Climate change mitigations measures and road transport: a review

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***Abstract*—** Climate change is almost considered as issue of global interest. As it described by the projections from global and regional models will bring many weather changes. The transport sector is responsible for about 23% of world energy related greenhouse gas emissions and road vehicles account for more than three quarters of total transport energy use. In this context, 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. This paper reviews the impact of road transport with respect to climate change inducing greenhouse gas emissions. Moreover, it analyses the main mitigation practices and policies that road transport is expected to be decarbonised through road transport research review.

***Keywords*—**climate change, global warming, road infrastructure, transport

I. Introduction

OVER recent decades, the scientific evidence has confirmed that anthropogenic greenhouse gas (GHG) emissions are causing global average temperatures to rise [1, 2]. 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 [3]. Between 1906 and 2005, the global mean air temperature increased by 0.74^{o}C (Fig.1). The IPCC (Intergovernmental Panel on Climate Change) estimates that the total warming effect of human activities is at least 10 times larger than that of natural factors, in particular changes in solar activity. The IPCC examined six different emissions scenarios in order to determine how climate change will change under different conditions. Over the next century, CO_2 levels are predicted to increase over the next century from 369 ppm to between 540 and 970 ppm, compared to about 280 ppm in the pre-industrial era. This translates to an increase in globally averaged temperatures of between 1.4 to 5.8^{o}C over the period 1990 to 2100. Total annual anthropogenic GHG emissions have increased by about 10 $GtCO_{2-eq}$ between 2000 and 2010. This increase directly came from the energy (47%), industry (30%) and transport (11%) [1, 2] (Fig.2).

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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 [4, 5]. Through international agreements (Kyoto protocol, UNFCCC Accord, EU ETS) governments have sought to decrease GHG emissions. The Stern Review (2007), [6], estimates based on economic models that the cost of business-as-usual will be equivalent to losing at least 5% of GDP each year. The climate deal agreed, in Paris 2015, by 195 countries is the first universal and legally binding agreement to tackle current and potential impacts of climate change. It constitutes a major and promising step towards building a low-carbon and climate-resilient world.

Transport remains a critical support system for the smooth functioning of societies and economies. 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 [3, 7] . 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, 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 [9]. On the other hand, the transport sector is responsible for about 23% of world energy related greenhouse gas emissions and road vehicles account for more than three quarters of total transport energy use.

This paper reviews the impact of road transport with respect to climate change inducing greenhouse gas emissions. Moreover, it analyses the main mitigation practices and policies that road transport is expected to be decarbonised through road transport research review.

II. Europe and climate change Procedure

A. *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 [10].

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" [11].

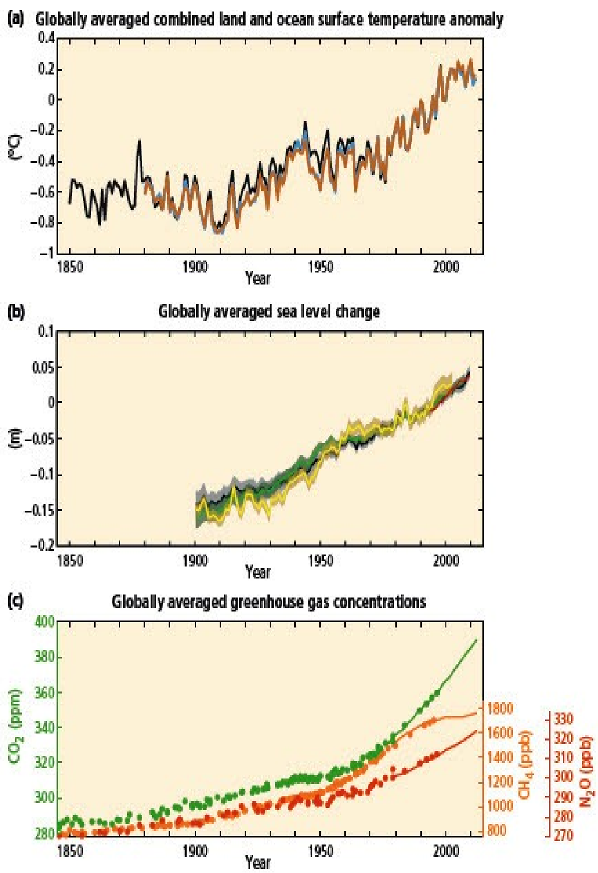

Fig. 1 indicators of changing global climate system [2]

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 (Fig.2)

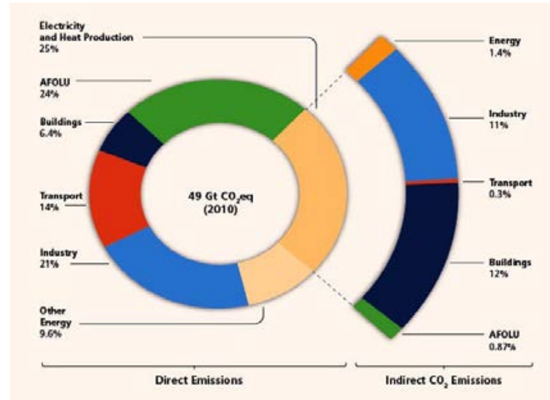

Fig. 2 greenhouse gas emissions by economic sectors [2]

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 EU emissions trading system (EU ETS) has been formulated as a cornerstone of the European Union's policy to combat climate change and its key tool for reducing industrial greenhouse gas emissions cost-effectively.

The European Commission's White Paper, in 2009 [11], 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 [12, 13].

The integration of environmental considerations within the transport sector was significantly extended with the publication in 2011 of the *Transport White Paper* [14]. 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.

The Europe 2020 Strategy for sustainable growth includes, among others, the targets of reducing greenhouse gas emissions (GHG) by 20%, increasing the share of renewable in the EU's energy mix to 20% and achieving the 20% energy efficiency target by 2020. The EU is currently on track to meet two of those targets, but it will not meet its energy efficiency yet.

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. It constitutes a major and promising step towards building a low-carbon and climate-resilient world, an opportunity where the economy be reinvented in a cleaner, greener and more efficient way.

The latest projections by EU Members States, included in *Trends and projections in Europe 2015* Report (EEA) [15], 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.

B. The climate model predictions

Projections of future climate change are derived from simulations with general circulation models and regional climate models using different emission scenarios for GHGs. Despite substantial progress in understanding and modeling the climate system, there will always be substantial uncertainties about future climate change, in particular at the regional and local levels [16]. The basic reason is the unknown level of future GHG and air emissions which depends on demographic, socio-economic and technological development as well as the implementation of mitigation measures and policies. The level of future expected GHG emissions is the interface between mathematical modeling, geographical information science and regional issues.

It is important to note that when assessing the progress in understanding the potential impact of climate change on any system, it is useful to consider the conceptual framework within which climate change impact assessment (CIA) should ideally take place. CIA of the transport sector would determine the relationships between the intensity of a given meteorological parameter and the observed disruption. Tol's conceptual framework (1998) provides the fundamental components of CIA dividing into three main tasks: a) determination of relationships between weather and the system in question, ii) extrapolation of these relationships onto future climate using climate projections, iii) modification of the projected impacts with reference to scenarios for development within the system [17].

However, Jaroszweski [3] emphasized the need to utilize an interdisciplinary approach to CIA taking into account both climate and socioeconomic scenarios. When you submit your final version, after your paper has been accepted, prepare it in two-column format, including figures and tables.

C. The climate in Europe

In Europe, the annual average temperature increased by approximately 1.3°C between pre-industrial times and the decade of 2002 to 2011. 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 [4, 18].

Observed climate change has already led to a wide range of impacts on environmental systems and society as for example coasts, sea level, river flows, terrestrial biodiversity and ecosystems, forest growth. The above impacts are projected to continue due to further climate change. Vulnerabilities differ across Europe depending on local conditions. Moreover, socio-economic developments are a key driver, namely can either aggravate or reduce the projected impacts [8].

Table 1. Predicted effects of climate change in Europe

- Slightly higher increase in mean temperatures than global mean
- 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

III. Transport and Climate Change

A. Transport, energy 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 (EC EU, 2015), (EEA Report, 2015).

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%. Transport sector accounts for 31.6% of total energy consumption (EU-28) where road vehicles account for more than three quarters of total transport energy use. Oil is the dominant fuel source for transportation (is about 94 % dependent on oil, 84 % of it being imported, diesel (35%) and gasoline (47%)) [19, 20].

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 3, 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 (EC EU, 2015) [19, 20].

All the GHG emissions and energy consumption figures are presented indicating the scale of the issue relating the road transport and climate change

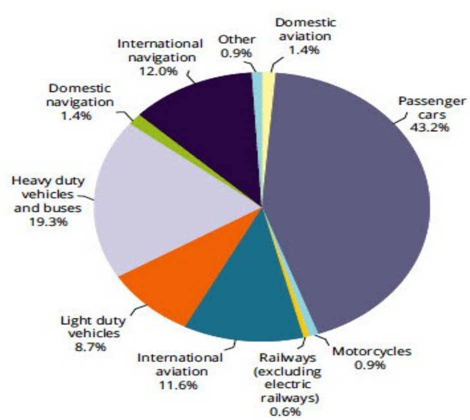

Fig. 3 the contribution of different modes of transport to GHG emissions (EU-28), 2013 [19]

B. *Climate effects on road infrastructure*

Despite the importance of road transport as a key driver of economy, little research has been conducted. 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”. These events determine the limits and the thresholds for design and construction characteristics. 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, and so, they are having a higher probability for floods and erosion, higher risk of slides and avalanches.

It is clear, that good regional projections of climate change, such as precipitation intensity or temperature is necessary precondition in order to design and construct a resilient road infrastructure. Road transport will have to face many challenges, in order to withstand the negative impacts of climate change: 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 [21, 22]. 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.

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 many uncertainties associated with the climate change predictions and, consequently, the degree of exposure of road infrastructure to climate hazards. 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 [22, 23].

IV. Policies on mitigation measures on road transport

A. *Mitigation and adaptation policies*

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.

The problem of climate change has to be examined through the prospective of multi-level governance as this a problem which transcends any one level of government and is influenced by the actions of individuals and organizations as well as formal institutions [24].

Aggressing climate change requires two types of response: mitigation measures or actions in order to reduce greenhouse gas emissions (GHG), to limit the magnitude or rate of long-term climate change and secondly adaptation measures to cover a wide range of activities and policies that seek to prepare societies for a changing climate and to deal with the unavoidable impacts (EC White Paper, 2008). Mitigation together with adaptation to climate change contributes to the objective expressed in Article 2 of the UNFCCC. Adaptation and mitigation strategies are complementary strategies for reducing and managing the risks of climate change. They are interrelated i.e. increasing adaptation opportunities imply decreasing urgency to implement mitigation measures and vice versa [4]. An effective implementation of measures depends on policies and cooperation at all scales and it can be enhanced through integrated responses that link mitigation and adaptation with other societal objectives.

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" [2].

B. *Mitigation policies in road transport*

Research from institutions and agencies has illustrated that the greatest source of transport emissions is from vehicular traffic. From this evidence, there is the requirement for implementation of different mitigation policies and actions focused on vehicle technology and fuels, operational improvements, construction and maintenance practices and enhanced planning and design. The effectiveness of the above reduction policies for road transport depends on national and regional scale. Demographic, social and economic variables play an important role in assessing whether a measure will operate or not.

Dalkmann and Brannigan (2007) suggest that a combination of three different strategies –"avoid", "shift" and "improve"- each including specific policy measures (as planning, regulatory, economic, information, technological) can be used to reduce CO_2 emissions from transport. The effectiveness of the approach, which tackles all of the key drivers of greenhouse gas emissions from the transport sector, relies on the implementation of a combination of policy measures [25].

The Synthesis Report 2014 of IPCC (Intergovernmental Panel on Climate Change) demonstrates the basic mitigation measures for transport [2]:

- reduction of carbon intensity of fuel
- reduction of energy intensity
- compact urban form and improved transport infrastructure and modal shift
- journey distance reduction and avoidance

These measures intersect and interlink with other concerns as economic, social or environmental. As a result, potential co-benefits or adverse side effects are created. The magnitude of the effects depends on local circumstances as well as on the implementation practice, pace and scale.

The World Road Association, in its paper "*Road Transport System and Environment Preservation*", recognizes that the reduction of greenhouse gas emissions will be a result of multiple approaches and the combination of numerous measures. The measures that are presented are based on four basic policies [26]:

- fiscal measures to reduce traffic demand or increase car efficiency (road pricing congestion charges, parking charges, incentives for low emission vehicles, fuel tax)
- behavioral measures used to promote the switch to more efficient modes of transportation (change of spatial structures, energy-efficient transport modes as public transport, cycling and pedestrian networks, car pooling, car sharing, land use and transport planning)
- vehicle technologies employed to deliver more efficient and less polluting vehicles (fuel efficiency, biofuels, electric cars)
- design elements of the road network and increased use of recycled materials in road construction (measures in design, construction, maintenance and operation)

However, indirect taxation schemes are often unpopular and public acceptability can be low unless the revenue is reinvested appropriately, while land use planning and regulatory measures are fully supported by society and key policymakers [27].

The European Commission Report *"Roadmap for moving to a competitive low carbon economy in 2050"* mentions that technological innovations can help the transition to a more sustainable road system by acting on three main factors:

- vehicle efficiency through new engines, materials and design
- cleaner energy use through new fuels
- better use of networks and safer and more secure operation through information and communication

The above three factors in combination with measures such as pricing schemes to tackle congestion and air pollution, infrastructure charging and improving public transport provide better effectiveness.

In this context, Stanley et al [28] propose six key ways by which road transport GHG emissions can be reduced:

- reduce urban car kilometers traveled
- increase the share of urban trips performed by walking and cycling
- increase public transport's mode share of urban motorized trips
- increase urban car occupancy rates
- reduce forecast fuel use for road freight
- improve vehicle efficiency

It is highlighted that the compact urban settlement pattern can contribute to the above key areas, from reducing necessary trip lengths to increasing the attractiveness of public transport, walking, cycling for movement. In this way, the average trip length is kept below the threshold where walking and cycling are viable options for mobility. Policy approaches that pursue an integrated approach to land use and transport are likely to achieve greater emission reductions than approaches that ignore these linkages [28, 29].

The sustainable mobility paradigm of Banister [29, 30] is an alternative approach that looks at actions to reduce the need to travel by substitution, to encourage modal shift by transport policy measures, to reduce distance reduction by land-use policy measures and to encourage greater efficiency by technological innovation. The sustainable mobility paradigm is moving towards an objective-based planning system that is trying to implement a range of policy interventions but with the support of all stakeholders. It must balance the requirements along the physical dimensions (urban form and traffic) against those concerning the social dimensions (people and proximity). In the context of social dimension the personal utility must be placed.

Innovation and investments in environmentally sound infrastructure and technologies is a driver key to reduce greenhouse gas emissions. However, technological advances cannot alone resolve the problem. Technology through improvements in energy efficiency and research into new fuels is a solution for the required reduction in CO_2 but it is an expensive and long term solutions. A combination of economic, planning and technological innovation,
including both land use and transport elements, provides more efficient solutions.

From the other aspect, policies to change behavior and travel habits are quite significant. The significance of habits empirically and theoretically is well-explored by Schwanen et al. [31]. Habits are also a key issue in transport patterns because this makes the changing of individual behavior. Behavior change is a shift from car use to more sustainable transport modes or eco-driving.

V. Conclusion

Road transport will have to face many challenges in future. The implementation of mitigation measures is important to address climate change consequences in road infrastructure. The presented measures and policies based on mitigation via technology, economic instruments and infrastructure provision. While individual factors have only small impacts to reducing transport GHG emissions, the combination impact of various factors is significant, emphasizing the importance of taking an integrated and systematic approach, including both land use and transport elements.

It is important a holistic approach to be adopted that employs a combination of policy instruments as drivers of transport demand taking into account of economic and demographic context. The implemented measures have to simultaneously discourage carbon-intensive travel behavior while introducing incentives to adopt more sustainable travel behavior. The interactions between different policy measures have to be examined and analyzed considering short and long term impacts and possible rebound effects. 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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