



# European Transport Research results on Climate Adaptation issues

**ETRA Workshop on Climate Change - "European Researchers Act"**

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# Climate Change Definition(s)

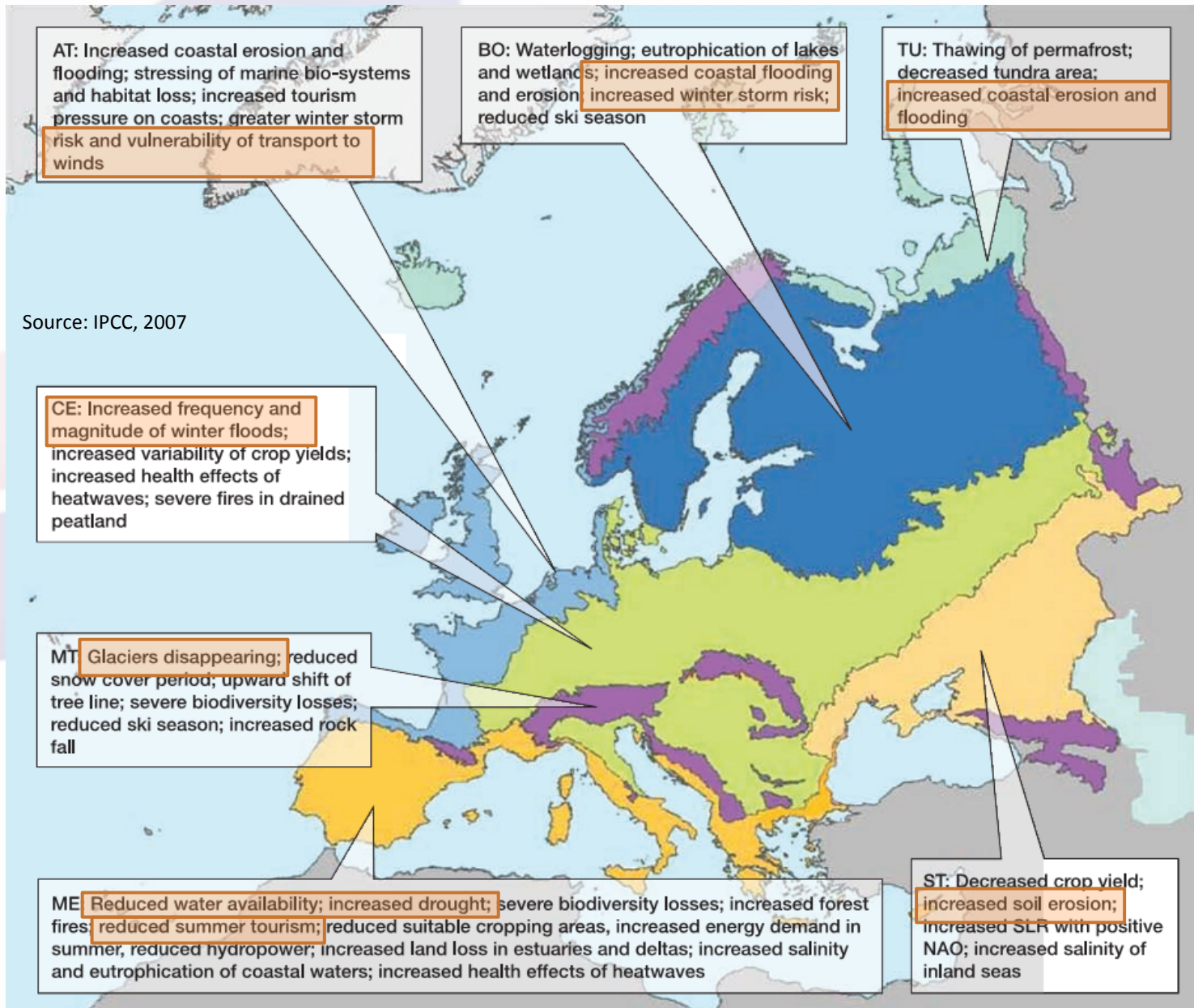
## Intergovernmental Panel on Climate Change (IPCC):

- A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.
- It refers to any change in climate over time, whether due to natural variability or as a result of human activity.

## United Nations Framework Convention on Climate Change (UNFCCC):

- 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.

# Impacts of Climate Change



# Impacts on Transportation

- “Climate change will affect transportation primarily through increases in several types of weather and climate extremes... very hot days; intense precipitation events; intense hurricanes; drought; and rising sea levels, coupled with storm surges and land subsidence.”
- “The impacts .... will be widespread and costly in both human and economic terms and will require significant changes in the planning, design, construction, operation, and maintenance of transportation systems.”

# Impacts on Transportation

Damage caused by severe rain and flooding in Maryland, US



Source: USDOT, 2006



Source: Chery A. Meyer, 2006

Flooded areas, Russia



Source: Lenkin, 2013

Extreme snow, UK



Source: Gowthorpe, 2013

# Impacts on Transportation

Superstorm Sandy, New Jersey, 2012



# How to address Climate Change

- Mitigation: Policies and strategies that reduce GHG emissions and/or enhance Greenhouse Gas absorption and storage – GHG “sinks” (IPCC, 2007)
- Adaptation: Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects (IPCC, 2007)
- Confronting Climate Change: Avoiding the unmanageable (mitigation) and managing the unavoidable (adaptation) (UN report, 2007)

# Adaptation

Adaptation means

*... anticipating the adverse effects of climate change and taking appropriate action to prevent or minimise the damage they can cause, or taking advantage of opportunities that may arise...*



# (Indicative set of) Adaptation policies in EU countries

Country	Policy action
Austria	Identification of recommendations for actions to adopt to the climate change in Austria (2008). Federal Ministry of Agriculture, Forestry, Environment and Water Management
Belgium	National Climate Plan (2007). Centre for Economic and Social Studies on the Environment.
Finland	National Strategy for Adaptation to Climate Change (2005). Finish Environmental Authority.
France	National plan for Adaptation Climate Change (2011). Ministry of Ecology, Sustainable Development, Transport and Housing.
Germany	German Strategy for Adaptation to Climate Change (2008). Federal Environment Agency.
Greece	The environmental, economic and social impacts of climate change in Greece (2011). Bank of Greece.
Ireland	Irish National Climate Change Strategy (2007). Environmental Protection Agency.

# EU level strategies



The EU Strategy on adaptation to climate change (2013), European Commission.


Adapting infrastructure to climate change, Commission staff working document (2013), European Commission.

The Covenant of Mayors Initiative on Climate Change Adaptation

The European Climate Adaptation Platform: Climate-ADAPT

EU Civil Protection Mechanism

European Program for Critical Infrastructure Protection: EPCIP



# Tools for addressing climate change and transportation (developed within EU research and innovation projects)

- **Management Tools:**
  - Identification of critical infrastructure
  - Substitutability of modes during Extreme Weather Events
  - Quantification of Extreme Weather Events' impacts
- **Policy tools:**
  - Linking climate change impacts with optimal adaptation strategies
  - Roadmaps towards reduced vulnerability of the transport system (& integration into Decision Support Systems)

# EU research projects

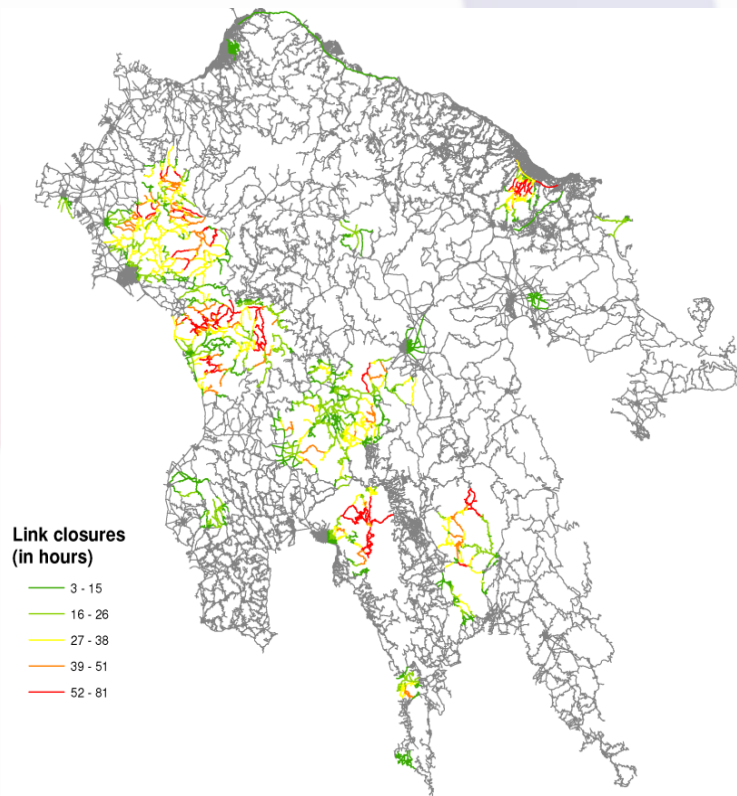
- WEATHER project (FP7):
  - Weather Extremes: Impacts on Transport Systems and Hazards for European Regions
  - info at: <http://weather-project.eu>
- MOWE-IT project (FP7):
  - Management of Weather Events in the Transport System
  - info at: <http://mowe-it.eu>
- RAIN-EX project (CIPS):
  - Risk based approach for the Protection of Land Transport Infrastructures against Extreme Rainfall
  - info at: <http://rainex-project.eu>
- DECIDE (INTERREG):
  - Decision Support System for Disaster Emergency Management

# Identification of Critical Infrastructure

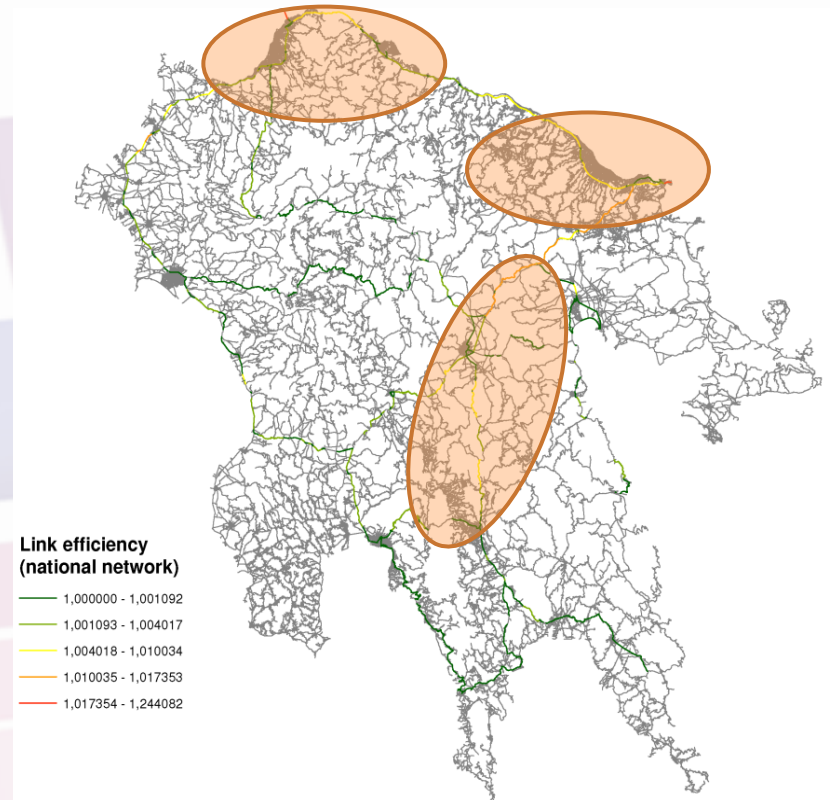
- Which infrastructure and transport network components are most critical (and must thusly remain operating under CC related EWE)?
- Nagurney and Qiang (2008) propose a methodology for calculating criticality of network links, using the total demand of the network and the difference in the travel time as consequence of the closure of a link

# Identification of Critical Infrastructure

- Application on the Peloponnese 2007 wildfires



Closed network links during the 2007 wildfires

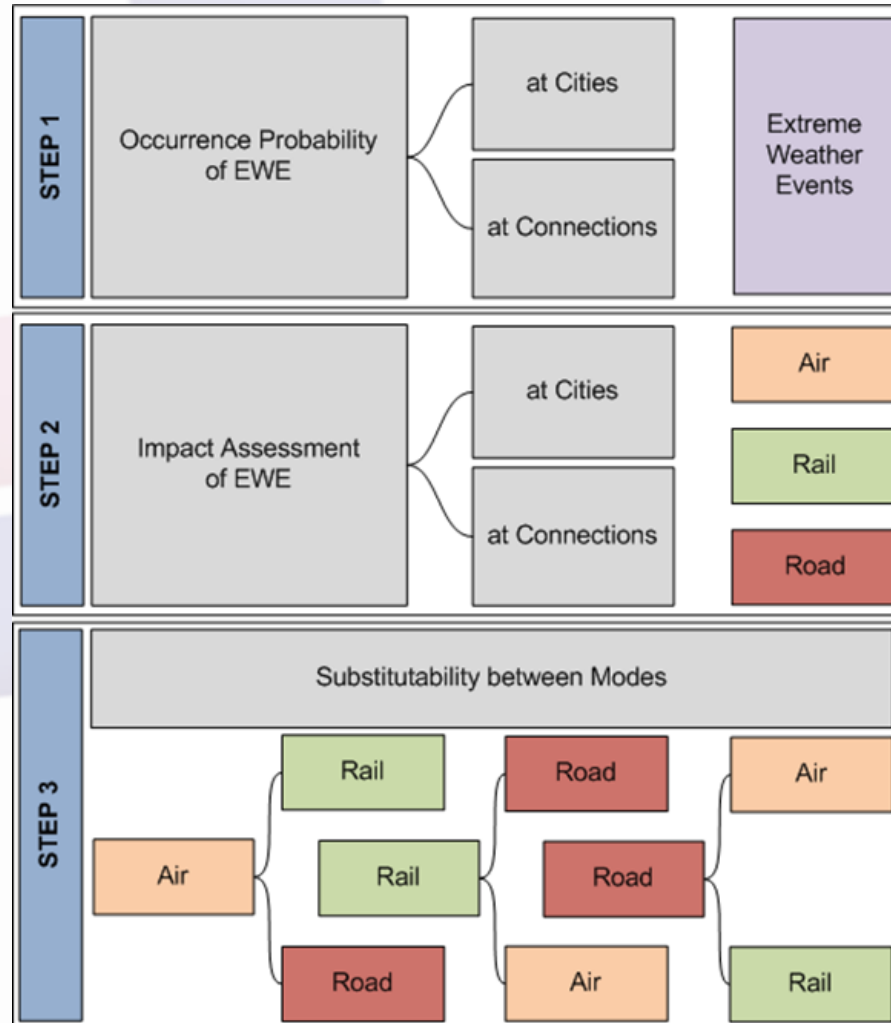


National network - Critical links

# Substitutability of modes during Extreme Weather Events

- Networks of all transport modes are rendered vulnerable, their operation and functionality is hindered
- Which are the substitutability opportunities between transport modes in case of CC related EWE?
- Need for a methodology to
  - estimate the impacts of EWE both at cities' level as well as their in-between connections
  - able to capture also the combined effects of simultaneous events occurring at different locations of a transportation network

# Substitutability of modes during Extreme Weather Events

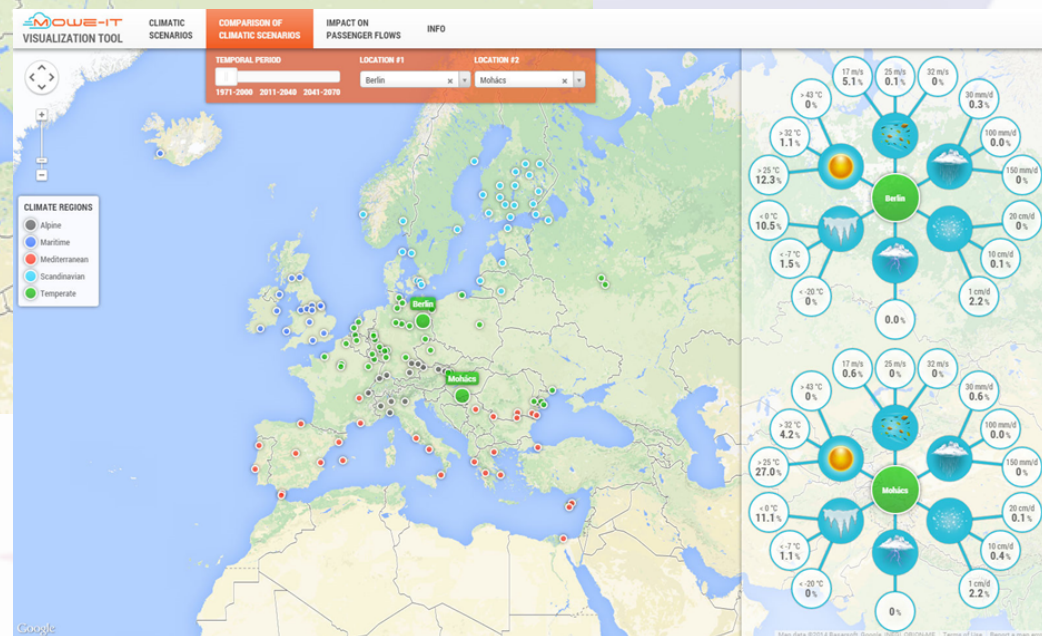
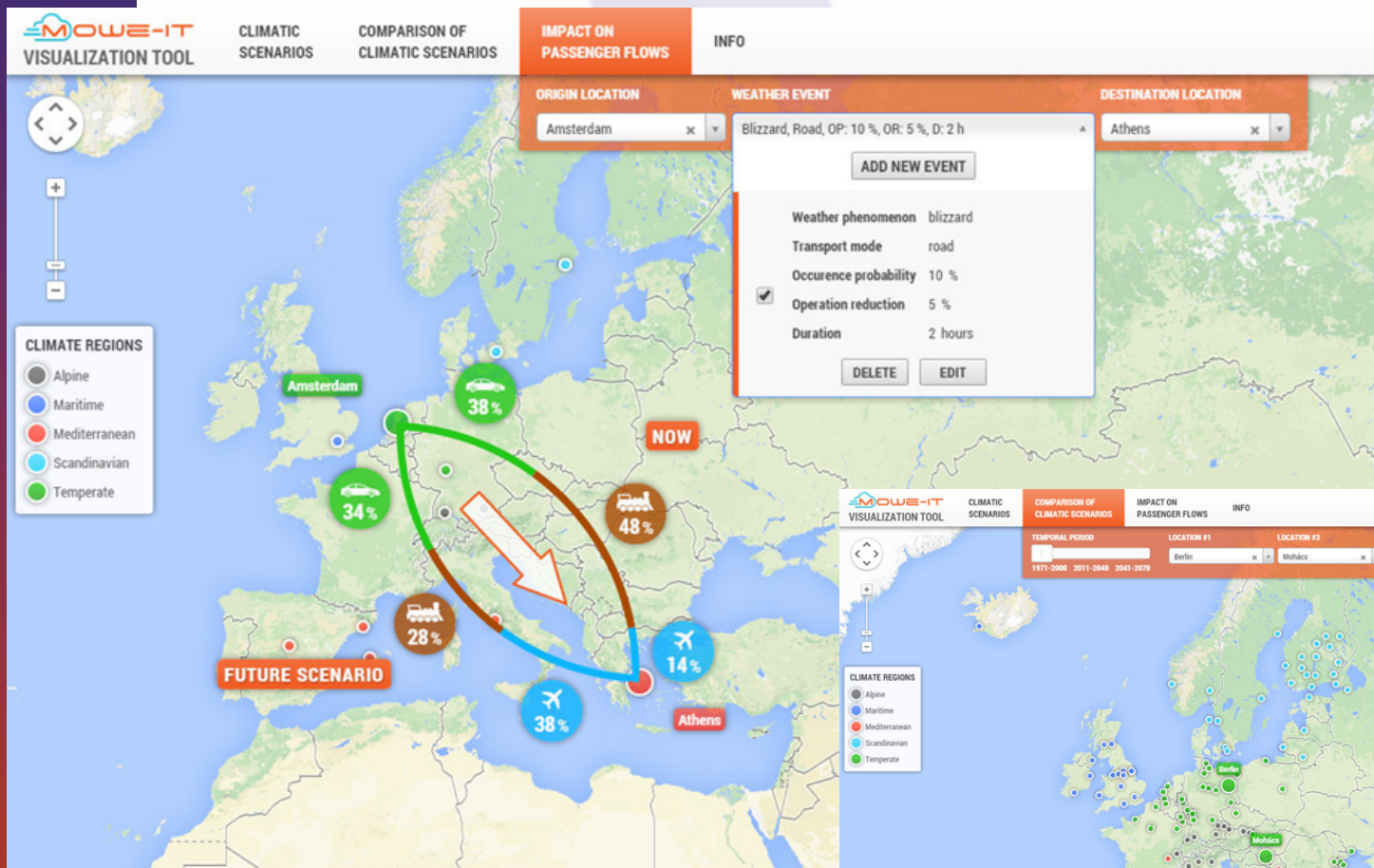




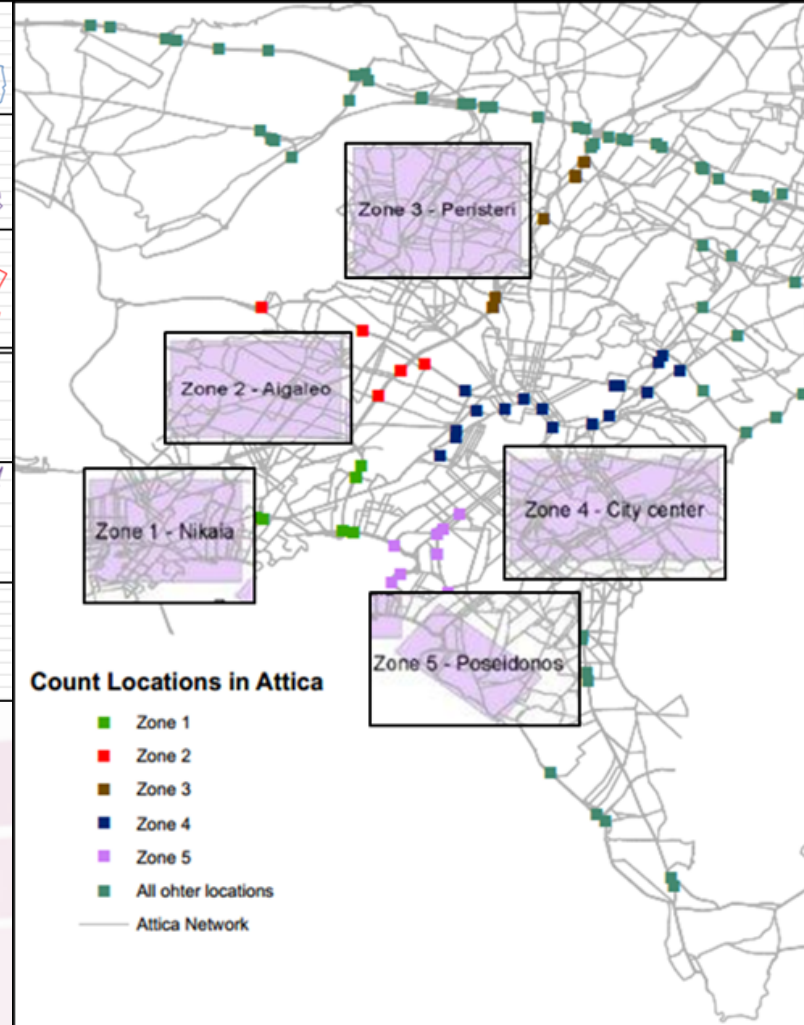
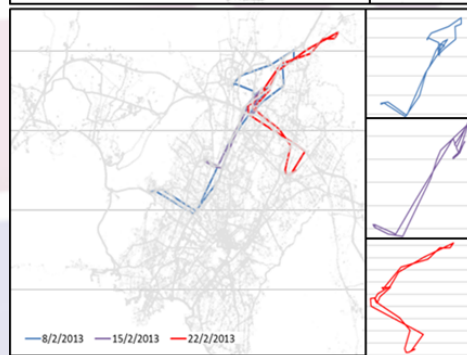
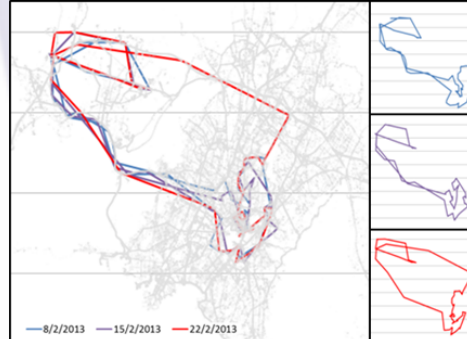
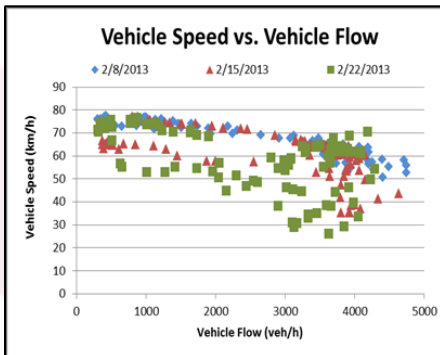
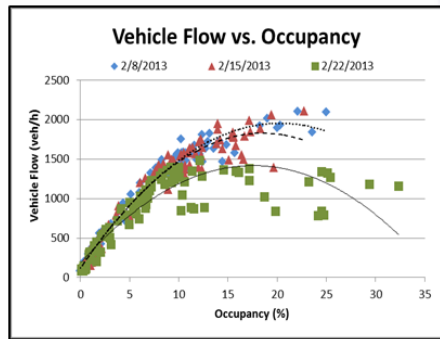
# Substitutability of modes during Extreme Weather Events

- The methodology does not only capture isolated events, but also combined effects of simultaneous events occurring at different locations within a transportation network
- The approach can account for the estimation of the impacts of EWE both at and in-between cities' connections
- The methodology can be used as a Decision Support Tool for policy makers and planning authorities, for assessing the resilience of passenger transportation networks.

# Substitutability of modes during Extreme Weather Events

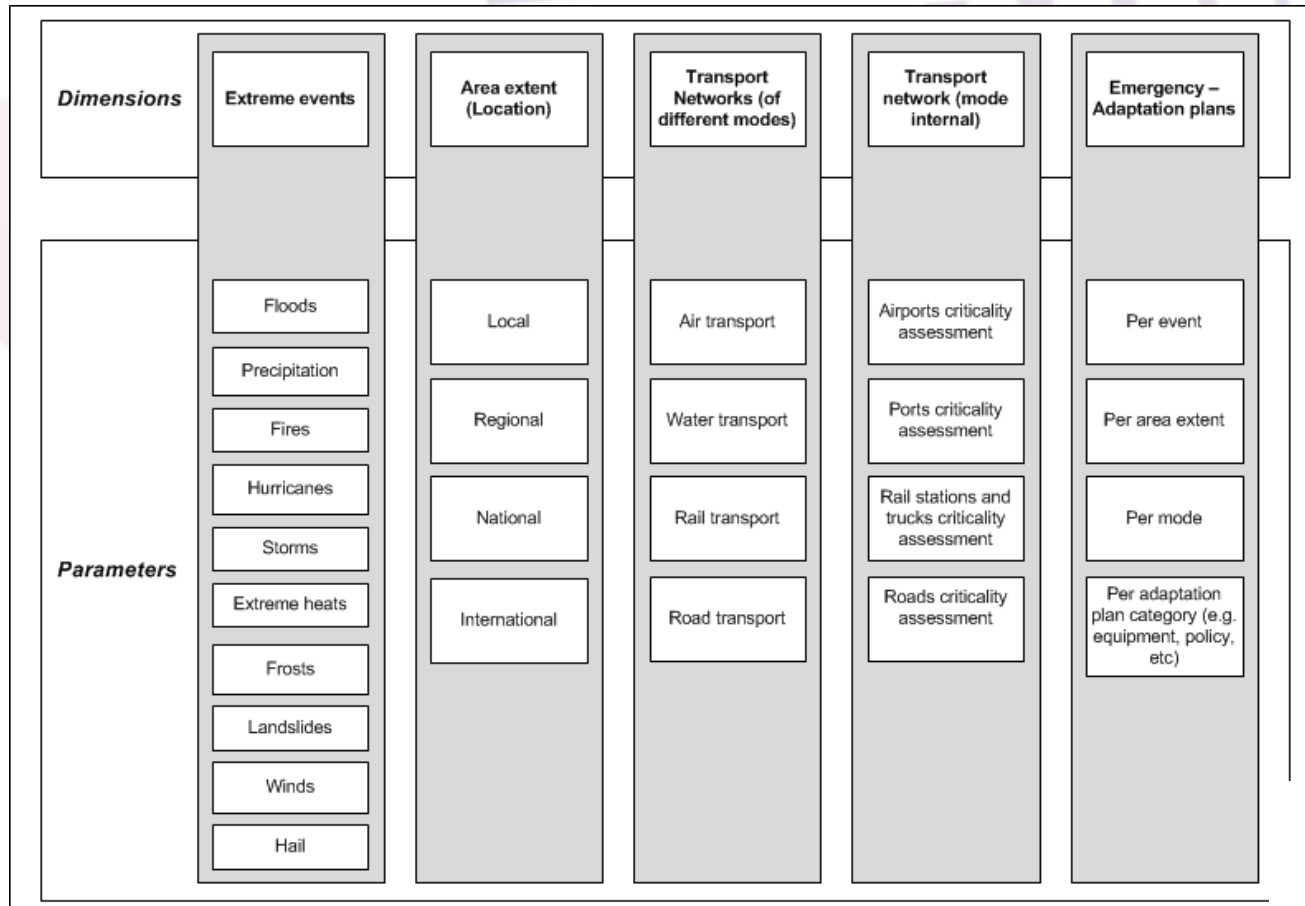


# Impact assessment of extreme rainfall



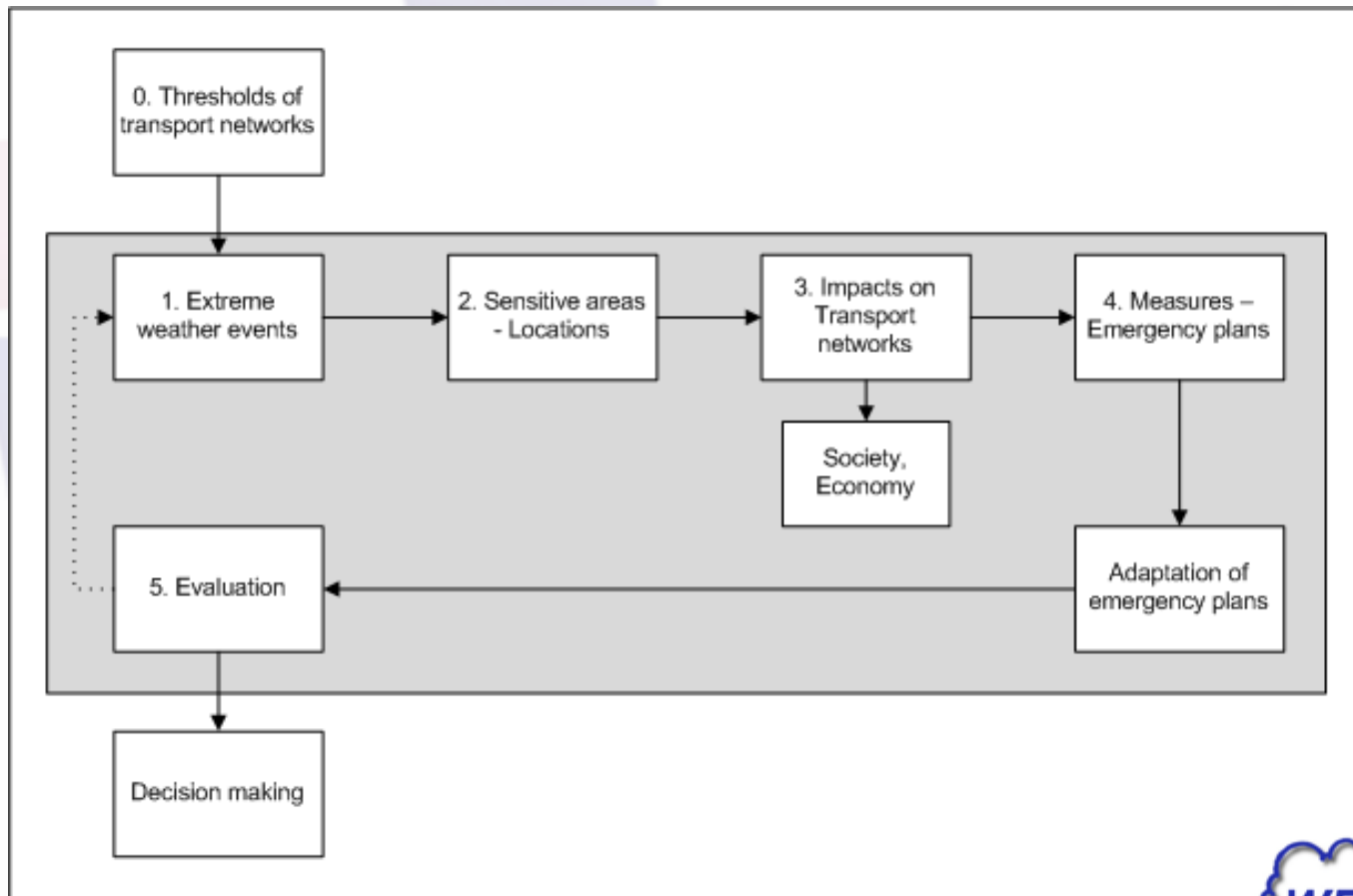
# Linking climate change impacts with optimal adaptation strategies

- Objective: determine adaptation measures that minimize impacts and economic losses
- Dimensions and parameters



# Linking climate change impacts with optimal adaptation strategies

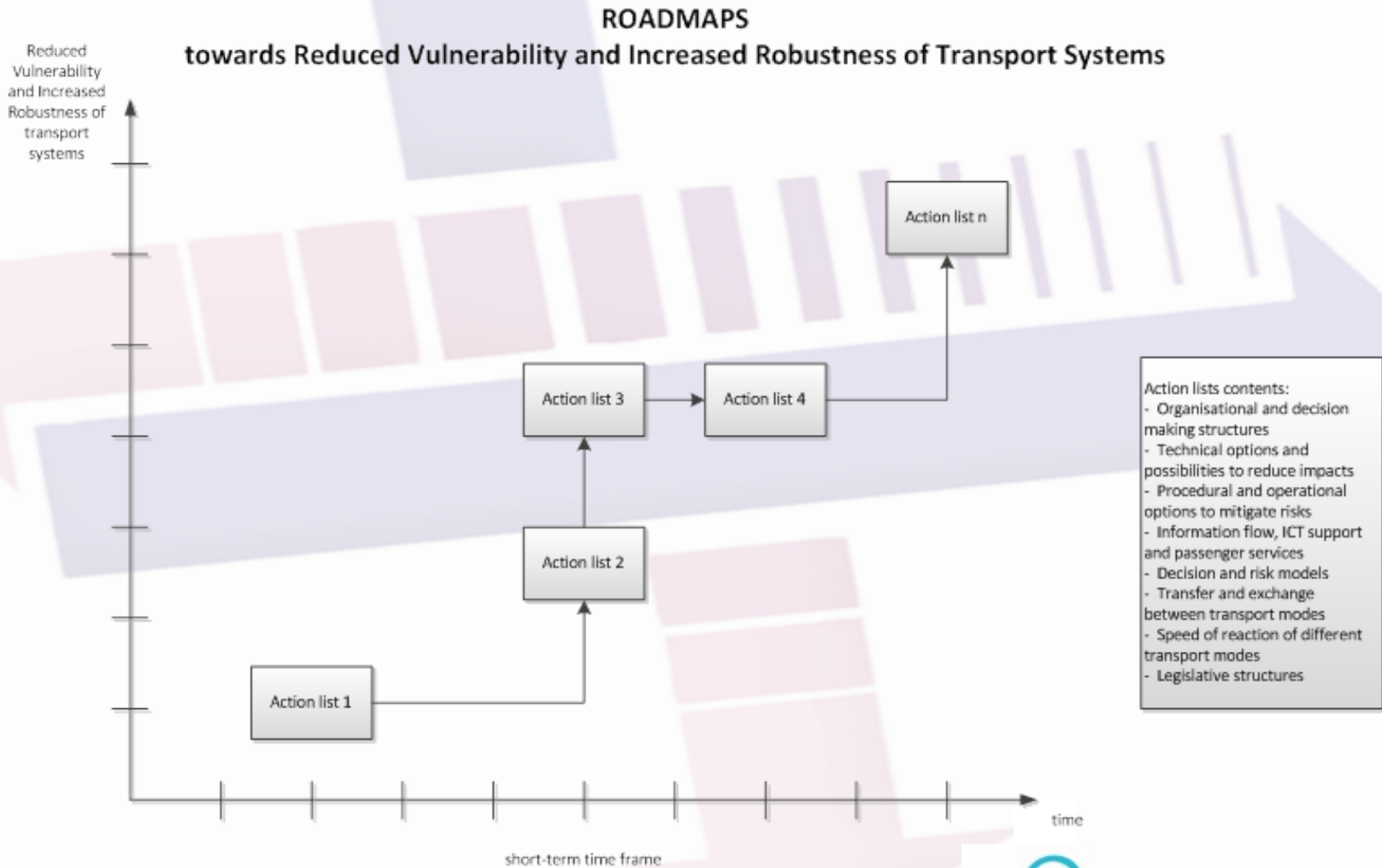
## Integrated framework



# Roadmaps: Prioritizing adaptation measures

- Temporal dimension of adaptation measures
  - when should a specific measure be implemented and what is the proposed time-plan of its implementation
- Financial dimension of adaptation measures
  - how much will each implementation cost - both with a qualitative (low, medium and high cost) and a numerical indication (in €)
- Contribution of each adaptation measure to the enhanced resilience of each examined transport mode
  - how well does each measure contribute to the protection of transport infrastructure and the perseverance of transport network operations against climate change

# Roadmaps formulation



# Indicative adaptation measures for road transport

Technical measures	Organization measures	Procedural measures	ICT measures	Decision & risk models	Legislative measures
Use of new materials	International weather info exchange	Capabilities for adapting timetables of scheduled modes	New business models for providing emergency information	CBA guidelines for logistics companies	Review of maintenance contracts and procedures
Assets with quick restoration capabilities	Involvement of all stakeholders	Priority & emergency route plans	Personalized provision of information to travelers	Risk exposure assessment for logistics companies	Speed limit enforcement
Use of wind breaks	Networks of all stakeholders		ITS & weather monitoring systems		
New design standards	Increased educational material				





# Adaptation measures databases for all modes

Organizational and decision making processes	Technical options	Procedural and operational options	Information flow and ICT support	Decision and risk models	Legislative options
R1: Construction of dikes and creation of flood barriers for protection against water (29, 22, 8)	R16: Provision of reliable, instant and -if feasible- personalized information on duration of the incident and travel options (23, 36)	R31: Regular clearance of cycle lanes and sidewalks during winter (25)			
R2: Innovative pavement materials resistant to corrosion (25)	R17: Roadside vegetation, absorbing generated heat, protecting roads (25)	R32: Development of intelligent feedback systems in vehicles to sustain user attention (9)			
R3: Improved drainage in intersections (25)	R18: Design of new heat-resistant asphalt mixes (25, 29, 27, 22)	R33: Conduction of public campaigns in order to raise public awareness regarding local hazard situations (5, 8)			
R4: Elevation of coastal road networks (30)	R19: More heat-resistant bridge joints (29, 27)	R34: Priority plans that maintain access to hospitals, emergency stations (25)			
R5: Design of and investment in new assets with "quick restoration" capability	R20: Adaptation of timetables and service intensities under adverse weather conditions (5, 37)	R35: Definition of priority routes for road clearance in case of large scale impacts (27, 38)			
R6: Setting and implementation of international standards for weather and emergency information (5)	R21: Need for alternate routes for freight transport in Arctic areas (31)	R36: Adoption of operational, physical, technical, procedural and institutional integration of weather and traffic control services (8)			
R7: Consultation with and co-ordination of highway authorities, subcontractors, suppliers and key stakeholders to adjust adaptation strategies (36)	R22: Need for improvement of drainage-sewer systems as well as for more road-side rain pits (25, 22)	R37: Review of maintenance contracts and procedures to make them flexible and effective even under rapidly changing weather conditions (8, 25)			
R8: Provision of shelters for non-motorized transport (28)	R23: New asphalt mixes that help in faster drainage of standing water (32)	R38: Preparation and broad communication on disruptions and alternatives with the public, using a variety of communication channels (5)			
R9: Preparation for sufficient salt stocks and road clearing equipment availability before and during winter or storm seasons (8)	R24: Enhancement of road layers to prevent washing-off (25)	R39: Tracking of "chain reactions" of extreme weather events, particularly in agglomeration areas (5, 35)			
R10: Establishment of networks of urban, regional and national stakeholders: transport companies, authorities and users (25)	R25: Installation of signs that warn the driver/pedestrian on upcoming flooded network (23)	R40: Coordination of emergency plans amongst transport modes and networks (37)			
R11: Issuance of educational and information material on emergency cases, planning and maintenance to related authorities (5)	R26: Strict speed limit enforcement during storm events (25)	R41: Implementation of appropriate risk management procedures in order to be prepared for adverse conditions (25)			
R12: Development of timely communication and coordination plans involving stakeholders and freight operator associations (35)	R27: Measures of protection against slope subsidence around road/rail network to avoid cut-off links (33, 22)	R42: Standardization of weather information and hazard warnings across Europe (8)			
R13: Development of suitable business models for the provision of emergency information systems (8)	R28: Additional pumping in tunnels (22)	R43: Assessment of logistics companies' risk exposure and establishment of appropriate adaptation plans (5, 8)			
R14: Provision of cost-benefit assessment guidelines to logistic companies (25, 8, 37)	R29: Installation of wind-breakers (25)				
R15: Organization of the supply of trapped drivers' passengers with the help of volunteers and aid organizations (8)	R30: New design standards relating components of road network (signs, lighting) enhancing protection of users (28)				

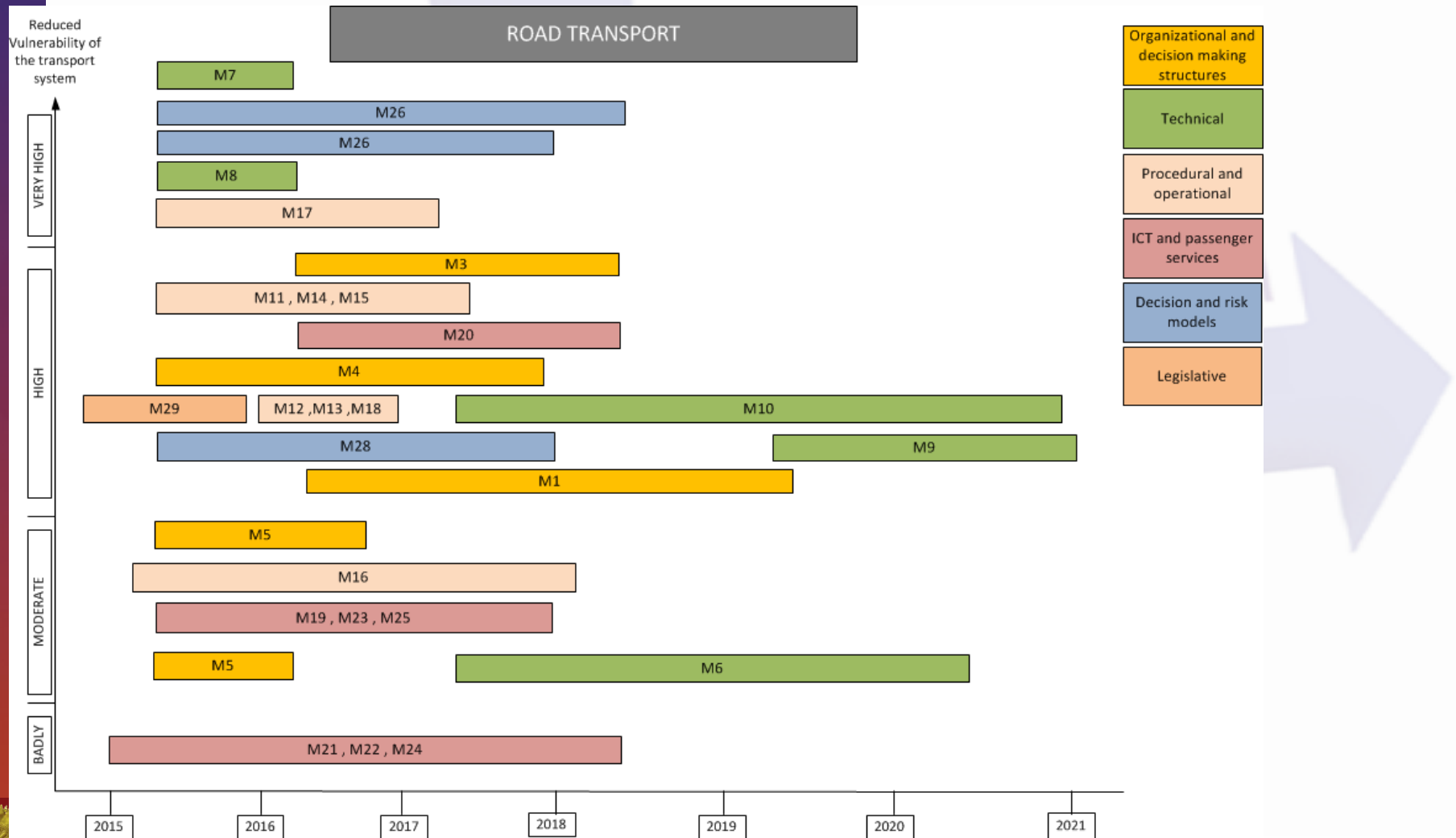
Organizational and decision making processes	Technical options	Procedural and operational options	Information flow and ICT support	Decision and risk models	Legislative options
Ra1: Construction of dikes to protect infrastructure from high water level (29, 22)	Ra13: Installation of redundancy and emergency capacity (pass-by trucks, switches, operation on opposite lane) (22)	Ra25: Incorporation of climate change projections into the design of drainage to cope with predicted future flooding frequency and magnitude (5)			
Ra2: Application of protective measures, e.g. barriers, trapbays (25, 22)	Ra14: Establishment of more drainage pits and bigger capacity on the run-off pipe (25)	Ra26: Installation of common control and steering centers including rail and emergency services (25)			
Ra3: Reinforcement of existing barriers/dikes (22)	Ra15: Protection of underground stations and planning for emergency evacuation (25)	Ra27: Enhancement of flood resilience of rail infrastructure (8)			
Ra4: Integration of different types of asset monitoring databases (37)	Ra16: Installation of local weather forecasting systems (37)	Ra28: Emergency planning and preparation with fire brigade and other emergency services, practice emergency plans for severe weather events (27)			
Ra5: Improvement, maintenance and monitoring of infrastructure (35)	Ra17: Reduced speed limits during storms (25)	Ra29: Training for troubleshooting and information provision in case of events and in abnormal operations (25)			
Ra6: Improved systems that warn drivers and repair teams about possible rail problems (25)	Ra18: Design of a risk-based approach for speed restrictions and line closures (25)	Ra30: Planning for replacement services (e.g. bus) (25)			
Ra7: Improved ventilation on underground stations (25)	Ra19: Preparation of logistic plans to deploy equipment and spare parts in case of hazards (25)	Ra31: Development of flood and wind/storm prediction models incorporating better weather forecasts and more detailed information on topography, infrastructure, geology and hydrology (37)			
Ra8: Temperature monitoring-warming systems in underground infrastructure (25)	Ra20: Measures of protection against slope subsidence around road rail network to avoid cut-off links (33, 22)	Ra32: Hazard, vulnerability & risk mapping in cooperation with weather services (5, 8)			
Ra9: New design construction for minimization of rail stress (27)	Ra21: Elevation of rail infrastructure as well as bridges (22)	Ra33: Development of flood and wind/storm response strategies; establishment of meteorological thresholds and triggers for actions (5)			
Ra10: Preference of continuous welded rails (22)	Ra22: Additional pumping in tunnels (22)	Ra34: Identification of critical basins; construction of further sub-surface drains in problematic flooding areas (8)			
Ra11: Re-planning of rail schedules due to increased frequency of high temperatures (14)	Ra23: Protection of open-air rail infrastructure against winds (wind-breaker) (25)	Ra35: Planning of emergency routes or diversions, due to cut-off network (25, 31)			
Ra12: Regular substitution of railroad base materials, due to thawing (31)	Ra24: Circuit breaker system for lines that move through urban environment (25)				

Organizational and decision making processes	Technical options	Procedural and operational options	Information flow and ICT support	Decision and risk models	Legislative options
A1: Construction of barriers-dikes to protect infrastructure in coastal airports from water inundation (22)		A13: Realignment of runways, due to changeable cross-winds (31, 23)			
A2: Elevation of runways (22)		A14: Implementation of SESAR developed technologies and procedures aiming to optimize capacity in disruptive conditions (36)			
A3: Redesign of drainage system (22)		A15: Development of travel re-arrangements and additional costs for journeys in case of multi-modal traffic chains (35)			
A4: Inclusion of climate change aspects in the ATM airport master plan (30)		A16: Development of a measurement system to assess and compare the vulnerability of airports and airspace (22)			
A5: Capacity improvement of restricting equipment (e.g. snow removal equipment, air-conditioning) (29)		A17: Transparency boost in the comparison of the impacts of disruptive events (consistent statistical evaluation processes) (25)			
A6: Longer runways to accommodate aircrafts landing at high-density air (29, 30, 22)		A18: Improvement of local weather and disruptions forecast (forecasts with improved geographical and timely precision may help to reduce the disruptive impact) (8)			
A7: Heat resilient runway tarmac (22)		A19: Identification of regions with possible permafrost thawing (27)			
A8: Relocation of runways built on surfaces affected by thawing (30)		A20: Revised building-codes could limit implications of extreme weather events (8)			
A9: Need for increased repairs on runways located upon ground affected by thawing (22)		A21: Planning of emergency routes or diversions, due to cut-off network (25, 31)			
A10: Runways with tarmac mix that accelerates drainage of standing water (32)		A22: Exclusion of high-risk flood areas from any development activity (25, 22, 28)			
A11: Installation of wind-breakers (25)		A23: Development of evacuation plans and alternative routes (27)			
A12: Reinforcement of airport infrastructure against flooding (29)		A24: Prohibition of construction near high-risk areas (24, 22, 28)			

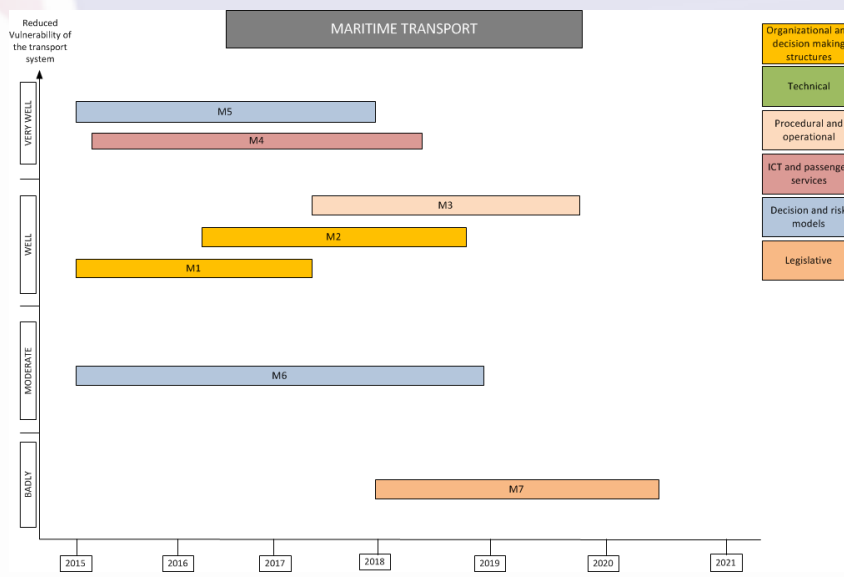
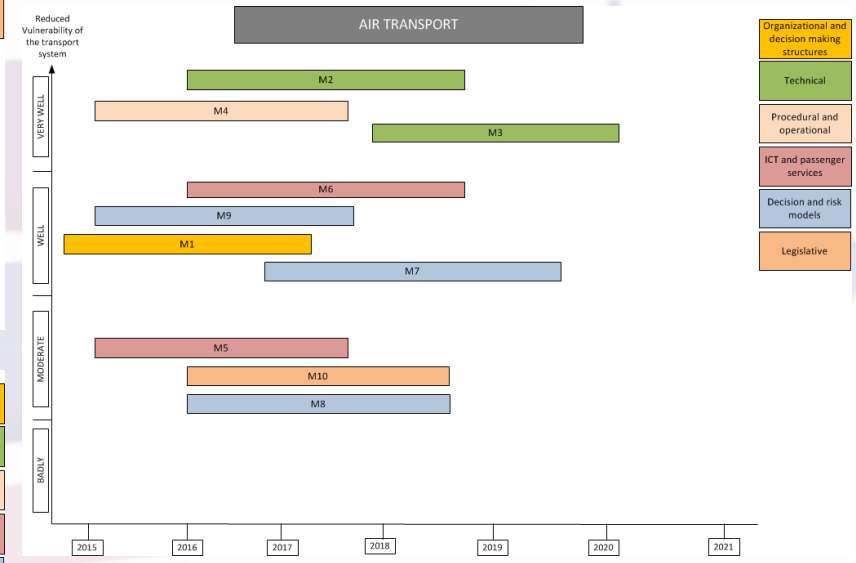
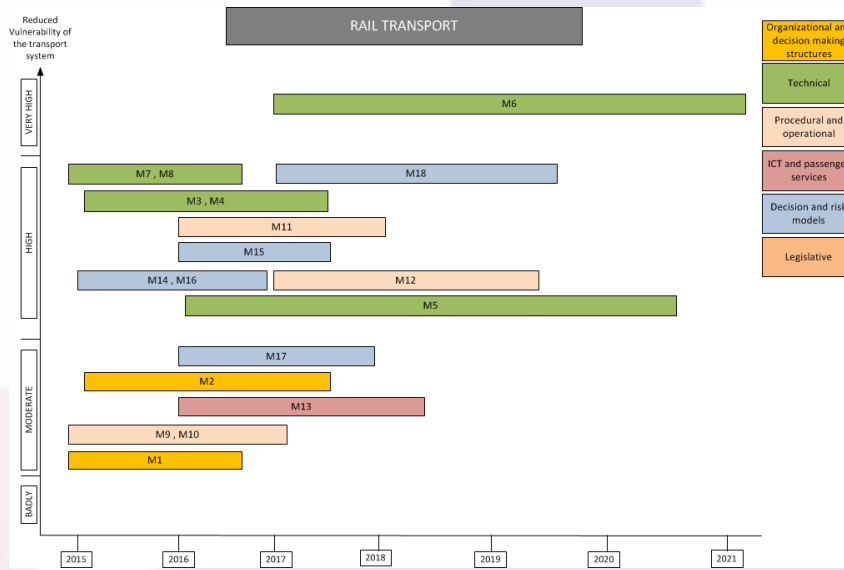
Organizational and decision making processes	Technical options	Procedural and operational options	Information flow and ICT support	Decision and risk models	Legislative options
DWW-M1: Rehabilitation of harbor infrastructure (8, 22)	DWW-M14: Production of wave weather warning forecasts through comparison of weather forecast model outputs against reliable observed data for the forecast location (25)	DWW-M17: Elevation of harbor infrastructure above possible surge level (2, 29)	DWW-M27: Elevation of harbor infrastructure above possible surge level (2, 29)	DWW-M39: Issuance of guidelines on the application of environmental legislation relevant to ports and waterways (25)	
DWW-M2: Tsunami protection infrastructure (8)	DWW-M15: Transition of non-wooden materials to post-construction procedure (23)	DWW-M28: Construction of barriers and protection walls to avoid water inundation (27, 22)	DWW-M29: Stronger ship attachment mechanisms, cargo load/unload mechanisms (34)	DWW-M41: Technological innovation for fleet modernization: fleet operation, port & terminal infrastructure (22, 28)	
DWW-M3: New design standards for ships for protection against larger waves or shallow channels/harbors (29)	DWW-M16: Constant monitoring of infrastructure environment temperatures (29)	DWW-M18: Enhanced insulation and refrigeration of warehouses (29)	DWW-M30: Reinforcement of docks, cranes etc. to withstand violent winds and bigger waves (22)	DWW-M42: Collaboration between weather services, oceanographic institutes and other stakeholders providing experience and resources (8, 22)	
DWW-M4: Redesign, reduction and reinforcement of water beds for protection of harbor and general sea transport infrastructure against larger waves (28)	DWW-M17: Enhanced insulation and refrigeration of warehouses (29)	DWW-M19: Regular maintenance and repair of damaged infrastructure (28)	DWW-M31: Regular monitoring of infrastructure conditions (22)	DWW-M43: Implementation of the State Statement of Environment & Island Navigation Development by providing technical assistance (25)	
DWW-M5: Regular sediment removal from sea bed (8, 22)	DWW-M18: Regular maintenance and repair of damaged infrastructure (28)	DWW-M20: Clarification of models managing the safety investments in various port ownership situations (27)	DWW-M32: Design of water retention basins in case of severe flooding (29)	DWW-M44: Provision of adequate berths, anchorages and shore connections to facilitate larger number of vessels (27, 29, 30)	
DWW-M6: Infrastructure insurance to compensate for potential damage (29)	DWW-M19: Clarification of models managing the safety investments in various port ownership situations (27)	DWW-M21: Increased access to harbors and new routes for ship transport (22)	DWW-M33: Development of a state-of-the-art waterway management system as well as further modernization and extension of waterway related infrastructure (8, 27)	DWW-M45: Improved infrastructure management by waterway administrations (8)	
DWW-M7: Extension of functions and the integration of the River Information Services (RIS) systems (27)	DWW-M20: Increased access to harbors and new routes for ship transport (22)	DWW-M21: Need for alternate routes for freight transport in Arctic areas (31)	DWW-M34: Establishment of a "green" link "line" for the purpose of rapid reactions in cases of severe disturbances in navigation caused by hydrological/meteorological phenomena (22)	DWW-M46: Continuous and differentiated monitoring and analysis of the development of the river's water discharge regime (3)	
DWW-M8: Development of innovative methods for the improvement of river monitoring (clear stress, sediment transport, morpho-dynamics etc.) (25)	DWW-M21: Need for alternate routes for freight transport in Arctic areas (31)	DWW-M22: Creation of a European river engineering and IW transportation science partnership (8, 25)	DWW-M35: Operation of an integrated smart network of waterway infrastructure (27)	DWW-M47: Continuous and differentiated monitoring and analysis of the development of the river's water discharge regime (3)	
DWW-M9: Provision of vertical quays to accommodate transshipment under extreme low water conditions (2)	DWW-M22: Creation of a European river engineering and IW transportation science partnership (8, 25)	DWW-M23: Comparison and balance of ecological effects, transport objectives and economic profitability (5, 27)	DWW-M36: Increase of awareness of different stakeholders on climate change impacts on IWT and related industries (27)	DWW-M48: Improved infrastructure management by waterway administrations (25)	
DWW-M10: Improvement of the quality and reliability of wind forecasts by using WRF (United Area Model) down to a 2 km resolution (25)	DWW-M23: Comparison and balance of ecological effects, transport objectives and economic profitability (5, 27)	DWW-M24: Creation of a European inland waterway network with national administrative barriers and with a necessary harmonized legislative and regulatory framework (27, 29)	DWW-M37: Issuance of marine forecasts for inland navigation logistics barriers and additional value added services for logistics chain modifications (28)	DWW-M49: Development of an efficient and harmonized regulatory framework (27)	
DWW-M11: Responsibility allocation concerning weather stations in ports (6)	DWW-M24: Creation of a European inland waterway network with national administrative barriers and with a necessary harmonized legislative and regulatory framework (27, 29)	DWW-M25: Protection of infrastructure from water inundation (2, 29)	DWW-M38: Provision of adequate flood defense systems (the vessel of higher damage sensitive hydrographic structures) (29)	DWW-M50: Creation of an efficient and harmonized regulatory framework (27)	
DWW-M12: Improvement of transshipment infrastructure, making it effective under different water level conditions (25)	DWW-M25: Protection of infrastructure from water inundation (2, 29)	DWW-M26: Increased need for sediment removal from sea bed, result of larger waves and flood (22)	DWW-M39: Issuance of guidelines on the application of environmental legislation relevant to ports and waterways (25)	DWW-M51: Development of inland schemes to create innovative, adapted, efficient and more environmentally friendly vessels (28)	
DWW-M13: Standardization and system harmonization for adoption of technologies in ports by authorities and to secure a way to enforce the implementation (27)	DWW-M26: Increased need for sediment removal from sea bed, result of larger waves and flood (22)		DWW-M40: Collection, recording, validation and sharing of information on water depths (8, 28)		



# Roadmap: Road transport



# Roadmaps for all modes of transport



# Conclusions & Further research

- Increased research interest on the topic within Horizon 2020
  - Mobility for Growth / Secure societies / Climate & environment
- Need to translate research results into tangible inputs for stakeholders and decision makers
- Need to establish global cooperation initiatives
- Need for technical and technological innovation
  - New materials
  - Early warning systems
  - “New” transport modes, eg. Electric vehicles
  - New technologies for transport: ITS, ATIS, C-ITS
  - New indicators, metrics and tools (eg complex network analysis)
- Need for dynamic adaptation (vs one-shot long term planning)

## Related publications

- **E. Mitsakis**, A. Papanikolaou, G. Aifadopoulou, J.M. Salanova, C. Doll, **G. Giannopoulos**, C. Zerefos (2013) An integrated framework for linking climate change impacts to emergency adaptation strategies for transport networks, *European Transport Research Review*
- **E. Mitsakis**, **I. Stamos**, A. Papanikolaou, G. Aifadopoulou, H. Kontoes (2013) Assessment of climate change impacts and extreme weather events on transport networks: Case study of the 2007 wildfires in Peloponnesus, *Natural Hazards*
- **E. Mitsakis**, **I. Stamos**, M. Diakakis, J.M. Salanova Grau (2014) Impacts of high-intensity storms on urban transportation applying traffic flow control methodologies for quantifying the effects, *International Journal of Environmental Sciences and Technology*, 11 (8), pp. 2145-2154.
- **E. Mitsakis**, **I. Stamos**, J.M. Salanova Grau, G. Aifadopoulou (2014) Optimal allocation of emergency response services for managing disasters, *Disaster Prevention and Management* 23 (4).
- **I. Stamos**, **E. Mitsakis**, J.M. Salanova Grau, G. Aifadopoulou (2015) Impact assessment of extreme weather events on transport networks: A data-driven approach, *Transportation Research Part D: Transport and Environment*.
- M. Diakakis, E. Lekkas, **I. Stamos**, **E. Mitsakis** (2015) Vulnerability of transport infrastructure to extreme weather events in small rural catchments, *European Journal of Transport and Infrastructure Research*.
- **I. Stamos**, **E. Mitsakis**, J.M. Salanova Grau (2015) Roadmaps for adaptation measures of transportation to climate change, *Transportation Research Record: Journal of the Transportation Research Board*.

# There's No Planet B

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