STRIA Road Map

Transport Infrastructure

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1. Executive Summary

This report is one of a series of seven roadmaps that consider each core aspect of the European transport system. Addressing the subject of transport infrastructure, the report reviews the current state of transport infrastructure and the challenges faced by owners and operators as they meet changing demands for transport provision at low cost and with low or no Green House Gas emissions.

The report contributes to an overall Strategic Transport Research and Innovation Agenda, that in turn supports the Energy Union targets of reducing GHG emissions. The headlines emerging from this roadmap that contribute to the overall STRIA initiative are addressed in the answers to specific questions posed by the co-ordinating panel:

1. *How the considered technology area can contribute to tackling the Energy Union challenges of decarbonisation and energy security?*
   Transport infrastructure is an integral part of the overall European Transport system, regardless of mode. Building new infrastructure or upgrading existing is expensive financially, requires use of carbon intensive materials, and imposes other environmental disadvantages. However, the infrastructure itself is typically accountable for around just 5% of total GHG emissions. The contribution from infrastructure is therefore to minimise the emissions embedded in construction and arising from maintenance, and to then accommodate the system changes required in each mode as it reduces the operational carbon emissions.

2. *Where an integrated approach; both in terms of integration across sectors as well as integration across technologies is needed?*
   Within each roadmap clarify what "integrated approach" means, which are the concrete R&I implications of such approach and specific requirements
   Integration is required on two fronts. Firstly, integration between transport modes so that users (freight and passenger customers) can make informed choices about the most efficient mode or combination of modes for each journey. This means clear user information on cost (financial and carbon), and ease of transfer between modes enabled by simplified payment or ticketing systems, user centric system design, and transparency of fair pricing.
   Secondly, integration is required within each mode so that infrastructure owners and transport operators can better optimise the overall engineering and operating system for service level, financial cost and environmental impact.

3. *Outline the timeline of the actions/initiatives. Specify which innovations/solutions could be deployed within 5-7years. Specify as well the possible bottlenecks/barriers related to the actions/initiatives envisaged*
   Although transport infrastructure has very long operational life, there are too many variables associated with user demand, technological change and social change to be able to plan specifically to 2050. Instead, the roadmap identifies policy and research changes that are intended to enable infrastructure to accommodate the many demands that will be made of it over the period to 2050. In the short term – 5 years – there are clear policy initiatives recommended to bring about transparent transport pricing that is consistent across all modes. This is supported by research into social attitudes, and how citizens can be engaged to support carbon reducing transport pricing and investment in new transport infrastructure. There are various barriers identified, including social acceptance, and the

difficulty of harmonising a charging regime where existing environmental charges and taxation are inconsistent across modes.

4. *Which are the roles of the public (EU, national and local level) and private? Who should do what?*
   Unlike much transport operation, transport infrastructure is either promoted by or actually owned by public sector organisations at state or regional level. Where the infrastructure is privately owned, it is then subject to degrees of economic regulation, so following policies set by member states. The report sets out detailed assessments of the respective roles of EU, member state and private sector partners at chapter 6. In summary, the Commission sets overall charging and carbon taxation guidelines, and should set incentives for research into carbon reduction in infrastructure. Member states should focus on achieving access to mobility that is not constrained by mode, and ensuring that this is at the lowest practicable cost for transport users. It is for the member states too to set the incentives for private sector transport operators and for private sector investors in infrastructure that encourage innovation on carbon, on user service and on modal integration.

5. *What overall impact in terms of CO2 emission reduction and use of cleaner energy can be expected by the development and deployment of the considered technology/technology solutions? Specify other relevant impacts resulting from the development and deployment of the considered technology*
   The direct impact on transport carbon emissions from changes to infrastructure is, as noted above, low. However, the recommended areas for research and innovation will be essential for the other participants in the transport system to achieve their potential energy savings. More widely, operating transport more seamlessly across mode and between operator and infrastructure owner will mean growing demand can be accommodated on proportionately less infrastructure, and with materially better service to users.

6. *Which gaps (science, technology, innovation, market, policy, consumer acceptance, user needs) and potential game changers need to be taken into account?*
   The report identifies a number of areas where consumer or user acceptance will be needed, especially in the area of charging. There are no major technology barriers to change in the infrastructure arena.

7. *How policies driven by demand could contribute to the development and deployment of the considered technology (i.e. public procurement).*
   As noted above, much of the transport infrastructure is either owned by or commissioned by the public sector. Public sector policies need to change significantly to genuinely incentivise operators to develop low carbon operations, and the public sector needs to change its appetite for risk if it is to successfully drive change in user acceptance.

8. *Where does the international cooperation in R&I represents an added value? how?*
   The road map report does not specifically address the advantages and disadvantages of international co-operation. However, the report does make several references to interoperability and to consistency across markets and states. International co-operation in research and innovation offers the potential for investment by private sector organisations in the expectation of a large enough market across Europe. International standardisation will make transport systems consistent for users, thereby encouraging use of the most efficient mode. And international standardisation will make the system much more flexible in the face of changing demand as resources can be redeployed into the areas of current or emerging demand.

2. Introduction

2.1 Background and objectives of the Road Map

Transport systems are a fundamental part of our modern social and economic infrastructure. In the case of the European Union, transport systems enable the free movement of goods and services, enable generation of economic wealth across all member states, and enable the import and export of goods and services to and from the region.

While transport systems bring huge benefits, this comes at a price. In particular, the consumption of energy to build and operate our transport systems means that transport is a major contributor to the overall production of CO_2 / greenhouse gasses, and is the cause of much of the poor air quality experienced in towns and cities.

The 2011 Transport White Paper *Road Map to a Single European Transport Area – Towards a Competitive and Resource Efficient Transport System* states: "Infrastructure shapes mobility. No major change in transport will be possible without the support of an adequate network and more intelligence in using it. Overall, transport infrastructure investments have a positive impact on economic growth, create wealth and jobs, and enhance trade, geographical accessibility and the mobility of people. It has to be planned in a way that maximises positive impact on economic growth and minimises negative impact on the environment." The 2011 EU White Paper goes on to set out policies for reducing the environmental impact of transport systems, with a reduction of Green House Gas (GHG) emissions of 60% against 1990 levels by 2050. This is acknowledged to be an extremely demanding target.

This road map is one of a series that considers the overall transport system in Europe. Taking just the infrastructure aspects of transport, this document assesses the requirements for change to infrastructure to meet the wider environmental policy objectives and seeks to identify the areas where the next generation of research and innovation are likely to be of greatest benefit.

In this report Infrastructure comprises the basic physical facilities and installations necessary for the operation of road, rail, civil aviation, inland waterways and shipping, plus the additional infrastructure necessary for the propulsion and refuelling of transport vehicles, the coordination, monitoring and management of transport, ensuring secure and safe operation, and allow for the transfer of passengers and freight. Infrastructure therefore includes physical networks, terminals and intermodal nodes, information systems and refuelling and electrical supply networks.

2.2 Approach and structure of the Road Map

The approach taken by this report is to offer a straight forward overview of transport infrastructure, and to identify some of the aspects where wider requirements of the transport system impact on infrastructure in general and on the GHG emissions arising from infrastructure in particular. The report aims to cover transport without a specific analysis by transport mode, though in many cases the different characteristics of each mode mean that specific modal observations are necessary.

The report concentrates on the transport modes with greatest overall GHG emissions, so carbon neutral modes such as cycling and walking are not addressed. Similarly, the report makes less reference to international shipping and civil aviation because of the limited impact the commission can have on those modes at this time.

In writing this Road Map report, the authors have set out the current characteristics of transport infrastructure – the state of the art. They then move on to summarise the challenges facing transport infrastructure under a set of headings, before identifying the opportunities for addressing those challenges from a carbon / GHG perspective. Finally the road map offers recommendations for targeting research and innovation, discusses the respective roles of public and private sectors in delivering that research and innovation, and briefly discusses potential means for financing and funding the associated investments.

2.3 Methodology for the development of the Road Map

This Road Map has been prepared in a very short space of time, and draws on the current knowledge and experience of transport infrastructure experts. The methodology adopted for its preparation has been a limited literature search supported by expert knowledge and advice from practitioners in the key transport sectors. A wider group of peer reviewers was invited to critique the initial drafts of the Road Map, and a workshop with members of this group was held in Brussels in early June 2016.

Because of the very tight time constraints, this Road Map has been prepared in isolation from the other STRIA parallel work streams. The author team considers that a further iteration of this study would be appropriate once all seven Road Map documents have been completed and published.

2.4 Overview – Green House Gas Emissions and Carbon in Transport

The targets for reduction in Green House Gas (GHG) emissions are exceedingly demanding in a world where increasing population and increasing GDP are driving increasing transport of people and of freight. But the targets set in the 2011 white paper and in the series of global climate change accords are absolute levels of carbon emissions. It is essential therefore that we do not just think of reducing carbon emissions, but that we all think of carbon as a finite resource with strict carbon budgets to be adhered to.

In transport, the main contributors to GHG emissions are road transport, civil aviation and shipping. Road is the predominant mode for passenger transport movements, with rail the next largest mode. Road is also the predominant mode for freight transport movements, with rail and then inland shipping making significant contributions to overall capacity

Cycling & Walking are low or zero carbon means of transport over short distances, and many member states are investing in cycle networks and safer cycling, and promoting walking for very short journeys. While cycling and walking are good very low carbon modes, their use for the very shortest journeys means that they are unlikely to make a material contribution to the decarbonisation of the overall transport system for passengers and freight. Therefore, these modes are not discussed further in this report.

Road transport is currently 75% - 90% of carbon emitting transport use and, for passenger cars, emits more per passenger km or tonne km than rail primarily because of fossil fuel use. However the most efficient new generation of vehicles, including buses, are more carbon efficient. All modes rely on electricity generated by low or zero carbon producers to achieve their full environmental potential.

When considering GHG emissions it is difficult to separate the emissions directly arising from construction and maintenance of the infrastructure from those arising from operation. Typically, up to 95% of emissions are emitted by vehicles using the infrastructure. However, the design and the operation of that infrastructure can have a material bearing on the total operational emissions.

3. Baseline and State of the Art

3.1 Today's conditions

Transport infrastructure is made up of the fundamental facilities and systems serving operators and users. While transport is often categorised by mode, it is more relevant for this study to think of the different transport functions.

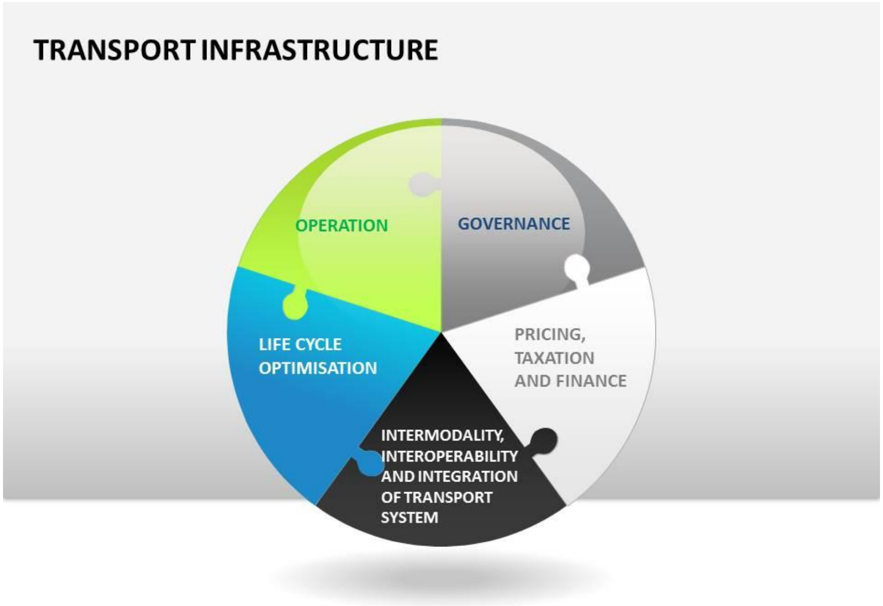
- urban public transport networks—including light rail (metro and tram), heavy urban commuter rail, bus, urban highways and bus lanes
- inter-urban or inter-regional —including strategic highways, main line inter-city and high speed rail, inland shipping, domestic aviation
- international gateways – airport hubs and major sea ports— along with other regional ports and airports;

In addition, there is extensive supporting infrastructure

- traffic and transport control systems, aimed at ensuring safe, secure, efficient, reliable and resilient transport (air, railways, maritime, inland waterways)
- Information and communication technologies used for customer information, and for tracking, charging, ticketing and billing
- Areas for logistics activities including logistics hubs, dry-ports and distriparks
- energy facilities including electrical traction power networks necessary for infrastructure and transport operation.

The existing infrastructure continues to evolve, with investment by infrastructure owners to accommodate changing demand, changing vehicle types, and to improve network performance. Examples are the construction of new container terminals to accommodate the latest generation of post-panamax large container ships, or the installation of electric car charging points. The latter are predominantly installed in urban areas by public authorities to encourage use of zero emission cars.

Transport infrastructure in the EU faces some key challenges. Throughout this Road Map we discuss these under six headings, identified as the areas where there is the potential to control or change infrastructure provision and operation. These areas are: 1) governance; 2) pricing, taxation and finance; 3) intermodality, interoperability and integration of transport systems; 4) life cycle optimisation; and 5) infrastructure operation. The baseline for each one of these challenges is described below.



3.1.1 Governance

Governance refers to the structures and decision-making processes that allow a state, organization or group of people to conduct affairs (World Economic Forum, 2016). In the current EU transport context, Governance should be regarded as the set of processes and results that, considering different public and private stakeholders, is oriented to achieve defined goals. In the context of STRIA, there are a number of characteristics of governance affecting transport infrastructure.

There are several levels of governance which lead to a multi-facetted structure, with several levels of interconnections that affect decision-making processes. Governance is made more extensive and more complex by the separation between management / administration of different modes, and by the split between state owned or private regulated infrastructure and partially or unregulated private sector users or operators.

Attempts to foster cooperation through planning, financing, construction and operation of main European corridors have not always been successful. While there is a high level of standardization of products, services and processes, these have had limited impact in improving interoperability between systems or regions.

There is a high and sustainable level of research and Innovation activity at the EU level, primarily relating to the design of vehicles and the use of technology in vehicle operation and automation. The level of investment into infrastructure research and innovation is low. This is due in part to the dominance of public sector or regulated private sector ownership (and thus low levels of competitive pressure) and the pressures of financial constraint over the last decade.

Because transport infrastructure is large scale, expensive, and has a disproportionate impact on the lives of communities, investment decisions are usually formed or made at a political level. This can be problematic as infrastructure facilities are to be planned for the long-term, while political decisions and public opinion are frequently short term ones. Where the political focus is on high-level policy, the impact is positive in bringing about a planned and consistent wave of investment. But where the political focus is on individual projects or locations the result can be delay to progress or abandonment of an otherwise sound investment.

Alongside political interest, increasing pressure from community and social groups means that a wider transport benefit can be reduced or lost as a result of local objection.

While building new infrastructure assets ranks high on political agendas, operations and maintenance practices can be low priority and subject to disproportionate shortage of funding. This results in short term deterioration in performance and, in the long term, higher total costs for heavy repair or rebuilding.

3.1.2 Pricing, taxation and finance

One of the ways of contributing to decarbonisation of transport is through setting up the right incentives in the sustainable use of transport systems for all transport modes. The 2011 Transport White Paper acknowledges this point by saying: “Price signals play a crucial role in many decisions that have long-lasting effects on the transport system. Transport charges and taxes must be restructured in the direction of wider application of the ‘polluter-pays’ and ‘user-pays’ principle”.

For all transport modes, the cost of providing transport infrastructure is met directly through user charges or indirectly through taxation. In closed systems (rail, aviation) users pay for the infrastructure as a part of their overall transport charge. For open systems, primarily road, there is either no direct infrastructure charge, or the infrastructure charge is levied directly to the user in the form of a toll.

Pricing has traditionally been acknowledged as one of the most effective incentive mechanisms on users to take decisions according to wider social interests. As emitting CO_2 gets more expensive for transport operators, they are incentivised to switch to cleaner fuels, acquire greener vehicles and make a better use of the capacity provided by both vehicles and infrastructure. Pricing is also used to incentivise users to spread peak hour demand, thereby reducing congestion and delay, and with it reducing CO_2 emissions. While off peak discounting is well established for air, metro and rail fare paying passengers, road congestion charging schemes have only been applied in a few cities and have had limited overall impact.

As well as managing demand, charging for use of transport is a viable means of securing funding for further improvement. This investment might include Intelligent Transport Systems (ITS) equipment, more energy-efficient alignments, and better connection facilities among modes – measures that contribute to lower carbon emissions by users. Closed systems including airports and rail can capture user charges in this way. For road transport this is harder to achieve.

In spite of all these advantages, the present situation regarding infrastructure charging, financing and taxation within the EU is not optimised to promote decarbonisation. Infrastructure charging approaches are not homogeneous across modes, or between countries. Two main market-based instruments are being used to incentivise carbon reduction - energy taxation and emission trading systems (ETS). Taxation is currently applied to fuels used in land transport, while the ETS applies to other energy sources in some transport modes indirectly, or directly in the case of the aviation sector.

In the case of aviation and shipping, which are both international industries, attempts at the introduction of regional market based measures, such as the inclusion of aviation in 2012 in the EU ETS, have been controversial and raised objections within the international community.

While some countries are implementing road charges to heavy vehicles tied to the externalities they produce, there are still many European countries that do not apply road charges. Of those that do, some are intended to incentivise lower emissions but others are simply a means of equalising the cost of operation regardless of the state of registration. The different taxes implemented across modes do not guarantee a homogenous and fair carbon charging approach.

On the procurement side, while in the last few years some innovative approaches have been promoted, such as Public Private Partnerships (PPPs), innovative mechanisms have not yet incorporated incentives to encourage contractors to implement approaches to minimize carbon emissions over the infrastructure life-cycle. The Green Public Procurement scheme is still in its inception phase, but has potential.

3.1.3 Syncromodality, Intermodality, interoperability and integration of transport systems

Intermodality, interoperability and integration of transport systems have been high on the European policy for several decades. Since the concept appeared in the 1980s the idea of integration of transport systems evolved from the integration of physical networks, to the integration among multiple modes of transport and the integration of transport systems.

In the context of this road map, the following definitions are considered.

- *Intermodality* refers to the seamless transportation of freight or passengers through multiple modes of transport under a single form of organisation and/or billing.
- *Interoperability* is the (technical) ability of a passenger, transport operator, vehicle or other means of transport to operate seamlessly on multiple networks or parts of networks, that could be physical, digital or financial.
- *Integration of transport systems* refers to the overall process of treating transport modes in terms of infrastructure, coordination, information sharing, billing, accessibility etc. as one.

In particular improvements in intermodality, interoperability and integration of transport systems would support decarbonisation of transport by favouring shift to the most appropriate mode, reducing congestion, and improving efficiency and coordination in the use of the infrastructure.

When discussing the topic of intermodality, interoperability and integration of transport systems traditionally a distinction between freight and passenger transport has been maintained, as policies and research in these areas have been developed with a specific focus on the users, although in many cases the movement of people and goods is carried out using the same infrastructure or by the same transport operator. Notwithstanding the need to consider in many cases the movement of passengers and freight in conjunction, since this distinction is still maintained in the majority of policy, research and infrastructure development projects, and especially in the context of intermodality, interoperability and integration of transport systems, the rest of this section will maintain that distinction.

Considering current freight network operation, there are different levels of integration across Europe. While in some parts of Europe freight can easily move across modes with little disruption, there are other parts of Europe where mode change is inefficient. Similar differences exist in terms of interoperability of electronic and coordination systems.

The transfer of freight between modes during a journey is time and cost intensive, involving repacking, offloading and reloading, administration, and time lost due to uncoordinated scheduling etc. Notwithstanding policy and incentive schemes the market share by mode has remained stable in Europe over the years with a dominance of road transport over rail, short-sea shipping and inland waterways. The lack of integration of node specific data systems serves to reinforce the status quo and hamper modal switch.

The present situation for passenger transport is a little better, particularly in city and metropolitan areas. Here the density of population coupled with congestion, expensive real estate, and high levels of tourism justify investment in good public transport systems with improved levels of interchange between say heavy rail, metro and bus / surface transport. Outside the city areas, however, limited rural connectivity, resulting from diminishing population in rural areas and changes in production activities has reinforced reliance on cars.

3.1.4 Life Cycle Optimisation

In the last few years, lots of research projects and initiatives have emerged regarding life cycle optimisation of transport infrastructure: labelling, reuse and recycle of materials, green public procurement, clean transport strategy, etc. Most of the activity, included as DG Environment priority, has been focused on the reduction of pollutants from road vehicles and ships, development of policies on sustainable transport systems, and decoupling transport from Gross Domestic Product (GDP) growth. There remains a lack of a global approach for life cycle optimisation of the transport systems, and in particular the infrastructure elements of those systems.

Transport infrastructure is carbon intensive in its construction, especially with the use of concrete for structures, and in the use of paving materials for roads, airports and seaports. Yet it is unusual for the initial design to consider the likely service life required before the infrastructure will be modified or enlarged. If this was done, it might be concluded that the design life for the initial infrastructure could be reduced from the normal “indefinite” design life to one that better matches that of the technology to be installed or the vehicles using the infrastructure.

Many transport infrastructure owners recognise the importance of optimising the cost of infrastructure over the full lifecycle, though far fewer are in a position to manage the carbon or environmental cost over the full operational life. Of those who do have some capacity to plan the whole lifecycle cost, there are often short term pressures of affordability or programme time that drive short term suboptimal decisions.

Incentives within transport mean that new infrastructure is often financially cheaper and easier to deliver than a large scale upgrade of existing infrastructure, but with greater carbon impact. Nevertheless, the rise in modern asset management systems coupled with the commercial availability of low cost monitoring of asset performance means that Innovative construction technologies are appearing that allow longer component life between maintenance interventions. These systems are also supporting the use of more predictive maintenance, offering less disruption to users. This move towards "condition-aware" infrastructure is in its infancy in the transport infrastructure market today, but is recognised as offering large benefits financially and environmentally.

3.1.5 Operation

Most transport infrastructure types are closely operated to manage capacity, performance and safety of users. Operational activities range from mitigating severe weather (especially ice, snow and flooding), through routine control of traffic movement to ad hoc reactive response to incidents that prevent operation. For most modes the focus of operations is to obtain optimum capacity or throughput for the existing infrastructure. For rail, signalling systems are improved to reduce train headway and increase train length, thereby increasing capacity and service level. For shipping, operation is characterised by increasing efficiency and in container transport by the extensive use of automation to reduce ship dwell-time, to accommodate larger ships, and to reduce port-operating costs.

Road is unique in being an open access system – there is little or no restriction on demand. Operational control is increasing on strategic highways (Autoroutes and primary urban routes) to increase capacity and reduce frequency and severity of disruptive incidents. Automation (e.g. truck platooning) and digital technology, as a tool to increase utilisation of existing transport infrastructure, and as a means of imparting materially better user information.

While intensive operation of a transport system can increase capacity for a given amount of infrastructure, there are associated risks of disruption when part of the system fails – vehicle breakdown, extended vehicle dwell during turn round, slow down of flow in poor weather conditions, etc. The consequences of this drop in performance are poor user satisfaction, and increased carbon consumption by inefficient operation of delayed traffic. Therefore, there is a complex optimisation between quality of system performance, cost and carbon impact of additional infrastructure, and the cost and carbon impact of disrupted operations. Few infrastructure owners are in a position to take these optimisation decisions.

3.2 Today's challenges

Once the state of the art has been described, we move on to discuss the challenge facing infrastructure for all transport modes in Europe, as well as specific challenges facing particular modes.

At the top of the list of global challenges is growing demand on existing transport systems. Even though for most member states the last recession saw a period of no or negative growth in transport demand, mobility is expected to grow since it goes hand in hand with wealth and quality of life. In some countries freight transport growth appears to be being progressively decoupled from GDP. This suggests that, by increasing operational utilisation, it is possible to do more with the same infrastructure. Meanwhile for international aviation and shipping, GDP growth in other world regions can drive transport growth to and from the European Union.

There is an increasing demand for high standard of service, with growing intolerance by users of transport service and infrastructure non-availability or failure. In particular, transport systems are increasingly expected to keep fully operational during severe weather events. This demand for increased reliability is compounded by the need to adapt infrastructure to withstand more frequent severe weather events – climate change adaptation. This change is compounded by a user expectation that transport infrastructure will be available at all times and not closed for routine maintenance.

Transport infrastructure is designed for particular types of traffic flow and for specific classes of vehicle, and is then put to use for long periods of time. Yet user demands can change quickly – passenger growth on urban commuter transport is linked to employment and GDP, airport passenger flows can change dramatically as business or tourist destinations emerge or close in short timescales. In addition, the advance of vehicle technology is placing new demands on transport infrastructure for data connectivity and changing operational practices. This is placing a new challenge for transport infrastructure to be far more flexible in use and easier to adapt quickly to changing and especially rising demands.

Infrastructure is frequently underfunded for maintenance activity. Competitive cost pressure incentivises infrastructure owners to avoid necessary maintenance and asset replacement work, and public sector infrastructure owners find it hard to prepare formal business cases for maintenance that meet conventional economic appraisal criteria.

Growing digital connectivity enables individuals and freight consignors to use transport systems in different ways and to have access to large amounts of real time performance data. In some regards this can help users manage their own use of the infrastructure (through rail or highway journey information). This growing connectivity also presents challenges to transport operators and infrastructure owners as better real time information enables users to plan their own alternative routes during times of congestion or disruption – effectively removing operational control from the transport operator.

Transport systems have been under continuing pressure to improve the safety of users for many years. That pressure is continuing, especially in road transport where fatal and serious injury remain a social and economic problem. However, pressure is increasing too to reduce the risk exposure to maintenance workers and to others working on the system. Alongside safety, the owners of transport infrastructure have made substantial investments in protecting their assets against physical and electronic attack. This is likely to be an area of increasing importance in the near future.

While state governments recognise the value of new transport infrastructure, particularly for the contribution to economic activity, they are less able to make best use of their existing infrastructure. It is crucial to increase the assets´ productivity and longevity, and therefore, against the backdrop of increasing user demand, constrained financing and an ageing asset base.

3.2.1 Governance

It is the role of Governments and of governance systems to connect networks, policies and strategies at different levels (administrative, network, mode, etc.) to develop a real global transport policy. In practice this is difficult to do, especially against the more pressing priorities for governments in health, security, or education. However, a major change in this area is required if transport systems and transport infrastructure are to achieve the planned levels of decarbonisation.

The level of cooperation between public and private sectors in transport provision is usually focussed only on operational performance of the transport service. Good governance covering both public sector and private sector participants is required to incentivise both to offer better operations, and more importantly to collaborate on the reduction of operating and embedded CO_2 This can be achieved by means of providing the enhanced legal framework and supporting governments in the introduction of incentives

Until recently, transport governance has not addressed transport externalities for different modes, considering emissions, noise, waste production, protection of the environment, accidents, etc. This is a challenge for the Commission and for state governments.

While the priority in this STRIA Road Map is to reduce carbon and GHG emissions, transport is provided for the fundamental purpose of enabling mobility of people and goods, and doing so with low environmental impact. Governance of transport needs to ensure that principles of the Energy Union are compatible with mobility economic growth, employment and competitiveness.

3.2.2 Pricing, taxation and finance

Setting up a smart infrastructure charging and financing policy across modes is one of the key challenges of the EU to reach the objectives of the Framework Strategy for a resilient Energy Union with a forward-looking climate change adaptation and mitigation policy. The first step towards implementing an effective system is to define a homogenous charging system for different transport infrastructure aimed at encouraging the maximum reduction of carbon emissions, compatible with economic and financial sustainability and avoiding duplication of charging regimes. Those charging systems need to recognise the need for low cost transport networks, and to ensure that affordability does not become a barrier to achieving the Commission's wider social ambitions.

In many areas the concept of charging for environmental reasons is unpopular. Research is required to identify measures to improve the social acceptability of transport charging policies, particularly in the road sector, by better explaining its advantages to society.

Different approaches to taxation of transport fuel, both by fuel type and by transport mode, mean that perverse incentives remain for operators to use less sustainable modes and fuel sources. A tax harmonization framework for transport energy consumption would level the playing field for transport operators, and remove risk of future tax changes for infrastructure operators.

Whole life GHG emissions are not routinely considered at the planning stage for new infrastructure, and are rarely considered for upgrade or operational changes to transport. Methodologies are needed to support the most efficient use of the financial resources obtained from infrastructure charges and to incentivize measures aimed at promoting a greener mobility.

Procurement mechanisms do not adequately incentivize the industry to promote innovation to minimize carbon emission and optimize performance over the infrastructure life-cycle.

3.2.3 Syncromodality, Intermodality, interoperability and integration of transport systems

The challenges for both freight and passenger transport systems start with the need to really design and operate around customer need, and to develop customer centric transport to make intermodal transport work. This in turn should lead to a reduction in the currently unacceptable lack of integration between transport modes.

With this lack of integration across transport modes, the level of service resilience is relatively unplanned and is inadequate. Coupled with insufficient attention to users' specific needs for the start and end of journeys – the first and last mile – independently planned and operated modes act as a real deterrent to modal transfer and the use of the environmentally optimum mode.

The growth of digital systems and mobile information means that transport users, and increasingly the transport operators, demand more timely and accurate provision of information, with that information provision spanning across modes

A further challenge to the development of integrated transport solutions is the lack of adequate business and financial models that support the development of intermodal, interoperable and integrated transport systems. A combination of policy making, infrastructure ownership, licencing and commercial objectives leaves commercial operators to work on a strictly modally focussed basis. This has continued even where different modes are operated by the same parent or group company.

Freight transport bears all the challenges of poor system performance, poor resilience and first/last mile problems described above. Because of the nature of the goods being carried, freight can quickly become the poor relation to passenger movements and thus bear a disproportionately high part of those factors. In addition, the nature of freight flows from producer to consumer means there are imbalance problems in container systems for intermodal transport, resulting in large scale empty container movements.

Passenger systems also suffer the common integration and intermodal challenges, often because networks have been developed for single modes and are not suitable for changing user needs and integration with other modes;

Probably the biggest challenge for passenger transport operators is to provide much better journey planning and travel information for users in easy to use formats. This data will then help operators and users alike to develop better processes for managing the transfer between routes or modes, including providing easy payment or ticketing systems working on a “pay once per trip” basis.

3.2.4 Life Cycle Optimisation

One of the biggest challenges facing transport infrastructure and the decision to invest money and carbon in infrastructure is to only build the infrastructure that is really required. Better operational practice, combined with full exploitation of digital and control technology mean that new infrastructure is not necessarily the correct option. Strategies like autonomous driving, demand management, improvement of air traffic control or implementation of European Rail Traffic Management Systems are examples of best practices with a high potential to maximize asset utilization, yet infrastructure owners are poorly placed to best anticipate how these developments will impact their systems.

The infrastructure design phase often considers carbon and emissions only for the original construction phase. The carbon intensity of operation, maintenance and eventual decommissioning is not routinely considered, and there is often a view that infrastructure designers can do little to influence the overall emissions from use of the infrastructure over subsequent years.

Transport infrastructure and energy networks are generally designed independently, yet are wholly interdependent for many years of subsequent operation.

There are few incentives in place, either financial or reputational, to design infrastructure to truly integrate with its environment.

3.2.5 Operation

The operation of transport infrastructure is the area most affected by digital technology, and by rapid changes in demand or in required service standards. Transport infrastructure needs improved operating resilience, whether avoiding vulnerability to single system or component failure - especially on rail systems that are intrinsically dependent on multiple critical systems - or increasing protection to planned attack. Meanwhile the impact of climate change is driving asset owners to adapt their infrastructure, particularly to increase resistance to high intensity rainfall and flooding events.

ITS systems have the potential for more efficient operation of transport systems, but their benefits are impacted by the high cost and relatively short life of Information and Communication Technologies (ICT), while uncertainties on how vehicle automation will affect operation of open systems means that infrastructure owners are finding it hard to plan investments with confidence.

For rail, the transition of railway signalling from conventional systems to fully digital railway with European Rail Traffic Management System (ERTMS) moving block principles is a once in a lifetime opportunity to increase capacity. But this opportunity comes with the risk of bespoke national / member state solutions and high cost eroding many of the potential benefits.

Overall, these pressures on infrastructure owners drive them to increase redundant capacity in order to provide resilience, and to increase flexibility in the infrastructure parts of the transport system. This in turn increases the carbon cost associated with infrastructure, though at the potential of limiting the excess emissions arising during disrupted transport operation.

3.3 Links with other Road Maps

This Transport Infrastructure Road Map links with all other Road Maps being prepared in this programme. Taking the Road Maps in turn, the key links are:

3.3.1 Traffic/Network management

The efficient use of infrastructure is achieved through traffic and network management; firstly to maximise the throughput of movements by reducing headway, reducing dwell time and stops, and improving turnaround time at the end of travel legs; secondly, by improving the resilience to unplanned incidents and then speeding up the recovery to full service after such an incident. In addition, traffic management includes the means of charging for use of the transport network, and thereby incentivising the use of lower carbon options. As noted above, there is a real trade-off between reducing the extent of infrastructure and thus the embedded carbon against the mitigation of additional emission of GHG at times of disrupted operation.

3.3.2 Connectivity and Automation

Improving connectivity and automation between modes is a relatively undeveloped aspect of transport systems. Connectivity is better developed for freight transport, and is partly developed for urban passenger transport in some cities. In general, connectivity for passenger transport between road and main line rail is undeveloped.

3.3.3 Electrification

While railways have a good proportion of routes electrified, there remains potential to increase electrification to a higher proportion of the network across Europe, and to harmonise on common standards for electrification and train control. To achieve optimum decarbonisation of the rail infrastructure, it will be necessary to switch more of the electricity generation systems to low or zero carbon sources.

Electrification of the road vehicle fleet is starting to be seen as a credible change. The most important link, though, is with the design and provision of a road vehicle charging network based on standardised charging systems and reliable access for users on a “when required” basis. For conventional vehicles using fossil fuels, the re-fuelling network is developed and operated by the private sector. Steps to create a network of charging points for electric vehicles has to date been led by public authorities by providing incentives or by procuring charging points. There is however little evidence that road infrastructure owners are accepting the role of providing charging points, or that they will eventually do so. Therefore there is a continuing uncertainty on the responsibilities for providing or enabling electric vehicle charging networks.

3.3.4 Alternative Fuels

The introduction of homogenous carbon charges to energy production used for transportation purposes will be crucial to promote a more rapid penetration of alternative fuels. The development of alternative fuel sources for the various modes is most likely to be steered by vehicle manufacturers. Infrastructure owners are likely to be reactive to such developments, and not play a central role.

3.3.5 Smart mobility

Infrastructure pricing and financing approaches, along with other policy measures, are essential for promoting smart mobility. On the one hand integrated ticketing has to allow for the different carbon intensity of the transport modes. On the other hand, one of the most important challenges of smart mobility is being financially attractive from the outset. Finally, there is a need to guarantee a connection between smart rural and smart urban mobility.

Shared (or crowd-sourced) mobility is arguably the most rapidly growing and evolving sector of the sharing economy. When it comes to this kind of mobility, centralised thinking and 'traditional' transport planning can do only little: citizens must step in and fill in the gaps at neighbourhood level by co-creating mobility solutions. There are already enough assets to work with: existing private and commercial vehicles, transportation grid, tracking and measurement capabilities, smart devices, and so on.

3.3.6 Vehicle design and manufacturing

The design and capability of vehicles is intrinsically linked to the design of infrastructure, and varies significantly across modes. For closed systems such as rail and aviation, infrastructure is specifically designed to accommodate particular design of vehicles, and is adapted as new vehicle types are developed. In open systems as shipping and road transport, vehicles are designed and developed independently of the infrastructure to operate on the available infrastructure networks. Over time, those infrastructure networks are adapted to increase capacity, and to operate more safely given the capabilities of the vehicles and the vehicle operators using those networks.

In the case of roads, car and truck manufacturers design and produce common products for sale in global markets. Therefore it is not credible for the road network of one national or local operator to be tuned to suit one particular technology. Nevertheless, as vehicle automation increases and energy supply requirements change, the operators of the most heavily used strategic networks in each member state will have to adapt their own roads to suit the emerging vehicle requirements.

4. Achieving policy objectives and targets

The preceding chapters in this report have analysed the current status of transport infrastructure across the European Community, and the challenges that infrastructure owners face in meeting the demands of transport operators and users. This chapter identifies some of the measures that can be taken to meet these challenges. While the primary purpose of this Road Map is to support the policy objective of decarbonising transport systems, the proposed measures do also support a wider range of EU social and economic policy objectives including making transport affordable for citizens, making transport systems easily accessible to support diversity and opportunity, and making transport systems environmentally cleaner.

4.1 Governance

Within transport infrastructure, the purpose of Governance is to encourage infrastructure owners, transport operators and users – passenger and freight – to make the right decisions that support the EU policies. To this end there are a number of areas where the Commission might promote Research and Innovation to best effect.

Research should particularly consider the new technology based tools, including social media channels, that will **engage the population in shaping local proposals for decarbonisation** – either through charging or through other initiatives to change travel patterns.

Transport projects and transport infrastructure are usually appraised on the basis of individual projects, and primarily on economic and affordability criteria. **Decarbonisation should be considered as a key variable for the planning process**, both at project level and at a higher transport policy level. Research investment should be considered for developing infrastructure project appraisal tools, applicable to all kind of transport infrastructure, that prioritise alternatives promoting decarbonisation, not only for the infrastructure itself, but also for use through the whole life cycle.

Governance measures are necessary to set energy policies across transport, and thus for infrastructure. Governance tools include **regulation on energy provision, standardisation, and taxation**. Policy will also determine the role that infrastructure owners will play in either providing or operating alternative energy distribution networks to transport. The most significant area is in electrification of road transport, where policy on provision and on cost recovery for vehicle charging is required.

While decarbonisation of transport infrastructure is a high priority, so adaptation of that infrastructure to be more resilient to the effects of climate change is also important. There is a proliferation of initiatives by various infrastructure owners into the climate change adaptation, but development of a common EU tool for the **assessment of transport infrastructure vulnerability in natural or man-made disasters** would be beneficial in setting best practice across member states, and would be available to the very large number of transport infrastructure owners such as local government who do not have capacity to research and define standards for themselves.

Innovation is needed to **strengthen transport planning and provision across regional and state boundaries**, both for strategic network planning and at an operational level. More effective governance will support investment in better quality transport links across those borders, and will support better operation to make services more frequent and more reliable.

Transport users demand reliable and cost effective transport systems. While there is often popular demand, especially at the political level, for investment in new high profile projects it is often more sustainable and cost effective to invest in the maintenance and improvement of existing infrastructure and systems. Improved governance processes, including improved appraisal criteria, will **highlight the greater carbon efficiency of infrastructure reuse and the potentially greater cost efficiency** too (which in turn means lower cost to users).

Research and Innovation is an essential aspect of good transport infrastructure management. However, research budgets are restricted – especially for publically owned infrastructure organisations – and innovation is often targeted on meeting short term operational, capacity or reliability problems. **Stronger governance is necessary to encourage research into the medium and long term reduction of carbon in transport infrastructure**. That governance should then incentivise the application of that research to full effect.

4.2 Pricing and Taxation Finance (Incentives)

The use of charging mechanisms in transport varies widely between modes, and takes the form of direct user charges, or taxation, or a mix of the two. The use of charging as a means of paying for transport infrastructure is widely accepted, whereas the use of taxation or indirect charging to encourage behavioural change is not so widely accepted.

A priority is to **set a strategy for improving public awareness towards infrastructure pricing** in order to overcome one of the most important barriers to its implementation: public opposition to this measure. That strategy should guide European governments as they replace current energy taxation approaches by more homogenous and rational charges that incentivise a reduction in carbon emissions. This measure is aimed at overcoming the inertia of European governments to change the traditional taxation approaches to fuel fossils.

Measures to achieve decarbonisation and wider EU policy objectives should include extensive research to define a **means for implementing a homogenous carbon charging approach for all transport modes** in Europe in order to guarantee the maximum decarbonisation compatible with the fair competition and seamless integration among modes.

Alongside pricing to reflect the cost of carbon by mode, the commission should consider further research into **incentivizing the use of infrastructure in the off-peak periods** where there is more capacity available. This would have the dual benefit of reduced CO_2 emissions in the peak periods as congestion reduces, and mitigating the demand for new infrastructure and the embedded carbon that comes with infrastructure building. There are recent examples of congestion charging being introduced, with the best known examples being London and Stockholm. However, there are many more places where congestion charging has been rejected, either by political representatives or by referendum. Further research work is required to determine **how to secure public support for road charging based on congestion and environmental criteria**.

An important area for early assessment and policy making will be on the question of **taxation on vehicle fuels**. At present electricity for electric vehicles is taxed at much lower rates than traditional fossil fuels, regardless of how it is generated. This acts as an incentive towards uptake of electric cars and vans, but over time the revenue from vehicle use will decline substantially. That has the potential to increase demand for road transport further, with associated congestion and thus demand for road building.

Public transport ticket systems could be better integrated between modes and between operators. Technology exists and is proven for electronic charging to be made directly from users' accounts via contactless payment card, obviating the need for ticket based travel. Yet despite the advances in technology, individual transport operators in both the public and private sectors continue to develop incompatible travel card or toll collection systems. Research and innovation into both passenger public transport and road vehicle charging systems to give genuine interoperability will improve the acceptance of user charging, encourage transfer between modes, and reduce operating costs.

4.3 Syncromodality, intermodality, interoperability and integration of transport systems

User needs, whether passenger or freight, are essentially agnostic to which transport mode they use. Despite this, transport infrastructure is planned and managed in a single mode way, and most transport operations have little or no integration between the modes. To improve customer service, to extract much better efficiency on use of infrastructure, and to reduce transport carbon a heavy focus on intermodality and integration of systems is necessary.

The rapid development of **ICT systems** will enable big developments in the **integration of information in ticketing, journey planning, and traffic and congestion management**. This will enable users to make better modal decisions and the improvement of interoperability across networks. Improved management, operations and maintenance through the interconnectedness of mobile sensors, mobile applications and in general the opportunities offered by the Internet of Things (IoT) so that transport service providers, users and authorities can improve the visibility of transport processes.

As identified in the challenges section, total journeys run from an origin point and arrive at a destination point, and often neither of these is on the optimum network. Whether for passenger or freight, consideration of this first mile / last mile factor is important. The aviation industry may be a good reference point, as airports are by definition modal interchanges with excellent road and rail transfer options for air passengers and air freight.

Co-modality and synchromodality will penetrate further in logistics, so that shippers will increasingly book a-modally and transport and logistics service providers, under the supervision of a supply chain manger or integrator, can contribute to a synchromodal solution. Innovating to use **Blockchain technology** in the supply chain and logistics would allow for a real-time planning of inventories, passenger flows, equipment and routing.

There is a pressing need to **integrate multimodal transport nodes in metropolitan and urban areas**. In one aspect this will require innovative building and planning solutions where architects, urban planners, developers, regulators and society come together. But it will also require closer management of all transport systems, with road, rail, bus and metro all under the strategic command of one transport authority. That authority is then empowered to prioritise between the different modes, and to introduce standard charging and ticketing systems across the full network to simplify use.

The uptake of unconventional transport systems both for freight (e.g. drones) and passengers (e.g. biking, automated vehicles) will require **rethinking of intermodal nodes**. Research into the optimum density of freight distribution points may be useful. However, the innovative use of new technologies and systems will require authorities and governments to think a long way ahead -there is a risk that innovation to solve problems of congestion, speed of delivery or other areas of commercial competition have the unintentional by-product of increasing carbon consumption.

4.4 Life cycle optimization

Digital and systems technology is developing rapidly, yet is not fully utilised in the planning, operation and maintenance of transport infrastructure. ICT and digital systems offer big opportunities for improved service through management of traffic flow, integration across modes, direct user charging, and for real time monitoring of asset condition. Similarly developments in vehicle technology, particularly in the automation of vehicles, offer the potential for more efficient use of infrastructure capacity and the reduction of unplanned disruption. **Integrated planning of the transport infrastructure in a way that anticipates and exploits this increasing level of operational and vehicle technology** has the potential to reduce the amount of new build infrastructure required, and to operate the existing infrastructure in a more efficient manner.

Considering transport infrastructure specifically, the development of low cost monitoring devices and data storage is leading to a growing ability for **close infrastructure asset monitoring**. Where infrastructure is fitted with monitoring devices its condition can be monitored in order to better plan maintenance interventions only when necessary, and it's performance under actual traffic or loading conditions can be recorded, leading to better utilisation.

With the growing demand for digital communication to and from moving vehicles, there will be a related demand for a **much higher capacity digital infrastructure to carry the operational digital data** as well as users own demands for data on the move. In most cases it will be for transport infrastructure owners to ensure that this digital capacity is provided, including the high quality secure digital infrastructure that will be needed for operating their particular systems.

Develop alignment criteria for infrastructure aimed at minimizing carbon emission over its life-cycle. The measurement of carbon expended in the construction, maintenance, and eventual deconstruction or recycling of infrastructure is un-developed. While whole lifecycle costs are commonly considered for financial purposes, it is unusual to do so for carbon. As part of a whole life carbon approach, the Commission should consider whether a form of energy labeling for transport infrastructure, or more likely for the whole transport system, would be a useful means of helping passengers and freight shippers make informed transport decisions.

While there are many initiatives in progress or being planned to increase the energy efficiency of transport, and thus to reduce the carbon emissions, planning of transport infrastructure is usually carried out independently of planning for national and regional energy networks. To achieve the optimum overall carbon consumption of the system, **improved integration of transport infrastructure and energy systems** is necessary.

4.5 Operation

The first aspect of transport operations to help reduce carbon is to **operate each mode or system in as efficient manner as possible**, using operational measures to increase capacity or throughput. In a managed system such as ports, airports and rail the timetabling or scheduling of movements means that maximum productivity can be achieved for a given amount of infrastructure before investment in additional infrastructure is contemplated. This approach does minimise the amount of carbon embedded in infrastructure construction and used in maintenance, but may come at the expense of reduced flexibility or spare capacity to meet peak demand or to accommodate disrupted traffic flows. One area for useful research would be to **understand better the carbon trade-offs between investing carbon in excess infrastructure capacity, and the carbon used by traffic movements delayed by congestion or disruption** while the infrastructure operates at full capacity.

For all transport networks, **advanced operational systems that monitor traffic flow also enable rapid detection of disruptive incidents**, enabling the network manager to respond quickly and return the system to normal working condition.

For roads, ITS functionality brings high levels of driver information and traffic control. This enables a road operator to manage speed and traffic flow to maximise throughput on a route. Nevertheless, road transport for passenger and freight remains an open access system where the network operator has little power to regulate flows to optimum levels.

For rail, the move towards fully digital train control systems is a long overdue move away from 19th century principles of train management. There is potential to very substantially increase the capacity of rail routes using digital train control, and there is also the opportunity to do this in a way that is consistent and genuinely interoperable across all member states. The main challenge for moving to a digital railway is the very long timeframes being considered by most infrastructure owners. There is real opportunity to innovate the deployment of genuinely digital railway operations in order to release capacity at a much earlier stage.

Current ITS systems tend to be independently configured, and are frequently bespoke developments for specific national or regional applications. The working life of ITS and control systems is also relatively short – as little as 10-25 years – and much shorter than the life of the infrastructure itself. A move towards **more standardised commercially available ICT systems** should bring advantages of quicker system delivery and configuration, and lower unit cost through economies of production scale.

From a user perspective, the most important innovation for transport operations is to **improve the integrated operation across modes**. Better multimodal operation planning and information provision will make it easier for passengers and freight to switch between modes. Innovations include open sourcing network operational data in real time for independent application developers to use innovation to exploit this and other sources of data, and universal payment (ticketing) channels that mean users do not need multiple ticket types or multiple account registrations to travel.

4.6 New Innovations

Many of the routes for better transport operation and reduced carbon emissions are based on innovating current technologies and systems. But for the step change in carbon emission that is required, there need to be some altogether new innovations too, **innovations that change how people use transport**. The Commission should continue to support research that may identify new technology that might offer just such a breakthrough, and to research the application of existing technologies to make them commercially and operationally viable.

One such innovation is the concept of **Mobility as a Service**. This has been developed at a modest level in some areas through on demand car sharing, or e-hailing systems. However the concept of the car becoming a personal surface transport module interesting – where vehicle automation enables easy access to on demand vehicle for (say) use in suburban or rural environments for the last stage of a rail mainly rail journey. Such a concept would enable modal shift to happen for many more journeys than is currently the case, and would make the total vehicle fleet much more efficient than at present.

5. Strategic implementation plan

In order to support the objectives of Energy Union 2050 and targets set up in this Road Map, actions described below are included as part of a Strategic Implementation Plan; they should be balanced and coordinated with other actions included in other STRIA Road Maps (Traffic/Network management, Connectivity and automation, Electrification, Alternative Fuels, Smart Mobility and Vehicle Design and Manufacturing).

The Strategic Implementation Plan should be revised periodically, in order to provide an answer to the new mobility challenges that will appear in the following years. Horizon 2050 is too far to assume that transport systems, services, business and performance will be similar to the existing ones today. EU community (EU institutions, Member States Governments – and regional and local ones - but also industry and other stakeholders, such as citizens) will need transport infrastructure for the new mobility demands of passengers and goods.

A first classification of areas of work has been done, according to the existence of a significant technological component in the Research & Innovation priority area; thus, those areas of work with more technological load will be linked to a higher effort in R&I and participation of academia and private sector, while other areas of work with a low technology presence will need political commitment, development of legal frameworks and other actions at a policy / strategic level, being more public-oriented.

5.1 R&I priorities involving actions at a policy / strategic level.

The following priorities are envisaged:

Area of work	***SYSTEMIC ANALYSIS***
Target	Ensure a **global consideration of transport systems as a whole** for decarbonisation aims, not only for infrastructure life cycle, but also for intermodal effects.

Strategic implementation plan	
Action	Time horizon
✓ Create a platform of collaboration among standardization bodies and European institutions, in order to develop a common vision for a systemic transport system, ensuring coordination of appraisal, procurement and standardization activities.	2017-2018
✓ Identify regulatory incentives and barriers that are stopping a better use of infrastructure.	2017-2018
✓ Consider decarbonisation as a key variable for the planning process; support research for the development of infrastructure project appraisal tools that prioritise alternatives promoting decarbonisation.	2020
✓ Develop a methodology for a systemic cost-benefit analysis, including decarbonisation objectives and costs, as well as other externalities, for all transport infrastructure projects, during the whole life cycle, including system and intermodal effects. Benefits of infrastructures should be considered at a local/regional/national and European mobility levels.	2020
✓ Gain a better understanding on carbon trade-offs between investing carbon in excess infrastructure capacity and the carbon used by traffic movements delayed by congestion or disruptions.	2020
✓ Standardize the systemic cost-benefit analysis to reach a homogeneous implementation.	2025
✓ Develop policy orientations for the wide implementation of the systemic cost-benefit analysis in Member States.	2025
✓ Support the development of the tools for systemic cost-benefit analysis to facilitate the use of this technology.	2025
✓ Develop policy orientations to promote a global policy for the reuse and recycle of materials for transport infrastructure during its whole life cycle	2025
✓ Strengthen transport planning and provision across regional and state boundaries, ensuring better quality transport links across borders.	2025

Proposed KPI	- % of infrastructure projects under the systemic cost-benefit analysis. - Number of units (e.g. tonnes) of reused and recycled material utilized for transport infrastructure construction and upgrading. - Subsequent saving in carbon emission and energy consumption derived from the utilisation of reused and recycled material.

Area of work	***TRANSPORT PRICING***
Target	Develop a homogenous EU **carbon charging approach for all transport modes** in Europe in order to guarantee the maximum decarbonisation compatible with the fair competition and seamless integration among modes.

Strategic implementation plan	
Action	Time horizon
✓ Define the methodology for carbon charging, and homogenization of carbon taxation, including other environmental issues such as noise, land use, etc., as well as a potential redefinition of vehicle taxes.	2020
✓ Use of big data and activity based models to better understand users' reaction to charging in order to fine tune infrastructure pricing strategies towards encouraging decarbonisation.	2020
✓ Develop an EU Directive for carbon charging.	2025
✓ Setting up of a strategy for Governments and citizens to overcome public inertia to this measure, putting transparency as the centre of the messages.	2025

Proposed KPI	- Social acceptance to carbon charging (surveys). - % of transport network under carbon charging in 2030, 2035, 2040, 2045 and 2050. - % of European countries with homogenous carbon pricing approaches. - Revenues from carbon charging effectively applied on decarbonisation policies.

Area of work	*INTERMODALITY*
Target	**Upgrade the existing EU strategy for intermodality**, synchromodality, interoperability and integration of transport systems from a customer perspective, highlighting the objectives for decarbonisation, with the final objective of integration of transport infrastructure, not only in rural areas, but also in urban ones.

Strategic implementation plan	
Action	Time horizon
✓ Conduct an analysis of the main weaknesses and bottlenecks for a real transport integration, interoperability and intermodality, from the customer perspective; analyse the potential of synchromodality.	2020
✓ Integrate information in ticketing, journey planning and traffic and congestion management, in order to support better modal decisions and improve interoperability across networks.	2020
✓ Ensure that public transport ticket systems are properly integrated between modes and operators.	2020
✓ Development of demonstrators and small scale implementation, in order to show technologies and new forms of information sharing needed to improve the integration of transport systems, challenges for intermodal nodes, etc.	2025
✓ Develop policy orientations for EU transport integration, synchromodality, intermodality and interoperability.	2025
✓ Promotion of infrastructure development taking into account trends in logistics: focus on new infrastructure that allows fast transhipment of modular load units.	2025

Proposed KPI	
	- % of total length of Trans European Network with a minimum standard of intermodality and interoperability. - Number of connected mobility control centres.

Area of work	*ADAPTABILITY*
Target	Ensure transport infrastructure is able to **adapt its performance to the continuous advances** which happen and will appear in the future, thus allowing new mobility services for passengers and goods.

Strategic implementation plan	
Action	Time horizon
✓ Create a collaboration platform for public and private stakeholders in transport, in order to ensure that steps taken by the services providers and industry are in accordance with transport infrastructure advances, while keeping safety and security at the backbone of the service.	2020
✓ Develop a map of priorities for common agreement (e.g. infrastructure required for new fuel vehicles and electric vehicles or autonomous driving).	2020
✓ Create better connectivity from industry to the transport network.	2020

Proposed KPI	- Degree of satisfaction of stakeholders involved.

Area of work	*INFRASTRUCTURE BREAKTHROUGH*	
Target	Create the **framework to allow the required infrastructure breakthrough** to face the challenge of the mobility of the future.	
Strategic implementation plan		
Action		Time horizon
✓ Introduce decarbonisation incentives (as well as other environmental implications such as noise or land use) in procurement processes, in accordance with Green Public Procurement, Innovation Public Procurement and other future initiatives, thus allowing the creation of new products and services		2020
✓ Develop a legal framework for the implementation of the incentives in procurement processes		2025
✓ Develop an EU labelling system for transport infrastructure, incorporating objectives of Energy Union, based on existing EU-funded initiatives and results.		2025
✓ Ensure that Research and Innovation activities are linked with policy objectives for decarbonisation of transport infrastructure and, at the same time, still keep the European Transport Industry in its key position for competitiveness		2020
✓ Prioritize technologies for carbon capture and storage, as well as conversion of carbon in other products.		2020
✓ Provide a space for non-conventional innovation in Research Programs, including, for example, donations or crowdfunding for financing, blockchain technology applications in passenger and freight logistics.		2020
✓ Develop new contractual performance indicators, incentives, innovation, technology, etc. aiming the reduction in the number and consequence of transport accidents, considering not only infrastructure but also human behaviour.		2020
Proposed KPI	- New niches for R&I identified yearly in collaborative platforms. - Trends in safety – Serious incidents; Killed and Seriously Injured.	

Area of work	*SOCIAL ACCEPTANCE*	
Target	Gain **social support for decarbonisation decisions** taken at a European level, based on transparency and information to citizens.	
Strategic implementation plan		
Action		Time horizon
✓ Develop new participation processes to gain social acceptance for policy options of decarbonisation strategies (going beyond the traditional public consultation).		2025
✓ Create a platform for transparency for EU decarbonisation transport-related matters, gaining social awareness on this field of work.		2025
Proposed KPI	- Degree of satisfaction of industry stakeholders and citizens (surveys).	

5.2. R&I priorities with significant technology component

The following priorities are envisaged:

Area of work	*CAPACITY*	
Target	Encourage and support Member States in the **maximization of asset utilization** for transport infrastructure and system, ensuring that policies lead to a carbon reduction.	
Strategic implementation plan		
Action		Time horizon
✓ Develop policy orientations for ICT for decarbonisation of transport infrastructure.		2020
✓ Establish infrastructure for information and data collection and management to monitor the performance of the infrastructure (asset utilisation rate).		2025
✓ Develop technologies for the reliable anticipation of peak hours and effective provision of alternatives for passengers and goods, trying to balance lack of capacity in certain modes with exceeding capacity in others.		2025
✓ Develop the required standards for the implementation of trade off with CO_2 emissions in all means of transport for the whole life cycle.		2030
✓ Support technology evolution to accelerate the rapid deployment of new business models.		2030
Proposed KPI	- Number of hours of congestion / delay for selected itineraries. - Subsequent saving in carbon emission and energy consumption derived from congestion reduction.	

Area of work	*ENERGY*	
Target	Facilitate a **progressive reduction of energy consumption of transport infrastructure** in the whole life cycle and from a systemic and intermodal perspective.	
Strategic implementation plan		
Action		Time horizon
✓ Advance regulation on energy provision, standardization and taxation, especially considering the role of infrastructure owners in providing or operating alternative energy distribution network (such as electrification).		2020
✓ Improve the presence of innovative fields of work in Research Programs, such as energy harvesting, implication of proper maintenance of road infrastructure in energy consumption and carbon production, etc.		2020
✓ Incentivize the reduction of energy consumption and energy generation during each stage of transport infrastructure in procurement processes.		2025
✓ Support improved integration (national, regional) of transport infrastructure and energy systems is necessary.		2025
Proposed KPI	- % of energy consumed in transport which is own-generated by transport itself.	

Area of work	***OPEN DATA***	
Target	Facilitate the **creation of added value services** for transport stakeholders and final customers based on the collection of data from multiple sources.	
Strategic implementation plan		
Action		Time horizon
✓ Develop technology solutions for the proper and effective data collection from decentralized sources, including mobile devices, and the creation of new customer-oriented services.		2025
✓ Ensure that open data collection and use is balanced with the required security issues regarding transport performance, and privicay of personal user data.		2030
Proposed KPI	- Connected mobile devices used for mobility purposes.	

Area of work	***RESILIENCE***	
Target	**Improve the capacity of transport infrastructure to withstand disruption, absorb disturbance and adapt to changing conditions under extreme circumstances**, due to climatological, man-made or other effects.	
Strategic implementation plan		
Action		Time horizon
✓ Identify and categorize main hazards to be considered for transport infrastructure resilience, as well as organizational and technical dimension of resilience.		2025
✓ Develop methodologies and tools to measure the resilience of transport infrastructure.		2030
Proposed KPI	- Number of incidents and events causing disruption and quantification of its effects.	

6. Identification of the public and private roles

Transport systems are complex in their design and operation, and are subject to a high degree of public sector ownership, operation or regulation. This public sector participation applies to much of the transport infrastructure across modes, applies to transport operations for many railway systems and to operations for many urban or city metro and bus systems. Where private sector organisations own or operate transport systems this is frequently under regulated arrangements. As a result, the public sector has a large role to play in either directly investing in research and innovation to reduce infrastructure carbon, or working through its industry regulators to set the right controls or incentives for private sector operators to make those investments.

The predominant role of the public sector in leading the development of infrastructure is generally justified on the grounds of the long-lived nature of infrastructure, the often large capital that needs to be raised to build infrastructure, the high user demand, environmental and political risks associated with certain projects, and the public interest nature of most types of transport infrastructure. As a result of deregulation, tighter public budgets and the increasing specificity of certain infrastructure, options have been developed to involve the private sector through public-private partnerships (PPP).

The private sector, however, is increasingly being called to complement the role of the public sector not only as a contributor and often as a main source of finance for the construction and maintenance of the infrastructure but also in terms of research and innovation. The European transport industry is the largest industrial R&D investor in the EU. Investment in transport-related R&D increased from €38.2bn in 2008 to €42.8 bn in 2011[1]. Of this transport infrastructure amounted to approximately €200 million only underlying the limited performance of the construction sector in terms of research (R&D intensity of less than 0.3)[2]. Therefore new methods need to be identified for a better inclusion of the infrastructure sector in transport-related innovation projects.

In general the role of the public and private sector should be such so that the most suitable party bears the risks associated with the innovation and adequate incentives exist in terms of tendering provisions so that efficiency and innovation ensue. There is also evidence of the limited innovation potential of public agencies[3] and there is an urgent need to identify how to include innovation in national and European transport agency work processes. The inclusion of national and local agencies, infrastructure providers and regulators in transport projects has been a first attempt to increase the penetration of innovation in policy decision, although often public bodies participation has remained only on paper. Particularly relevant is the need to coordinate and harmonize research efforts in order to minimize duplication.

Within the broader issues discussed above specific roles can be identified for the European Commission, Member States and the private sector.

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[1] Tobias Wiesenthal, Ana Condeço-Melhorado, Guillaume Leduc, Innovation in the European transport sector: A review, *Transport Policy*, Volume 42, August 2015, Pages 86-93, ISSN 0967-070X, http://dx.doi.org/10.1016/j.tranpol.2015.05.003.

[2] Notwithstanding the difficulty of capturing innovation processes in the construction sector, traditionally dominated by heuristics and tacit knowledge, the low R&D intensity is confirmed in a variety of studies at a local and international level e.g. NESTA, Hidden Innovation – How innovation Happens in Six 'Low Innovation' Sectors, National Endowment for Science, Technology and the Arts (NESTA). Research report (2007); OECD, 2009. Responding to the Economic Crisis-Fostering Industrial Restructuring and Renewal, Industry and Innovation, OECD (July 2009).

[3] Anthony Arundel, Luca Casali, Hugo Hollanders, How European public sector agencies innovate: The use of bottom-up, policy-dependent and knowledge-scanning innovation methods, Research Policy, Volume 44, Issue 7, September 2015, Pages 1271-1282, ISSN 0048-7333, http://dx.doi.org/10.1016/j.respol.2015.04.007.
(http://www.sciencedirect.com/science/article/pii/S0048733315000670)

6.1 Role of the European Commission

The Commission should set overall policies to meet decarbonisation goals, including setting emissions limits for vehicles and for infrastructure, and should set standards across transport for interoperability of vehicles, and develop a standard market for infrastructure systems and components.

The Commission should also set overall taxation guidelines including providing incentives for harmonisation especially in those cases where transport modes compete at an European or international level.

Incentives for public sector and regulated private sector organisations to invest in research is low. The Commission should develop, support and monitor R&I projects with particular attention to transport infrastructure and within the construction industry and its public sector clients.

The Commission is best placed to develop specific guidelines aimed at improving harmonisation and coordination of projects with a European impact and potential so that lessons can be more easily transferred among countries and operators.

Fostering the development of network effects across borders to favour low-carbon modes of transport is a role that only the commission can lead, as its work to ensure comparable levels of mobility and quality of transport infrastructure across the full European network.

Specific interventions that the Commission should consider include:

- Continued support in terms of incentives to R&I, TEN-T, CES and other financial instruments in an accessible manner especially for small and medium enterprises to overcome perverse transport incentives;
- Develop market-based measures that can contribute to changing user behaviours at an EU level;
- Sustained effort in defining clear regulation on emission budget per transport sector and further elaboration on Intended Nationally Determined Contribution (INDC);
- Sustained effort in defining regulatory standards for new technologies and alternative fuels to minimise uncertainty on regulatory compliance.

6.2 Role of Member State public sector including regulatory authorities

Member States develop and implement national transport policies within the context of overall EU goals. As part of this, member states should prepare national level transport decarbonisation strategies, including approaches to infrastructure decarbonisation.

Whether infrastructure is operated by public or private sectors, member states need to develop innovative business measures to reduce carbon aligned with international best practice and commission research where the private sector is unable to do so.

Member states are in a strong position to ensure equitable access to mobility and transport, and that the costs of transport systems, including the infrastructure, are kept as low as practicable consistent with good reliability and performance.

Specific Interventions should include:

- Drive the commercialisation of key renewable energy sources;
- Integrate renewable power generation and carbon capture and storage technologies in the infrastructure;
- Integrate public sector support to R&I and other instruments necessary for infrastructure development, fuel transition, etc.;

- Ensure necessary infrastructure is built, maintained and operated with appropriate levels of marginal capacity to accommodate changes in use or demand;
- Ensure the transition to sustainable transport is financed.

6.3 Role of Private Sector, including Public / Private Partnership

The private sector can increase its investment in capital infrastructure and equipment, and increase its focus on developing transport infrastructure with much better carbon performance.

It is too easy for private sector investors to consider only financial performance. The best in the sector balance social and environmental impact alongside commercial criteria in business operating and investment decisions, and in developing innovative operational changes.

Where the market incentives support innovation and research, the private sector should actively seek out and invest in new research that carries medium and long term business advantage

The private sector should consider more collaborative behaviour, and use industry sector organisations and trade bodies to orchestrate research and innovation for the benefit of all member companies.

Private sector enterprises respond effectively to Regulatory measures to support long term improvements in environmental performance, and should play a stronger part in developing those measures with their regulatory bodies.

Specific focus to include:

- The support to the development of innovative business models to better incentivize private investment in infrastructure.
- Assess the inclusion of user-based financial mechanisms in innovative transport (infrastructure) solutions.

7. Resources and Financing

For the effective implementation of this Road Map it is crucial to define the financing sources necessary to undertake the actions outlined in the strategic plan. One of the most critical aspects of infrastructure financing is obtaining the necessary resources for the maintenance of transportation infrastructure. This is important as more effective maintenance, performed on condition, in faster time with reduced effort would likely have relevance on transport decarbonisation.

Another issue that is important in dealing with financing is the need to promote transparency in the use of funds either budgetary or private. A better knowledge by the society on how resources are allocated can effectively contribute to create public awareness on the cost of infrastructure that may help policy makers justify their decisions.

7.1 Sources of funds

The way to draw resources can be analysed from a twofold point of view: funding and financing approaches. Financing refers to the agents who will disburse money upfront to cover the initial investment required; while funding refers to the agents who will pay the infrastructure cost in the end. Financing sources may be:

- budget grants provided at different government levels (EU, national, regional, local, etc.),
- financial securities (equity and debt) that expect a certain profitability in the future:
  - from the European Investment Bank (EIB),
  - from private banks,
  - from capital markets (bonds, venture capital funds, infrastructure funds etc.).

Governments and multilateral banks may also contribute to facilitate private financing by providing guarantees to risky projects that are expected to have a high social value over its life cycle. This is a means of incentivizing private investors to provide support to risky projects that may contribute to decarbonisation.

Once a certain project has been developed it is necessary to raise resources to pay back the initial investors. The ultimate agents that may fund a certain project are:

- users of the infrastructure through charges;
- taxpayers (at the EU, national, and local level), often funding in order to secure wider social or economic benefits;
- beneficiaries who take advantage of positive externalities generated by the implementation of the measures adopted in this Road Map through "value capture"; and,
- benefactors or donors who might contribute either directly or through the use of new technologies (crowdfunding).

7.2 Instruments to support R&I

The actions defined in this Road Map to promote transport decarbonisation through a smarter use of infrastructure may be split into policy measures, which will have to be mostly promoted by governments in order to take more rational decisions or encourage changes in the behaviour of the users; and breakthrough technical and operational solutions that will have to be invented, tested and implemented. The way of funding and financing policy measures and breakthrough solutions will be different so they deserve to be treated separately.

7.2.1 Funding and financing policy measures

Policy measures include aspects such as new infrastructure planning approaches more geared towards decarbonising transport, the implementation of carbon charging approaches, awareness campaigns, etc. These actions usually require little resources. In some cases, such as carbon charging, it will generate revenue that may be used to finance other measures.

In spite of this, promoting innovative and harmonized policy measures is usually complicated for governments at different levels for several reasons such as inertia, fear of changing, lack of knowledge, social opposition, etc. Because of that, innovative policy measures towards a smart decarbonisation of infrastructure will have to be promoted through different actions such as R&D projects aimed at disseminating good practices, breaking barriers, produce guidelines, promote cross-fertilization, etc.

Research and development programs to promote innovative policy actions will be mostly funded by taxpayers since it is difficult to associate them to foreseeable returns in the future. The EU will play a key role in promoting these types of policies for several reasons: first, because decarbonisation targets require coordination at the European level; and second because the EU is the most suitable player to disseminate good practices across national and regional governments.

The EU budget has some programs where R&D actions may be easily accommodated. In the "Competiveness for growth" item of the EU budget there is room in the "Research and Development" section and also in the "Connecting Europe Facility" (CEF) section. Presently, the Horizontal Priorities of the CEF encourage new technologies promoting decarbonisation. This point could also be expanded to policy actions contributing to this goal.

Another source of revenue for R&I activity may come from carbon charges applied to CO_2 emissions of transport in the EU. A small percentage of carbon charges implemented could be allocated to a "decarbonisation fund", which could be managed by the European Investment Bank. The resources of this fund may be used to promote both policies and technologies contributing to decarbonize transport.

Additional innovative measures to draw resources for this type of actions must be explored in the future. Individuals and firms may contribute as donors to funding R&D actions aimed at conducting policy measures towards decarbonisation. The government may provide incentives through, for instance, tax benefits. If this approach is implemented, the government will have to ensure that there are not perverse incentives arising.

Other source that is worth to be explored to finance policy actions is crowdfunding. This is a form of alternative finance, which has emerged outside the traditional financial system. It consists of funding a project or venture by raising monetary contributions from a large number of people often via internet. Many people might be willing to give money to initiatives aimed at promoting decarbonisation through this new approach.

7.2.2 Funding and financing breakthrough technical and operational solutions

Putting in practice breakthrough solutions includes the phases of research, development, implementation and deployment. The research and development phase may be financed either by the industry itself that decides to invest in R&D as a future business opportunity or by governments at different levels interested in opening up new research areas to find out innovative solutions for decarbonisation. All the mechanisms described in the previous section such as donations, crowd funding or contributions coming from carbon charges are also replicable to finance the R&D phases of breakthrough technical solutions.

However financing the implementation and deployment phases turns out to much more complicate since these actions usually entail high-risk large investment volumes. The budget of the EU may contribute to the implementation and deployment of breakthrough solutions mostly through CEF, but also through the European Regional Development Fund (ERDF) and the Cohesion Fund. In this respect, it would be interesting to revise the regulations of these funds so that they may prioritize solutions contributing to decarbonisation. In the future these funds might oblige projects to conduct a carbon balance assessment over their life cycle as a prerequisite for receiving money from the EU budget.

Regardless of budgetary contributions, the implementation and deployment phase of breakthrough solutions may require large amounts of high-risk capital that will mostly come from private investors through equity and debt instruments. Equity will usually be provided by private companies interested in commercializing its know-how. However raising debt to deploy breakthrough innovations aimed at decarbonizing transport may be an issue since lenders usually perceive this type of investment as highly risky. In order to circumvent this problem the following solution might be adopted:

- Develop credit facilities from the European Investment Bank (EIB) to finance the implementation and deployment of breakthrough solutions aimed at reducing decarbonisation.
- Provide guarantees or credit enhancement approaches to reduce the risk perception of private investors. The EIB could be entrusted to manage and develop this type of products.

The role of transport infrastructure regulators may also be crucial to stimulate research, drive innovative behaviour, and implement capital investment. Regulators may require infrastructure companies to make investment and, at the same time, set access charges to recover that investment over time. Regulatory incentives can be set to:

- Undertake research into technology or processes to meet new lower carbon infrastructure targets;
- Promote innovate in business practices to enable use of lower carbon infrastructure; and
- Raise investment in new low carbon infrastructure.

The different funding and financing mechanisms described above, along with incentives to stimulate R&D, may be structured through innovative business models that may raise funds and, at the same time, incentivize research practices to promote decarbonisation.

8. Conclusions and Recommendations

Throughout this report we have repeatedly seen the total interdependence between transport infrastructure and the transport vehicles that use that infrastructure. When considering Green House Gas emissions, the very high majority of emissions arise from the use of infrastructure through its life. Yet despite that, there are many areas where infrastructure design and operation can be developed to improve the efficiency of transport system operation and to reduce GHG emissions.

There are a number of conclusions that we can draw from this review, with the associated recommendations for future research or innovation. Firstly, charging for the use of infrastructure in a consistent manner across all modes will be essential to incentivise the use of low carbon and low impact modes. Charging regimes need to gain social acceptance, which is a role for the Commission and for member states, and they need to incentivise infrastructure owners and transport operators to deliver their services at low cost to the users who depend on them.

All too often initial project appraisals are based mostly or wholly on financial and economic cost. Future transport infrastructure investment appraisal must give equal weighting to the carbon or GHG emissions costs associated with the development and use of that infrastructure.

At present transport users are faced with too many barriers to switch between transport modes. Extensive research and innovation is needed into simplifying movement between modes based on most efficient mode for the purpose. That research should include operational aspects supporting first / last mile options as well as reliability of connections through the transport journey and ease of charging or ticketing. Digital technology should contribute significantly as an enabling tool for these changes.

The demands of users for transport are changing rapidly, and can be expected to continue to change despite the long term nature of high value infrastructure. There are significant challenges to infrastructure owners and operators to develop infrastructure that is as efficient as possible for the expected demand, but that has better levels of flexibility and adaptability to changing demand than is currently the case. There is a complex optimisation to be done between efficient use of infrastructure to support routine operation, and the provision of high cost excess capacity to provide that flexibility and to provide resilience during disrupted operation.

The design and maintenance of infrastructure is most closely linked with operation of traffic that uses that infrastructure. In many cases more efficient operating procedures or alternative timetable solutions can reduce or avoid the need for additional expensive infrastructure. Similarly, advanced traffic management systems and infrastructure asset monitoring can help maintain high operational performance on sensitive critical transport infrastructure.

Overall, transport infrastructure is – regardless of transport mode – at the heart of the European transport system. There is a high potential to reduce both embedded and operational carbon in the system, but that will require changes in energy mix, changes in how people use the various modes, and changes in how users pay the direct and external or environmental costs of their travel.

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