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Acting on climate change

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Executive summary

During the COP21 meeting in Paris in 2015, it was decided to have a comprehensive plan for acting on climate change. Although this meeting did not provide legally binding agreements, the message was still clear: climate change is becoming increasingly evident, and the consequences will affect us all, including all types of transportation modes.

For national road authorities, it is important to recognise the changes in time in order to reduce greenhouse gas emissions and provide more resilience for existing and proposed roads.

Acting on climate change is not a unified topic for road owners; both mitigation and adaptation to climate change are different sub-topics. The objective of mitigation is to minimise the magnitude and impacts of climate change by introducing methodologies to minimise greenhouse gas emissions (GHG). The objective of adaptation is to upgrade the infrastructure to increase resilience and robustness, e.g. to flooding.

Despite the dissimilarities, adaptation and mitigation share the need for long-term planning for an uncertain but undoubtedly different future. Both topics are, therefore, presented in this report.

Planning for GHG reductions according to national targets

The planning of the transport system is usually based on the forecasting of future traffic volumes. The forecast is based on current trends in society, predictions of future economic growth, and costs of transport. All over Europe, these trends and models point towards further growth in transport and traffic volumes. The highest growth is predicted in eastern Europe, where car ownership is getting closer to the levels in western Europe. Safety factors and seamless mobility can justify improved road networks, but the forecasts also indicate a need for larger roads with greater capacity. These new roads lead not only to more traffic and, therefore, more GHG emissions, but also to higher energy use and GHG emissions during construction, operation, and maintenance. In its last report, the IPCC warned that infrastructure developments that lock societies into GHG-intensive emissions pathways may be difficult or very costly to change and that this reinforces the importance of early action for ambitious mitigation.

In order to reach climate objectives, there is a need for technical solutions in energy-efficient vehicles, partly or fully dependent on electricity and a replacement of fossil fuels with bio fuels. However, these solutions will not be enough if large reductions in GHG emissions are to be accomplished. There is then also a need to change direction in the planning and development of society and infrastructure in accordance with behavioural changes. Such a development is a clear paradigm shift from planning for more traffic with cars and trucks towards sustainable mobility with accessibility through walking, cycling, and public transport thus reducing the reliance on cars, coupled with improved logistics and a modal shift leading to reduced truck volumes. In view of the paradigm shift from today's increasing car and truck traffic towards a more sustainable transport system, forecasting is very unreliable. Consequently, other methods are needed.

Section 1 of this report focuses on climate change mitigation. Based on examples from Sweden, Norway, Hungary, and Poland, the report explores an alternative planning method. The first step is to describe the current situation, what the trends are, and what the contributing factors are, in order to provide a general picture of the problem. A clear objective is also needed. Since most countries do not have precise GHG objectives for road transport, an example of how national objectives can be translated into a road transport objective is given. Then the gap between the trend and the GHG objectives can be described for road transport. An inventory of possible measures to reduce GHG emissions should be made. This has already been done in many countries and by the EU Commission. While these inventories can be used, updates may be necessary, and consideration should be given to new ideas. Possible measures to reduce GHG emissions can be clustered into packages. From these packages, scenarios can be drawn up and tested against GHG objectives and other targets. Backcasting from the scenarios that meet objectives can be used to develop an implementation strategy that includes policy instruments and measures that allow for progress towards meeting the objectives. Due to uncertainty, it is recommended that checks be made at regular intervals to allow the strategy to be adjusted.

Vehicles that use the infrastructure are not the only source of greenhouse gases and energy usage. Other major sources are the construction, maintenance, and repair of the infrastructure (and also the construction, maintenance, and repair of vehicles and the production of energy). The more complicated the infrastructure project (such as tunnels and bridges), the higher the greenhouse gases emitted and energy used. This also has to be taken into account in the sustainable development of the infrastructure. This report describes both methods of calculating GHG emissions from infrastructure and methods of procuring more energy-efficient infrastructure construction, maintenance, and repair.

Strategy and action planning for adaptation activities

The degree to which roads are adapted to the challenge posed by climate change varies hugely between the different national road authorities (NRAs). At the same time, the consequences of climate change are already at a stage where roads are affected noticeably more frequently than they were a few years ago, a fact experienced and recognised by multiple NRAs. In order to maintain safety and mobility on national roads, the time has come to implement the many tools and methodologies developed in recent years in various national and international projects. However, initiating and anchoring climate change adaptation within an organisation is a demanding and oftentimes overwhelming task. This can lead to a de-prioritised approach, despite the benefits of investing in proactive adaptation measures.

Section 2, adapting roads to climate change, focuses on the following key aspects; strategy, action planning, methodologies/tools, and awareness. It is the strong belief of Task Group I4 that emphasising, describing, and template-forming these topics can lead to more climate change adaptation across borders, thereby resulting in more resilient roads.

The section on strategy focuses on management, improvement, prevention, and cooperation, and provides a template with specific examples on areas to work with. These include examples of information to road users, incident management, implementation through planning phases, tools for risk analyses, legislative work, research, information-sharing and much more. A template for an action plan is provided, giving examples of how to ensure responsibility and anchor climate change adaptation in the organisation in order to steer the organisation towards a more climate-resilient profile. An organisational awareness of climate change adaptation in an interdisciplinary context is considered undeniably crucial in this regard, since this will form the basis of how to act and prioritise resources.

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Strategic planning of adaptation and mitigation

In 2015, two critical markers of the root and consequence of climate change were passed: 2015 was the warmest year on record on a global scale and the first year where 400 ppm of atmospheric carbon dioxide was exceeded throughout most of the year[i]. Road authorities are already observing an increase in the consequences of extreme weather. Thus, as the year 2015 has shown, it is becoming increasingly urgent for road authorities to address the topic of climate change so that they can maintain a continuous level of safety and mobility on roads. In terms of providing an opening for timely actions to stop the rising emissions in greenhouse gasses that contribute to climate change, the 2015 COP21 summit was arguably the most successful climate change conference since the 1997 Kyoto summit in terms of general agreement for a joint undertaking by crucial countries, especially centred on climate change mitigation.

In brief, the measures emerging from the meeting included agreements on keeping global temperatures well below a 2ºC rise relative to pre-industrial temperatures by peaking emissions of greenhouse gasses (GHG) as soon as possible and even pursuing efforts to limit the temperature increase to 1.5º C. Furthermore, $100 billion will be set aside every year for climate financing, e.g. adaptation purposes, for developing countries by 2020, with progress to be reviewed every five years.

Climate change mitigation is fundamentally dissimilar to climate change adaptation. Mitigation measures strive to minimise the magnitude and impacts of climate change by introducing methodologies, legislation, and/or reduction measures to lessen greenhouse gas emissions. Climate change adaptation is the overall term for upgrading, ensuring, and/or upgrading items, mechanisms, infrastructure, etc. to be able to manage consequences of present and future climate conditions. Climate change adaptation measures are often proactive in nature.

Despite the dissimilarities, adaptation and mitigation both share the need for long term planning for an uncertain but undoubtedly different future. Both topics are, therefore, presented in this report.

The mitigation part of the report shows how road transport can help keep global warming well below 2º C and possibly also 1.5º C. Technical measures for improved energy efficiency, electric vehicles, and biofuels will not be enough in isolation. There is also a need for a paradigm shift in the planning and development of society and infrastructure in accordance with behavioural changes towards passenger transport that includes walking, cycling, and public transport and towards goods transport with improved logistics and increased transport on rail and water. Emissions of greenhouse gases from the construction, operation, and maintenance of infrastructure also need to be reduced.

Even if mitigation is implemented with a target of achieving a 1.5º-C reduction, there is always the risk that this target will not be met. If mitigation of rising temperatures and climate change are not adopted, the consequences could be very serious. In order for risk management to be successful, adaptation has to aim for a greater climate change than the world has agreed to mitigate for. The opposite would of course be very dangerous. Therefore, in the adaptation section, guidelines and templates are provided for compiling a strategy and an action plan for adapting roads to future challenges.

[i] www.noaa.gov

Section 1: Mitigating climate change

Public transport in Dublin (photo: Håkan Johansson)

1 Introduction

Present trends in global greenhouse gas emissions will give rise to increases in the global mean temperature of 4–5 °C. If this trend continues, it will have extreme consequences on life on earth that are difficult to estimate. It is, however, not too late to change the trend. There is also a possibility of limiting the temperature increase to 1.5–2 °C or less in line with the Paris Climate Agreement (United Nations, 2015). This is an objective on which all participating UN countries have agreed. Limiting the temperature increase to less than 1.5 °C means that global emissions have to be reduced to zero in the period 2045–2060 and emissions thereafter must be negative (Rogelj et.al., 2015). The latter can be achieved, for example, by burning biomass in power plants together with carbon capture and storage (BECCS). Energy efficiency, demand management, and stringent early reductions are keys to limiting global warming to less than 1.5 degrees. Since it is the sum of the emissions over the years that impacts on the climate, it is very important to start decreasing emissions as soon as possible. For every year that is spent without emission reduction, it becomes more and more difficult to limit climate change to levels that will not be extremely dangerous. Taking into account historic emissions and the higher standard of living there, the more affluent part of the world has to decrease its emissions faster and more.

The transport sector is one of the largest contributors to greenhouse gas emissions, being responsible for 26 per cent of global emissions, and this share is increasing (IEA, 2015). Of the emissions generated by the transport sector, road transport dominates.

The roles of national road authorities (NRAs) and their responsibility to contribute to the reduction of GHG emissions from the transport sector differ. Some have a broad responsibility not only for road transport but also for other transport modes. Others have a more limited responsibility for a small but nationally important road network (see Table 1.). Even if the responsibilities differ from country to country, all NRAs have an important role to play in the mitigation of climate change in the transport sector. This report focuses on two important areas for NRAs: the planning of the transport system in line with climate objectives and the reduction of GHG emissions from infrastructure from a life cycle perspective.

In all parts of Europe, trends and modelling predict further growth of transport and traffic volumes. The highest growth is predicted in eastern Europe, where the number of cars per capita is approaching that in western Europe. Safety factors and seamless mobility can justify an improved road network, but the forecasts also indicate a need for larger roads with greater capacity. These new roads not only induce more traffic and therefore more emissions of GHG, but also higher energy consumption and emissions of GHG during construction, operation, and maintenance. In its last report, the IPCC warned that infrastructure developments that lock societies into GHG-intensive emissions pathways may be difficult or very costly to change and that this reinforces the importance of early action for ambitious mitigation.

In order to reach climate objectives, there is a need for new technical solutions in the field of energy-efficient vehicles that are partly or fully dependent on electricity and a replacement of fossil fuels with bio fuels. However, these solutions will not be sufficient if large reductions in GHG emissions have to be accomplished. There is, therefore, also a need to change direction in the planning and development of society and infrastructure in combination with policy instruments to change behaviour. A technical solution could have worked at a time when the problem was not so urgent, but even so, it would not have been a good idea to rely only on technical development. If the technology failed, there would be no backup plan. Further growth in transport volumes and vehicles will also have other severe effects on the environment, health, and urban life. Such a development is a clear paradigm shift from planning for more traffic with cars and trucks towards sustainable mobility with accessibility through walking, cycling, and public transport, leading to reduced car volumes and towards improved logistics and the modal shift to rail and waterborne transport instead of increased heavy goods vehicle volumes.

Transport systems are usually planned on the basis of forecasts of future traffic volume. Traffic forecast calculations are made using tools that describe how transport demand is affected by changes in infrastructure, transportation costs, economic development, population structure, and economic structure. In order to forecast transport volumes, assumptions relating to the development of all these parameters have to be made. Uncertainty in each variable contributes to a cumulatively greater uncertainty in the transport volumes forecast. The models are also calibrated with data from the past, which also contributes to the uncertainty of the forecast.

Changes in behaviour (for example the willingness to get a driving licence or own a car) must be included in the model in order to prevent false results. This can be done using changes that are currently known, but not, of course, with future changes that are either not currently known or fully understood. Forecasts are therefore best suited to shorter periods without trend breaks (Hickman and Banister, 2014). Although the future is always uncertain, the world currently faced major uncertainties in relation to energy and material supply that will affect economic development, transport costs, etc. There is also a lot of uncertainty surrounding the technological development of vehicles. Will there be a transfer to electric vehicles? If so, this will have a large impact on transport costs. Will the current trend towards urbanisation continue? If so, what will our cities look like in the future? Will they be compact and resource efficient or will there be urban sprawl?

Under such paradigm shift conditions, forecasting is very unreliable. Instead there is a need for other methods that should be able not only to handle the uncertainties, but also to help plan for a more sustainable future, a future where climate objectives and other societal objectives can be met. The problem is to find an approach that covers all the driving factors involved in climate mitigation.

This report is the output of the work done in CEDR's task group I4 (TG I4) on mitigation and adaptation to climate change. Based on examples from Sweden, Norway, Hungary, and Poland, which were members of this group, this report explores a planning method that can work as an alternative or complement to the usual planning method based on transport models and a forecast in line with business as usual (BAU). One basis for the report is a survey that was carried out within TG I4. All countries represented in the group including Austria, Denmark, Hungary, Ireland, Italy, Norway, Poland, Sweden, and Switzerland, responded to this survey.

Greenhouse gases and energy use come not only from the vehicles that use the infrastructure. A considerable amount comes from the construction, maintenance, and repair of the infrastructure (a proportion also comes from the construction, maintenance, and repair of vehicles and the generation of energy).The more complicated the projects (for example tunnels and bridges), the greater the amount generated by infrastructure. This must be taken into account in order to ensure the sustainable development of infrastructure. Chapter 8.2 describes methods of calculating GHG emissions generated by infrastructure and methods for procuring more energy-efficient infrastructure construction, maintenance, and repairs.

Table 1: The role of national road authorities

The role played by NRAs in reducing GHG emissions from the transport system differs from country to country.

Transport modes
Most NRAs are responsible for road transport only (the scope and extent of this responsibility is different in each country). In a few cases, the NRAs are also responsible for other transport modes (for rail, aviation, and water in Austria and for rail transport in Sweden). Sweden also has a special responsibility for the long-term planning of all four transport modes.

Co-modality
Although not directly responsible for transport modes other than roads, some NRAs (Italy, Hungary, Norway, and Poland) are responsible for co-modality issues. This means that most NRAs still have at least an indirect impact on transport modes other than roads. Dealing with co-modality generally takes the form of cooperation with other transport agencies. In Hungary and Norway it also means responsibility for cycling infrastructure.

Energy and climate mitigation
Most NRAs have a certain role to play in energy and climate mitigation. However, this role varies considerably depending on a number of factors including national legislation, administration, organisational issues, and how precisely defined GHG reduction goals are for road transport (without clearly set targets, no administration can be expected to assume responsibility). Even if the responsibility differs, all NRAs can reduce GHG emissions from the infrastructure itself.

Road user behavioural issues
This kind of responsibility is generally 'all-or-nothing'. Some NRAs are responsible for most aspects of road user behaviour, while others have very limited or no responsibility at all.

Planning
All NRAs are involved in the long-term planning of the road transport system. Some of them are responsible for preparing such plans, while others play a mostly advisory and consultatory role in the planning process. Most countries have long-term transport plans covering all transport modes. While this situation provides a favourable environment for the comprehensive and climate-conscious strategic planning of transport, environmental planning regulations on EIA and Strategic EIA unfortunately lack specific provisions that would guarantee that climate objectives are taken into account during the different planning stages.

2 Method for reaching climate mitigation objectives

Figure 1 provides an overview of the method that will be described in this report. It starts with the identification of objectives. This and subsequent steps are explained in more detail in the following chapters. Throughout this report, discussions and workshops with stakeholders and policy-makers are recommended in order to ensure broad acceptance of the result and to stimulate action.

Even if some of the individual steps in the method are used in many countries, they are rarely used together as an alternative to the widely used forecasts in transport planning. The questionnaire that was sent out to the nine European countries in TG I4 included questions about working with road transport climate mitigation issues within the individual administration and the country. One question asked whether alternatives to prognosis-based planning (forecasting) were used, e.g. basing planning on a vision of future society in line with climate and other societal objectives. No country answered this question with a 'yes'. One can assume that the countries gave a relatively conservative response to this question as it is known, for example, that both Sweden and Norway have developed alternative scenarios. However, these scenarios may (at least until now) have had limited influence on the final national transport plan or road projects, which may be the reason for the answers given.

TG I4 does not claim to have developed the theory behind the method outlined in this report. However, the report does give examples illustrating how it is used in practice. Here, for example, the group refers to Hickman and Banister (2014).

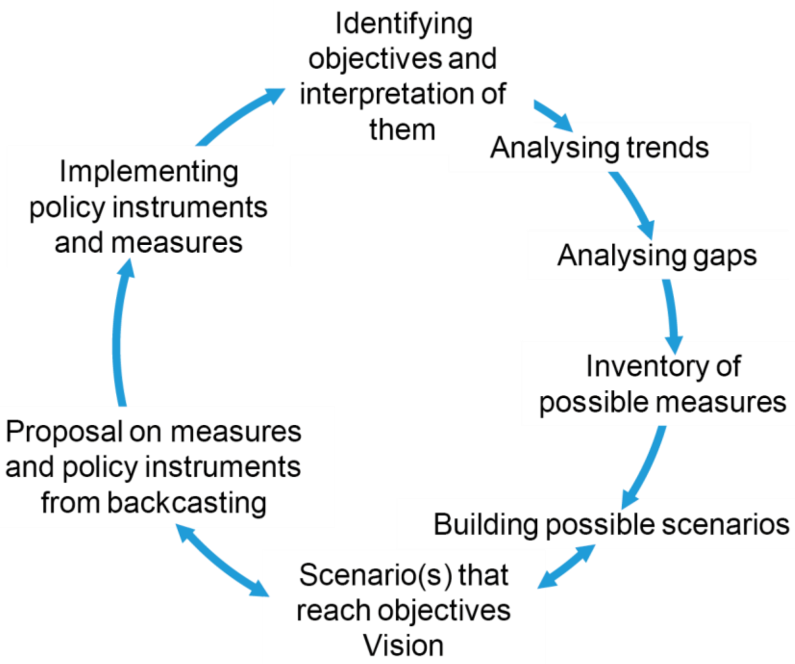

Figure 1: Outline of the method

3 Identification of objectives

It is not possible here to give a detailed and precise description of how objectives for reducing GHG emissions in Europe are employed at different levels (national, transport sector, road transport subsector, etc.). Nevertheless, the findings of the aforementioned survey may shed some light on the situation in this field. The conclusion drawn from the answers of the countries in TG I4 is that while countries generally have reduction objectives at national level, only a few countries also have fixed objectives for the whole transport sector or specifically for the road transport subsector. This is not very promising considering that it is not easy to reach goals in situations where only large scale objectives are available and where there are no clearly defined objectives for smaller-scale operative levels. In those cases where there are no sectorial objectives for the transport sector or the road transport subsector, it may be necessary to adapt the national objectives to the desired level.

In 2011, the EU Commission adopted the White Paper entitled 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system', which included reduction objectives (see Figure 2) and measures for certain timeframes, with preliminary results expected in 2020 and 2030 and final results in 2050 (EU Commission, 2011). The perspective and measures presented in this white paper focused on multimodality and on the reduction of GHG emissions, including a 'zero emissions' scenario for certain timeframes. Since its adoption, some transport strategies (local or national) and climate strategies have included the provisions mentioned in the White Paper. For example, the Polish Transport Development Strategy until 2020 with a perspective to 2030 sets out the goal of creating an integrated transport system (Polish Ministry of Infrastructure and Development, 2013).

In the EU, the short- to medium-term GHG emission reduction goals for those sectors not included in the emission trading system (e.g. transport without aviation) are described in Decision 406/2009/EC, which is known as the 'effort-sharing decision' because it ensures a fair distribution between the member states of the efforts to contribute to emission reduction. Each country has individual reduction targets that range between -20 per cent (Denmark, Ireland, Luxembourg) and +20 per cent (Bulgaria) according to each country's per capita GDP.

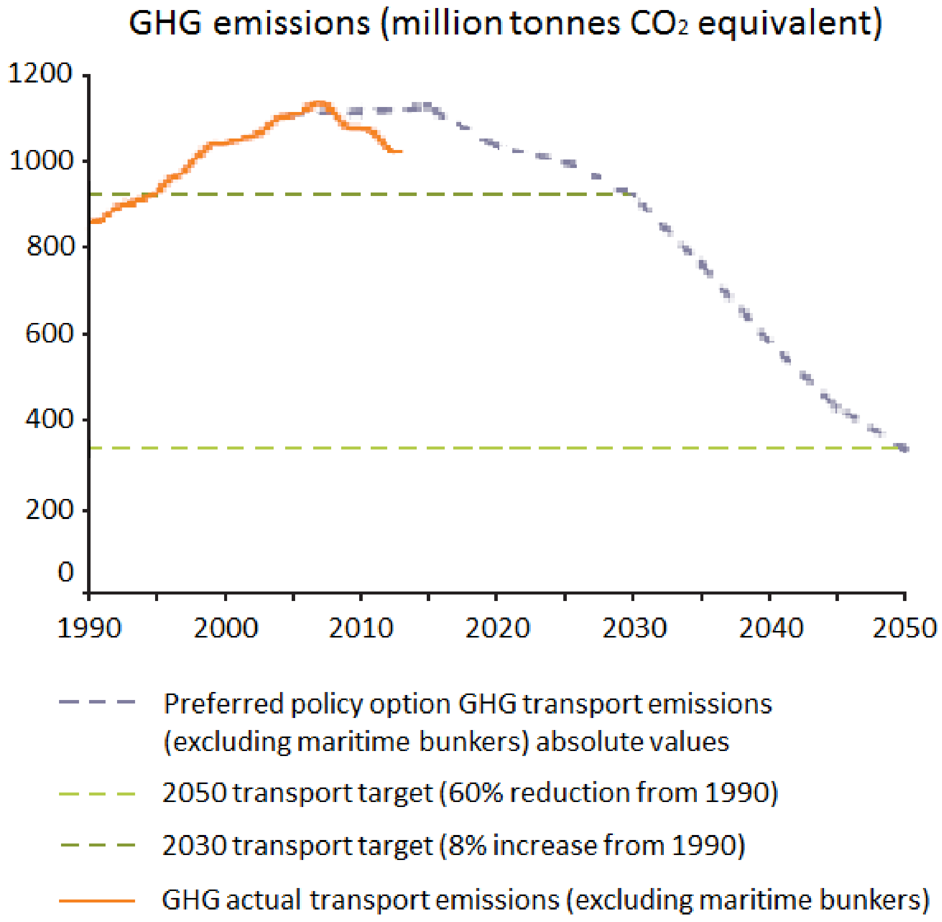

Figure 2: Emissions from transport in the EU and reduction targets (EEA, 2015a)

The objectives set in the EU must also be set in the context of the new climate agreement made at the UN COP21 meeting in Paris 2015. The agreement aims to hold 'the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change'. The agreement itself does not include targets for reduction of GHG emissions. Scenarios that hold temperature increases below 1.5 °C above pre-industrial levels imply a transition to a future where net zero carbon emissions are achieved worldwide between 2045 and 2060. The key in this scenario is high energy efficiency, demand management, and stringent early reductions. After 2045–2060, negative emissions are needed in those scenarios that use, for example, biomass power plants in combination with carbon capture and storage (BECCS).

The White Paper on Transport can be one basis for reduction objectives and strategies at the level of the road transport system. Some institutions and researchers, however, are calling for a much faster reduction of GHG emissions than the figures in the white paper and other strategic documents from the EU Commission. Andersson (2012), for example, stresses that in order to keep global warming below

2 °C and with respect to equity between rich and poor countries, the wealthier part of the world (Annex 1 countries) need to reduce their emissions by 40 per cent by 2015, 70 per cent by 2020 and 90 per cent by 2030 compared with 2010. That would still impose extremely demanding reduction burdens on the rest of the world. In addition, the need to keep global warming below 1.5 °C will make it even harder.

Some countries go further than the EU objectives. In Sweden in 2009, the government and parliament decided on a vision that Sweden should be climate neutral in 2050 and that the (road) vehicle fleet should be independent of fossil fuels in 2030. To most operators and stakeholders, it was unclear what the 2030 objective really meant. One very simple solution would have been to say that the vehicle fleet was already fossil-independent if it used synthetic petrol and diesel from biomass, but it is likely that this would have satisfied neither the politicians nor the possible victims of climate change. Then in 2010, the Swedish Transport Administration made its own interpretation of the vision, saying that the objective is interpreted as being an 80-per cent decrease in the (direct) GHG emissions from road transport by 2030 compared with 2010 (Swedish Transport Administration, 2010). This interpretation has been used by the Swedish Transport Administration since then. It was also proposed by the Commission on fossil-free road transport (2013) and it is also now used by some other organisations.

If a road authority defines objectives (for example by interpreting national objectives), it is important to get acceptance for these objectives through discussions with important stakeholders and policy-makers.

4 Analysing trends and gaps

Besides getting wide acceptance for the objectives from different stakeholders and policy makers, it is also important to get acceptance for the description of trends and gaps. Most countries in Europe had the highest GHG emissions from road transport before the economic crisis that begin in 2008/2009 (EEA, 2015). A few countries (for example Poland and Romania) have also noted increasing emissions after that period. It is also important to stress that there are considerable differences between the European countries in this respect: emissions from road transport per person is about 32–40 per cent lower in Hungary and Poland than the EU average (see Figure 3).

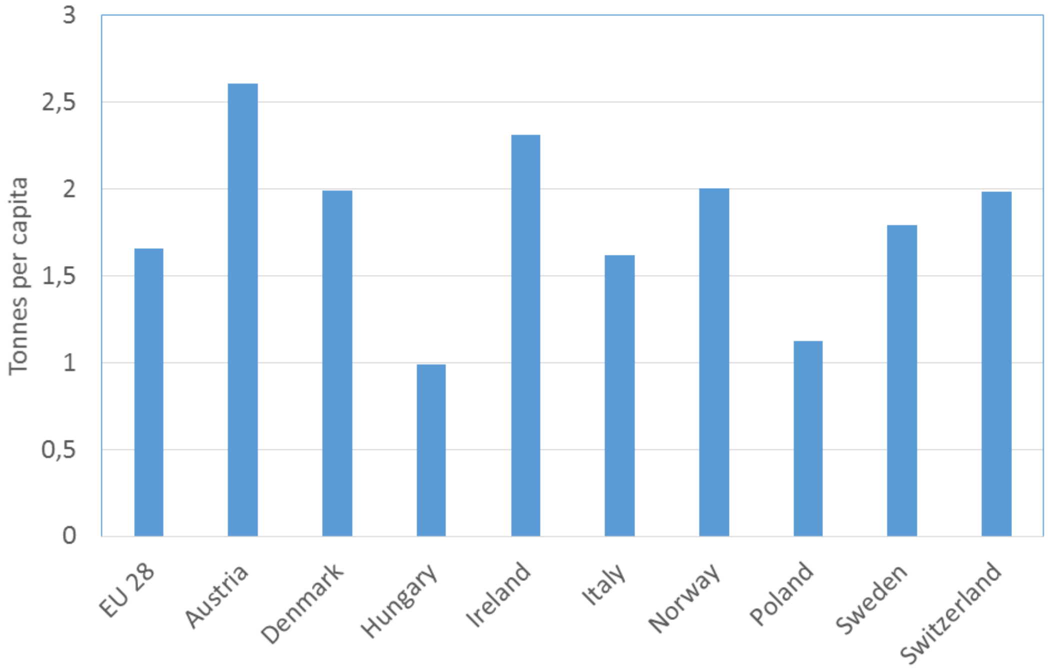

Figure 3: GHG emissions from road transport per capita in 2013 in the countries represented in TG I4 and EU28

The road sector has increased its share of total GHG emissions from 13 per cent in 1990 to 19 per cent in 2013 (see Figure 4).

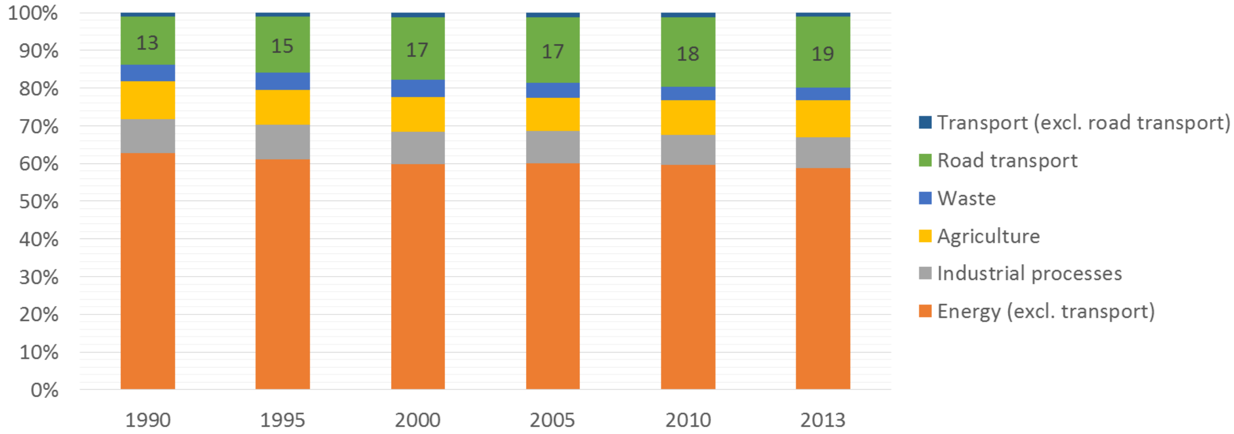

Figure 4: GHG emissions per sector in the EU-28 (EEA, 2015b)

According to the EU Monitoring Mechanism Regulation (MMR), all European countries are obliged to make projections for GHG emissions until 2030, including those from road transport. All countries should therefore have a picture of the trends of GHG emissions from road transport.

Once they do, the identified trends can be compared with the objectives. Here the recommendation is to use a simple illustration that can be easily understood and communicated. One example is given in Figure 5. It clearly shows the gap between the trend of the agreed measures and policy instruments, BAU in yellow, and the objectives in green. The figure also shows in grey the effect of traffic growth on the use of fossil energy, assuming that present-day vehicles and fuels remain in use.

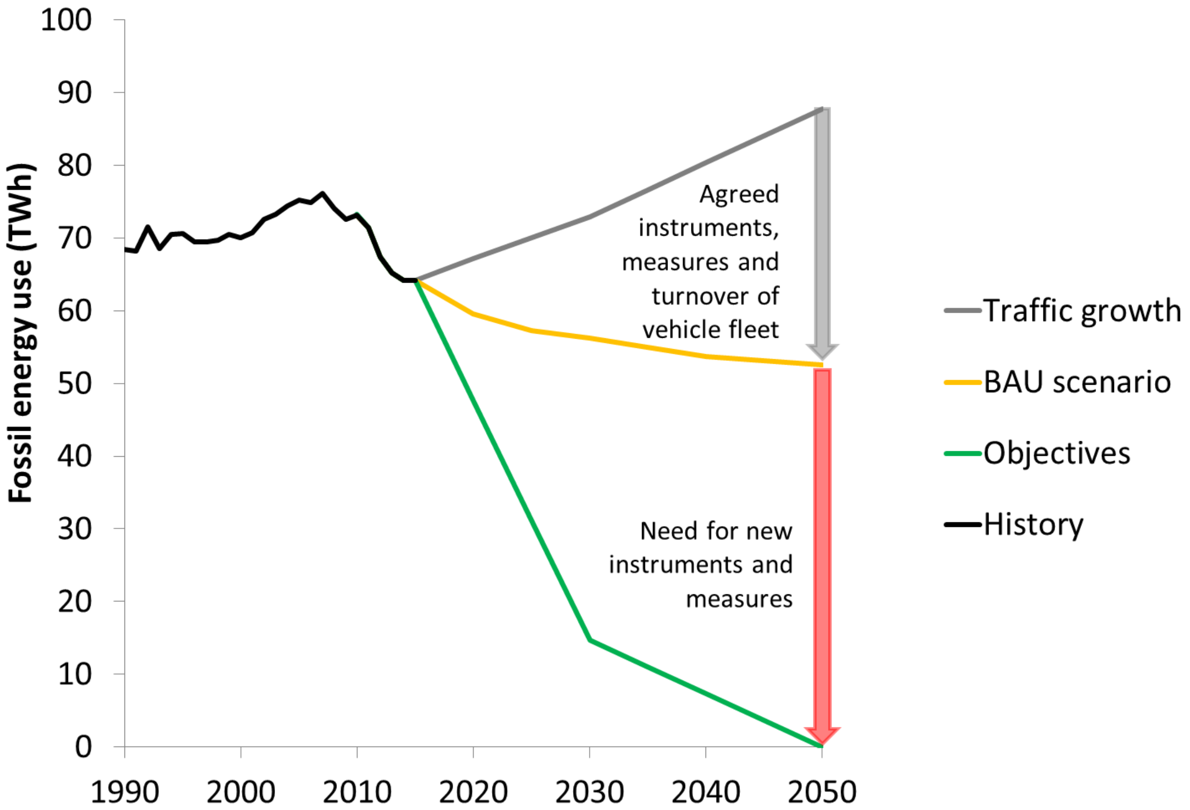

Figure 5: Illustration of the gap between BAU and objectives

Besides the GHG emissions from fossil-fuelled vehicles, the transport system also contributes to GHG emissions through the production and distribution of fuels, the production, maintenance, and scrapping of cars, and the production, maintenance, and shutdown of infrastructure. When emissions from the fuels used in traffic and emissions from the reinvestment and maintenance of transport infrastructure are added up in a lifecycle perspective, the transport infrastructure is responsible for approximately 10 per cent of GHG emissions (Swedish Transport Administration, 2014). The Swedish Transport Administration has also set objectives for reducing GHG emissions from the infrastructure in a lifecycle perspective that are in line with the national climate objectives.

In order to develop and work with measures to reduce emissions, it is also essential to understand the trends and the drivers that work behind them. Analysing the parameters 1) traffic, 2) energy efficiency, and 3) share of renewable (or fossil) energy will provide a good picture what is driving the development of the emissions. In most countries in Europe, parameters 2) and 3) are now contributing to the decrease in emissions.

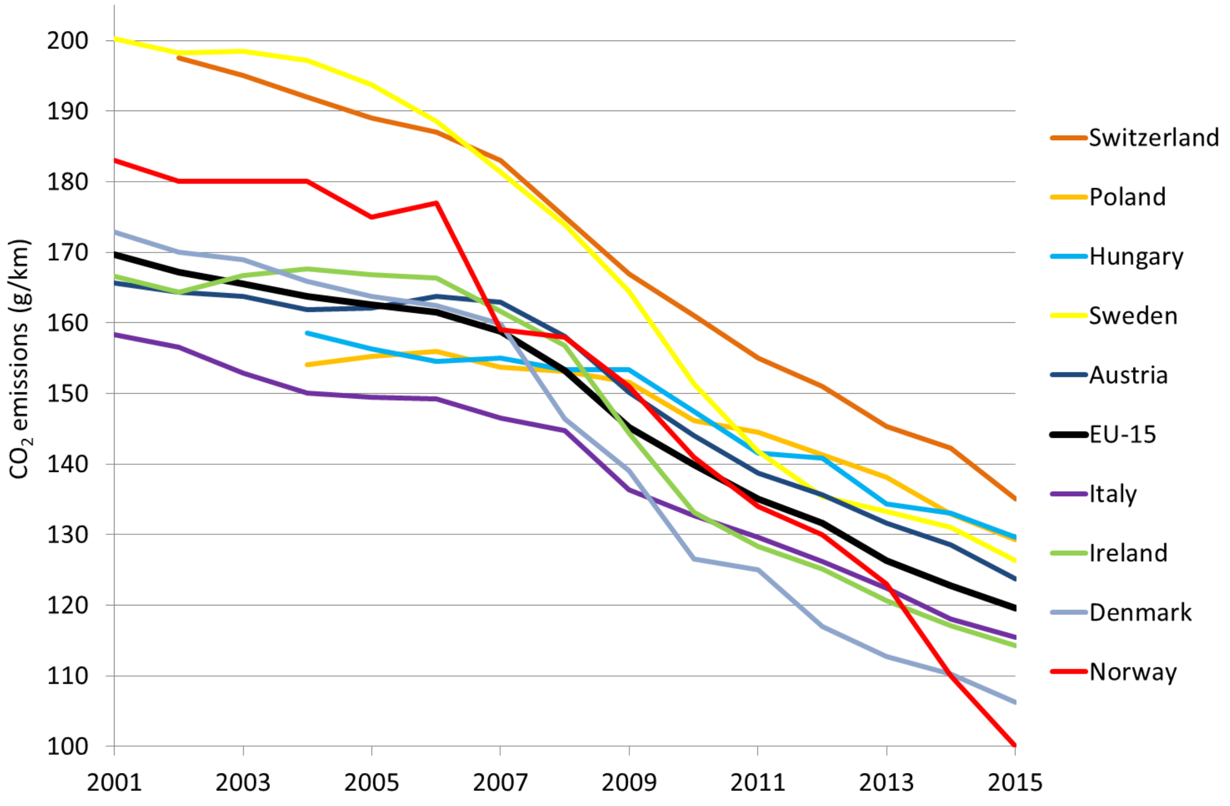

Figure 6: CO_2 emissions from new passenger cars for the countries represented in TG I4 and EU-15

Most European countries experienced an increase in passenger car transport volumes from 2000 up until the end of the decade, when the economic crisis slowed this development. Since then, levels have been more stable, with either a slight increase or decrease. Of the countries represented in TG I4, Poland (continuing considerable increases) and Italy (considerable decreases) are clear exceptions. Looking to the future, not all countries have official forecasts of transport volumes. For those countries that have, traffic growth is similar to the historic development over the last 20 years, at least for the first 10–20 years. With the exception of Poland, growth between 2000 and 2030 is expected to be around 40 per cent. Some countries predict slower growth in their scenarios after 2030. In line with development in Poland over the last 20 years, the forecast is for very high growth with close to a 240-per cent increase between 2000 and 2040.

Goods transport volumes are available for seven of the nine countries represented in TG I4. Four of the countries (Austria, Hungary, Norway, and Switzerland) experienced significant growth in goods transport on roads of between 2 and 4 per cent per annum on average between 2000 and 2010.

Denmark and Sweden had about the same level of goods transport on roads in 2010 as in 2000, while goods transport in Italy significantly decreased by nearly 3 per cent per annum on average. The slow growth or decline can mainly be explained by the economic crisis that started in 2008/2009. Growth in Austria, Hungary, and Switzerland can mainly be explained by increasing transit. Norway was not hit as badly by the economic crisis as the rest of Europe. Four countries (Denmark, Norway, Sweden, and Switzerland) have forecasts for goods transport. The prognosis for an increase in goods transport volumes between 2000 and 2030 varies between 60 and 100 per cent.

Besides setting objectives for the emissions of GHG from road transport, objectives can also be set for the driving parameters. This is the purpose of the subsequent steps in the method: taking an inventory of measures and building scenarios that meet the objectives. Setting objectives for the driving parameters may be assimilated more easily by different actors and stakeholders than only having an overall objective for GHG emission reduction. One good example is the Norwegian objective to transfer the growth of passenger transport in larger cities to public transport, cycling, and walking so that passenger car traffic does not increase. The objective was first set in the National Climate Strategy (Miljøverndepartementet, 2012) and was later included as an objective in the National Transport Plan (Samferdselsdepartement, 2013). The practical implementation of this new policy will be regulated in agreements between the state, counties, and cities. The agreements will include economic incentives and the monitoring of key indicators in fields such as traffic development, parking, and land use (localisation of jobs and housing).

Even if Sweden has not taken a political decision like the one in Norway, the Swedish Transport Administration has identified that in order to be in line with the climate objectives illustrated in Figure 5, there is a need for a 10–20 per cent decrease in passenger car traffic volume by 2030 compared with 2010, and no growth in heavy goods vehicle traffic is allowed. It is also important to remember that although objectives or restrictions on car traffic at local level are common in Europe, they are generally aimed at other environmental objectives such as noise reduction.

5 Inventory of possible measures

The next step is to build an inventory of possible measures. There is a large amount of data available in this field. Besides international references such as the EU Commission (2011), IEA (2015), and IPCC (2014), national projects that create the potential for different measures have often been carried out. The real work is to collect and compile this data and adapt it to national conditions. The potential of measures will change over time, depending on how and when they have been adopted. There is therefore a need to keep the database up to date. It is also recommended that measures be structured or packaged. One way is to structure the measures as listed below:

- lower transport growth and use of more efficient transport modes
- improvement in resource and energy efficiency
- renewable energy and materials with lower carbon footprints

The first bullet point includes measures that reduce the number of vehicle kilometres travelled by passenger cars and trucks. This can be achieved by alternatives to transport like telecommuting or reducing travelling distances by developing more compact cities. It can also be achieved by a modal shift from travelling by passenger car to travelling by public transport, cycling, or walking. For trucks, the travelling distance can be reduced by improving logistics or the modal shift to rail or waterborne transport. For infrastructure, this bullet point is also about planning and constructing the infrastructure for the future sustainable transport system. In its last report, the IPCC warned that infrastructure developments that lock societies into GHG-intensive emissions pathways may be difficult or very costly to change and that this reinforces the importance of early action for ambitious mitigation.

Energy efficiency can be improved by using more efficient new vehicles while scrapping old and inefficient ones or by using them more efficiently, including eco-driving and driving at lower speeds. Ecodriving should be seen as an educational requirement in the training required for a driving license. In Sweden and Norway, it has been a necessary part of the driving test since 2008 and 2006 respectively. Poland also introduced this requirement recently (1 January 2015). It is important to mention that eco-driving is a freely available measure, as it basically requires only a shift in behaviour, but not any improvement in vehicle or propulsion technology. Driving at lower speeds, especially on motorways, also contributes to a reduction in fossil fuel consumption and in turn has a positive effect on the home budgets of vehicle users. Diving at lower speeds in cities also improves safety for pedestrians and cyclists and strengthens the alternatives to the car. For infrastructure, this means more resource-efficient construction and maintenance, for example, using lighter structures with equal or improved strength.

Electric vehicles both improve energy efficiency and provide an opportunity for a switch from fossil fuels to renewable energy. In addition to electricity, biofuels and (in the long term) hydrogen also create this possibility. In terms of infrastructure, energy efficiency means using renewable fuels in trucks and machinery for construction and maintenance and using asphalt, concrete, steel, and other materials that have a lower carbon footprint.

Tables 2–6 provide an update of the data included in the previous CEDR mitigation report and gives a good overview of the potential offered by different individual measures and packages of measures (CEDR, 2013). The data is based on a backcasting scenario for the road transport system in Sweden with an objective to reduce CO_2 emissions from the sector by 80 per cent by 2030 compared with 2010 (Commission on fossil-free road transport, 2013 and Swedish Transport Administration, 2016). Some adjustments have been made to make this more valid in a European context. In chapter 3, TG I4 stresses the need for reductions of CO_2 emissions in that order of magnitude to be in line with the Paris Climate Agreement. However, most countries have not yet decided to make such emission reductions. With less stringent reduction targets, full use of the potential will not, of course, be needed. The choice could then be between a more technical scenario without such a considerable reduction in car and truck traffic and a less technical scenario with some reduction in car and truck traffic.

Shared space in Oslo, Norway (photo: Knut Opeide)

Table 2: Potential to reduce VKT (vehicle kilometres travelled) growth by 2030 and 2050

	Potential by 2030 (reduction of VKT growth)	Potential by 2050 (reduction of VKT growth)
Urban planning for reduction of car VKT	-10%	-20%
Improved public transport (x2/x3 frequency)	-7%	-13%
Car sharing	-3%	-5%
Internet shopping	-3%	-5%
Virtual meeting and telecommuting	-4%	-6%
Congestion charges, parking policies, and fees	-3%	-6%
Generally reduced speed limits	-3%	-3%
Total	**-30%**	**-45%**

According to the Urban Land Institute US (Growing cooler, 2008), the potential for reducing VKT growth by 2030 through urban planning is 7.7% as a result of increasing population density, and another 11.4% from reduced highway construction. The IEA (Transport Energy and CO_2, 2009) estimates a potential of 10%. According to the IEA (Transport Energy and CO_2, 2009), cycling has the potential to take another 5% of travelling in urban areas. The Commission on Fossil-Free Road Transport (2013) gives a 10% potential for Sweden by 2030 and 20% by 2050. For 2030, the potential is as follows: 4% for the localisation of population within existing urban areas (no further sprawl), 1% for more central localisation, 1% for localisation near public transport, 1% for more diverse land use (increased mix of functions for job/studies, settlement, and service), and 3% for design/facilities for walking and cycling. The figures of 10% for 2030 and 20% for 2050 are used here to calculate the potential of various measures to reduce VKT growth by 2030.

There is a further potential for VKT reduction through improved public transport with 100% growth in public transport forecast (bus, coach, tram, and metro) by 2030, using 0.5 elasticity of demand with respect to service frequency. This gives a 7% decrease in passenger car use when service frequency is doubled and 13% with triple frequency using statistics of passenger travel for EU-28 from EU (2015). Reduced travelling time combined with increasing reliability and comfort can mean even less passenger car use. This is somewhat higher than the ULI study (Growing cooler, 2008), which reports a potential of 4.6%, and that of the IEA (Transport Energy and CO_2, 2009), which indicates a potential of 5%.

The IEA (Transport Energy and CO_2, 2009) reports a potential of 50% reduction in VKT for former car owners who switch to car sharing. Studies show that 10–25% of car owners are interested in car sharing, which gives a potential of 5–12.5% reduction. The Commission on Fossil-Free Road Transport (2013) gives a 3% potential for Sweden by 2030 and 5% by 2050, which is used here as a conservative potential. The impact of the future introduction of autonomous driving is uncertain. Either these cars can outcompete public transport or will be an integrated part of a public transport system (Ellen Macarthur Foundation, SUN, McKinsey Center for Business and Environment, 2015).

The Commission on Fossil-Free Road Transport (2013) gives a 3% potential for Sweden by 2030 and 5% by 2050 for the reduction of VKT through increased share of Internet shopping/e-shopping. This is based on the assumption that the share of retail sales that is done through e-shopping increases from 5% in 2012 to 25% in 2030 and to 42% in 2050.

The Commission on Fossil-Free Road Transport (2013) gives a 4% potential for Sweden by 2030 and 6% by 2050 for the reduction of VKT through increased share of telecommuting and virtual meetings. The potential consists of the following: 1.5% for telecommuting by working at home, 1% for studying at home, and 2–3.5% for virtual meetings.

The IEA reports a reduction potential of 5% for 'parking policy and road pricing' in Transport Energy and CO_2 (2009). The Commission on Fossil-Free Road Transport (2013) gives a 3% potential for Sweden by 2030 and 6% by 2050 for the reduction of VKT through congestion charges, parking policies, and parking fees. 1.6% of this is achieved through increasing the average parking fee by 10 SEK (1.1 €). Further parking policy potential can be realised by increasing the distance to the parking place relative to public transport and bicycle parking. In the city, where the measures are implemented, the effect is much larger.

Reducing speed also affects VKT indirectly. According to the Commission on Fossil-Free Road Transport (2013), a general 10-km/h reduction of speed limits on rural roads can reduce VKT by 3%. This is assumed to be implemented by 2030 and yields no further reduction by 2050.

The total is not a sum of the figures above, since the combined effect will be lower than that of the individual measures. Percentages of reductions cannot be added, but should be multiplied instead, as has been done here.

Table 3: Potential to reduce tonne kilometre growth by 2030 and 2050

	Potential by 2030 (reduction of tonne kilometre growth)	Potential by 2050 (reduction of tonne kilometre growth)
Modal shift to rail and waterborne	-15%	-25%
Improved urban logistics	-4%	-7%
Route planning and increased load factor	-9%	-15%
Longer vehicles	-1%	-5%
Consumer and production patterns	Not available	Not available
Total	**-25%**	**-45%**

The potential represented by a modal shift assumes that 30% of truck transport over 300 km can be shifted to rail or waterborne transport by 2030 and 50% by 2050. This is in line with the objectives in the EU Commission 2011 White Paper on Transport. The estimation that truck transport over distances greater than 300 km accounts for approximately 50% of all truck transport is based on Eurostat 2014 data for the 29 countries of the European Economic Area (http://ec.europa.eu/eurostat/data/database). Our calculations show 0.5 × 0.3 = 0.15 by 2030 and 0.5 × 0.5 = 0.25 by 2050.

In projects, improved urban logistics have been shown to reduce truck traffic by 30–70%. An assumption of a 30% reduction by 2030 and 60% by 2050 has been made here. According to Eurostat, for 2014, truck transport over distances less than 50 km account for 12% of truck transport (tonne kilometre). This gives a potential of 0.12 × 0.30 = 4% by 2030, and 0.12 × 0.6 = 7% by 2050.

According to the IEA, Transport Energy and CO_2 (2009), empty transport can be reduced by 5%. The share of transport involved accounts for 88% (in city logistics 12%); a large share of these will be reduced by 30% due to modal shift. Our calculations show 0.88 × 0.7 × 0.05 = 0.03 by 2030. The UK Department for Transport (Computerised Vehicle Routing and Scheduling for Efficient Logistics, Freight Best Practice Programme, 2005) estimates that route planning can yield fuel reductions of 5–8%. Here we assume that the total potential for city logistics and route planning is 9% by 2030 and 15% by 2050.

For the potential represented by longer vehicles, we assume that exemptions for longer vehicles are granted only for restricted routes where shifting from rail to road does not represent a risk, for example as an incentive for intermodal transport for the first and last part of a logistic chain. Assuming that this accounts for 2% of goods transport volume and that the increase in length and weight improves efficiency by 50%, this means 0.02 × 0.5 = 0.01 by 2030. If the share of transports that can be carried out using longer vehicles can be increased to 10% by 2050, then the reduction potential will increase to 5%.

The total is not a sum of the figures above, since the combined effect will be lower than that of the individual measures. Percentages of reductions cannot be added, but should be multiplied instead, as has been done here.

Table 4: Efficiency improvements

Vehicle type	Potential for entire vehicle stock by 2030	Potential for entire vehicle stock by 2050
Passenger cars and light duty trucks (excl. electric drive)	46% (41%)	66% (48%)
Long haulage and coaches (excl. electric drive)	25%	45% (40%)
Urban buses and urban trucks	56%	60%
Other improvements (eco-driving, lower speeds)		
Passenger cars and light duty trucks	15%	15%
Heavy duty (trucks and buses)	15%	15%

The potential for passenger cars and light duty trucks is calculated using EU regulations that are already in place for new vehicles stipulating that average CO_2 emissions do not exceed 95 g/km by 2021. New regulations are expected to be implemented, requiring further reductions to 70 g/km by 2025 and 50 g/km by 2030. Electrification will play an increasingly important role in reaching these targets. By 2021, the electrification share of mileage for new vehicles in the scenario is 7%, increasing to 22% in 2025, 40% in 2030, and 70% in 2050. In the vehicle stock (new and old vehicles) ,the improvement by 2030 is 46% (20% electrification of total mileage). For combustion engines only, the corresponding figure is 41%. The corresponding figures for 2050 are 66% and 45%.

The potential for long haulage and coaches assumes that new vehicles will be 20% more efficient by 2020 and 30% more efficient by 2030 (compared with 2010). This gives an improvement in stock of 25% by 2030. It is assumed that by 2050, heavy duty trucks with conventional drivetrains could be 40% more efficient. This is based on IEA figures (Energy Technology Perspectives, 2010), which predict a potential of 40–50% by 2050. In addition, it is assumed that 25% of the kilometres driven will be electric as a result of an electrification of the major goods road network. The EU Commission (2014) writes that cost-effective, state-of-the-art technologies can reduce CO_2 emissions from new HGVs by 35%.

The potential for urban buses and urban trucks assumes that from 2025 onwards, all new buses and trucks will be fully electric. All-electric urban buses and urban trucks are assumed to provide an energy efficiency improvement of 60%, but in 2030 there will still be some buses and trucks with conventional drive trains, lowering the potential to 56%.

Other improvements include eco-driving and speed surveillance. For passenger cars and light duty trucks, lower speed limits will also have direct effects. The possible introduction of autonomous driving may have a greater impact, but these are uncertain and not included here.

Table 5: Renewable energy

Fossil fuels in road transport can be replaced by

- sustainable biofuels in conventional engines that run on petrol and diesel
- sustainable biofuels in engines specially made for these fuels
- sustainable electricity or hydrogen from renewable sources.

The easiest and fastest way to introduce renewable energy into the road transport sector is by using sustainably produced biofuels in conventional engines. One potential restriction in this respect is that some biofuels might not meet the standards of petrol and diesel and therefore require adapted engines. This, for example, is the case with FAME (Fatty acidy methyl ester) in diesel or ethanol in petrol. Synthetic petrol and diesel produced from biomass through hydrotreating (HVO, hydrated vegetable oils), gasification, or the Fischer-Tropsch process offers a way of meeting the standards for petrol and diesel and can be blended into petrol and diesel in high proportions.

Ethanol is the most common biofuel in the world. It can be blended with petrol in conventional petrol engines to a proportion of up to 5-15%. The proportion depends on the relevant regulation in that part of the world. Up until recently in Europe, for example, most engines were adapted to cope with a 5% blend. Newer vehicles, however, must be adapted to cope with a 10% blend. Dedicated E-85 flex fuel cars are needed for higher proportions. The second most common biofuel is biodiesel, most of which takes the form of FAME. There are limits to the opportunities for using this blend in conventional diesel engines without adaption.

Another biofuel is biogas, which needs dedicated engines and distribution systems. Except for the difference in its origin (from biomass instead of fossils), biogas is the same as natural gas and therefore shares the same infrastructure for distribution and vehicles as natural gas. Methane can be used in vehicles either as compressed gas (CNG or CBG) or as liquefied gas (LNG or LBG). Liquefied gas contains much more energy per volume and therefore offers a longer range than compressed gas. Until now, compressed gas has been most commonly used in both passenger cars and urban buses. The alternative fuel infrastructure directive (2014/94/EU) requires member states to build infrastructure for CNG and LNG fuels along the TEN-T core network by 2025 at latest. In the urban, suburban, and other densely built-up areas, the infrastructure for CNG shall be built by 2020 at the latest. There are possibilities to reduce GHG emissions by using biogas instead of fossil natural gas (both are methane). The directive on alternative fuels does not, however, make any differentiation between biogas and natural gas.

There are also other biofuels for dedicated engines that may be interesting in the future. These include, for example, DME and methanol. Besides the availability of biomass, energy-efficient, and cost-efficient production and distribution techniques, it is important that there is a sufficient market for these vehicles. An ambitious venture in a small or even medium-sized country is often not enough to get the vehicle industry to develop a special engine model for that market.

The electrification of road transport can be achieved by
- plug-in hybrids
- battery electric vehicles
- fuel cell vehicles
- the electrification of streets and roads for the continuous transfer of electricity to vehicles

Both plug-in hybrids and battery electric vehicles use batteries to store electric energy that has been charged from the electric grid. The plug-in hybrid vehicle also has a combustion engine and uses fuel (fossil or biofuel) that extends the available range, while the battery electric vehicle relies only on the energy stored in the batteries. The commercial breakthrough of battery electric vehicles and plug-in hybrids for passenger cars depends not only on subsidies and taxes, but also on the development of battery prices. However, recent prognoses for the development of battery prices looks very promising, so a breakthrough is more likely to come within five rather than ten years. For urban buses, the breakthrough could come even sooner. Another possibility for electrification comes in the form of fuel cell vehicles, which store the energy as hydrogen in a tank instead of a battery and uses a fuel cell to transform this hydrogen into electricity to drive the engine. In the long term, it is difficult to say if the market will be dominated by plug-in hybrids, battery electric vehicles, or fuel cell vehicles. There is also the possibility of the electrification of streets and roads for the continuous transfer of electricity to vehicles. In urban areas, this is a well-known technique that is still used by trolleybuses in many cities in Europe. There are now projects in some countries to develop techniques that can be used by heavy duty trucks on motorways too. The advantages of electricity are its very high energy efficiency when used in vehicles compared to combustion engines and the fact that it can be produced sustainably in many different ways from solar power, wind, hydroelectric sources, and biomass. The alternative fuel directive also requires member states to build an infrastructure for the charging of electric vehicles in urban, suburban, and other densely populated areas by 2020 at the latest. For hydrogen and for the countries that chose to develop it, the infrastructure must be built by 2025 at the latest.

The Commission on Fossil-Free Road Transport (2013) gave a potential for biofuel production in Sweden of 25–35 TWh per year by 2030. More recent estimates have lowered the production potential to 17–22 TWh. Of this, 15–20 TWh was estimated as being available for road transport (other use was non-road mobile machinery and other transport modes). The 15–20 TWh biofuels are only 20–25% of the energy that road transport uses today in Sweden. Taking into account the fact that Sweden, with its large natural resources, is probably one of the best-placed countries in Europe to produce biofuels, it becomes obvious that a low-carbon road transport system cannot rely on biofuels alone. The Commission shows that by combining measures for reducing VKT, increasing energy efficiency, and electrification, the need for fuels could be reduced to 27 TWh, of which 15–20 TWh could then be replaced by biofuels, leaving 7–12 TWh of fossil fuels, which would mean a reduction of fossil fuels of 84–90% by 2030 compared with 2010. This strategy would also allow for the possibility to export biofuels after 2030 when production capacity increases and energy use drops even further.

Table 6: Resource-efficient infrastructure with low carbon footprint

Energy use and GHG emissions are not limited to the vehicles using the infrastructure. Construction, maintenance, and operation of the infrastructure also require energy and give rise to GHG emissions. About 10 per cent of the emissions from road transport are not traffic-related but are generated during construction and maintenance. These emissions are dominated by the manufacture and use of concrete, steel, asphalt, and fuel consumed by vehicles and machines in these processes. The largest share of emissions comes from the construction of new roads and the major reconstruction of existing roads. Considerable reductions in GHG emissions can be achieved in the early stages of planning, when alternatives are still available. Later on in the process too, the potential for emission reduction is still high in relation to the choice of materials used in the works.

Chapter 9.2 deals with methods for calculating and implementing reduced GHG emissions from a lifecycle perspective when planning an infrastructure and procuring for it.

Energy use and GHG emissions from infrastructure from a lifecycle perspective can be reduced in:

- the planning phase, by considering alternatives,
- the design phase, by considering different types of construction, and
- the construction, operation, and maintenance phases, by considering different logistics, vehicles, machinery, materials, and fuels.

In the early planning phase, alternatives are considered, preferably using the four-step principle. From a lifecycle perspective, the lowest GHG emissions are often achieved if the problem can be solved using the first or second step in the principle, leading to an outcome where no new infrastructure is required. The exception to this can be, for example, building an infrastructure for public transport with the result that so many people will use public transport instead of passenger cars that the decrease in emissions from passenger cars is larger than the resulting increase in emissions from public transport and the infrastructure. It is then important to have a lifecycle perspective of the emissions including both the infrastructure and the traffic on it.

When the decision is taken to build a new road (step four), there are more alternatives to consider, for example with regards to the terrain where the road will be located. It is also important here to have a lifecycle perspective that includes both traffic and infrastructure. When the blasting of rock, earthworks operations, the construction of bridges and tunnels are taken into consideration, a straight road can result in higher GHG emissions during construction. However, it results in lower emissions from traffic compared with an alternative where the road follows the terrain.

It is very difficult to give a potential for reduction of GHG emissions in the planning phase. However, this potential can be high if GHG emissions relating to route selection and the location of the infrastructure are taken into account in the decision-making process. WSP (2015) has investigated the possibility of reducing GHG emissions in the design and building phase by 15% by 2020, 30% by 2025, and 100% by 2050 compared with 2015. The study comes to the conclusion that it is possible to reach the objectives for 2020 and 2025. For 2050, the introduction of the CCS technique for steel and concrete production is necessary in order to achieve a climate-neutral infrastructure. The study also comes to the conclusion that the objective for 2020 can be reached without increased costs. Examples of measures include the optimisation of bridges and other structures with respect to the amount of concrete used, the use of alternative materials such as wood in construction, the reduction of specific emissions from concrete by mixing with fly ash, and the use of biofuels and green electricity when producing concrete, asphalt, and steel. WSP also looked at the possibilities of reaching the same objectives for operation and maintenance of infrastructure. Even though there are larger uncertainties in this respect, it is also possible to reach a 15% reduction by 2020.

In a parallel study, the same objectives were used to come up with a strategy to reduce the GHG emissions from road ferries owned and used by the Swedish Transport Administration (SSPA, 2015). This study came to the conclusion that it was possible to reach the objectives by 2020 and 2025. It could be done through a combination of electrification (hybrid and battery electric ferries), auto-mooring, and biofuels. This would, however, mean an increased cost for the Transport Administration. Future reduction of battery prices, which could reduce total costs considerably, were not included.

In Norway, the government has a policy when issuing an invitation to tender for new ferries that low emissions and zero emissions should be considered. A fully electric ferry with capacity for 120 cars has been constructed and has been in operation since the beginning of 2015.

Actions already taken in the CEDR countries

In some countries, NRAs have already introduced climate mitigation strategies for transport policies at national level. The strategies and legislative levels differ from country to country.

In Denmark, most actions are indirect, for example optimisation of the traffic flow.

In Norway, 'Urban Environment Agreements' are being developed for the country's nine largest cities. In early 2016, one of these agreements was signed for the city of Trondheim. These agreements state that there shall be no increase in passenger transport by car and all increases in transport demand should be handled by public transport, walking, and cycling.

In Sweden, the emphasis has been put on the energy-efficient use of transport modes and the energy-efficient management of infrastructure. The decision has also been taken to carry out climate and energy calculations on all new major infrastructure projects. This will be the basis for measures to reduce energy consumption and GHG emissions from the infrastructure and traffic from a life cycle perspective. Sweden has also introduced 'Urban Environment Agreements', even if the scale is not as large as in Norway.

In Switzerland, research projects that are important for energy efficiency and climate mitigation are being evaluated and published. In addition, brochures containing information about daytime running lights and other issues relating to climate mitigation and energy-saving are being developed. CO_2-emmission regulations for new passenger cars and trucks (based on EU regulations) have been introduced, as has a regulatory framework for alternative and efficient engines.

Italy is focusing on detailed traffic modelling and monitoring, while Ireland has introduced an Environmental Strategy (four-phase strategy) to facilitate the integration of environmental issues into road scheme planning, construction, and operation.

Some countries have introduced eco driving as an element in driving tests. In Sweden, it was introduced in 2008 (the former Road Administration (now Transport Administration) was one of the major parties involved in 'importing' the eco-driving concept to Sweden from Finland in the late 1990s). The administration also provides the public and businesses with material on eco-driving. A variety of brochures on eco-driving and other issues related to climate mitigation/energy saving have been produced. Eco-driving has also been implemented in the operation of road ferries. In Norway, eco-driving was made a part of driving tests in 2006. Poland introduced it on 1 January 2015.

The majority of NRAs in the countries represented in TG I4 have decided to develop or introduce climate mitigation strategies and objectives. Some countries, like Poland, base their strategies and objectives on overall reduction targets. Italy has decided on a strategy, but its development is still ongoing. Most of the countries have a law or bill concerning CO_2 or GHG reduction as a whole. Along with these laws, catalogues of instruments, measures, and road maps are mentioned, as well as fixed limits of GHG emissions. Some countries (Sweden, Switzerland, and Italy) also refer to energy strategies as a whole, where climate mitigation isn't the only objective (others include energy efficiency, resource-effective energy supply, abandonment of the use of nuclear power, etc.).

In most instances, climate mitigation strategies are not limited to the NRAs but have been implemented across the whole government administration. This means that NRAs are integrated into their respective country's overall climate mitigation strategies and objectives.

At a national level, GHG reduction objectives are common. Ireland, Poland, Hungary, and Norway have no further objectives on a sectoral level. Sweden, Switzerland, Austria, and Denmark have objectives for either the entire transport sector, for the road transport sector, or both.

The objectives differ in terms of both their specified period and the percentage of reduction involved. At national level, the reduction objective is set mostly in comparison with the 1990 level and reduction objectives for 2020 range from 20 per cent (Switzerland, Italy, Poland) to 40 per cent (Sweden). By 2050, Ireland plans to reduce CO_2 emissions by 80 per cent, Sweden plans to be climate neutral, and Denmark plans to use 100 per cent renewable energy.

Regarding the entire transport sector, objectives may be the same as at national level (Italy) or lower (Switzerland, Austria). Denmark does not set a limit for GHGs, but has an objective of achieving a 10 per cent share of biofuel in 2020. The rest of the NRAs have no specific goals.

Italy has a fixed reduction goal for road transport only: a 20 per cent reduction, which is the same as at national level. Sweden has set itself the objective of having a fossil-independent fleet by 2030. However, this objective has not yet been defined in detail. Switzerland has set itself the objective of reducing the average emissions (g/km) output for new passenger cars. Norway has also set itself an objective for GHG emissions from cars, namely that by 2020, emissions shall not exceed 85 g of CO_2 per kilometre. In the EU, the objective is to reach 95 g/km by 2021.

Six of the nine countries represented in TG I4 regard infrastructure as one of the most important factors in the reduction of GHG emissions.

Only the NRA in Sweden has directly taken part in developing a strategy for the reduction of GHG from the transport sector.

6 Possible scenarios, including those that reach the objectives

There are different ways of developing scenarios from the packages of measures available and different reasons for doing so. One frequently used method is to use a scenario cross that consists of four different scenarios based on two different parameters or dimensions that represent important uncertainties that have a large impact on emissions. In the transport sector, two such parameters are transport growth and technological development. In the four different scenarios, the influence of the packages of measures will vary. One reason for creating scenarios instead of using just the BAU forecast may be to prepare better for different eventualities and to have a real choice about how to react to these eventualities. Here, however, we focus on finding scenarios that meet the objectives. Depending on how difficult the objectives are, one or more scenarios can be enough. Some elaboration may be needed to adjust the scenarios, putting more emphasis on certain measures and less on others, etc. It is essential to have at least one scenario that meets the objectives.

Figure 7 shows an example of the work completed in Sweden with different scenarios for future GHG emissions from the transport sector with a focus on road transport (Swedish Transport Administration, 2012). In this case, only one of the scenarios met the objectives in Figure 5. This scenario, the Climate Scenario, included both high technological development of vehicles and fuels and a more transport-efficient society. The potentials used in the scenario are mainly those given in Tables 2–5.

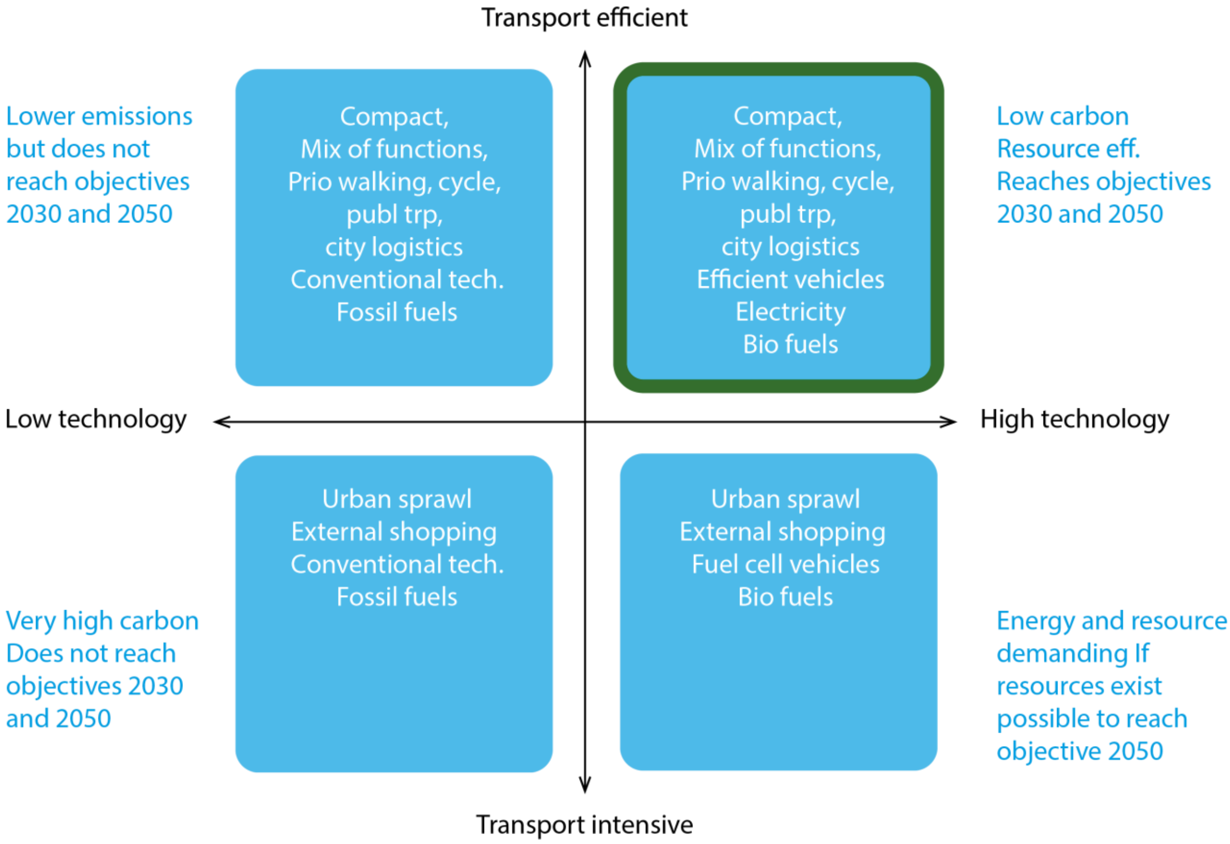

Figure 7: Scenario cross including four different scenarios based on the parameters transport growth and technological development

The effect of the Climate Scenario on the use of fossil energy is also illustrated in Figure 8. The top of each bar illustrates the situation without new measures for given time frames. The grey part of the bar shows the use of fossil fuels after the implementation of targeted measures. From the bars, it is possible to see the contribution of the different types of measures. The energy use for given time frames are indicated by the sum of grey, green, and yellow parts of the bars. According to this scenario, Sweden will export some biofuels to other countries from 2040 onwards. The scenario is mainly based on the potentials indicated in Tables 2–5.

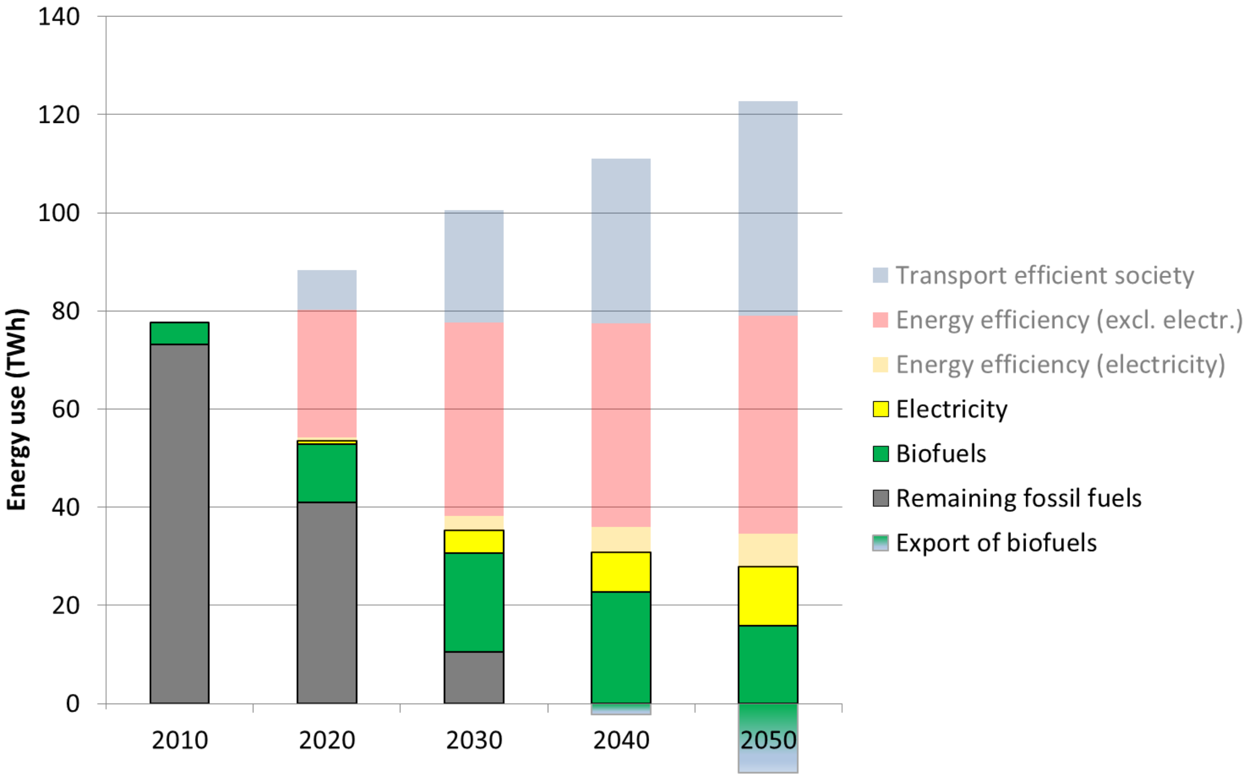

Figure 8: Scenario outlining the use of fossil energy for road transport in Sweden (with and without new measures)

Apart from the scenario cross, other methods can be used to create scenarios. In the Norwegian project called 'Metode 21', for example, a number of supplementary methods have been elaborated. Metode 21 is based on the recognition that when planning, it may be necessary to supplement the transport models with other methods. The most useful methods identified were scenario analysis, backcasting, and expert panels (including in depth interview and Delphi studies). These methods were tested in five different case studies in 2013 and 2014 in connection with work on the Norwegian National Transport Plan. A description of the method and application of it are given in Norwegian National Rail Administration and Norwegian Public Roads Administration (2015).

In Poland, the main document defining future transportation trends is the 2013 Transport Development Strategy (Polish Ministry of Infrastructure and Development, 2013), which identifies threats to the environment caused by pollution. The strategy includes data on the external costs of the negative impact of transport, of which 29 per cent are the costs of polluting the environment. This figure breaks down as follows: 11 per cent for air pollution, 5 per cent for climate change, 11 per cent for noise pollution, and 2 per cent for other costs. Mitigation measures were set for the goal of reducing GHG emissions by 20 per cent by 2020. To reach these goals, implementation of 'directions of intervention' were described. These fields contain:

- organisational and system changes (i.e. promotion of energy-efficient solutions, intermodal transport, smooth modal shift, promotion of cycling and public transport, establishing Low Emission Zones (LEZ), tolling and fees, monitoring of emissions).
- Investments (i.e. modern fleets of vehicles, 'green' infrastructure, ITS, route variants planning, impact of mitigating measures, improved safety and security).
- Innovative technologies (i.e. cleaner propulsion: hybrid, fuel cells, hydrogen, electric vehicles, modern construction methods that are climate resilient, mitigating of vibrations and noise).
- Monitoring and indicators (i.e. levels of GHGs, mortality, passengers per vehicle).

The implementation of the strategy is necessary because outdated and obsolete infrastructure still exists in some parts of Poland, which contributes to the generation of pollutants, mainly due to congestion and the fact that it is impossible to introduce modern solutions. The construction of new infrastructure and the modernisation of the existing infrastructure are currently seen as a priority.

Due to the lack of reliable data on possible trends until 2050, the scenarios developed in 2013 in Hungary as a basis for the National Transport Infrastructure Development Strategy are rather rough estimations. However, even on this basis, it is very likely that taking the 1990 GHG emissions from transport as a reference level, emissions will increase by as much as 200 per cent by 2050 in the BAU scenario (here meaning: 'do-nothing-special'). If structural changes in vehicle technology and fuels (similar to those occurring in advanced western European countries) are taken into account, the increase in emissions can be limited to about 100 per cent by 2050. A third scenario that was based on a higher ratio of electric propulsion and a lower ratio of fossil fuel decreased the GHG emissions to 80 per cent by 2050 (Hungarian Transport Administration, 2013). Neither scenario can reach the EU objectives by 2030 or 2050. Another assessment was conducted in 2015 for the 'National Climate Change Strategy 2014–2025 with a view to 2050' (Hungarian government, 2015). Two scenarios were assessed here: one with the maximum, the other with the minimum GHG emissions. In the GHGmin scenario, GHG emissions from passenger transport are constantly decreasing. In the GHGmax scenario, GHG emissions increase until 2030, then decrease until 2050. The GHG emissions from goods transport increases constantly in both scenarios. The total GHG emissions from transport follows the trend for passenger transport as it decreases constantly in the GHGmin scenario, and increases until 2030 then decreases until 2050 in the GHGmax scenario. The results above clearly show not only the need for new measures and policy instruments, but also shows that technical solutions are not enough. It is also necessary to have measures and policy instruments leading to less transport growth and to increased use of more resource-efficient modes such as cycling, public transport, and goods transport via rail and water.

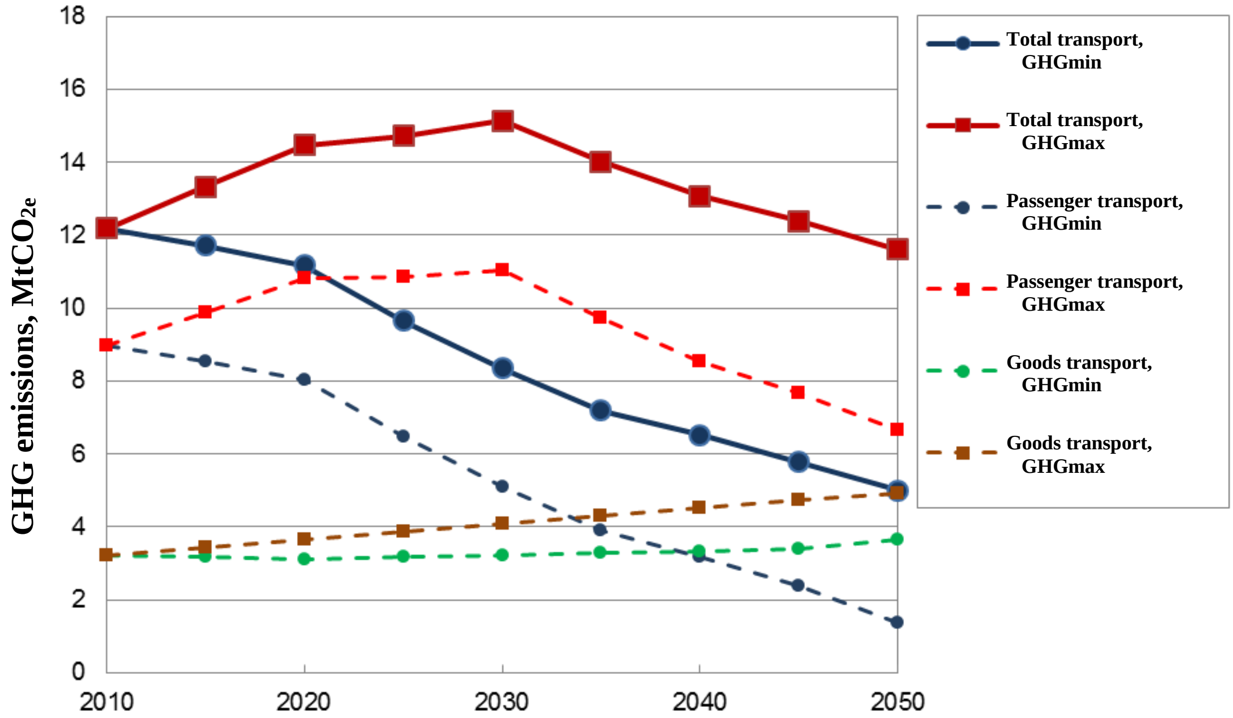

Figure 9: GHG emission trends from transport in Hungary (Hungarian government, 2015).

7 Using the scenarios to identify measures and policy instruments

The basic idea is to use the scenarios that meet the objectives when planning the transport system and in the design of policy packages. In this chapter we concentrate on the former. These scenarios include a growth of traffic and transport volumes that is in line with the framework of the objectives. This probably means less growth in road traffic than in the BAU forecast. If the objectives are difficult to meet, the scenarios may even include a decrease in road traffic volumes compared with the present-day situation. On the other hand, this probably means greater increases in other modes such as walking, cycling, and public transport on road and rail as well as greater increases in goods transport via rail and water than in the BAU forecast. It is recommended that the scenarios be used in strategic planning, including all relevant modes, since it influences the whole transport system.

In Sweden, the Climate Scenario has been used as an alternative basis for two consecutive national transport plans. In 2011, the Swedish Transport Administration was commissioned to assess the capacity demands of the transport system until 2050 as a basis for the National Transport Plan for 2014–2025. The Transport Administration took the initiative and also developed a climate scenario to use as an alternative to the BAU forecast. At a late stage in the process, a climate package was specially designed to meet the challenges in the climate scenario with more public transport, cycling, and goods transport via rail and water etc.

One problem was that the work with the climate scenario and especially the climate package was not prioritised due to the fact that the climate scenario was only an initiative taken by the Transport Administration itself and not something that was commissioned by the government. In 2015, the Transport Administration was commissioned to provide a basis for the next National Transport Plan for 2018–2029. This time, the administration was asked to elaborate the need for infrastructure investment and maintenance for three different futures: 1) one where measures and policy instruments were already decided, 2) one that also included politically announced policy instruments and 3) one that included more policy instruments to reduce the emissions of GHG gases. In the case of the last future, the Transport Administration decided at an early stage to use the existing and recently updated Climate Scenario that fulfilled the climate objectives (as the Transport Administration had interpreted them). Strategic planning involves experts in the planning of infrastructure, construction, maintenance, environment, traffic safety, cycling, public transport, and urban planning. Many of these experts have considerable experience in strategic planning and have been involved in previous national plans. The two first futures were, therefore, something that the experts were quite familiar with and knew the requirements to be fulfilled. The Climate Scenario was, however, something completely new for most of them. For this reason, a number of workshops were arranged internally at the Transport Administration at both national level and regional level.

The first step in the workshops was to familiarise the experts with the Climate Scenario, describing the future of it in 2030, one year after the National Transport Plan would have been fully implemented. The future in 2030 was described in terms of changes in traffic and transport volumes compared with both 2015 and the BAU forecast for 2030. Characteristics in the Climate Scenario in 2030 were also described as increased urban densities, land development in urban centres and along public transport, the mix of different functions in the city, streets that promote cycling and walking, lower speeds both in cities and in the countryside, etc. After this introduction, the experts were asked to start describing the measures that would be needed to make the Climate Scenario a reality in 2030 using the four-step principle (see below). Here, the experts were urged to start with 2030 and plan backwards to 2015. This method is usually called 'backcasting'. Other questions asked were: what challenges result from the development? What opportunities are created and how are these opportunities used? After the workshops, the experts continued to work on the scenario with the support of the workshop leaders from the Environment Unit within the Transport Administration. This was not the only workshop organised: there was also a backcasting workshop with external academic experts, consultants, and businesses and a workshop with other national authorities on the policy instruments needed to reach the Climate Scenario by 2030. To further improve the knowledge on policy instruments, a separate project was also launched. The results of the work were presented in a report by the Transport Administration at the beginning of 2016 (Swedish Transport Administration, 2016).

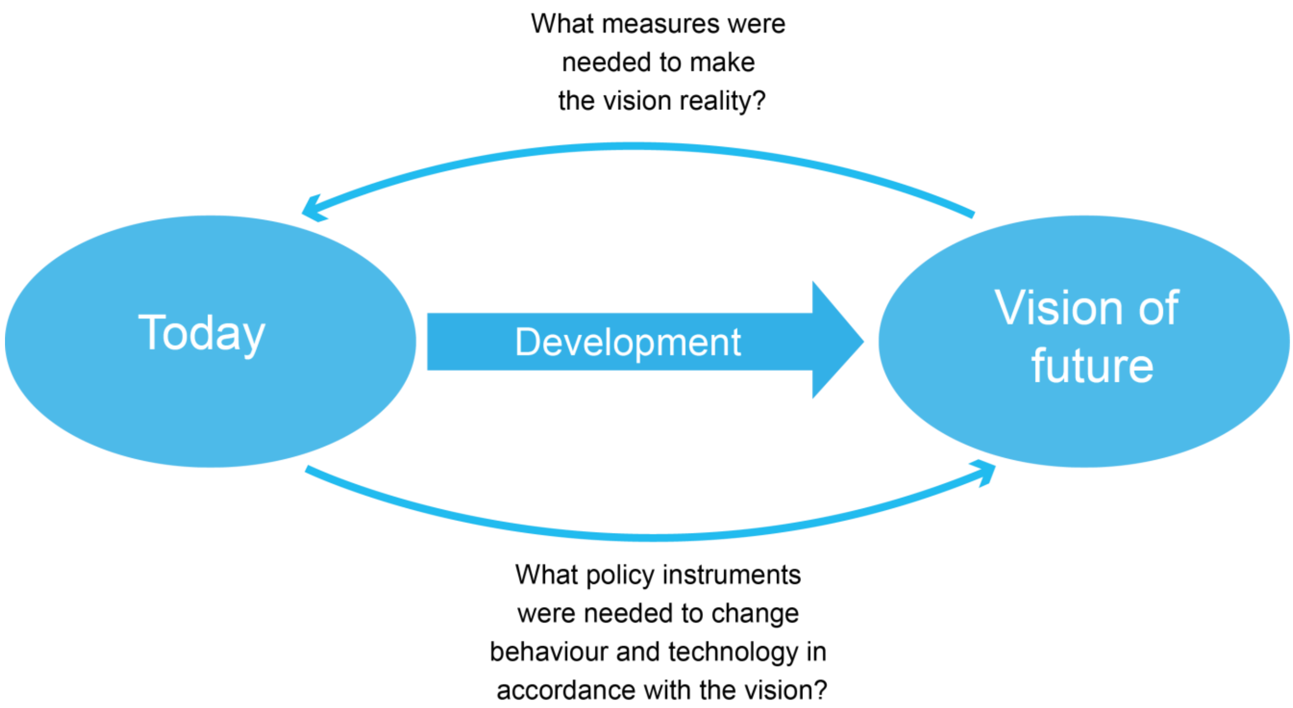

Figure 10: Illustration of the backcasting method used in the workshops

Four-step principle

The 'Four-step principle' is a very useful tool as it provides a logical basis for choosing the appropriate measures to achieve accessibility and other objectives at the lowest cost to society at large.

The four steps are:

1 **Rethink:** selection of the mode that will provide the best solution to the problem. This means introducing measures in order to affect transport demand and mode choice. This includes planning, pricing, and regulation. The purpose is to transfer transport to safer and more sustainable modes or to alternatives to transport such as telecommuting.
2 **Optimise:** utilisation of existing infrastructure, new management, no reconstruction or physical adjustments. This means providing for more efficient use of existing infrastructure. This includes planning, pricing, and regulation. The purpose is to use infrastructure in a more efficient, safer, and more sustainable way.
3 **Improve:** limited amount of reconstruction and improvement of existing assets.
4 **Invest:** construction of new infrastructure and major improvements. This means use of additional land.

The main advantage of the 'four-step principle' is that it allows all stakeholders to gradually consider all possible solutions, therefore reducing to a minimum the risk of omitting the best solution. It allows them to consider solutions that ensure good and sustainable accessibility without increasing mobility for cars and trucks. In some cases, there are also other limitations besides GHG emissions. For example, this method is perfectly suited to a situation where there are existing constraints regarding development, the landscape, or the environment.

The first two steps ('rethink' and 'optimise') involve actions relating to existing infrastructure. Therefore no new elements are introduced and solutions do not require additional land. Their main focus is on management and the utilisation of available technology. These two points are feasible if the problem to be addressed can be handled within existing infrastructure (including all modes). If the transportation network is already dense and sophisticated and has numerous nodes and various modes, as in many well-developed economies, space in itself sets restrictions. In this case, it will not be possible to solve the problem with technical measures alone.

The third step ('improve') requires a limited amount of reconstruction and improvement. It also focuses on existing infrastructure and cannot, therefore, be perceived as a brand new investment. Actions taken during this step may require additional land. However, this may not always be the case. Sometimes infrastructure can be adjusted for future modification during the initial design. In Poland, for example, it is usual to plan ahead during the construction of dual carriageways, leaving a reserve strip between the carriageways inside the road area that can be used for future widening.

A reserve area for third lanes on the S8 expressway near the city of Wieluń in central Poland (photo: Grzegorz Łutczyk, GDDKiA)

In the case presented above, increasing the road capacity by widening does not entail use of additional land, and does not interfere with road water treatment systems, screens, road lighting, technology ducts for optical fibres, and electricity, all of which are situated at the edge of the roads. Roadworks are limited to the necessary minimum, which also means that fewer machines and transport are required. This in turn helps reduce consumption of fossil fuels and reduces the impact on both climate and environment.

The final step ('invest') requires the largest financial resources and additional land. It also requires the completion of the design and the various administrative procedures needed to obtain all necessary permits and approvals. These may include the construction of brand new sections of road, which is currently the usual choice in the eastern part of the EU or major adjustment of the existing transport route in the western part.

Norwegian Metode 21 in Climate Cut

The Climate Cut project was originally intended to form the basis of a long-term climate strategy or climate policy for the Norwegian Public Road Administration (NPRA). In the first phase of the Climate Cut project, managers and key employees in the NPRA were surveyed using extensive qualitative interviews to ascertain the status and challenges relating to climate mitigation and the transport system. The focus of the internal project was, for various reasons, gradually changed to a more short-term action plan, while the strategic challenges of the climate work were discussed in connection with the climate report for the National Transport Plan 2018–2027. For this reason, the use of Metode 21 was included in this work, where the need for alternative planning methods was greater (Norwegian National Rail Administration and Norwegian Public Roads Administration, 2015). The following processes were completed:

- qualitative interviews with managers and key personnel in the mapping phase;
- Delphi surveys, which gave a picture of the expected developments in selected issues;
- a scenario process that started with key factors and mini scenarios as building blocks for larger holistic scenarios;
- the development of three normative scenarios, where the objectives are reached, but not necessarily the preferred future;
- Expert Panel, i.e. experts in the fields of transport, society, and climate, who were invited to join the process to reflect on the findings and their quality;
- backcasting, where those involved worked backwards from the descriptions of the future in 2050 to present time;
- analysis of the work for further use in the strategy process of the National Transport Plan.

The work began by identifying key factors and participants at the first meeting. In the second session, about 50 mini scenarios were written down. These were used by the working group to develop three scenarios. From the three scenarios that were drafted, the consultant developed three future scenarios.

These activities served as complementary approaches to the identification of opportunity and risk associated with future development. They also helped to identify connections across sectorial boundaries based on the goal of a low-carbon society in 2050. One Delphi survey was answered by 15 professional bodies. The survey was designed as a questionnaire in order to obtain expert advice from various disciplines. The purpose was to get expert views on key trends, asking experts what they expected to happen and what, in their view, a desirable outcome would be.

The project leader concluded that the work was very informative and provided a broader basis for more confidence in being able to conclude the ongoing strategic assessments.

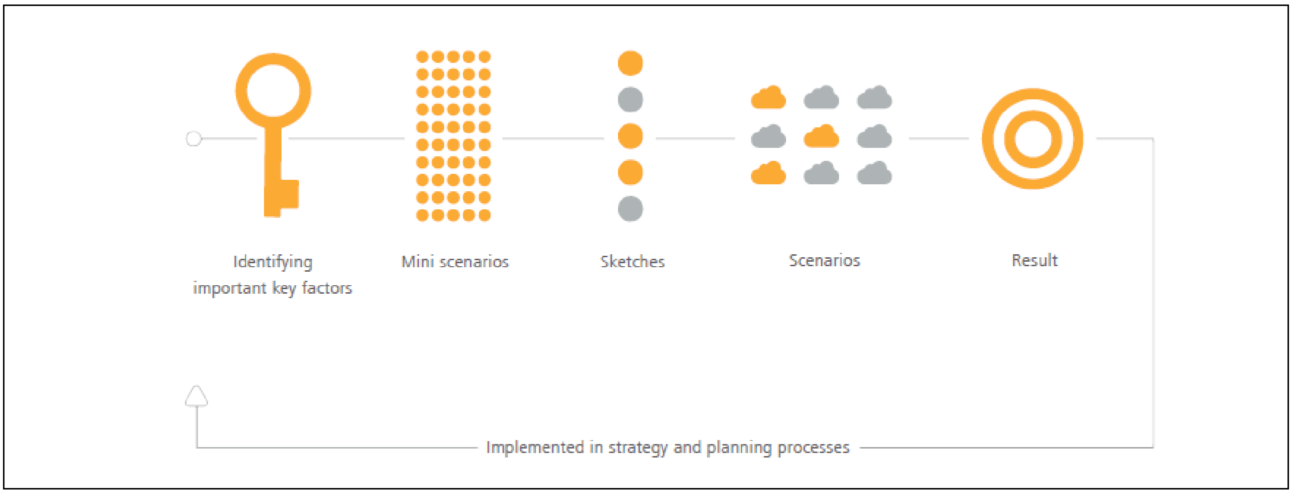

Figure 11: Illustration of the use of Metode 21 in Climate Cut

Metode 21 was also used for concept planning for the city of Hønefoss. Four scenarios were developed as images of the city and the region in 2040. One lesson learned from using the methodology in this planning area was that it allowed uncertainties to be identified and dealt with in the project. Such uncertainties are difficult to capture using traditional tools such as transport models and economic analysis.

8 Implementation

8.1 Using scenarios in line with the objectives in the CBA

Strategic planning does not go into detail on individual projects. Instead it should provide a basis for political decisions on the framework such as budget and strategic direction for the national transport plan. Once a political decision has been taken, the planning continues, analysing the needs for measures using the four-step principle. This provides a basis for a national transport plan consisting of different measures, infrastructure projects, and maintenance. This is then forwarded to the government who ratify the National Transport Plan with or without amendments.

One basis for prioritising different infrastructure projects is cost-benefit analysis, CBA. In Sweden, CBA has been used in relation to the climate scenario. This scenario was used in the socio-economic models as a sensitivity analysis for the main analysis with BAU forecast. It is a well-known fact that the costs in the CBA are dominated by the cost of journey time. Therefore measures that lead to large time savings lead to a result that concludes that the project as whole is profitable. However since the Climate Scenario includes less passenger car traffic and truck traffic than the BAU (main analysis), the time savings and the profit drops to almost the same degree (some other parameters like traffic safety might contribute to the profit). Figure 12 shows the differences in profit for new road infrastructure projects proposed for the national plan 2014–2025 in the main analysis and in the Climate Scenario. It also shows that the effect of increasing the valuation from 1.45 SEK per kilo carbon dioxide to 3.50 SEK had only limited influence on the profit. The high valuation of time compared to other parameters such as greenhouse gas emissions can, of course, be criticised, but the example shows that this is of limited importance compared to the growth of traffic assumed.

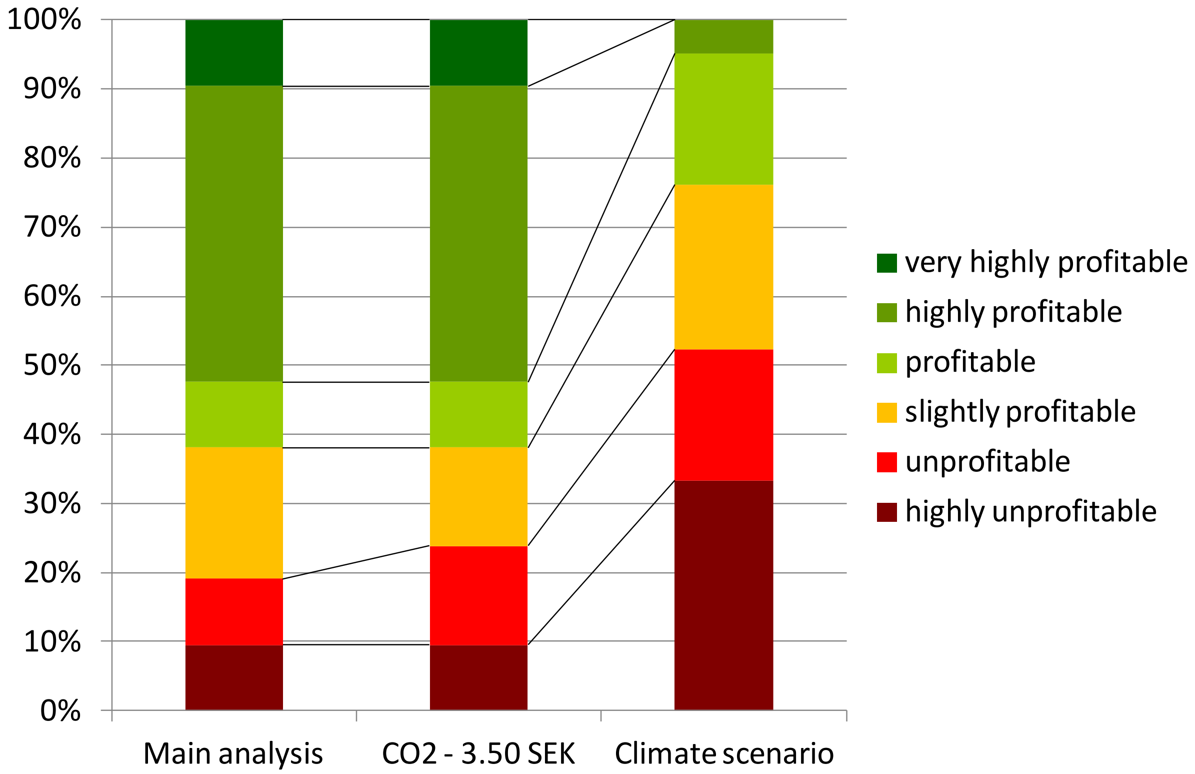

Figure 12: Analysed projects broken down into the different classes of profit for the main analysis, for a higher valuation of CO_2, and for the climate scenario

8.2 Methods to calculate and work for reduced GHG emissions in a lifecycle perspective in planning and procurement of infrastructure

In addition to the traffic on the roads, the maintenance and operation of infrastructure and the construction of new infrastructure also generates GHG emissions. It is therefore important to consider not only the direct emissions from machinery and trucks but also the indirect emissions from materials and energy, including the extraction of raw material, the processing of materials, and transportation in all phases, including to the site of production or maintenance. The demolition of old infrastructure should also be included. In Sweden, it is estimated that emissions from infrastructure from a life cycle perspective accounts for 5 to 10 per cent of the total emissions from traffic and infrastructure. This is a rough estimate, but it gives an order of magnitude of the size of the emissions. Even if the emissions from construction are not as high as the emissions from traffic, road authorities can still influence emissions either directly or through requirements in construction procurement documentation.

Figure 13 shows an example from Norway of how GHG emissions are distributed between different materials and fuels in a motorway project. Figure 14 shows another example for all major road projects included in the Swedish National Transport Plan 2014–2025. Both pictures show that GHG emissions are dominated by concrete, steel for reinforcement and other construction, diesel for machines and trucks, and asphalt. Reducing the need for these materials through lighter construction, a reduction in mass transport, and the use of more efficient vehicles and machines together with materials and fuel with less GHG emissions are ways to reduce a project's overall GHG emissions. The examples below from Norway and Sweden show how one can work to get better control of the emissions and to reduce them.

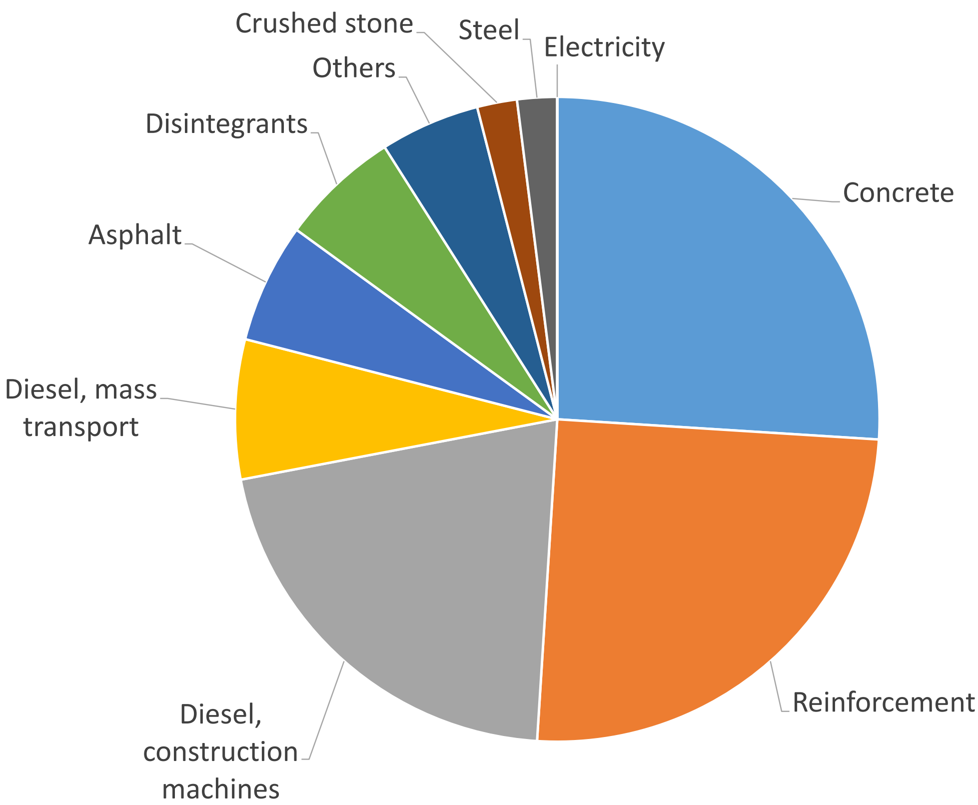

Figure 13: Distribution of GHG emissions for a motorway project in Norway (Norwegian Public Roads Administration, 2015)

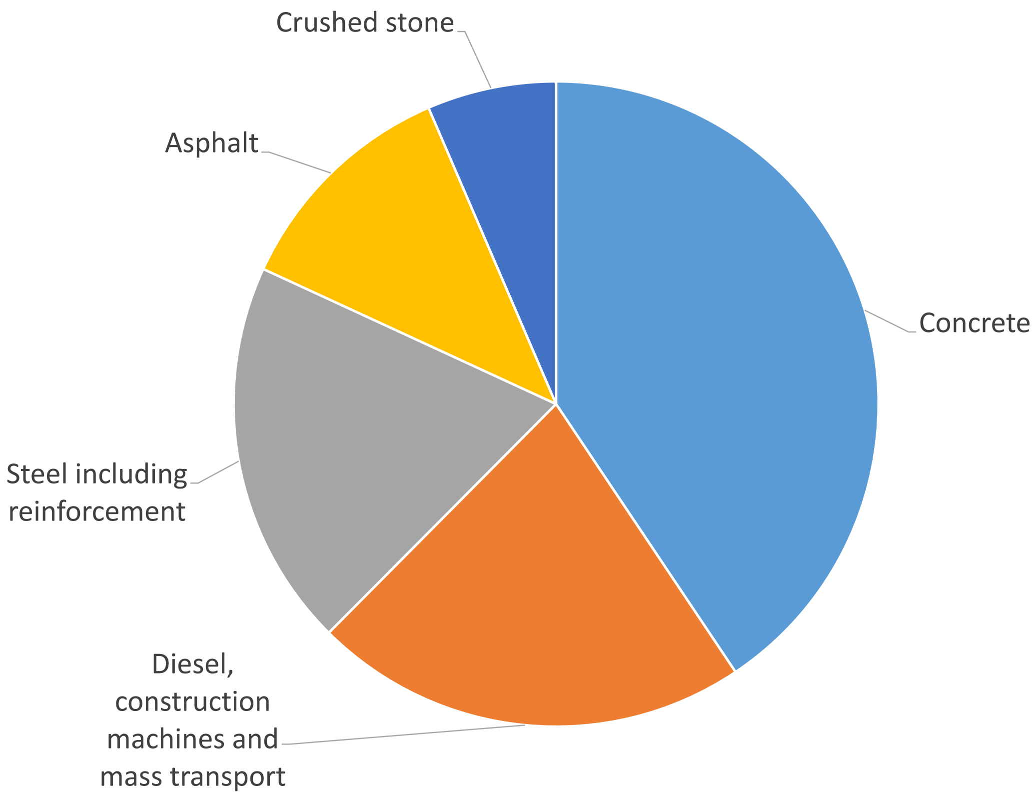

Figure 14: Distribution of GHG emissions for major road projects in Sweden (WSP, 2015)

Example from Norway

The methodology that was recently developed in Norway incorporates the impact of GHG emissions during the construction phase and from relevant maintenance work throughout the lifetime of the project. These indirect emissions, together with direct emissions from traffic, are incorporated into a cost-benefit analysis (CBA). The methodology has been standardised and is integrated into the standard software package EFFEKT, which is used for performing CBA.

Regarding construction, the methodology summarises emissions from the extraction of raw materials, the processing of materials, and construction. The underlying principle for calculation is that GHG emissions are equal to input factors multiplied by emission factors. Input factors may include concrete, steel, disintegrants, transport, etc. Emission factors are derived for all input factors from the environmental database Ecoinvent and adapted to Norwegian conditions. The reason for the small number of input factors used (around 20) is that this analysis is carried out at an early planning stage when knowledge about the material used in construction is limited. For example, only one quality of steel is used; the same applies to concrete. The closer one gets to the start of construction work, the easier it should be to differentiate more and use more specified input factors.

The emissions—consisting of CO_2 (carbon dioxide), N_2O (nitrous oxide), and CH_4 (methane)—are calculated in tonnes of CO_2-equivalents. To convert this volume into monetary terms for CBA applications, a unit value of NOK (Norwegian Kroner) per tonne is used.

This methodology is primarily designed for calculating GHG emissions from ordinary roads in open terrain, steel and concrete bridges, ferries and tunnels—all of which are elements that may be part of an ordinary transport project. The method is now used for most proposed projects in the new National Transport Plan.

As mentioned above, so far, GHG emissions have been calculated at an early planning stage. However, experience shows that more accurate calculations are needed when approaching the construction phase. For this reason, a more detailed calculation programme for GHG emissions is under development. The results will become part of tender documents, and constructors will be prompted to reduce GHG emissions.

Example from Sweden

Calculations of GHG emissions and energy use during the life cycle have also been made in Sweden for all projects included in the National Transport Plan for the years 2014–2025. A methodology has been developed and used to make calculations for the largest projects and a number of 'standard projects'. Total GHG emissions during the life cycle (including traffic) were calculated for the largest projects, standard projects, and indicative parameters. This gave an estimation of GHG emissions and energy use for the whole National Transport Plan.

The method used for the national plan has been developed into a tool, Klimatkalkyl, that can be used for operational calculations of GHG emissions and energy use for new infrastructure projects. In April 2015, the Swedish Transport Administration made it mandatory to use Klimatkalkyl to calculate life cycle GHG emissions and energy use for all new infrastructure projects with a total cost over 50 million SEK (€5.4 million). Successive calculations have to be carried out from the early planning stage until the infrastructure project is completed and ready to be opened to traffic. This allows potential to be exploited at every step. Klimatkalkyl is updated regularly. In future updates of the method, it will also be possible to make calculations not only for new infrastructure projects but also for the operation and maintenance of existing infrastructure.

Carrying out calculations is a first step towards getting a picture of GHG emissions and energy use from infrastructure construction. From this, large emitters and potential reductions can be identified. As described above, GHG emissions from infrastructure from a life cycle perspective are dominated by the use of concrete, steel, asphalt, and fuel consumed by vehicles and machines.

Based on the experience gained from calculating GHG emissions and energy use from infrastructure, the Swedish Transport Administration began developing requirements to reduce GHG emissions and energy use from infrastructure in 2014. The purpose of the requirements was that they would be used during the procurement of consultants and contractors. Early in the process, some basic principles were identified:

- The requirements should be long term so that the consultants and contractors get sufficient time to develop cost-efficient strategies to develop solutions to deal with them. More ambitious requirements later are preferable to less ambitious requirements with no lead time.
- The requirement for a reduction in GHG emissions for a certain year about 5 years from now should be complemented by an indicative more long-term target 10 years from now. This gives the consultants and contractors long-term rules to develop solutions for the future.
- Technically neutral requirements on reductions of GHG emissions that describe what should be achieved instead of how it should be achieved. In this way, consultants and contractors can chose the most cost-efficient solution.
- Monitoring should be mandatory for every contract that is subject to the requirements. Monitoring of individual contractors for all contracts that they have secured can also be completed. By comparing the results of different contractors and benchmarking them, a form of competition between them can be established.
- The requirements should be complemented by research and development activities together with the consultants and contractors. The focus should be on reducing the cost of promising solutions with large potential to reduce GHG emissions.
- Barriers for using cost-efficient solutions should be identified as well as solutions to unlock these.

It was decided that the requirements should include the whole infrastructure including construction, operation, and maintenance of existing infrastructure and also the procurement of railway-specific materials that the Transport Administration provides to the contractors. The requirements should include consultants for planning and design as well as contractors for construction, operation, and maintenance.

Preliminary targets to reduce GHG emissions and use of energy that the requirements would be based on were derived from national climate and energy targets. A research project was conducted in 2014 and 2015 to describe the consequences of the preliminary targets and two alternative levels (WSP, 2015). The research project also provided a basis for designing requirements in procurement. The project identified potential reductions of GHG emissions for different measures including design and materials (see also Table 6). These measures were put together in scenarios that met the different target levels. The scenarios together with possible requirements were then presented and discussed during a number of workshops held with consultants and contractors. The overall conclusion was that the derived target from the national GHG objective of a 15-per cent reduction in GHG emissions from new infrastructure projects between 2015 and 2020 could be achieved at no extra cost. It was also concluded that a 30-per cent reduction by 2025 could be achieved. However, the cost of doing so is more uncertain. To achieve a 100-per cent reduction—thereby contributing to the national objective of a Sweden without net GHG emissions by 2050—carbon capture and storage in production plants for cement and steel are necessary. The consultants and contractors that took part in the workshops were generally positive about the fact that the Transport Administration was going to put in place requirements to reduce GHG emissions in procurement.

Based on the results of the research project, the Swedish Transport Administration has introduced requirements on all new consultant and contractor contracts for new infrastructure projects (with total costs of over 50 million SEK) starting from 2016 and that will be concluded 2020 or later. Pilots will also be carried out for projects with a shorter lead time. Requirements for operation and maintenance contractors as well as for smaller projects (50 million SEK or less) will be developed at a later stage.

Consultants and contractors are expected to meet requirements during both the planning and construction phases (see Figure 15). During the planning phase, the exact location of the road is not yet set and the design is not well defined. Depending on what solution is subsequently chosen, GHG emissions can vary considerably. GHG emissions are, however, only one of the many parameters that are considered when the Transport Administration chooses the final solution. When procuring the consultant for the planning phase, the consultant is required to

- compile climate calculations for the different alternatives,
- present the most important aspects for GHG emissions for the different alternatives, and
- present measures that can reduce the GHG emissions.

Bonuses can be used to encourage the consultant to deliver a good product. This can also affect a consultant's future prospects to win contracts. Regarding the proposals on measures to reduce GHG emissions and other important factors, the Transport Administration can make a decision on an alternative. In order to encourage the region within the Transport Administration that makes the decision to choose alternatives with low GHG emissions, internal performance management is used with annual emission objectives per region.

The Swedish Transport Administration uses both performance contracts and turnkey (design) contracts for contractors. The objective is to increase the latter. When a decision has been taken to use performance contracts, a consultant is first procured to carry out the design of the project. Before proceeding with the procurement, the Transport Administration calculates the potential to reduce GHG emissions in the project using a specified method. On average this meets the objectives mentioned above (15 per cent reduction by 2020 compared with 2015). In the design phase, the consultant shall propose measures that fulfil the specified reduction of GHG emissions (in per cent) compared with a certain base level. The consultant shall specify proposals for:

- design measures that can be decided by the Transport Administration
- quantitative reduction requirements that can be used in the procurement of a contractor.

The consultant also updates the climate calculation for the project.

In the next phase, the contractor for the construction contract is selected. Here, the Transport Administration uses the input from the design phase to decide on the design and a quantitative reduction of GHG emissions compared with a certain base level that the contractors have to fulfil. This is then specified in the procurement documentation. At the end of the contract, the contractor has to show, using a third party-certified climate declaration, that the requirement for reduction of GHG emissions has been fulfilled. If the required reduction is exceeded, the contractor may be entitled to a bonus, the size of which will be specified in the procurement documents. The results may also affect the contractor's chances of winning future contracts.

The method used for turnkey (design) contracts is essentially the same as for construction contracts. The main difference is on the level of requirements, which are higher because the design phase is also included.

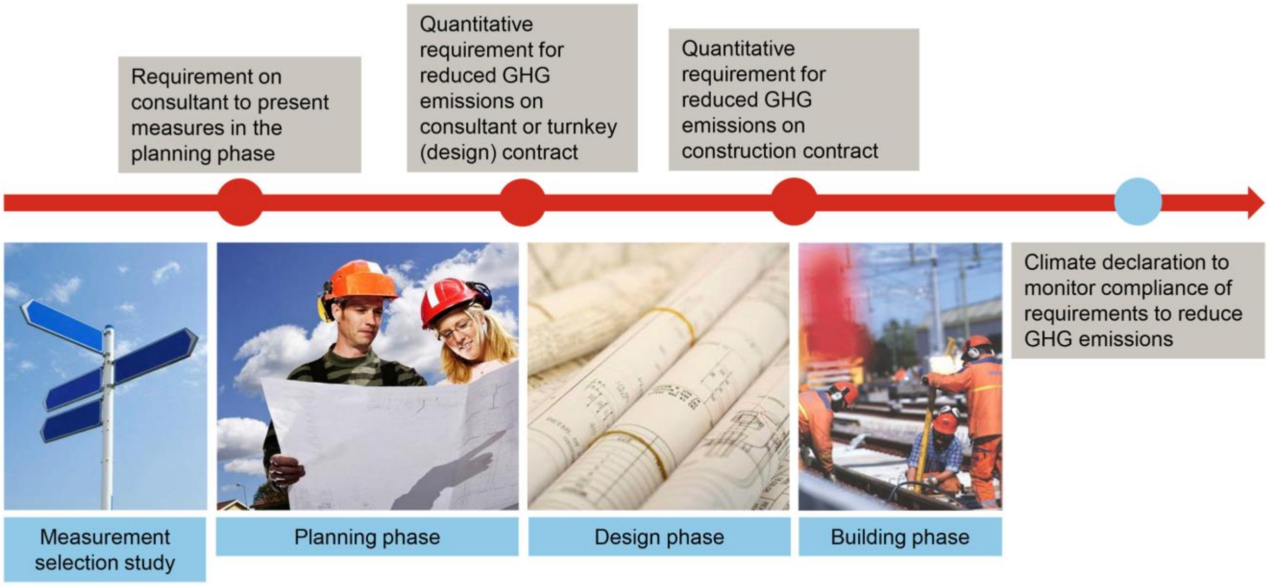

Figure 15: Requirements on consultants and contractors in different phases of a project

Examples from other countries

Methods of calculating and working towards reduced GHG emissions in an LCA perspective when planning and procuring infrastructure have not yet been implemented in Poland or Hungary. In Poland there are, however, plans to introduce it. The Strategic Environmental Impact Assessment (SEIA), included in the Prognosis of Environmental Impact made for the National Road Construction Programme for the years 2014–2023 clearly states that the continuing release of emissions into the atmosphere will contribute to climate change in the future. The SEIA notes that emissions from the transport sector are 23% of those from the energy sector. It also stresses that mitigating measures must be assessed at every stage of the planning phase—i.e. selection of route variant, feasibility studies, and design—so measures can be introduced during the construction, operation, maintenance, and the dismantling of roads.

8.3 Dealing with uncertainties

There are always uncertainties about the future. There is an uncertainty about the impact of measures and policy instruments, and there are also uncertainties about the future economy, behaviour, etc. This implies a need for continuing work: analysis of trends and gaps, an updating of knowledge about measures, policy instruments and scenarios. If the trend diverges too much from the path leading to the objectives, new policy instruments and measures might have to be implemented. It is recommended that development is analysed at regular intervals, and action is taken if required. This is necessary for strategic plans for infrastructure, transport systems, urban planning, and policy instruments.

It is very important to stress that uncertainties about the future should not prevent us from doing things that we now know will be needed in the short and long term in a sustainable transport system. In

Budapest, Hungary, for example, a new approach is now emerging. This approach includes efforts to popularise cycling and to improve communication techniques and the service level of public transport in order to change travel habits and make public transport more popular and more convenient in the city.

9 Reformulation, research, and assessment needs

As long-term (or strategic) planning is crucial in the development and management of the decarbonisation process, it is necessary to put more effort into reformulating this kind of planning and making it a really comprehensive, climate-conscious, and flexible tool for climate change mitigation. To achieve this, the firm commitment of the EU and national governments to take successful action is needed. EU legislation should be revised and updated to incorporate more pronounced obligations to assess the climatic impacts of certain projects or plans. Methodological guidelines should also be developed (preferably at EU level) to facilitate and ease the practical application of EU legislative documents and harmonised national regulations. This complex legislative process most possibly requires new research dedicated to supporting the practice of long-term planning and individual project planning.

The practical solutions described in the previous chapters and other solutions yet to be developed should be supported and promoted by continuous research and assessment in order to identify and fill the gaps in knowledge and to monitor the performance and results of the adopted solutions.

The latest experience points towards the need to apply the backcasting approach especially for the long-term planning of infrastructure and transport development in order to ensure the fulfilment of GHG reduction targets. It is also important that proper assessment techniques be utilised in the planning of individual projects. Both strategic and project planning are expected to evaluate climatic implications from a life-cycle perspective and to conduct a cost-benefit analysis.

Reformulation, research, and assessment need to apply to at least the following components of the proposed new planning process:

- definition of objectives
- trend analysis
- measures and policy instruments
- policy packages
- building databases, developing calculation methods and predictive models for traffic and social changes ('traditional' forecasting models can't handle the climate challenge, a backcasting approach is needed)
- scenario creation with backcasting
- scenario evaluation (fulfilment of the targets)
- cost-benefit analysis
- life-cycle analysis
- development of new methods

Free access to results in the above-mentioned fields could probably accelerate the paradigm shift process in planning.

Finally, the climate change mitigation objectives for reduction of GHG emissions should also be taken into account during the implementation of road infrastructure projects or other technical solutions, and the operation and management of road infrastructure as well. This purpose would be best served by climate-oriented procurement, the development of which may also require a substantial amount of reformulation, research and assessment.

10 Conclusion and recommendations

The experiences from Sweden and Norway show that the best results in strategic planning are probably obtained if the initiative to use alternative planning comes from the government, e.g. backcasting from a climate scenario. On the other hand, the Swedish Transport Administration would probably not have been so well prepared if it had not taken the initiative in the previous strategic plan. One might consider it obvious to start with the climate objectives and other important objectives when planning for a future transport system and infrastructure that will often be there in 50 years or more. The survey done in TG I4 shows, however, that most countries still plan on the basis of a BAU-based forecast. The examples show that using alternative methods to forecast on the basis of BAU gives different results that can work as an additional basis for a more robust and sustainable decision.

The shift in planning for the transport network requires a significant change in thinking, as BAU scenarios do not meet climate objectives in the longer perspective. New regulations and government actions are crucial in adjusting current models. They will differ geographically, as various countries in Europe face different challenges.

In addition to long-term planning, road authorities need to take responsibility for reducing GHG emissions from the infrastructure that they manage. Doing climate calculations for both new infrastructure and for the operation and maintenance of existing infrastructure, will provide a good basis for measures to reduce the GHG emissions. Requirements on the reduction of GHG emissions from a lifecycle perspective should also be used in the procurement of infrastructure and maintenance.

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Section 2: Adapting to climate change

The flooding of a main road in Copenhagen (photo: Søren Bendtsen)

1 Introduction

Adaptation is increasingly important

Climate change adaptation on roads can be defined as the concrete measures implemented to reduce vulnerability to more extreme weather phenomena in the future in order to increase resilience and robustness for continuous road safety and mobility. Evidently, by following the trend in how leading scientific publications (e.g. from the IPCC report of 2007 to the report of 2013/2014) have modified likely climate scenarios over recent decades and even years, there is no repudiating that the consequences of a future warmer climate are considered ever more substantial.

It is now hard to regard a reliance on climate change mitigation measures to manage these consequences (e.g. for future road management) sufficient as a sole solution. This is why more attention is being paid to adaptation measures coupled with continuous mitigation research and implementation.

A new task for NRAs

However, as with actions relating to the mitigation of climate change, allocating resources to climate change adaptation and successfully anchoring this subject in an organisation, e.g. a national road authority (NRA), can be a highly demanding task that can often be overwhelming. Interdisciplinary approaches are needed for the implementation of climate change research and development projects alone. This regularly results in time-consuming processes with many potential political and technical pitfalls. As a part-consequence of this, few NRAs have incorporated climate change adaptation into their respective standards for everyday management, construction, and maintenance. A number of measures are available for the adaptation of roads to climate change, offering something for most NRAs or countries/regions.

For this reason, raising awareness and providing more research results on climate change adaptation is not considered as valuable as addressing the means to optimise the use of existing measures of adaptation. This could facilitate the implementation of climate change adaptation on a broader scale and lead to less overwhelming initiatives for individual NRAs.

Objective of the report

The objective of the work leading to this report was to investigate and highlight research, developed tools, and success stories of implemented and applied adaptation methodologies. In this way, a tangible and comprehensible inventory is provided. This inventory can help to initiate and implement a higher degree of climate change adaptation in NRAs, with experiences, methodologies, and lessons learned, e.g. from other NRAs, enhancing the political and technical aspect of adaptation measures combined.

More specifically, there is a focus on the following key aspects of initiating climate change adaptation, from concept to implementation: strategy, action planning, methodologies/tools, and awareness. Emphasising, describing, and template-forming these topics can, and will, lead to greater climate change adaptation across borders, resulting in more resilient roads. The templates made for a strategy and an action plan were made, as far as possible, in such a way as to enable application regardless of geography, organisation, etc.

2 Strategy for climate change adaptation

Making a strategy for climate change adaptation is a valuable tool for initiating changes in the way the road authority deals with unpredictable challenges.

A strategy is a plan for the future that reaches far ahead. It is important to know in which direction to head in order to move at all. The objective can, and probably will, move during a process. Consequently, it is important to enable ongoing revision of the strategy as knowledge and organisations change over time. In order to craft a sustainable strategy, it is important to convey this comprehensively. What's more, it must be capable of being translated into relevant plans of action.

Working with climate change is a matter of navigating towards targets that are constantly moving and are hard to locate precisely. Therefore, navigation is centred on decisions relating to concrete objectives and targets and subsequently standing by these decisions until it is evident that a change in objective is necessary. If no change is made, the organisation will not be able to navigate and staff will carry on as usual.

Strategy forms the basis for prioritisation. This is a central purpose since very few NRAs can embrace all working processes. There are often more opportunities and bright ideas than resources available to carry them out. In this context, the strategy will act as a guide to prioritising where to allocate resources. Prioritisation is often closely linked to economic factors. This is also the case in climate change-related projects. In order to drive the implementation of climate change projects into the organisation, it is important to be prepared for argument, both for and against. Such considerations will provide a better basis for a successful strategy.

Organisational anchoring

Organising the work of drawing up a climate change adaptation strategy is an important inaugural step. If the composition of a group is carefully thought out, is anchored in and has responsibility in the organisation itself, the likelihood of success will increase.

It is therefore imperative that representatives of the organisation are chosen to either form the group or at least act as a steering committee. Among other things, the purpose of assigning representatives is to ensure the organisation's support for decisions. The group should comprise people with both management and technical expertise. Include each section of the organisation, e.g. planning, construction, traffic division, etc. It is important to appoint someone with responsibility for the strategy and to clarify the mandate, e.g. appointing a 'climate coordinator'. Initially, find out whether your organisation has a guide to drawing up and implementing a strategy. Then you will know the limitations of and possibilities for the final result.

Decisions before making a strategy

Before the template is filled in, the following questions need to be considered. It is not necessary to answer them all prior to drawing up a strategy, but it is essential to be aware of them.

1 What challenges do you want to address (flooding, storm surges, strong winds, increasing heat, sea level rise, rising/falling groundwater level, rock-falls, avalanches, river flooding, etc.)?

2 What is the existing state of the road network? How vulnerable is it? Do you have any experience of former climate- or weather-induced incidents and where in the organisation can you find the knowledge?

3 What do you expect the future will bring (e.g. in 2020, 2050, and 2100)? How many incidents do you expect and how severe do you think it can get?

4 How do you want to measure (and talk) about the future? Human fatalities, number of incidents, hours of delay, kilometres of closed road sections, etc.?

5 How can awareness be created through an action plan?

6 What kinds of incidents are covered by the strategy? Is, for instance, winter maintenance part of your strategy?

7 Is it for both existing roads and planned roads?

8 What data is available (topographic maps, drainage, risk-maps, etc.)?

9 What kind of instruments and tools are available? (risk identification methods, databases for incident statistics, etc.).

10 Can you do a cost-benefit analysis on different solutions?

2.1 Templates for an adaptation strategy

Below are suggested templates for drawing up an adaptation strategy. A strategy can be used to assist an organisation to commit to adaptation activities and it can help implement the adaptation instruments an organisation wishes to incorporate into everyday work schemes. These templates are examples of a strategy where water is the main challenge in the form of precipitation, rising groundwater, or storm surges. It is easy to include other climate change challenges, e.g. increasing storms, heat waves, and rock slides.

The templates consist of four main subjects: management, improvement, prevention, and cooperation (Figures 1, 2, 3 and 4).

The first column contains subjects that can be integrated into the final strategy. It is complimented by a description or examples of what to include. Most NRAs will have other issues as well, so think carefully and ask colleagues whether there are other subjects that should be included. The template below contains a second column for writing notes relating to the process of creating a strategy suitable for your NRA. The templates are based on the Danish and Swedish strategies (Danish Road Directorate 2013, Trafikverket 2014). The templates can be requested in PDF-form from Marianne Grauert (marg@vd.dk) or Christian Axelsen (cax@vd.dk.).

Management

Incidents causing decreased mobility and safety on roads as a result of extreme weather are empirically unavoidable. Such incidents are projected to increase in the future due to the consequences of climate change. Management is, therefore, a subject of multiple topics, all of which are all crucial parts of an adaptation strategy. Examples of management topics include incident management, information management, clearing-up management, and available depot equipment.

For example, incident management includes plans for how to handle specific situations in a climate change-induced crisis, such as flooding and landslides. Furthermore, a plan for incorporating climate incidents into general emergency planning and drills could beneficially be included in climate change incident management.

Examples of management subjects to include in an adaptation strategy:

Incident management
How to handle given situations in a climate change-induced crisis e.g. flooding and landslides?
- Incorporating climate (weather) incidents into emergency planning
- Drills that include weather incidents
- Guidelines
- Call-out service

Information
Road users need to be informed about any incidents, road closures, hazards, and dangers.
- Traffic Information Systems
- Media (radio and television)
- SMS, smartphone, GPS systems

Clearing up
After an incident (e.g. flooding), the road needs to be restored and reopened.
- Guidelines available in the NRA maintenance division
- Draining water and removing debris
- Evaluation of construction integrity

Depot equipment
Equipment can be stored in strategic places for deployment so that roads can be managed and re-opened quickly.
- Replaceable bridges
- Pumps
- Portable protection systems, e.g. sandbags

Management

Incident management How to handle given situations in climate change induced crisis e.g. flooding and landslides? • Incorporating climate (weather) incidents into emergency planning • Drills that include weather incidents • Guidelines • Call-out service	
Information Road users need to be informed about any incidents, road closures, hazards and dangers. • Traffic Information Systems • Media (radio and television) • SMS, smartphone, GPS- systems	
Clearing up After an incident (e.g. flooding), the road needs to be restored and reopened. • Guidelines in maintenance division • Draining water and removing debris • Evaluation of construction integrity	
Depot equipment Equipment can be stored in strategic places for deployment so that roads can be managed and re-opened quickly. • Replaceable bridges • Pumps • Movable dams and sandbags	

Fig. 1: Template of management activities that form part of an adaptation strategy

Improvement

Improving roads in order to make them more resilient to future higher stresses caused by more frequent extreme weather events is a key aspect to achieving higher resilience and thereby preventing the occurrence of incidents as frequently as projected. Improvement and prevention, as a part of a climate change adaptation strategy, can cover a variety of initiatives ranging from proactive desk-work to on-site upgrading.

Improvement involves the analysis and logging of climate change-related incidents in order to improve future handling of incidents and thereby adapt. Thus, a benchmark for a climate change-related incident has to be specified for the specific NRA. Through such benchmarking, pinpointing stretches of roads where incidents are over-represented can facilitate a more focused and effective allocation of resources to climate change adaptation. A methodology entitled *QuickScan* for identifying such stretches of roads (see chapter 5 and appendix) has been developed in the ROADAPT project.

Examples of improvement subjects to include in an adaptation strategy:

Guidelines for analysing an incident
How to analyse and log climate change-related incidents in order to improve the future handling of such incidents.

- Guidelines for call-out service
- Guidelines for maintenance
- Evaluation

Database
Store data so that vulnerable locations (e.g. insufficient drainage or blue spots) can be tracked and identified.

- Responsibility for the database
- Cooperation with relevant authorities on information-sharing and the exchange of database information

Implementing improvements to the road
Is it possible to make some improvements that will minimise risk?

- Is it financially viable?
- Development of a suitable cost-benefit analysis

Cooperation between relevant/related authorities
To ensure that relevant authorities plan and implement measures in accordance with the same plan and to avoid duplication of work

- Floods can be caused by failing recipients within different authorities
- Coordination of planning between relevant authorities
- Coordination of emergency planning

Monitoring
The installation of monitoring systems can help road owners manage an incident in time.

- Dikes
- Drainage systems
- Vulnerable spots of high importance
- Cooperation with meteorological services

The road to Æbelø, Denmark, at low tide (photo: Tim Krat)

Improvement

Guideline for analysing an incident How to analyse and log climate change-related incidents in order to improve the future handling of such incidents. • Guidelines for call-out service • Guidelines for maintenance • Evaluation	
Database Store data so that vulnerable locations (e.g. insufficient dra-inage or blue spots) can be tracked and identified. • Responsibility for the database • Cooperation with relevant authorities on information-sharing and the exchange of database information	
Implementing improvements to the road Is it possible to do some improvements that will minimise the risk? • Is it financially viable? • Development of a suitable cost-benefit analysis	
Cooperation between relevant/related authorities To ensure that relevant authorities plan and implement mea-sures in accordance with the same plan and to avoid dublica-tion of work. • Floods can be coursed by failing recipients situated at different authorities • Coordination of planning between relevant authories • Coordination of emergency planning	
Monitoring The installation of monitoring systems can help road owners manage an incident in time. • Dikes • Drainage systems • Vulnerable spots of high importance • Cooperation with meteorological services	

Fig. 2: Template of improvement activities that could be included in an adaptation strategy

Prevention

Risk mapping is considered a central measure for incident prevention. Resources for climate change adaptation are often limited, which means that efficient and potent solutions are needed. In risk-mapping adaptation, needs are identified, effectively revealing where adaptation resources are spent most efficiently. The ROADAPT QuickScan methodology is an example of a risk-mapping approach. As with the QuickScan methodology, the main purpose of the Blue Spot model, which was developed by the Danish Road Directorate, is to identify road stretches that are vulnerable to extreme weather occurrences.

In this context, it is important to emphasise that multiple models rely on multiple types of data inputs. Such data may not be available to the same extent across national borders, which may render such analysis unfeasible in some countries. At the same time, this highlights the need to procure additional data to increase prevention activities.

Examples of prevention subjects to include in an adaptation strategy:

Risk analyses and risk maps
How will your organisation identify and assess risk areas in order to enhance prioritisation and decision-making?

- Vulnerability screening, as in Blue Spot mapping
- Geological mapping of land slides
- Mapping of relevant existing tools

Legislative work and standardisations
Incorporating climate-change adaptation into rules and regulations is a powerful implementation measure.

- Road standards
- Guidelines
- Any law relating to roads

Descriptions of adaptation instruments in planning, construction, and maintenance
To ensure that adaptation is integrated into all planned construction, road widening, and re-routing projects

- Incorporate adaptation measures into organisational guidelines for project leaders
- Are there other relevant places?
- Information meetings

Research and development
To obtain knowledge and to allocate resources in the most effective way

- Research and development strategy
- Overview of funds and resources allocated to climate change

Flooding at Kristinehamn bridge (photo: Leif Johansson)

Prevention

Risk analyses and risk maps How will your organisation identify and assess risk areas in order to enhance prioritizing and decision- making? • Vulnerability screening as in Blue Spot mapping • Geological mapping of land slides • Mapping of relevant existing tools	
Legislative work and standardisations Incorporating climate change adaptation into rules and regulations is a powerful implementation measure. • Road standards • Guidelines • Any law relating to roads	
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Research and development To obtain knowledge and to allocate resources in the most effective way. • Research and development strategy • Overview of funds and resources allocated climate change	

Fig. 3: Template of prevention activities that could be included in an adaptation strategy

Cooperation

A significant part of most road networks are situated adjacent to other land uses that are managed by multiple authorities, institutions, etc. In order to ensure the most effective possible planning and implementation of climate change strategy and to achieve a higher success rate of adaptation, it is considered fundamental that the needs of relevant external partners be integrated into the strategy. Identifying relevant third parties and focusing on interdisciplinary approaches is, therefore, especially important in climate change adaptation since many different factors are involved.

For example: the increase in more extreme precipitation will result in a greater need for water management within NRAs in order to keep roads safe and open. Since water does not recognise and necessarily observe borders between various authorities, managing any future increase in water requires an interdisciplinary and inter-organisational approach. Drainage systems in particular may necessitate a shift from NRA-led management directly to municipality-led management. In this case, a unified approach between an NRA and a municipality is vital to ensure optimum conditions for climate change adaptation.

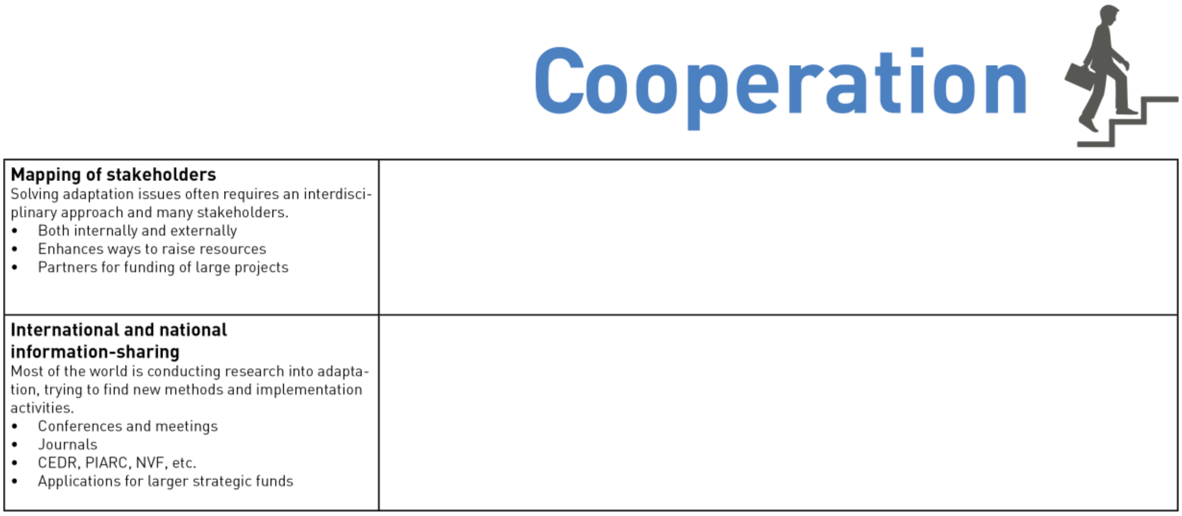
Examples of cooperation subjects to include in an adaptation strategy:

Mapping of stakeholders
Solving adaptation issues often requires an interdisciplinary approach and many stakeholders.

- Both internally and externally
- Enhances ways to raise resources
- Partners for funding of large projects

International and national information-sharing
Most of the world is conducting research into adaptation, trying to find new methods and implementation activities.

- Conferences and meetings
- Journals
- CEDR, PIARC, NVF, etc.
- Application for larger strategic funds



Mapping of stakeholders Solving adaptation issues often requires an interdisciplinary approach and many stakeholders. • Both internally and externally • Enhances ways to raise resources • Partners for funding of large projects	
International and national information-sharing Most of the world is conducting research into adaptation, trying to find new methods and implementation activities. • Conferences and meetings • Journals • CEDR, PIARC, NVF, etc. • Applications for larger strategic funds	

Fig. 4: Template of cooperation activities that could be included in an adaptation strategy

3 Action plan

Producing an action plan is an important step when introducing climate change adaptation to your organisation and will act as a strong support when implementing a strategy. In order to change common practice at all levels—from executive to technicians—a clearly defined action plan that requires everybody to comprehend the inherent implications and take more ownership is needed. The following steps are vital when it comes to drawing up and implementing an action plan.

- Clarify and detail the goals in the strategy.
- Pinpoint who is responsible for the individual projects and make sure that they are a part of the overall planning process for the road authority. If possible, describe small individual projects in detail.
- Prioritise the most urgent goals in the strategy.
- Set the most realistic timeline possible.
- Coordination between projects in different areas of the organisation is a key aspect when producing an action plan. Make sure that valuable cooperation and networking is identified.
- Project costs can be very difficult to foresee; a lot of initial adaptation projects do not need special funding.
- Defining deliverables helps to balance expectations.

Creating a risk analysis for the entire action plan can highlight the main risks, for example the consequences of inadequate funding. Actions to reduce risks can be planned, thereby enhancing the likelihood of the action plan's success.

The two figures that follow include an action plan template that includes three examples and a blank version of an action plan template.

Action plan

Bullets in the strategy	Description and goals	Who is responsible?	Priority	End user	Time perspective	Overlap and cooperation	Costs	Deliverables
Legislative work and standardisation	Identify all laws/directives/ norms/standards guidelines that are relevant to climate change adaptation.	Environmental/Technical department	1	Can affect all parts of the organisation	2016	EU-laws	€5,000	List of relevant documents
Assessment of natural hazards and collection of the information in a standardised way	The goal is to draw up guidelines for the systematic collection of incidents in order to be able to analyse events across the national state road network.	Maintenance division	2	Can affect all parts of the organisation	The guidelines should be ready by the end of September 2016	Traffic accident investigators	€10,000	Guidelines for the construction and maintenance of a system
Increase in the number of possibilities to reroute traffic	To have a well-functioning rerouting system for a large part of the state network. When a climate-related event closes the highway, alternative routes that are not affected by this event must be available.	Traffic division	1	Traffic division	2016-2019	Municipalities and other road owners, police	€2,000	Major highways have an updated plan for rerouting incl. signs.

Fig. 5: Action plan including examples

Action plan

Bullets in the strategy	Description and goals	Who is responsible?	Priority	End user	Time perspective	Overlap and cooperation	Costs	Deliverables

Fig. 6: Template of action plan activities

4 Climate change awareness

Awareness of the subject in question is a key part of both a strategy and an action plan and essential to their success. Climate change is a growing concern in most European countries and their NRAs. It is undisputed that the changing climate in the twenty-first century will have drastic effects on existing infrastructures. In order to prevent negative climate change-related impacts on infrastructures, operations and, ultimately, the economy as a whole, adequate mitigation and adaptation measures must be defined and met. It is therefore very important to raise awareness within NRAs in order to realise adaptation strategies effectively.

Due to the complexity of the issue, the implementation of a communication management plan could be vital, ultimately transporting the benefit of adaptation strategies and action plans through awareness of the topic. Here, communication paths could work either top-down, bottom-up, or even both ways. On the one hand, intensified communication and encouragement of climate change adaptation within CEDR has to be promoted under the lead of those NRAs that are having the most noticeable climate change-related effects on their infrastructure. On the other hand, increased communication in order to generate awareness must be established by intrinsic processes within the NRAs (e.g. implementation of a climate change steering committee), eventually leading to proper anchoring of climate change adaptation within the organisation. These two approaches can be done subsequently or in parallel.

This should enforce an understanding of climate change-related events and raise awareness about how these events affect the infrastructure in different ways (e.g. heavy rains vs. droughts, frost damages vs. heat damages).

Awareness at CEO and department level

Within NRAs, climate change awareness stands and falls with the foresight of corporate management. It is only logical that the importance of a topic like climate change is best transported when the sincerity of the management regarding the topic can be sensed by both employees and the public. This sincerity can be reached by the above mentioned top-down approach, where CEDR outlines the importance of the topic, or by bottom-up communication, for example, outlining rising maintenance costs in relation to extreme weather phenomena triggered by climate change will help raise the necessary awareness.

A simple tool for creating awareness within any NRA is increased focus on communication to all parts of the organisation. Such communication could take the form of obligatory short sessions with the respective departments on ways to incorporate climate change adaptation into everyday methodologies and thinking. In addition, a more general communication approach that takes the form of posts on the Intranet or addressing the topic in staff training could be useful. However, often it is simply a question of a certain event creating a 'window of opportunity' that has to be seized.

Using a window of opportunity

An example of a 'window of opportunity' is an extreme weather event on the scale of a catastrophe (e.g. mudslides, flooding, avalanches) that generates a discussion and ultimately a process on climate change and its national, regional, and economic impacts on any NRA and how the consequences can best be addressed and dealt with. Here, raising awareness is crucial, especially for a long-term approach. Another 'window of opportunity' might be the influence of rating agencies that are taking ecological sustainability into account. Poor ratings can deter investors, which in return raises awareness of the importance of certain topics such as climate change. Political events are another important key factor when it comes to raising awareness among the public and within the economy. Conferences such as the 2015 United Nations Climate Change Conference in Paris present another 'window of opportunity'. The media focus on the issue of climate change around the time of the conference and the effects that can be achieved by communicating the Paris Agreement can boost climate change awareness within organisations.

It is, therefore, very important that responsible officials and steering committees identify and anticipate 'windows of opportunity' in order to communicate adequately and sincerely the issue of climate change to CEOs and the management board so that they can be commissioned to create a corporation-wide climate change strategy, thereby raising awareness of climate change throughout the whole organisation.

Europe route 39, western coast of Norway (Instefjord-Kringla) (photo: Njål Farestveit, NPRA)

5 Overview of key risk identification methods

This chapter will compile and summarise key methods that can be used to identify risks that can have a negative effect on roads in relation to climate change. While some methods are very down to earth, e.g. the inspection of culverts or the mapping of recorded events, other methods rely on satellite data or advanced hydrological modelling. The methods also cover a wide variety of events ranging from specific hazards such as flooding, landslides, and a rise in sea level to more general risks such as the risk-mapping of all possible natural hazards.

Risk methodology approach

As already mentioned in this report, risk mapping is particularly valuable as part of a strategy for facilitating the implementation of climate change adaptation measures because it highlights specific stretches of roads where resources would be best allocated to ensure optimum use.

Risk identification methods can be divided into a number of different categories. One category consists of methods that are based on known facts. One example is the QuickScan method where professionals with different experience and from different backgrounds meet to talk about known risks along a certain road. The group might, for example, consist of geotechnical engineers, road engineers, planners, contractors, and project leaders (Bles et al. 2015). Another similar method is based on inventories of known risks along a chosen road, for example areas susceptible to landslides or erosion. The risks are identified, categorised, and classified. This method is also based on the knowledge and experience professionals have from working with roads (Swedish Road Administration, 2005).

Other methods in this category use historical data from natural hazard-related events, such as flooding. Databases of recorded events (for example when roads were closed down), can be used to identify spots that have previously been affected and might, therefore, be at risk again (Keller et al., 2014). It is also possible to use methods such as risk tree analysis that investigate natural hazards in order to gain experiences and identify risks and potential risk areas as part of resilience work (Santos et al., 2010).

Several methods fit into the category that has a broader, more general, approach. These methods can be seen as more of a handbook or manual where several maps and registers are used in order to analyse, visualise, and evaluate hazards and risks. Examples of these types of maps are danger maps, vulnerability maps, and earthquake maps (National Platform for Natural Hazard in Switzerland, 2005). Other methods are very specific in that they target a certain type of risk or focus on a certain part of the infrastructure, for example a method for rating rock-fall hazards along roads and quantifying the risks before necessary actions are taken (Settimo et al., 2012). Another possible method looks at how climate change affects the pavement deterioration process and how specific geographical areas along the roads are consequently at greater risk than others (Meagher et al. 2014). Another example of these types of methods is when a traditional risk-matrix is used for risk- and susceptibility (RAS) analyses of culverts with respect to weather-related events in order to identify vulnerable geographical locations on a longer stretch of road (Statens Vegvesen, 2011).

Many methods rely on access to different types of data, such as hydrological and terrain data. The Blue Spot model, for example, uses this kind of data. By using a high-resolution digital terrain model, it is possible to predict which areas could be flooded when precipitation increases (Axelsen & Larsen, 2014). By studying catchment area characteristics and land use, it is possible to investigate how risks increase, for example if woodland is cleared (Kalantari et al. 2014). Methods in this category sometimes use very advanced data, for example satellite data to identify areas that are vulnerable to rockslides, which makes it possible to monitor risks over a long period and complement ground-based monitoring (Lauknes et al., 2010) Sometimes, a combination of advanced data is needed, for example in the Alps, where the risk of rock-fall is substantially reduced by the protective function of forest trees (Müller et al., 2014).

Each method in the different categories requires different sets of data. Some of the more basic methods are based on few types of data and data that is accessible in most countries. However, it is not possible to use many of the methods without access to more advanced data, models, tools, and software. This can make it difficult to apply all methods.

Risk identification methods

Table 1 contains an overview of key risk identification tools, divided according to relevance. A further description of the listed tools and projects can be found in the appendix.

National Tourist Route 976, Andøya, Northern Norway (photo: Tomas Rolland, NPRA)

Table 1: Overview of key risk identification tools (for more information about the tools/methodologies, please refer to the appendix)

General and adaptation methodologies		
1	ROADAPT. Roads for today, adapted for tomorrow. Guideline: Part B. Performing a QuickScan on risk due to climate Change	CEDR member states
2	Vademecum. Hazard maps and related instruments. The Swiss system and its application abroad. Capitalisation of experience	Switzerland
3	Risk analysis on a chosen road stretch	Sweden
4	Total stop in traffic caused by nature-related events between 2007 and 2013. Examples of how statistics can be used as a risk identification method with respect to climate change	Sweden
Methodologies relating to flooding		
5	A method for mapping flood hazards along roads	Sweden
6	Learning from Tabasco's floods by applying MORT	Mexico
7	Quantifying the hydrological impact of simulated changes in land use on peak discharge in a small catchment	Norway
8	Risk mapping major Danish Roads for flood risk by Blue Spot analyses	Denmark
9	Risk- and susceptibility analyses of culverts with respect to weather-related events	Norway
10	Mapping Natural Hazard Impacts on Road Infrastructure—The Extreme Precipitation in Baden-Württemberg, Germany, June 2013	Germany
11	Mapping roads affected by flooding: A GIS-based study in Sotenäs municipality	Sweden
Methodologies relating to pavement and climate change adaptation		
12	Dealing with the effects of climate change on road pavements	PIARC
13	Method for Evaluating Implications of Climate Change for Design and Performance of Flexible Pavements	USA
Methodologies relating to sea level rise		
14	A probabilistic methodology to estimate future coastal flood risk due to sea level rise	UK
Methodologies relating to sea level rise, land slide, rock slides and rock-fall		
15	Detailed rockslide mapping in northern Norway with small baseline and persistent scatterer interferometric SAR time series methods	Norway
16	Rock fall risk assessment to persons travelling in vehicles along a road: the case study of the Amalfi coastal road (southern Italy)	Italy
17	Hazard and risk assessment of rock fall protective forests by evaluating the case study of Geschwendnerberg along the highway 'A9 Pyhrn Autobahn'	Austria
18	Adaptation to Climate Change in the Alpine Space; Adapt Apl WP 5.1: Hazard Mapping – Geological Hazards, Literature survey regarding methods of hazard mapping and evaluation of danger by landslides and rock fall	Austria, Germany, and Switzerland

6 Other related research and calls

This chapter looks at other climate change-related research that has been completed by various European and international bodies or is ongoing. The two most relevant bodies are CEDR and PIARC. Other work under European Commission and other bodies is also referenced.

CEDR Research Programme

In 2006, European National Road Administrations (NRAs) agreed to progressively share their road research priorities and open up their research budgets. Among other achievements, they have been able to organise successful transnational calls for projects and programme calls, which have delivered outstanding research projects that effectively target NRA needs.

The initial impetus for this initiative came from EU support through two ERA-NET ROAD projects. ERA-NET ROAD – Coordination and Implementation of Road Research in Europe – was a Coordination Action supported by the European Union’s 6th Framework Programme. Within the framework of this action, the call 'Road Owners Getting to Grips with Climate Change' was launched with CEDR member funding as the first cross-border funded joint research programme. Four research projects were initiated in 2007, namely IRWIN, P2R2C2, RIMAROCC, and SWAMP, which focused on issues such as winter maintenance, impacts on road pavements, risk assessment, and flooding. The objective of the research programme was to investigate issues of climate change adaptation that would provide road authorities with tools for identifying and preventing future problems to road infrastructure.

IRWIN sought to develop an improved local road winter index, which is sufficiently detailed and comprehensive that road authorities and owners can use it to assess the implications of future scenarios and climate change implications, and perform reliable cost-benefit analyses. The data collection phase in IRWIN revealed that there was enough archived RWIS (Road Weather Information Systems) data in only Sweden and Finland to perform the planned winter index development. However, the IRWIN climate change database can be considered as reliable as it is possible to be in today's climate research.

P2R2C2 investigated the likely impacts of climate change in Europe from the Alps northwards, on the moisture/ice condition in the pavement and the sub-grade, and the consequential pavement material behaviour and pavement response to traffic over a 100-year timescale. The outcome was the development of recommendations that national road owners could integrate into their specifications.

RIMAROCC provides a systematic method for risk management based on risk identification, risk probability, and risk consequences. The RIMAROCC method consists of seven steps and is a cyclical process of continuous performance improvement and capitalisation on experiences.

SWAMP addresses the critical issue of identifying the parts of the road network that are most vulnerable to flooding using a geographical information system. These parts are referred to as blue spots. The project deals with the issue of how to limit the effects of flooding, or if possible avoid flooding, at blue spots. The SWAMP project highlights issues to consider when creating national or even regional guidelines for inspections and maintenance. The suggestions are geared towards lowland areas that are relatively flat and mildly undulating landscapes, and do not explicitly cover steep, sloping areas.

The overall outcome of the programme was a recommendation that both SWAMP and RIMAROCC should be promoted across Europe in order to mitigate risks. In relation to both IRWIN and P2R2C2, some issues were raised that may make implementation difficult, such as lack of historical data.
At the conclusion of the programme, a final conference was organised to present the findings and the recommendations. It was stated that in order to maximise the value of the programme, a further conference should be organised after a number of years to review the progress on implementation by each road authority. There was, however, a feeling that there was no defined strategy for proceeding with the available results and that there needs to be a concerted effort to ensure that the tools and models are used across CEDR member countries.

Since 2010, the transnational effort has been continued through the CEDR Transnational Research Programme. A number of calls have been made under this programme in the years 2012, 2013, 2014, and 2015. The most relevant calls relating to climate change are those undertaken in 2012 and proposed in 2015. The 2012 Call included two projects under the programme 'Road Owners Adapting to Climate Change'. The first was design guidance for a transnational database of downscaled Climate Projection Data for Road impact models (CliPDaR) and the second was Roads for today, Adapted for tomorrow (ROADAPT).

ClipDaR: The road sector is very vulnerable to extreme weather phenomena, which can produce some highly significant economic and safety consequences. For this reason, it is essential to know as early as possible the extent to which global climate change could impact on national and European road networks. With the help of climate projections, specific impact models can be applied to estimate the relevant parameters for road maintenance. However, the reliability of given climate projections need to be assessed using ensemble approaches and downscaling methods. Much scientific work has been done to evaluate these approaches with regard to their reliability and usefulness for investigations on possible impacts of climate changes. Within this project, existing approaches and methodologies have been collated to identify a common approach on future applications by road owners. The project focuses on the review, analysis, and assessment of existing regional climate change projections regarding transnational highway network (TEN-T) needs with particular emphasis given to the results of a number of previous and ongoing projects. The main objective of the research is to provide recommendations for application by European road agencies.

ROADAPT: Infrastructure is the backbone of our society. Citizens, companies, and governments have come to rely on and expect uninterrupted availability of the road network. It is now recognised that a changing climate will have significant effects on the road infrastructure. This requires timely adaptation. However, there are great uncertainties involved in both the projections of future climate change and related socio-economic developments and estimating the consequences of these changes in transportation needs. In the meantime, there is a constant need for decisions and development of the road transport system. The prioritisation of measures in order to maximise availability with reasonable costs is one of the most important tasks of the road owners.

The ROADAPT project has provided a number of methodologies and tools enabling a rational, integrated approach to climate change adaptation based on tailored and consistent climate information. This includes guidelines for:

A The use of climate data for the current and future climate
B The application of a QuickScan on climate change risks for roads
C Detailed vulnerability assessment
D Socio-economic impact assessment
E Selection of an adaptation strategy

A final conference for the dissemination of the results of both ClipDaR and ROADAPT was held in October 2015 in Brussels. The outcome of the programme was two tools that could be implemented in member countries in order to assist with the adaptation to climate change. The current 2015 call includes a project relevant to climate change and is entitled 'Climate Change: From Desk to Road' involving participating CEDR members Austria, Germany, Ireland, Netherlands, Norway, and Sweden.

The aim of this programme is to undertake research on integrating climate change into decision-making processes and implementing existing research into practice. The expected research builds on the outcomes of earlier calls in relation to climate change, in particular 'Road Owners Getting to Grips with Climate Change' (ERA-NET ROADS Call 2008), 'Energy, Sustainability and Energy Efficient Management of Roads' (CEDR Call 2011), and 'Road Owners Adapting to Climate Change' (CEDR Call 2012). The present call focuses more on the implementation of tools and results. Projects resulting from this call will provide an insight into how to use and implement former results, how to actually 'get climate change adaptation done' and, as a result, can lead to the improvement of presently available tools and guidelines.

Specifically, this programme covers research into the following:
A Economic costs associated with integrating climate change into decision-making
B Embedding climate change into practice and procurement
  • Implementing existing climate change research
  • Embedding climate change into procurement processes
C Developing a transnational approach to water management in the face of climate change
D Driver behaviour: diagnosing driver decision-making (in a changing climate).

The closing date for this call is 15 March 2016 and the outcome of this programme will further help road authorities to adapt to climate change.

PIARC/World Road Association

Within the framework of its Strategic Plan 2012–2015, the World Road Association (PIARC) has set up a range of technical committees to deal with issues associated with roads and road transport policy and practices within an integrated sustainable transport context. One of these technical committees is TC 1.3 Climate Change and Sustainability.

The issues which TC1.3 intends to address are:
- 1.3.1 - Transport strategies regarding climate change mitigation and adaptation
- 1.3.2 - Tools for understanding climate change mitigation
- 1.3.3 - Appraisal of sustainability of transport infrastructure plans

Under TC1.3, a call for proposals was released in 2014, calling for the development of an International Climate Change Adaptation Framework for Road Infrastructure. The purpose of the project was to assist transport decision-makers in developing appropriate climate change adaptation responses for their road transportation infrastructure as it was felt that a framework based on collective experiences of countries in addressing impacts of climate change would be helpful to all countries.

The call requested the development of a proposal for a framework to address climate change adaptation that would set out a process for practical use by road asset owners and managers. The purpose of the frameworks would be to provide guidance for users to apply when addressing the impacts of climate change on road assets and identifying and incorporating adaptation strategies into decision-making processes in practice. The framework was to be applicable for all countries whatever their status of development and was expected to be flexible enough to apply at both national and local level. The project was awarded to URS in 2014 and involved a literature review along with consultation with road agencies. The road agencies that were consulted were Canada (Quebec), Japan, New Zealand, Norway, Malaysia, Scotland, USA, China, Mexico, Romania, Tanzania, and the Asian Development Bank.

The outcome of the project was the publication by PIARC of the 'International Climate Change Adaptation Framework for Road Infrastructure' in 2015. In addition to this publication, a spreadsheet is provided for making a strategy and an action plan.

The framework guides road authorities through the process of increasing the resilience of their networks and assets through four stages:

Stage 1: Identifying scope, variables, risk, and data
Stage 2: Assessing and prioritising risks
Stage 3: Developing and selecting adaptation responses and strategies
Stage 4: Integrating findings into the decision-making process

The framework provides very useful information to road authorities and also refers to an adaptation plan template that is available to road authorities alongside the framework document. It is available at http://www.piarc.org/ressources/documents/23556,WRA_CCAF_Work-Book.xlsx .

However, the adaptation plan template provided is an excel spreadsheet that needs to be populated by each road authority and does not provide as much information as that provided in Section 2.1.3 of this report.

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The S7 expressway bridge over the River Motława, Poland (photo: Grzegorz Łutczyk, GDDKiA)

7 Conclusions and recommendations

Implementation of climate change adaptation appears to be limited across national road authorities. Approaches, methodologies, and tools for adaptation to climate change have been developed in numerous forms to prepare infrastructure for more extreme future weather phenomena. Nevertheless, there is limited use, implementation, and anchoring of such methodologies across NRAs.

Although the reasons for this vary from NRA to NRA, the crucial reasons are considered identical regardless of the NRA. The main objective of this report is to identify and address these limitations in order to trigger and facilitate a higher degree of implementation.

Four general aspects were identified for the promotion and elaboration of implementation on adaptation in NRAs. These are:

- Creating awareness of climate change adaptation as a concept
- Producing strategies on climate change adaptation implementation
- Making action plans to align and organise activities
- Increasing knowledge and resources to make use of existing methodologies

By focussing on these four aspects, this report provides an output consisting of guides and recommendations to take implementation of climate change adaptation to the next level. Templates on strategy and action plan-forming are provided in order to inspire NRAs to have them as a central part of working with climate change adaptation. Furthermore, creating awareness is highlighted in this report; a high level of organisation-wide awareness is considered key to the success of implementation.

As mentioned numerous times in the report, climate change adaptation methodologies can come in many forms and include various procedures. This report states that in order to make full use of these methodologies, it is important to include strategy, action plans, and awareness in climate change adaptation. As an overview, key existing methodologies are listed in the report to highlight typical climate change challenges faced by NRAs.

It is recommended that NRAs, regardless of geography and the status of implementation, use the output of this report either directly to initiate climate change adaptation or as a source of inspiration to elaborate and strengthen ongoing activities. The output (e.g. the templates) is the result of international collaboration and is designed to be highly applicable for all NRAs at various organisational levels.

Adapting roads to climate change is ever more vital if safety and mobility are to be maintained. The consequences of an insufficient adaptation to climate change for future road authorities could be considerable. Adaptation has to aim to cover greater climate change than the world has agreed to mitigate for. The opposite would, of course, be dangerous.

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Appendix

1
ROADAPT. Roads for today, adapted for tomorrow. Guideline: Part B. Performing a Quick scan on risk due to climate Change
Thomas Bles, Mike Woning, and Yves Ennesser

The method is based on the RIMAROCC methodology but with some simplifications. The method consists of three workshops and desktop work before and after each workshop. The aim is to scan specific geographical areas in order to identify the major risks and focus on these so that road authorities use their resources efficiently.

In workshop 1, the highest climate change-relevant threats are identified using not only the data available but also the different participants' experience. Workshop 2 focuses on the specific threats and the risks that are associated with them. Locations for high-risk threats are also identified. In workshop 3, the layout of an action plan for further steps after the QuickScan are discussed.

The workshops are based on the participation of relevant stakeholders, such as road authorities and contractors. During the workshops, available knowledge, information, and experience are gathered in a way that is difficult to collect in individual interviews or questionnaires. Another benefit of using workshops is that it increases joint awareness and the possibility of reaching uniformity on the threats and risks. The method could be used as a way of informing, for example, maintenance contractors of threats and risks. The QuickScan can also be a way to transfer knowledge between road authorities and contractors and from a previous contractor to the current one.

In order to be able to compile or calculate the factors used in the study, the following must be available: professionals that have experience to share and are willing to do so, maps of roads, data on climate change threats.

2
Vademecum. Hazard maps and related instruments. The Swiss system and its application abroad. Capitalisation of experience
National Platform for Natural Hazards in Switzerland.

The National Platform for Natural Hazards in Switzerland has published a report about hazard maps and related instruments called 'The Swiss system'. The Swiss system is not so much about one detailed method as it is a handbook or manual on how to use several maps and registers in order to analyse, visualise, and evaluate hazards and risks. According to this system, the first step is to identify hazards, and then to analyse hazards, vulnerabilities, and risk. Finally, the measures for protecting people and assets must be developed. The maps and registers described in the report are:

- **Event maps and event registers** (a collection of information on events such as floods, landslides, and avalanches, registered in a coherent way)
- **Hazard indication maps** (the hazards are distinguished according to the type of hazard, source area, and flow path and impact area)
- **Danger maps** (geographical information systems (GIS) and different computer models are used to simulate natural hazards (mainly flooding, debris flow, rock-fall, avalanche, and slope failure)

- **Vulnerability maps** (map of potential damage. This is not, however, very well developed in Switzerland. The maps show possible economic loss from buildings in case of an event)
- **Risk map** (these types of map are not very developed or frequently used since risk is considered a continually changing issue)
- **Earthquake maps** (basic data from recorded events can be obtained and completed with soil properties)
- **Intensity maps** (provides the spatial extent and the corresponding intensities of a natural event, e.g. water depth, impact force of snow avalanches)

The report notes that these methodologies and the different types of maps and registers, have both advantages and disadvantages. The advantages are that it is transparent because guidelines are used and are comprehensible. The disadvantages, however, are that it does not target grass-root level and the result can be difficult to understand and interpret.

To be able to compile or calculate the factors used in the study, the following data must be available: several different types of data such as detailed topographic, geological, and hydrological data. Each map and register uses different data.

3
Risk analysis on a chosen road stretch
The Swedish Transport Administration

This method was produced with the aim of creating a homogenous method for the inventory and analysis of serious physical dangers along a chosen road stretch. The emphasis was placed on landslide, flooding, high water flow, and traffic accidents involving dangerous goods.

The method involves six steps. The first step is to identify which assets/objects can be damaged. In the next step, the dangers are identified. In step 3, the risk factors that can cause danger are identified and a collective assessment of the probabilities of the occurrence of the dangers is carried out. The probability of the danger is classified 1–5 in a probability/risk matrix.

Using the same matrix, step 4 contains a description of the consequences for the respective asset type if danger occurs. The consequences are also classified 1–5. In the fifth step, the total risk level is described and classified 1–3, where class 3 indicates a high-risk level that is not in general acceptable, class 2 a medium-risk level where safety actions should be considered, and class 1 a low-risk level that is in general acceptable. In the sixth and final step, possible risk-minimising measures are identified.

In order to be able to compile or calculate the factors used in the study, the following data needs to be available: detailed topographic, geological and hydrological data, soil map, recorded events, and road maps.

4
Total stop in traffic caused by nature-related events between 2007 and 2013. Examples of how statistics can be used as a risk identification method with respect to climate change
(Totalstopp i vägtrafiken orsakat av naturrelaterade händelser mellan 2007 och 2013. Exempel på hur totalstoppsstatistik kan användas som riskidentifieringsmetod med hänsyn till klimatförändringar.)
Emelie Gustavsson & Eva Liljegren (2014)

The accessibility of the national road network is affected by stops and various events such as natural hazards. One way to reduce the hours during which traffic is forced to stop is to identify locations where it has previously been stopped in order to prevent similar stops from happening again.

The main purpose of this report is to examine whether it is possible to use historical data from actual shutdowns as a risk identification method. This was done by compiling and analysing statistics for nature-related stops recorded by the Swedish Transport Administration (STA) and using geographic information systems (GIS). In addition, an Internet search was conducted to find unrecorded events (i.e. events that were not included in the original statistics but were reported by the media).

The result shows that several clusters were found, indicating that the road had been flooded in the same place on a number of occasions. In conclusion, this report shows that using historical data from actual traffic shutdowns on roads can be used as a way of finding locations that are more prone to flooding during intense rainfall. However, the Internet search showed that many events, about 30% of road floods that lead to a stop in traffic, were only reported by the media and not by the STA, indicating that the quality of the data from the STA needs to improve for the method to work.

To be able to compile or calculate the factors used in the study, the following data must be available: statistics of recorded nature-related events, road maps, and GIS systems.

5
Plus one throughout: a method for mapping flood hazards along roads
Zahra Kalantari, Alireza Nickman, Steve W. Lyon, Bo Olofsson, Lennart Folkeson

Kalantari et al. describe a method for mapping flood hazards along roads in Sweden using GIS and multivariate statistical analyses. In this method, road and catchment characteristics as physical catchment descriptors (PCDs) are studied. Kalantari's method aims to be used on a larger scale not using advanced hydrological model methods. Instead the method focuses on identifying regionally important PCDs as a first indicator of potential risk areas. The focus is on road-stream intersections.

The factors studied in the method were catchment elevation (mean), catchment length, catchment geometry, catchment slope, drainage density, local channel slope, topographical wetness index, soil data, land use, and road density.

According to Kalantari, the flood probability in the area studied relates to three different groups of factors: topography, soil texture, and land use. Examples of such factors are the topographical wetness index, road density in the catchment, soil properties in the catchment, and local channel slope at the site of a road-stream intersection. All factors used in the method were available or possible to calculate from existing databases.

To be able to compile or calculate the factors used in the study, the following data must be available: elevation data, flow accumulation map, geometric properties of the catchment such as perimeter and area, drainage network map, stream map, slope raster, soil map, and road map.

6
Learning from Tabasco's floods by applying MORT
Jaime Santos-Reyes *, Rafael Alvarado-Corona, Samuel Olmos-Peña

In this paper, Santos-Reyes investigates what can be learned from the flooding of the state of Tabasco in Mexico. The method used is the Management Oversight Risk Tree (MORT), a technique that aims to ensure that all aspects of an organisation's management are looked into when assessing the possible causes of an incident.

The MORT method is used not as much as a risk identification method but as a tool for investigating incidents, in this case a natural hazard, a flooding. However, by using an investigation technique, one can identify causal factors in the case of natural disasters in order to prevent them from happening. The authors claim that, in comparison with other accident investigation techniques, MORT is a relatively simple checklist approach. In the case study, branches of the MORT-tree such as maintenance, inspections, and operational readiness are evaluated in order to find causal factors that are relevant to the flooding and its outcome. In MORT analysis, most of the effort is directed at identifying problems in the control of a work/process and deficiencies in the protective barriers associated with it.

One of the factors mentioned in the study is the lack of an integrated monitoring system, for example for meteorological data, rainfall, and river levels. Another factor is the deficiencies in the inspections of the state of the flood defence systems.

To be able to compile or calculate the factors used in the study, the following data must be available: access to the MORT manual, detailed information about different parts of an event.

7
Quantifying the hydrological impact of simulated changes in land use on peak discharge in a small catchment
Zahra Kalantari, Steve W. Lyon, Lennart Folkeson, Helen K. French, Jannes Stolte, Per-Erik Jansson, Mona Sassner

The importance of understanding how different land uses can affect discharge at the catchment outlet is studied in this paper. The authors have studied four extreme historical rain events in Norway and simulated six different types of land use measurements in connection with these events. The types studied were current land use, arable land, reforestation, vegetation buffers, grassed waterways, and clear cutting.

The study shows, among other things, that clear-cutting had a strong impact on the water balance because of changes in evapotranspiration. However, it is stated in the paper that seasonality and catchment conditions affect hydrological response since it is, for example, important whether the ground is saturated after a long period of rainfall or very dry. Furthermore, the study shows that a simulation of a complete clear-cutting resulted in a 60% increase in peak discharge and a 10% increase in total runoff.

The authors point out that 50-year flow is mainly used for the dimensioning of culverts and bridges in Norway and Sweden. However, with a change in land use, for example reforestation, the size and the duration of peak flows can be reduced. Other management measures such as grassed waterways or vegetation buffers can also change the hydrological response in a way that will benefit the infrastructure.

To be able to compile or calculate the factors used in the study, the following data must be available:

a hydrological model (e.g. MIKE SHE), data on land use, evapotranspiration, soil type, typography, metrological data such as precipitation.

8
Risk mapping major Danish Roads for flood risk by Blue Spot analyses
Christian Axelsen and Michael Larsen

Assessing flooding risk is often one of the main focus areas in climate change adaptation activities. For this reason, the Danish Road Directorate developed a model to pinpoint sections of the Danish National Road Network that are particularly vulnerable to an increase in extreme precipitation phenomena. In combination with consequence evaluations of given floods, these sections are termed Blue Spots.

On a more technical note, Blue Spot-mapping is generated in a GIS-model employing various input-data. The model comprises three levels: level 1 provides a screening of all terrain depressions that are computed based on a hydrologically adapted digital terrain model. Level 2 produces a risk map by incorporating the amount of rainfall needed to fill a given depression alongside the integration of the imperviousness of the catchment area. Lastly, level 3 couples terrain characteristics with drainage system specifications in order to determine depths and retention time of a flooding scenario.

Moving from level 1 to 3, the number of identified Blue Spots decreases dramatically. The reaming identifications are then subjected to categorisation in terms of probability and consequence. The former is chiefly determined by the returning pattern of heavy rainfall events. The latter is quantified by socio-economic factors, such as safety, traffic intensity, traffic management systems, and high-priority road networks. Only in the case of a relatively high risk and consequence is the term Blue Spot applicable to such a specific road section.

The Blue Spot analysis is a valued central tool in the pursuit of fulfilling the high-priority strategy of the Danish Road Directorate in achieving the highest degree of climate adaptation using the allocated resources.

9
Risk- and susceptibility analyses of culverts with respect to weather-related events (Risiko- og sårbarhetsanalyser av stikkrenner mht værrelaterte hendelser)
Statens Vegvesen, Norway

This report by the Norwegian Road Administration presents risk- and susceptibility (RAS) analyses of culverts with respect to weather-related events. The analyses can be carried out at three different levels: general identification of the areas or objects that are prone to weather-related events such as flooding (level 1), more elaborate investigations using precipitation data for basic quantitative analyses (level 2), and special analysis including, for example, inspection of the culverts and more complex analyses (level 3). These three analyses can be used on specific culverts or to identify vulnerable geographical locations on a longer stretch of road.
The RAS analysis uses a traditional risk matrix that is based on consequences and probability. It is important that several indicators are defined as part of the analysis. Examples of indicators are: change in land use upstream, damage to the culverts or the area around them, mudflows, and experience from actual events.
In order to be able to compile or calculate the factors used in the study, the following data must be available: land use and change in land use upstream, precipitation data in comparison to the existing

capacity damages on the culvert and the area around it (e.g. erosion), sedimentation and slurry data, experience from operation and maintenance, and actual events.

10
Mapping Natural Hazard Impacts on Road Infrastructure—The Extreme Precipitation in Baden-Württemberg, Germany, June 2013
Sina Keller, Andreas Atzl

This article presents an explanatory approach to how extreme climate-related events can affect infrastructure. This is done by hazard mapping the extreme precipitation in Germany in June 2013 using precipitation data and weather-related traffic reports.

The precipitation data came in a raster format and was interpolated at a regional scale of a 1-km^2 grid. The traffic reports were provided by the police and consisted of more than 50 text announcements during the week studied.

Due to an unusually long winter with frost followed by abnormal precipitation rates in spring, the soil was oversaturated and the infiltration of water dropped when the extreme precipitation event occurred. The hazard mapping showed that floods and landslides mainly occurred in areas with three specific characteristics: steep slopes, draining river valleys, and locations with soft and clayey rock layers. Furthermore, the result showed that while the precipitation peaked on 31 May, the number of road incidents continued to increase for another two days.

To be able to compile or calculate the factors used in the study, the following data must be available: weather-related traffic reports, precipitation data, road maps.

11
Mapping roads affected by flooding: A GIS-based study in Sotenäs municipality
Anna Klara Ahlmer (2015)

In this study, Ahlmer compares a multi-criteria analysis with the Blue Spot model used by the Swedish Transport Administration. The two methods were put in relation to eleven actual flooding events. Although the aim of Ahlmer's study is to identify roads that are vulnerable to flooding, the multi-criteria analysis method can be used to identify other risks. Other factors can also be included in the analysis.

Ahlmer used a GIS-based multi-criteria analysis that included layers of land use, soils, slope, and closeness to roads in order to find areas that are indicated as being vulnerable. The Blue Spot model used DEM (Digital Elevation Model) to find areas of at least 10 m^3 that can be filled with water during extended or heavy precipitation. Both models were then compared with 11 real flooding events in a municipality in western Sweden. The result shows a clear connection between Blue Spots and earlier floods. However, the multi-criteria analysis only identified two flooded road sections. The study points out the importance of choosing and weighing the different layers in the multi-criteria analysis. For example, land use can be valued according to how much water the ground absorbs, which will alter the results accordingly.

To be able to compile or calculate the factors used in the study, the following data must be available: statistics of recorded nature-related events, road maps, maps of land use, elevation data, data on soil type, and access to GIS.

12
Dealing with the effects of climate change on road pavements
PIARC Technical committee D.2 Road Pavements

The PIARC report does not provide a method per se but more of a systematic approach to conducting risk and vulnerability assessments, divided into five steps. In the first step, the potential effects of climate change are identified. This means, for example, projecting the periodicity of extreme weather events and obtaining information about regional climate change events that are likely to impact road pavements.

The next step is to undertake a climate vulnerability assessment of road pavements in order to adapt the design, maintenance, and operation of pavements. Aspects to take into consideration are, for example, the degree of exposure of road pavements to climatic hazards and the sensitivity of road pavements to changes in climate.

The third step includes an appraisal of risks and subsequently also the identification of potential solutions and strategies for addressing vulnerabilities. In this phase, cost-benefit analysis can be useful. The next step is about integrating the solutions and strategies into adaptation plans. This could, for example, mean the modification of standards and operational procedures. The fifth and final step is to monitor and review since climate change adaptation is an ongoing process.

To be able to compile or calculate the factors used in the study, the following data must be available: climate projections and scenarios, pavement data, data on ground water level, a risk assessment tool.

13
Method for Evaluating Implications of Climate Change for Design and Performance of Flexible Pavements
William Meagher, Jo Sias Daniel, Jennifer Jacobs and Ernst Linder

This paper presents a method of assessing the implications of forecasted climate change on pavement deterioration processes. The focus is on the preparation and use of climate model data sets as inputs to the 'Mechanistic–Empirical Pavement Design Guide' (MEPDG) model to simulate flexible pavement performance and deterioration over time.

The method is illustrated by a case study that uses future climate model temperature data from three scenarios at four sites across New England (USA). Pavement distress predicted with future temperature scenarios is compared with that of MEPDG temperature data.

Although the simulated impact of future temperature changes on pavement performance was negligible for alligator cracking at the four study sites, asphalt concrete rutting differences were sufficient to warrant additional consideration and to suggest that climate change and variability in future climate scenarios could affect pavement design and evaluation.

The four sites were chosen to cover a range of climate conditions. However, the result does not indicate to a higher degree that any of the sites were more at risk than the others. This could mean that this method does not work as a tool for identifying specific vulnerable geographical locations since there are factors other than climate that have more effect on the pavement.

To be able to compile or calculate the factors used in the study, the following data must be available: MEPDG-model, climate data for future scenarios, traffic data, pavement data.

14
A probabilistic methodology to estimate future coastal flood risk due to sea level rise
Matthew J. Purvis, Paul D. Bates, Christopher M. Hayes

This paper presents a methodology for estimating the probability of future coastal flooding given uncertainty over possible sea level rise. Purvis et al. take as an example the range of sea level rise magnitudes for 2100 contained in the IPCC Third Assessment Report and infer a plausible probability distribution for this range. The authors then use a statistical method (Monte Carlo procedure) to sample from this distribution and use the resulting values as an additional boundary forcing for a two-dimensional model of coastal inundation used to simulate a 1 in 200-year extreme water level event. This yields an ensemble of simulations for an event of this magnitude occurring in 2100, where each simulation represents a different possible scenario of sea level rise by this time. Purvis et al. then develop a methodology to approximate the probability of flooding in each model grid cell over the ensemble. By combining these hazard maps with maps of land use values (consequence), they are able to estimate spatial contributions to flood risk that can aid planning and investment decisions.

The method is applied to a 32-km section of the UK coast in Somerset, south-west England and used to estimate the monetary losses and risk due a 1 in 200-year recurrence interval event under: (a) current conditions; (b) with the IPCC's most plausible value for sea level rise by 2100 (0.48 m), and (c) using the above methodology to fully account for uncertainty over possible sea level rise. The analysis shows that undertaking a risk assessment using the most plausible sea level rise value may significantly underestimate monetary losses as it fails to account for the impact of low probability, high-consequence events. The developed method provides an objective basis for decisions regarding future defence spending and can be easily extended to consider other sources of uncertainty such as changing event frequency–magnitude distribution, changing storm surge conditions or model structural uncertainty, either singly or in combination as joint probabilities.

To be able to compile or calculate the factors used in the study, the following data must be available:
a flood inundation model, probability distribution for possible future sea level rise, a Digital Elevation Model (DEM), forcing data (time series of discharge or water level), data on land use and responding monetary loss values.

15
Detailed rockslide mapping in northern Norway with small baseline and persistent scatterer interferometric SAR time series methods
T.R. Lauknes, A. Piyush Shanker, J.F. Dehls, H.A. Zebker, I.H.C. Henderson, Y. Larsen

Lauknes et al. (2010) use the improved access to satellite data to identify areas that are vulnerable to rockslides. The development of time series satellite data from SAR (Synthetic Aperture Radar) has made multi-temporal algorithms useful. This report investigates two methods. The first is small baseline (SB) which uses SAR image combinations with a short spatial baseline to reduce the effects of temporal and spatial decorrelation. The second is persistent scatter interferometry (PSI) which identifies image pixels in a stack of interferograms with the highest possible resolution.

The steps in the procedure are as follows: the spatial decorrelation in the DEM (Digital Elevation Model) is reduced; all pixels are referenced to a selected point (with high coherence and preferably a known deformation). Atmospheric differences can create unknown signals in the SAR images and are therefore filtered. The software StaMPS (Stanford Method for PS) is used to generate all PSI results with the ML-PS algorithm. After the PS pixels have been selected through Delaunay triangulation and interpolation, they get unwrapped to reduce the atmospheric and orbital effects with the SNAPHU software. The interferograms were processed using the Norut GSAR software.

The study observes that areas above 600–700 metres have a high coherence due to lack of vegetation. This could explain why the SB method has greater spatial coverage compared to PSI. The PSI could have more areas inside the resolution cell and is therefore detected in areas with more complex character, while the SB has better coverage in all areas. The two methods follow each other quite well for all selected points: the average difference between the two methods is approx. 0.5 mm/year. The results show that the block is subsiding up to 5 mm/year compared to the mountainsides.

Problems with the methods are that only summer and autumn SAR scenes can be used and seasonal variations are therefore lost. Another problem is the time dimension because all data points are collected at an interval of one year. Moreover, the quality of the SAR images relative to how the satellites are moving is an obstacle, although this can be solved through a combination of orbits in order to diminish the displacement. The InSAR methods can be complementary to the ground based monitoring.

To be able to compile or calculate the factors used in the study, the following data must be available:
SAR data (DEM - digital elevation model, in this case years 1992–1999 and only snow-free places), access to StaMPS software, SNAPHU software, and Norut GSAR software.

16
Rock fall risk assessment to persons travelling in vehicles along a road: the case study of the Amalfi coastal road (southern Italy)
Settimio Ferlisi, Leonardo Cascini, Jordi Corominas, Fabio Matano

This paper is about the assessment of rock-fall risk along the SS163 road, an important transport corridor with high traffic volumes, on the Amalfi Coast in southern Italy.

Three different places along the road, which is susceptible to rock-fall, have been chosen based on a historical catalogue of incident data. Two different methods were used to study the risk of rock-fall along the road. The methods chosen were RHRS (Rock-fall Hazard Rating System) and QRA (Quantitative Risk Assessment). The two methods can be seen as complementary tools to mitigate both direct consequences (life loss) and indirect consequences (traffic delays and diversions) associated with rock-falls.
RHRS is a qualitative method and consists of six steps. In the first step, the stability conditions of the slope are ranked according to its susceptibility and activity. The method has two different ratings of slope, the first one is a preliminary rating and performed in the second step of the method. The other rating is a detailed rating and is performed in the third step. In the fourth step, a cost-benefit analysis is carried out. The fifth step in the RHRS method is to establish rock-fall correction projects. The final step consists of a review and update of the data every year.

The QRA method is divided into three parts: risk analysis, risk assessment and risk management. Risk analysis includes hazard and consequence analyses but also a risk estimation. Risk assessment involves taking the outputs from the risk analysis and comparing them with valued judgements and risk tolerance criteria to determine whether the risks are low enough to be tolerable. Risk management identifies the measures that may be taken to mitigate risk to the community, for example by using different strategies.

The result of the two methods indicates that the computed societal risk cannot be tolerated, although the estimated individual risk to life satisfies the adopted tolerable risk criterion. By using the two methods, it is possible to detect sections of the road where recourses to mitigation methods could be best directed.

To be able to compile or calculate the factors used in the study, the following data must be available: historical catalogue of incident data, rock-fall simulation programme, road maps, traffic data, topographical map, geological information, soil maps, and climate data.

17

Hazard and risk assessment of rock fall protective forests by evaluating the case study of Geschwendnerberg along the highway 'A9 Pyhrn Autobahn'

(Wirkungsbeurteilung und Risikoanalyse eines Steinschlagschutzwalds an der A9 Pyhrn Autobahn)

Müller, Gerald et al. (2014, unpublished)

The frequency and intensity of natural hazards in alpine regions seem to have increased in recent decades. Regional planning institutions are asked to reduce the residual risk though sustainable development of alpine regions. Common technical protective measures are expensive and provide only small-scale protection, therefore a more cost-effective and sustainable method could be to integrate the forests, which have a protective function. This article discusses the assessment, analysis, and quantification of risk reduction by considering the protective effect of a forest along the A9 Pyhrn motorway, as at this point, the knowledge of the protective effects of forests is low.

This thesis applies the methodology of different available concepts for sustainability and monitoring research of protective forests and concepts of risk-based assessment, prevention, and management.

For the hazard assessment, all existing data, including field records, is used. These field visits are used for the qualitative description of current forest stand and structure, determination of rock-breakouts and geological conditions, current and past rock-fall activities, acquisition of surface characteristics along the transition zones of the trajectories and clustering of trajectories. At a later stage, a slope method is used to assess the falling range. The data is also used for the simulation of the hazardous scenarios, assessing of events and for analysing the impact of protection forests as well as for the rock-fall simulation with Rockyfor3D and evaluation of the risk analysis.

The simulation is also used to calculate trajectories of single, individually falling rocks in three dimensions. The hazard assessment of the study area is completed by calculating different scenarios of rock-fall hazard events considering the current forest stand and comparing it with the theoretical situation that no forest is available. The evaluation of the rock-fall is done by model validation and plausibility checks of all the input data and simulation results. The simulation is, therefore, based on four scenarios with different return periods.

Regardless of the forest stand for very frequent events, no risk can be expected along the highway. Partially existing protection measures in the form of wooden walls are considered to be sufficient due to simulated maximum impact energies and jump heights, to protect the highway from falling rocks. The risk assessment for frequent events is done by assuming that these protective measures are theoretically not available.

The positive influence of the protective function of the current forest stand is evident from the almost 40 % reduction in rock-fall risk. Even though the current forest stand does not entirely protect the highway from rock-fall events, however it significantly reduces the likelihood of rock-fall passages, mean jump heights, and maximum energy exposure.

To be able to compile or calculate the factors used in the study, the following data must be available: historical catalogue of incident data (if available), existing technical protective measures, danger zone plan, digital terrain model (DTM), Airborne Laser Scan (ALS), current rock-fall simulating programme (Rockyfor3D), road maps, traffic data, topographical map, geological, hydrological and geotechnical information, rock size and shape, vegetation (field data and/or aerial photo), soil maps, and climate data.

18

Adaptation to Climate Change in the Alpine Space; Adapt Apl WP 5.1: Hazard Mapping – Geological Hazards, Literature survey regarding methods of hazard mapping and evaluation of danger by landslides and rock fall. – Final Report, July 2010

Geologische Bundesanstalt und Amt der Kärntner Landesregierung (2010)

Landslides and falling rocks are gravitational natural hazards that pose safety risks for habitats, economic landscapes, and residential areas situated in the Alpine area. The countries concerned—including Austria, Switzerland and Germany—have chosen different ways of tackling these natural hazards.

The aim of the paper is both to provide an extensive overview of the available literature dealing with this issue and to explain the specific approaches of each individual country, presenting the different methodologies used for mapping natural hazards and evaluating the related risk potential. In addition, it includes evaluations of several measures that have already been implemented.

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