Climate Change and road transport: a review

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Abstract: - Climate change is almost considered as issue of global interest. Under a business-as-usual scenario, greenhouse gas emissions could rise by 25-92% between 2000 to 2030, resulting in a global mean surface temperature increase of 1.4-5.8°C between 1990 and 2100. Climate change as described by the projections from global and regional models will bring many weather changes. Road infrastructure will have to face many challenges: insufficient drainage capacity, landslide risk and its consequences on traffic safety, deterioration of roads and consequently higher demand for repair measures, environmental effects of precipitation increase. In this paper, the main challenges concerning climate change to road transport are described. Moreover, the main mitigation and adaptation actions and measures are presented.

Key-Words: - global warming, climate change, transport, road infrastructure

1 Introduction
Climate change is almost considered as issue of global interest. Warming of the climate change is unequivocal and since the 1950s many of the observed changes are unprecedented (increases in temperature, sea level rise, intensity and frequency of extreme climatic events) leading to a wide range of impacts on environmental systems and society [12]. The growing body of scientific evidence has confirmed that anthropogenic greenhouse gas (GHG) emissions are causing global average temperatures to rise. Between 1906 and 2005, the global mean air temperature increased by 0.74°C (Fig.1). Under a business-as-usual scenario, greenhouse gas emissions could rise by 25-92% between 2000 to 2030, resulting in a global mean surface temperature increase of 1.4-5.8°C between 1990 and 2100. However, the extent to which climate change creates future damages is still a debated issue. Calculations on future socio-economic vulnerabilities and the relevant mitigation and adaptation costs differ widely [14]. Through international agreements (Kyoto protocol, UNFCCC Accord, EU ETS) governments have sought to decrease GHG emissions. The Stern Review (2007) estimates based on economic models that the cost of business-as-usual will be equivalent to losing at least 5% of GDP each year [20].

Compared to other economically important sectors such as energy, water resources, agriculture, the consequences of changing weather conditions for the transport sector have not received much attention in the literature.

Road infrastructure, during their design life, could be subjected to a very different climate conditions. The cost of not taking this into consideration could be vast in terms of disruption to traffic, public safety and infrastructure repairs [21].

In this paper, the main challenges concerning climate change to road transport are described. Moreover, the main mitigation and adaptation actions and measures are presented.

2 European legislation in transport sector and climate change
Environmental protection against climate change is an area of major concern in the European Union and in the entire world. Europe’s general policy in order to reduce the environment impact of transport has been formulated since 2001 in the White Paper, where the concept of the need to integrate transport policy with environmental considerations was introduced [4]. The European Commission’s White Paper of 2009, states that “transport itself will suffer from the effects of climate change and will necessitate adaptation measures” [6].

The 3rd Conference in the field of climate change, held in Kyoto Japan, in 1997, presented a step forward in addressing climate change. Kyoto Protocol (2005) was a legal and economic device proposing targets for reducing the GHG emissions.
The United Nations Framework Convention on Climate Change (UNFCCC) has agreed to limit the increase in global mean temperature since pre-industrial times to less than 2°C, in order to prevent the most severe impacts to climate change (Copenhagen Accord 2009). Moreover, the UNFCCC formulates commitments from the participating countries to develop integrated national plans and actions on adaptation measures to reduce vulnerability. In this context, the European Commission’s White Paper, in 2009, outlined a two-phase adaptation policy in the EU aiming to build a solid knowledge base on the impacts and consequences and organize a combination of policy instruments. The Partnership for European Environmental Research (PEER) report 2009 compares adaptation strategies in nine European countries. Different strategies and interaction between government and sector policies on the regional and national level are presented [16], [17].

The integration of environmental considerations within the transport sector was significantly extended with the publication in 2011 of the Transport White Paper [7]. The need for a climate-resilient infrastructure is recognized and suggested as an integrated part of research work. The White Paper focused on the oil dependence of the transport sector and its contribution to GHG emissions. Along with the Roadmap for moving to a competitive low carbon economy in 2050, it was developed the objective of reducing Europe’s total GHG emissions by 80 to 95% by 2050 compared with 1990 levels. Specifically, in transport sector, the EU has the overall goal of achieving a 60% reduction in GHG emissions (including international aviation but not maritime bunkers) from 1990 levels by 2050, with an intermediate goal of reducing 20% transport GHG emissions from 2008 levels by 2030 (+8% against 1990 levels). Similarly, shipping emissions (international maritime bunkers) are to be reduced by 40% from 2005 levels by 2050.

On 13th December 2015, in Paris, representatives of 195 nations reached a landmark agreement that will, for the first time, commit nearly every country to lowering planet-warming greenhouse gas emissions to help reduce the most drastic effects of climate change. The COP21 (Conference of Parties) aimed to achieve an ambitious global agreement in order to include objectives and actions on climate change adaptation, focusing on vulnerable developing countries in particular. The agreement consists of a global action to keep the global average temperature increase below 2°C by the end of the century.

The latest projections by EU Members States, included in “Trends and projections in Europe 2015” report, show that the EU is heading for a 24% reduction in GHG emissions by 2020 with current measures in place, and a 25% reduction with additional measures already being planned in Member States. However, the analysis shows that to meet the target of a 40% reduction by 2030, new policies need to be put in place [10].

3 Transport and climate change
3.1 Transport and GHG emissions
Total passenger and freight transport demand noted increase in the EU-28 between 2000 and 2013. Passenger transport increased significantly until 2008, but it has remained broadly stable following the economic recession. In 2013 the number of passenger-kilometres was 8.4% higher than in 2000. Freight transport grew considerably in the EU-28 between 2000 and 2008. A sharp fall in freight demand occurred in the years immediately following the economic crisis and, following a limited recovery, freight volumes have since remained largely stable. In 2013, total freight transport was 7.3% higher than in 2000. In 2013, the
majority of EU transport was travelled by car, 72% of passengers and 49% of freight [11].

The amount and types of energy used by the various transport modes directly determine the magnitude of GHG emissions. Annual transport energy consumption grew significantly between 1990 and 2007. The economic recession (in 2007) caused a subsequent decline in transport demand and energy consumption. In addition, improved efficiencies and technological factors have also greatly affected the environmental performance of transport. Overall, between 1990 and 2013, there was a net growth of EU-28 transport energy consumption of 22.3%.

GHG emissions decreased in all the main sectors of EU economy, from 1990 to 2013, except transport; transport emissions increased by 19.4%. In 2013, the transport sector contributed by 24.4% of total EU-28 GHG emissions. Emissions will, therefore, need to fall by 67 % by 2050 in order to meet the 2011 Transport White Paper target.

In Figure 2, the contribution of the different modes of transport to GHG emissions, in 2013, is presented. Remarkably, road transport is the sector that was responsible for almost 73% of all GHG transport emissions and has contributed the most to the 1.3 % overall reduction of EU-28 GHG emissions in 2013 [11].

3.2 The main problem of road infrastructure
For the assessment period 1998 to 2010, the total costs borne by the transport sector (damages, repair and maintenance costs of infrastructures, vehicle damages, increased operation costs etc) across all weather changes were estimated at 2.5 billion EUR per year. The indirect costs of transport disruptions on other sectors were estimated at 1 billion EUR per year [8].

Road infrastructure are designed and constructed in order to withstand some events in the climate according to specific events based on past experience, named as “reference events”. Many environmental changes have been occurring due to global warming; an increase in unusual climate events, namely an increase in temperature and changes in precipitation patterns, the frequency of storms, with the associated changes in surface and ground water regimes. All these above are not mentioned as reference events, they are having a higher probability for floods and erosion, higher risk of slides and avalanches.

Road transport will have to face many challenges: insufficient drainage capacity, landslide risk and its consequences on traffic safety, deterioration of roads and consequently higher demand for repair measures, environmental effects of precipitation increase. Impacts on infrastructure, operation and the economy may be significant (more demanding conditions to be met by more effective emergency plans) or dangerous in some cases.

However, the extent of the gradual changes in the climate is under uncertainty, so it is difficult for road owners and operators to assess the vulnerability of their assets (infrastructure, pavement, earthworks, culverts, bridges) and adapt and plan for the future.

4 Main effects concerning climate change on road transport
4.1 The climate in Europe
Climate in Europe will change during the 21st century. Model predictions indicate that the mean annual temperature will rise by 1°C to 5.5°C and Europe might be divided in two main regions: northern and eastern Europe (warmer and wetter winter seasons will impose the main challenges) and southern, western and central Europe (warmer and dryer summers will be dominated). Table 1 reports the effects of climate change for Europe as predicted by an IPCC study [3].

Table 1: Predicted effect of climate change in Europe [3]
Warming in northern Europe largest in winter, for the Mediterranean largest in summer. Lowest winter temperatures increase more than average temperatures in northern Europe, highest temperatures increase more in summer than average temperatures in southern and central Europe. Mean precipitation increase in northern Europe and decrease in most of Mediterranean area. Extremes in precipitation very likely to increase in northern Europe. Increase in risk of summer drought in central Europe and Mediterranean. Changes in wind strength uncertain, although it is more likely that average and extreme wind speeds will increase.

Duration of snow season and snow depth very likely to decrease.

4.2 Climate effects on road transport

It is clear that road transport systems perform worse under adverse and extreme weather conditions, especially in regions with dense infrastructure networks and dense populations, where one single event may influence large parts of the transport system and affect substantial parts of the population.

In the following overview, the main challenges concerning climate change and road infrastructure are described, based on literature review. Moreover, additional effects are highlighted: [1], [2], [13], [15], [18], [19]

- Increase in frequency of very hot days
  1. Increased temperature of asphalt mixture of pavement: the binder phase loses stiffness, deformations will accumulate at a faster rate, binding ability of the bitumen decreases; becomes harder and less flexible
  2. Effects of the durability of road pavements by softening bitumen mixtures
  3. Increased need for maintenance and resurfacing; pressure on materials
  4. Restricting laying periods to the cooler part of the day to allow materials to cool
  5. Increased numbers of blow-outs
  6. Increased heat exhaustion of maintenance and operation staff
  7. Greater risk of wildfires
- Decrease in frequency of very cold days
  1. Increased frequency of freeze-thaw cycles, causing durability and fatigue problems
  2. Increased demand for de-icing chemicals on account of the higher frequency of freeze-thaw cycles
  3. Increased frequency of wet surface conditions allowing more water to ingress the pavement through cracks
  4. Reduced bearing capacity as a result of moisture ingress; higher incidences of expansion and contraction of water during freeze-thaw cycles
  5. Good drainage should be provided
  6. Improved working conditions for personnel in cold environments
- Increase in frequency of heavy precipitation
  1. Increased pavement construction risk: water damage can result in reduced lifetime for a bituminous pavement; reduced bearing capacity, water is allowed to infiltrate and remain in lower pavement layers and in the sub base
  2. Reduced road safety due to reduced skid resistance
  3. Reduced driving comfort; the presence of water causes splash and spray, greater risk of aquaplaning, limiting visibility and increasing discomfort
  4. Reduced road capacity; this result in traffic congestion with associated social costs
  5. Necessary drainage infrastructure capacity
  6. Higher run-off peaks, increased erosion and sediment transport, uncontrolled transport of pollution
  7. Failure frequency of existing structures is expected to increase if maintenance procedures remain unchanged
  8. Higher demand for inspection and maintenance of vulnerable assets like bridges, culverts
- Instability of embankments and slopes
  1. Infiltration increase causing loss of soil suction
  2. Reduction in effective stress due to rising groundwater levels
  3. Loss of root reinforcement due to changes in the type of vegetation or dying of vegetation
  4. Increase in seepage forces due to frequent and intense storms
  5. Increase in the frequency of rapid drawdown conditions
  6. Reduction of resisting forces due to erosion of the slope toe
  7. Increase in seepage velocity due to an increased groundwater temperature
  8. Reduction of soil cohesion due to increased temperature
  9. Vegetation losses as a result of wind changes
- Drought conditions
  1. Impacts on the construction and performance of geotechnical structures
  2. Shrinkage cracks of pavements
  3. Loss of skid resistance
4. Effects on vegetation adjacent to the road
   - **Sea level change**
   1. Trafficked areas unusable
   2. Reduced the bearing capacity of pavement structure in a way that is incompatible with its function due to rise in the water table
   3. The stormwater drainage system may need to be resized or relocated

5. **Mitigation and adaptation measures**

Many challenges for the current and future infrastructure have to be faced by road designers and operators. All the climate change effects on road transport that mentioned above can be recognized in all phases of road management: planning, design, construction, maintenance and operation. In the planning phase, the importance of good flood maps or landslide risk zones is the basis for a planning of water management. Adequate structural safety (landslide or flood or sensitive assets) in new weather conditions may change standard design procedures. Maintenance of drainage structures and culverts or pavements must be based to a greater degree on weather forecasts. Moreover, in the operation phase, traffic management, emergency plans, preparedness will depend on good knowledge of weather condition [2].

It is clear, that good regional projections of climate change, such as precipitation intensity, is necessary precondition in order to design and construct a resilient road infrastructure. At present, the probability that a particular climate event, occurs during a period of time, is difficult to be quantified in absolute terms about the damages to road assets. There are uncertainties associated with the climate change predictions and the degree of exposure of road infrastructure to climate hazards.

Many adaptation and mitigation measures may help address climate change. Effective implementation on road infrastructure depends on policies and cooperation at all scales [5],[9].

Mitigation consists of actions or measures to limit the magnitude or rate of long-term climate change, namely involves reductions in human emissions of GHG. Main mitigation strategies in order to reduce emission in road transport would be:
- reduction of carbon intensity of fuel
- reduction of energy intensity
- improved transport infrastructure – modal shift
- journey distance reduction and avoidance

Adaptation covers a wide range of activities and policies that seek to prepare societies for a changing climate. Main adaptation strategies in road transport would be:
- realignment/relocation of road
- design standards and planning for roads infrastructure
- integrating climate change considerations into national transport policy
- availability of less vulnerable routes
- improved technologies and integration with key sectors (e.g. energy)

![Fig. 3: Intense snowfall created serious safety transport problems (Egnatia Odos Highway, Greece)](image)

![Fig. 4: High precipitation intensity created serious safety transport problems (Egnatia Odos Highway, Greece)](image)
Communication and awareness raising will be important to ensure public support for measures and to help stakeholders to adapt. As IPCC Synthesis Report highlights “effective adaptation and mitigation actions will depend on policies and measures across multiple scales: international, regional and national. Policies across all scales supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation [12].

6 Conclusion
The increased demand for personal mobility, the dependence on reliable movement of goods and components in the supply chain and the observed disruption that weather causes to these, makes the study of current and future road transport resilience to climate change. Road transport will have to face many challenges in future. The implementation of mitigation and adaptation measures is important to address climate change consequences in road infrastructure. All aspects of actions and policies are dependent on a good knowledge base of climate change characteristics, and the risk assessment of the effects on the road network.

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