea level rise
c) 1 m sea level rise and 100-yr sea storm

~4% coastal infrastructure (in a 10 km coastal band) at risk of permanent or episodic inundation,

Triple in low lying zones

~18 billion € asset under risk at EU27 level
## Indicative EU27-wide costs

### Road infrastructures

#### Estimated costs:

<table>
<thead>
<tr>
<th></th>
<th>Current costs</th>
<th>Future costs changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>million €/yr</td>
<td>% MC</td>
</tr>
<tr>
<td>Damages and deterioration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather-induced wear&amp;tear</td>
<td>10 405</td>
<td>40.0%</td>
</tr>
<tr>
<td>Extreme weather damage costs</td>
<td>145</td>
<td>0.6%</td>
</tr>
<tr>
<td>Adaptation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>River bridges scour protection</td>
<td>322</td>
<td>0.6%</td>
</tr>
<tr>
<td>Road pavement (asphalt binder)</td>
<td>116</td>
<td>0.4%</td>
</tr>
<tr>
<td>Other measures (slope protection, infrastructure elevation,…)</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Total estimated costs</td>
<td>10 405</td>
<td>242</td>
</tr>
<tr>
<td>avoided cost (bridge scour)</td>
<td>-1 185</td>
<td>-4.6%</td>
</tr>
</tbody>
</table>

### Road infrastructure at risk of future SLR and sea storm surges

18 460

Other adaptation measures: ?

Other transport modes, components?
Discussion

**Current and future weather-induced damage costs**

Still fragmented costs estimates for transport infrastructure and operation

Unaccounted indirect impacts (propagation of through the economy in case of severe traffic disruption)

Weather together with other important stressors (e.g. growing traffic load, rail bridges)

EU-wide and, even country-wide costs masking regional and local disparity

High uncertainty in climate models => high uncertainty about adaptation needs and costs

**Adaptation**

Short to long infrastructure life versus uncertain future climate changes

=> short life maintenance cycle (e.g. pavement): gradual and iterative adaptation

=> long-life infrastructures: one-off adaptation or adaptative management strategy (e.g. sea port infrastructure elevation)

Changing maintenance practices

Engineering design standards (revision as a long process; public / private / EU initiative?)

Regional impacts and planning and EU-wide transfer of experience (e.g. rail buckling)

Case-by-case assessment

First insight that avoided costs significantly higher than adaptation costs
Research efforts to be continued

Notably in relation with abrupt climate changes:

Sea Ports: sea level and sea storm surges
(and possibly changing storm tracks)

Opening of the Arctic maritime road

New infrastructure designs (guidelines)
Traffic disruption and impacts on the whole economy

International cooperation
Thank You!

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TRANSTOOLS

Extreme weather event

- Need for emergency services
- Sub-optimal rescue operations

Transport infrastructure damaged or temporarily impassable

Closure and traffic deviation

Non closure but reduced capacity

Time cost change
- Fuel cost
- Labour cost

Alternative way (same mode)

Alternative mode

Trip postponed

Delayed supply to manufacture industry

Delayed supply to retail sector

Possible loss for transport user (tickets, accommodation, ...)

Gains or losses for some sectors (e.g., hotels, travel agencies, ...)

Trip canceled
Climate zones:

- Scandinavia (SC)
- Middle Europe (ME)
- Mediterranea (MD)
- Iberian Peninsula (IP)
- France (FR)
- Eastern Europe (EA)
- British Isles (BI)
- Alpines Regions (AL)
Current vulnerability to heavy precipitation

Annual precipitation (mm)

Heavy precipitation (nb days with p>50mm)

Prolonged intense precipitation: max 7-day precipitation (mm)

1990-2010, A1B-KNMI
Winter conditions \textit{(current costs: 248 million €/yr)}

Changes by 2070-2100 compared with 1990-2010 (Freezing Day Index - FDI)
### Methodology, data, assumptions

<table>
<thead>
<tr>
<th>parameter</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement grade performance as a function of 7-day maximum pavement temperature</td>
<td>based on Superpave (US), similar in Europe</td>
</tr>
<tr>
<td>Cost for asphalt binder per performance class</td>
<td>based on Superpave (US), similar in Europe</td>
</tr>
<tr>
<td>average maximum 7-day temperature</td>
<td>scenarios DMI, KNMI, METO</td>
</tr>
<tr>
<td>road infrastructure (motorways)</td>
<td>NUTS3 resolution</td>
</tr>
</tbody>
</table>

#### Remark:

**Following approach implemented by EPA**
## Adaptation: Rail track buckling

<table>
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</thead>
<tbody>
<tr>
<td>Stress Free temperature per country</td>
<td>~ available for 10 countries others: SFT~3/4 Tmax</td>
</tr>
<tr>
<td>Critical temperature for speed limits CRT70 ~ SFT + 2 degrees CRT30 ~ SFT + 13 degrees</td>
<td>only for &quot;inadequate ballast&quot; (VOLPE)</td>
</tr>
<tr>
<td>relation ambiant temperature and track temperature</td>
<td>Ttrack ~ 3/2 Tambiant</td>
</tr>
<tr>
<td>dayly maximum temperatures</td>
<td>scenarios DMI, KNMI, METO</td>
</tr>
<tr>
<td>number of days with Tmax &gt; critical levels</td>
<td></td>
</tr>
<tr>
<td>transport activity (pkm / tkm) long distance vs short distance free flow speeds value of time (euro/hour delay per passenger and per ton)</td>
<td>NUTS3 resolution NUTS3 resolution ~ 8 euros/hour<em>pass ~ 1 euros/hour</em>ton</td>
</tr>
</tbody>
</table>
Adaptation : Bridge scour

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<tbody>
<tr>
<td>Stock of river passing bridges (rail, main roads) and geographical location</td>
<td>Very fragmented data on stock (COST project, partial)</td>
</tr>
<tr>
<td>GIS based method to infer stock (roads, rail lines (TELEATLAS) crossing main rivers (GISCO))</td>
<td></td>
</tr>
<tr>
<td>Characterization of bridges</td>
<td>Inexistent data per bridge available for Europe (contrary to US : NBI database (e.g. physical conditions on substructure, water flow and channel, waterway opening, vulnerability to scour).</td>
</tr>
<tr>
<td>=&gt; assumed average deficiency factor assumed to be comparable to US (~27% bridges)</td>
<td></td>
</tr>
<tr>
<td>costs data (rip rap, concrete reinforcement)</td>
<td>same assumptions as EPA study</td>
</tr>
<tr>
<td>river bed material (sand vs other)</td>
<td>European Soil Database (ESDB)</td>
</tr>
<tr>
<td>Hyrdological variable</td>
<td>river discharge peak flows</td>
</tr>
<tr>
<td>scenarios KNMI as produced by IES (River Flood study)</td>
<td></td>
</tr>
</tbody>
</table>

Key assumptions (similar to EPA) :

- Under less than 20% change in 100-yr return peak flow by the beginning of the period, the initial bridge design is still adequate and no measure is needed.

- Under changes higher than 20%, measures are required to prevent bridge scour and this depends on the river bed material:
  - Riprap is the first adaptation measure and it is adequate up to a certain flow change (60% and 100% change for non sandy and sandy soils respectively).
  - Beyond these thresholds, the foundation needs to be reinforced with concrete.
Methodology, data, assumptions

Digital Elevation Model (DEM): Shuttle Radar Topography Mission (SRTM) data from NASA (USA). 90 m horizontal resolution. Not available for Finland (GTOPO30 global Digital Elevation Model was applied).

Sea storm surge: Dynamic Interactive Vulnerability Assessment (DIVA) database. Surge heights for several return periods (1, 10, 100, 1000 yr).

Transport infrastructure:
- Road infrastructures: Teleatlas
Methodology, data, assumptions

1 meter SLR individually or combined with sea storm surge height (e.g. 100-yr return) => Two new water levels

“Bucket fill” approach projects the new water height inland and inundates all land areas at an elevation below this level.

The two types of areas at risk of (permanent or temporary inundation) are then overlaid with the transport network infrastructure, to identify the linear distance in kilometers affected within each scenario (also airports, runways and port areas)

Caveats:

Data inaccuracy (protections, infrastructure elevation)
Bucket fill approach versus a more realistic approach (hydraulic processes, water pathway)

=> less accurate for low lying zones
=> first rough assessment to be followed by much more detailed analysis (LIDAR data, water pathway approach)