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A) Projektdaten

Kurztitel:	adapt2to4
Langtitel:	Adaptation costs – an economic assessment for prioritising adaptation measures and policies in a +2°C to +4°C world
Programm inkl. Jahr:	ACRP 3 (2010)
Dauer:	01.04.2011 bis 30.09.2014
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Projekt- und KooperationspartnerIn (inkl. Bundesland):	(P1) Environment Agency Austria (EEA, Umweltbundesamt GmbH, Vienna) (P2) Wegener Center, University of Graz, Research Group "Regional and Local Climate Modelling Analysis" (Graz)
Schlagwörter:	Klimawandelfolgen, Kosten, Verkehr, Adaptation
Projektgesamtkosten:	300,000 €
Fördersumme:	300,000 €
Klimafonds-Nr:	B068684
Erstellt am:	30.12.2014

B) Project overview / Projektüberblick

1 Kurzfassung

In Europa sind bereits heute rund 30 bis 50% der Straßenerhaltungskosten witterungsbedingt. Rund 80% dieser Kosten entfallen auf die Straße, gefolgt von Luft- und Schienenverkehr. Weiters dominieren Schäden an der Infrastruktur, während Auswirkungen auf Fahrzeuge sowie Zeitverluste bislang von untergeordneter Bedeutung sind. Der Großteil der witterungsbedingten Schäden im europäischen Verkehrssystem wird durch Niederschlagsereignisse ausgelöst, während Hitze und Sturm nur eine untergeordnete Rolle spielen (Enei et al., 2011; Nemry und Demirel, 2012).
Das ACRP-Projekt adapt2to4 beschäftigte sich daher sowohl mit den bereits jetzt auftretenden Auswirkungen des Klimas auf das österreichische Verkehrssystem als auch mit möglichen zukünftigen klimabedingten Schäden, mit einem Schwerpunkt auf den Bereich Infrastruktur.
Wesentliche Projektergebnisse sind:

- die Evaluierung und Georeferenzierung wetterbedingter Schäden an Straßenverkehrsinfrastruktur auf regionaler Ebene für unterschiedliche Schadkategorien (v.a. Überflutungen, Muren, Felsstürze und Sturm)
- die Abschätzung zukünftiger Ereignisse und Schäden mit Hilfe von Klimaszenarien auf regionaler Ebene (bis 2050)
- die Erhebung der Anpassungserfordernisse und -maßnahmen auf Bundes- und Länderebene
- die volkswirtschaftliche Bewertung unterschiedlicher Anpassungsmaßnahmen
- die Unterstützung der Österreichischen Anpassungsstrategie durch die Erstellung eines Fahrplans für die Anpassungsplanung der Verkehrsinfrastruktur in Österreich

Im Folgenden wird auf die zentralen Ergebnisse kurz eingegangen.

Heutiges Schadensbild: Anpassungsdefizit
Für Österreich liegt bislang kein einheitliches Schadensregister für Schäden an Verkehrsinfrastruktur vor. Im Projekt adpt2to4 wurden daher zunächst Schadereignisse und -kosten an österreichischen Landesstraßen in den Bundesländern Steiermark, Salzburg, Tirol und Vorarlberg gesammelt, klassifiziert und georeferenziert.
Auch in Österreich sind die weitaus meisten Ereignisse durch Niederschläge ausgelöst: 35% der Schadereignisse werden durch Hochwasser, 39% durch Massenbewegungen (Vermurungen und Hangrutschungen) verursacht. Die dritthäufigste Schadkategorie stellen Sturmschäden mit 14% dar. Schäden durch Lawinen treten aufgrund von effektiven Schutzmaßnahmen nur sehr selten auf (1%).
Die Kosten je Schadereignis unterscheiden sich jedoch erheblich je nach Schadkategorie, wobei Massenbewegungen hierbei ein wesentlich höheres Schadpotenzial aufweisen als Überflutungen. Deshalb sind 51% der Schadenskosten durch Massenbewegungen verursacht, im Vergleich zu 21% durch Hochwasser. Felsstürze machen 19% der gesamten Schadenskosten aus, Sturmereignisse führen nur zu geringen Kosten. Die Kosten pro Ereignis zeigen, dass seltene Lawinenereignisse sehr viel höhere Schäden verursachen als ein durchschnittliches Hochwasserereignis.

Auswirkungen des Klimawandels: sozioökonomische Effekte dominieren
Legt man die Schadenskosten auf das gesamte österreichische Straßennetz (Bundes-, Landes- und Gemeindestraßen) um, ergeben sich Kosten von jährlich durchschnittlich 18 Mio. Euro für den Zeitraum 1981-2010. Bei einem mittleren Klimawandel-Szenario steigen die durchschnittlichen jährlichen Kosten in der Periode 2016-45 auf rund 27 Mio. Euro an, und auf 38 Mio. Euro in der Periode 2036-65. Einen erheblichen Einfluss auf die zukünftige Schadenshöhe hat hierbei auch der Netzausbau und die damit verbundene Zunahme der exponierte Werte, nicht jedoch klimatische Veränderungnen. Dies ist darauf zurückzuführen, dass einige Regionen durch Erhöhung der Niederschläge gekennzeichnet sind, während es zu Niederschlagsabnahmen in anderen Regionen sowie zu saisonalen Verschiebungen kommt.
Vergleicht man diese Ergebnisse mit Abschätzungen für den Alpenraum aus europäischen Vergleichsstudien (EU-Projekt WEATHER), so zeigt sich, dass die im Projekt adapt2to4 ermittelten

Kostenschätzungen eher am unteren Ende angesiedelt sind. Legt man die WEATHER-Ergebnisse auf Österreich um, so ergeben sich für den Zeitraum 2000-2010 durchschnittliche jährliche Kosten von 47 Mio. Euro für die Straße und 16 Mio. Euro für die Schiene. Die niedrigeren Zahlen sind einerseits darauf zurückzuführen, dass es in Österreich sowohl Regionen mit Niederschlagszunahmen als auch -abnahmen gibt, wodurch der Nettoeffekt geringer ausfällt; andererseits beziehen sich die seitens der Bundesländer verfügbaren Basisdaten auf Reparaturkosten, weshalb nicht behobene Schäden in den Ergebnissen nicht aufscheinen. Schließlich berücksichtigt WEATHER nicht nur Schäden an der Verkehrsinfrastruktur sondern auch an Fahrzeugen sowie im Betrieb (Zeitkosten).

Volkswirtschaftliche Effekte von Klimawandelfolgen und -anpassung
Ein intaktes Verkehrssystem ist zentral für eine funktionierende Wirtschaft, Schäden an der Verkehrsinfrastruktur können daher weitreichende volkswirtschaftliche Konsequenzen haben. Mittels eines Computable General Equilibrium (CGE) Modell für Österreich wurde daher berechnet, welche volkswirtschaftlichen Effekte durch diese Infrastrukturschäden ausgelöst werden und inwieweit unterschiedliche Anpassungsmaßnahmen diese Effekte abfedern können. Hierbei zeigt sich, dass die ausgelösten volkswirtschaftlichen Effekte rund doppelt so hoch sind wie die Infrastrukturschäden selbst. Diese Verdopplung ist darauf zurückzuführen, dass das Verkehrssystem eine wichtige Rolle in der Erzeugung und im Verkauf vieler Güter und Dienstleistung spielt und höhere Kosten für Verkehrsdienstleistungen zu einem Rückgang der wirtschaftlichen Aktivität in diesen vor- und nachgelagerten Sektoren führen.
Durch unterschiedliche Anpassungsoptionen (Verbesserung der Abflusssysteme, mehr Gehölzpflege neben den Trassen, besserer Frühwarnsysteme, häufigere visuelle Überprüfung und Reparatur von Belagsschäden, Ausbau des Wildbach- und Lawinenverbauung) kann ein Teil der Infrastrukturschäden vermieden werden, diese sind jedoch auch mit Mehrausgaben verbunden. Netto ergibt sich somit eine Reduktion der volkswirtschaftlichen Kosten um rund 60%. Die verbleibenden 40% sind Residualschäden, die auch durch Anpassungsmaßnahmen nicht behoben werden können.

Ein Anpassungsfahrplan für Österreichs Verkehrsinfrastruktur
Im Zuge des Projektes wurden zunächst über 40 Anpassungsoptionen erhoben. In einem zweistufigen Verfahren wurden daraus von ExpertInnen die zentralsten Maßnahmen ausgewählt (12), welche dann in einem weiteren Schritt in einer Multikriterienanalyse bewertet wurden. Die zentralen Ergebnisse dieser Bewertung sind, dass Anreiz- und Informationsmaßnahmen (beispielsweise Verbesserung der Kommunikationspläne im Schadensfall) mittlere Kosten verursachen, sehr flexibel einsetzbar sind und ein hohes Schadensvermeidungspotenzial aufweisen. Im Gegensatz dazu führen Maßnahmen aus dem Bereich erhöhte Supervision und Erhaltung des Verkehrsnetzes zu hohen Kosten, verbunden mit mittlere Wertschöpfung, das Schadensvermeidungspotenzial wird dabei als geringer eingeschätzt. Schließlich führen technische Maßnahmen, wie beispielsweise zusätzliche Schutzbauten, zu hohen Kosten und positiven Wertschöpfungseffekten, sie sind aber eher unflexibel, d.h. können nicht zurückgenommen oder an veränderte Bedingungen adaptiert werden. Somit haben alle untersuchten Maßnahmen ihre spezifischen Vor- und Nachteile, weshalb eine Mischung bzw. Abfolge aus diesen unterschiedlichen Maßnahmenkategorien die Vulnerabilität des Verkehrssystems gegenüber klimatischen Veränderung am besten abfedern kann.
Daher wurden schließlich die am besten geeigneten Maßnahmen zu sechs Programmen zusammengefasst und diese in eine zeitliche Abfolge bis 2050 gebracht. Dieser sogenannte Anpassungsfahrplan startet mit der Schaffung einer Datenbasis sowie mit Planungsinstrumenten wie beispielsweise Gefahrenhinweiskarten. Darauf folgen dann Maßnahmen, die helfen, das derzeitige Anpassungsdefizit zu vermindern. Zentral dabei ist die Vermeidung eines starken Netzwachstums, die Integration von zunehmenden Extremereignissen in den Straßenunterhalt und Neubau sowie zusätzliche Investitionen in Schutzmaßnahmen für Massenbewegungen. Maßnahmen zur Anpassung an größtenteils erst künftige Risiken wie Neuauslegungen von Brücken (und die Schaffung von Umfahrungsmöglichkeiten neuralgischer ‚Arterienverbindungen' sowie den Aus- und gegebenenfalls Rückbau von bestehender Infrastruktur stehen am Ende des Fahrplans. Begleitend über den gesamten Planungshorizont kann Forschung und Entwicklung die Entscheidungsgrundlagen verbessern und Handlungsmöglichkeiten aufzeigen.

2 Executive Summary

In Europe, approximately 30 to 50% of current road maintenance costs are weather-related. Around 80% of these costs relate to road, followed by air and rail transport. Moreover, damages to infrastructure are dominant, while effects on vehicles and time losses are far from insignificant. The majority of weather-related damage in the European transport system is triggered by rainfall events, while heat and storm play only a minor role (Enei et al., 2011; Nemry und Demirel, 2012). The ACRP project adapt2to4 therefore dealt with both the current impacts of climate on the Austrian transport system as well as possible future climate-related damages, with an emphasis on transport infrastructure. Key outcomes of the project are:

- evaluation and geo-referencing of weather-related damages to road infrastructure at the regional level for different damage categories (especially floods, mudflow, landslides and storm)
- estimation of future events and damage based on regional climate scenarios up to 2050
- the collection of adaptation needs and measures at federal and provincial level
- the macroeconomic assessment of different adaptation measures
- the support of the Austrian adaptation strategy by creating a roadmap for adaptation planning of transport infrastructure in Austria

In the following, the main findings are summarized.

Damage costs up to now

At the start of the project, no unified registry or database for damages to transport infrastructure was available. Therefore data on damage events and associated costs to secondary roads for four Austrian provinces (Styria, Salzburg, Tyrol and Vorarlberg) were collected, classified and geo-referenced (for Styria and Salzburg). Evaluating this data revealed that the vast majority of events are triggered by rainfall: 35% of damage events are caused by flooding, 39% by mass movements (landslides and mudflows). The third most frequent category represents storms. Damage events due to avalanches are rare due to effective protection measures.

The costs by damage event, however, differ considerably depending on the damage category, with mass movements having a much higher damage potential than flooding. Therefore, 51% of the damage costs are caused by mass movements, compared to 21% due to flooding. While avalanche events are comparatively rare, they also have a much higher damage potential than an average flood event. Rockfall constitutes 19% of the total damage costs, storms only lead to comparatively low cost.

Socio-economic changes dominate impacts of climate change

Upscaling damage costs to the entire Austrian road network (federal, provincial and local roads) leads to average annual cost of 18 million euros for the period 1981-2010. In a mid range climate change scenario, the average annual cost increases to around 27 million euros in the period 2016-45, and to 38 million euros in the period 2036-65. A significant impact on the future damage costs is due the network expansion and hence an increase in exposed values, and less due to climate change. While some regions are characterized by increases in precipitation, precipitation is decreasing in others, and there is also a seasonal shift. As a consequence, the overall effect of changes in precipitation is modest for Austria in total.

Comparing these results to results gained in comparative studies for the Alpine regions in Europe (within the EU project WEATHER), reveals that adapt2to4 cost estimates are lower: Applying the WEATHER results to Austria for the period 2000-2010, yields average annual cost of 47 million euros for road and 16 million euros for rail. The lower figures obtained in this project are due to the fact that precipitation increases in some regions while it declines in others leading to an overall smaller effect for Austria in total; second, the damage cost registry data provides costs of repair whereas undetected or unrepaired costs are not included. Finally, WEATHER takes into account not only damage to transport infrastructure but also to vehicles and to operation (time costs).

Economic effects of climate change impacts and adaptation

An intact transport system is central to a functioning economy, damage to the transport infrastructure can therefore have far-reaching economic consequences. By using a Computable General Equilibrium (CGE) model for Austria, we therefore assessed the economic effects caused by these infrastructure damages and the extent to which different adaptation measures can mitigate these effects. It is shown that the induced economic effects are about twice as high as the infrastructure damage itself. This doubling is due to the fact that the transport system plays an important role in the production and sale of many goods and services and higher costs for transport services lead to a decline of economic activity in upstream and downstream sectors. Part of the infrastructure damage can be avoided by different adaption measures (enlargement of drainage system capacities alongside roads and rails, intensification of vegetation management next to roads and rails, improved early warning systems, more frequent visual road inspection, expansion of torrent and avalanche control), but they also lead to costs. This results in a net reduction of economic impact costs by around 60%. The remaining 40% are residual damage costs that cannot be avoided by adaptation.

An adaptation roadmap for Austria's transport infrastructure

In the course of the project, more than 40 adaptation options were collected. In a two-stage process, experts first selected the most important measures which were then evaluated in a multi-criteria analysis. The main results of this assessment are that incentive and information measures (such as improving communication plans in case of damage events) lead to moderate costs, are very flexible, and have a high damage avoidance potential. In contrast, measures in the field of increased network supervision and maintenance are associated with on average higher costs, having moderate positive effects on value added, and the potential of mitigating losses is seen as lower. Technical measures, such as additional protective infrastructure, are seen as having high costs but also highly positive effects on economic activity. But they are also rather inflexible, i.e. they cannot be taken back or adapted to changing conditions. Thus, all the measures have their specific advantages and disadvantages, so a mixture or sequence of these different types of measures may best ameliorate the vulnerability of the transport system to climate change. Therefore, the most appropriate measures were finally aggregated into six programs, and put it in a temporal sequence up to 2050. This so-called adaptation plans starts with the creation of a data base, as well as planning tools such as hazard maps. This is then followed by measures that help to reduce the current adaptation deficit. Central is here that a strong network growth is avoided, that the awareness for extreme events in road maintenance and construction is increased, and that additional investments in protective measures against mass movements are taken. Measures that address mostly risks in the future are new designs of bridges (and creating bypass options for neuralgic ‘arterial connections’) as well as the extension or, where appropriate, destruction of existing infrastructure are found at the end of the roadmap. Research and development to improve the basis for decision making and identify opportunities for action is a key accompanying measure over the entire planning horizon.

3 Background and project aims / Hintergrund und Zielsetzung

Introduction

Over the last few decades, research and policy have focused on the question how we can mitigate human induced climate change. Even if mitigation efforts prove to be successful over the next decades, a significant amount of human-induced climate change has become inevitable (CEC, 2007). Now that impacts of climate change are observed and more impacts are expected for the coming decades challenging many economic sectors and threatening ecosystems across Europe (EEA, 2008), adaptation to these impacts has been put on the agenda. Yet research on climate change adaptation is still fragmented, by focusing either only on some climate sensitive sectors like agriculture, energy and tourism, or on specific impact fields such as sea level rise.

One of these less researched impact fields is the transport sector. In Europe, approximately 30 to 50% of current road maintenance costs are weather-related. Around 80% of these costs relate to road, followed by air and rail transport. Moreover, damages to infrastructure are dominant, while effects on vehicles and time losses are far from insignificant. The majority of weather-related damage in the European transport system is triggered by rainfall events, while heat and storm play only a minor role (Enei et al., 2011; Nemry und Demirel, 2012).

While the European Commission has acknowledged the vulnerability of the transport system to climatic changes (European Commission, 2013a,b), research particularly on the economic and social consequences of adapting to climate change is rare. The project adapt2to4 seeks to address this gap by estimating key investments and recurrent expenses to reduce future climate change impacts on transport systems. In doing so, we particularly focus on road transport infrastructure as road transport is the dominant mode of transport and infrastructure is the dominant damage category according to European scale studies (Enei et al., 2011).

While adaptation may happen spontaneously by economic agents driven by self-interest, for many forms of adaptation, such as the construction of large infrastructure projects or the implementation of new spatial planning programs, a vital role arises to public policy through scientific and physical investment and regulation. Thus, government action is required to install accurate planned adaptation measures, but also to facilitate market-driven adaptation. Expenditures on adaptation as well as investment in adaptive capacity have to be justified – regardless whether it is public spending (policy-driven public adaptation) or private investment (market-driven adaptation as autonomous reaction of consumers/producers or incentivised by public policy).

A challenge for the scientific community is thus posed by the necessity to base the Austrian National Adaptation Strategy (NAS) on a sound analysis of policy-relevant uncertainties, as also indicated with respect to temperature increase by the project title 'adapt2to4'. In particular, we use a set of regional climate scenarios for Austria which fall into the potential range of global average temperature change of +1.7°C to +4.4°C until the end of the century compared to pre-industrial levels (A1B scenario, see IPCC, 2007, 13). Likewise, we consider different future socio-economic developments for transport network expansion.

Project key objectives

First, adapt2to4 aimed to conduct a comprehensive literature and project survey with respect to climate change impacts, vulnerability and adaptation costs and benefits at (sub-) national, European and international scale.

The project's second objective was to identify and assess the costs of adaptation needs and options at both the provincial and national level for transport infrastructure in Austria. Due to the already mentioned lack of available data on climate change impact and adaptation cost, a major project contribution is therefore to compile a database on climate change impacts on road infrastructure in four Austrian provinces.

As a third project goal, we developed an evaluation and decision support framework as key accompanying measure for the Austrian NAS. This consisted of (i) a macroeconomic assessment, (ii) a multi-criteria assessment, and (iii) an adaptation roadmap for road transport infrastructure in Austria.

For political investment decisions it is most relevant that the costs of adaptation measures, strategies and policies are compared for different climate change impacts given that climate signals vary considerably across different (global and regional) climate models and their underlying (socio-economic) emissions scenarios. Likewise, different socio-economic development may enforce or ameliorate damage costs and hence adaptation needs. In addition to economic criteria like cost-effectiveness, further non-economic (social and environmental) indicators were considered for devising an adaptation roadmap.

4 Project content and results / Projektinhalt und Ergebnis(se)

PROJECT GOALS

The present project addressed the following research questions:

- What are the key vulnerable sectors in Austria with respect to climate change impacts/potential damages, and which are the responsible entities with respect to market-driven and policy-driven adaptation decisions?

By focusing on transport infrastructure in more detail,

- What are the impacts, adaptation options and their respective benefits and costs?
- What are the implications of market-driven/policy-driven adaptation for the overall economy (sectoral feedback, overall and sectoral production levels, welfare)?
- In addition to economic criteria, what additional criteria guide the selection of adaptation options and how do they fit into the development of the Austrian NAS?
- What are the key features of an evaluation framework designed to support decision processes on adaptation measures and 'adapted futures', particular in respect to coping with uncertainties?

To address these research questions, the following methods/approaches will be applied:

- Literature and project review on climate change impacts, vulnerability and adaptation costs
- Analysis of regional climate scenarios and empirical-statistical downscaling and error correction of regional climate model results to generate input for the climate change impact assessment
- GIS-based data analysis and stakeholder involvement for climate change impact and adaptation assessment for transport infrastructure (detailed sectoral approach)

- Computable General Equilibrium (CGE) modelling for economy-wide assessment of adaptation benefits and costs and integration of bottom-up and top-down approaches
- Comparison of different adaptation options for the transport system by means of a multi-criteria analysis based on stakeholder involvement
- Development of an adaptation roadmap for Austrian transport infrastructure

PROJECT STRUCTURE

The project was organised in five work packages:

WP1: Cross-Sectoral Survey of Climate Change Impacts and Adaptation Costs (WP SURVEY): A survey of estimates on impacts and adaptation costs for vulnerable sectors, drawing on existing assessments, as well as on methodologies and results of different NAS across Europe. The key methods in WP1 were project and literature review as well as data analysis on the damage data of NatCat service by MunichRe.

The tasks/activities in WP1 were as follows:

- Table of core research projects, studies and publications on climate costs
- Evaluation of methods developed for the assessment of climate impacts and adaptation costs to evaluate
- Matrix of climate-sensitive economic sectors/branches in Austria
- Acquisition of climate damage data for 1980-2010 to identify key damage events in Austria

WP2: Identification of Impacts, Adaptation Measures and Costs for Transport Infrastructure in Austria (WP APPROACH): For transport, we undertook a comprehensive impact assessment for road infrastructure in Austria and identified the range of adaptation options and in particular their costs, both for market-driven measures at firm level and policy-driven measures at regional/national governance level. To that end, a preliminary estimation on the impacts of climate trends and weather variability was carried out and possible adaptation pathways were identified.

Methods employed consisted of data collection, statistical analysis, spatial analysis, and interviews.

The tasks/activities in WP2 were as follows:

- Acquisition, collection and comparison/consolidation of road damage data for the four provinces Styria, Salzburg, Tyrol and Vorarlberg as basis for impact assessment of road transport infrastructure
- Generation of 24 downscaled and error corrected regional climate scenarios for daily precipitation, temperature and snow height for entire Austria on a 1 km grid
- Development of an uncertainty estimation and visualization tool for impact relevant threshold parameters
- Impact cost assessment for road infrastructure (for the province of Styria)
- Identification of grey, green and smart adaptation options relevant for road and rail infrastructure
- Identification of adaptation pathways in the transport sector, their implications for public budgets (infrastructure) and ecological consequences

WP3: National Adaptation Cost Assessment for Infrastructure (WP ASSESS): Detailed information at sector level was integrated into a national-scale multi-sectoral computable general equilibrium (CGE) model. This way, specific adaptation measures could be studied with respect to their cross-sectoral, macroeconomic and welfare effects.

The main methodology was CGE modelling, including the modelling of interfaces to the impact cost and adaptation cost assessment, as well as scenario development.

- Specification of CGE model for macroeconomic assessment (input-output structure, sector aggregation)
- Derivation of transport infrastructure impact functions for damage events and damage costs and preparation of interfaces to CGE model
- Integration of impact functions for different road and rail sub-sectors into refined CGE model
- Integration of the different adaptation options including their costs and benefits (damage reduction potential)

WP4: Evaluation of Adaptation Options under Uncertainty (WP PRIORITIZE): The economic and non-economic consequences of different adaptation options where analysed in a multi-criteria analysis. Results of both the national cost assessment by means of the CGE model developed in WP4 and the multi-criteria analysis were then translated into policy support by devising an adaptation roadmap for the Austrian transport system. The main methods used where therefore CGE modelling, multi-criteria analysis based on stakeholder dialogue, an assessment of uncertainties, and the derivation of an adaptation plan.

The tasks/activities were therefore:

- Assessment of macroeconomic costs of climate change impacts on road and rail infrastructure in Austria
- Assessment of macroeconomic benefits and costs of different adaptation options
- Survey among decision makers (in public authorities at provincial governance level) on importance, state of implementation, and need of different adaptation options
- Selection and operationalization of criteria for a multi-criteria-analysis of adaptation options
- Multi-criteria analysis of those adaptation options which were identified as most important according to the survey
- Uncertainty estimation for the specific climate indices and socio-economic development (mostly expansion of road network); provision of statistics for relevant climate indices for the period 2021-2050 relative 1971-2010
- Evaluation of market- and policy-driven adaptation measures according to type/category of adaptation measure (infrastructure vs. information vs. increased maintenance)
- Development of an adaptation plan for transport infrastructure in support of the strategic and practical part of the Austrian NAS

WP5: Project Management and Coordination: This WP was responsible for the planning and management of two stakeholder and expert workshops as well as for the involvement of international experts into the project. Moreover, the WP performed initial concept exploration as well as overall project coordination and management.

The main tasks involved:

- Workshop planning and management (2 workshops)
- Integration of international expertise in the project
- Coordination of journal publications and reports
- Project controlling

PROJECT RESULTS

Climate impact/damage cost results (WP1)

One of the project highlights of WP1 was the assessment of costs of extreme events in Austria for the period 1980-2010. This assessment is based on the database of the NatCatService/MunichRe which collects damage events and costs due to major meteorological extreme events all over the world. For the 31 years from 1980 to 2010 (at 2010 prices), Austria's damage costs due to meteorological extreme events sum up to 9.3 billion Euro, as illustrated in Figure 1.

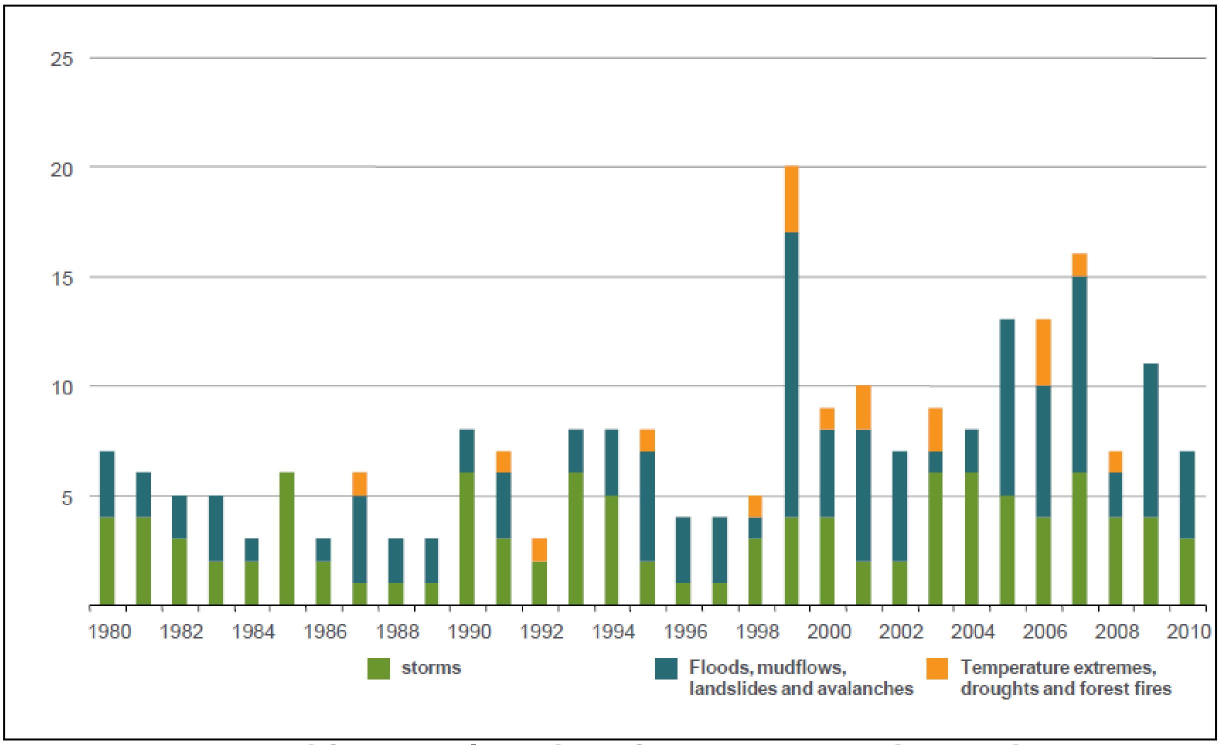

Figure 1: 30 year trend for annual number of extreme events in Austria.
Data source and processing: MunichRe/NatCatService.

Current climate change impacts for road infrastructure (WP2)

As basis for impact assessment of road transport infrastructure, a road damage database was established by the project team based on information from four different Austrian provinces (Styria, Salzburg, Tirol, Vorarlberg). For methodological details, see section C.6 below.

The average annual road damage costs to the secondary road network (federal and provincial roads) in four Austrian provinces are given in Figure 2. In all four provinces, floods, mudflows and landslides contribute about 80% of all road damage costs. In comparison, damages due to avalanches and snow pressure play a minor role for road damage costs, mostly due to installed avalanche control measures like galleries. Rockfall is of importance in high alpine areas with steep valleys (see e.g. Salzburg and Vorarlberg), but is overall less important when a large part of the secondary road network is in pre-alpine areas (e.g. Styria). In contrast, storm has been of more importance in Styria.

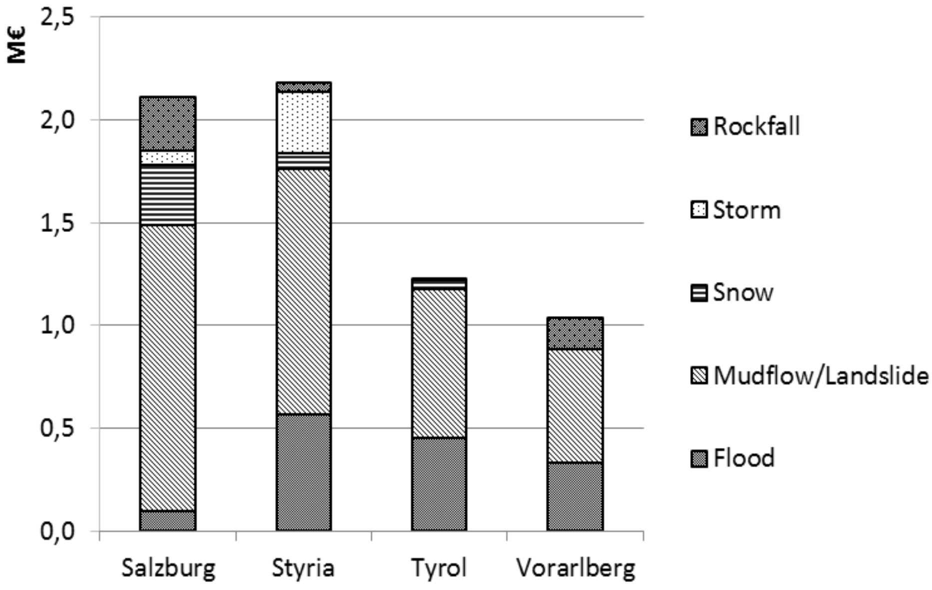

Figure 2: Average annual damage costs to secondary road network in four Austrian provinces (in million euros: Salzburg (ø2007-2010), Styria (ø2008-2011), Tyrol (ø 2006-2011), and Vorarlberg (ø2006-2010)

Data source: Amt der Salzburger Landesregierung (2012), Amt der Steiermärkischen Landesregierung (2012), Amt der Tiroler Landesregierung (2011), Amt der Vorarlberger Landesregierung (2011)

Figure 2 illustrate the geographical scope of damage events for Salzburg. Exemplarily, the damage categories "Storm", "Flood" and "Mudflow/Landslide" are shown. Storm events are most likely to occur in the northern lowland ("Salzburger Zentralraum") and in West-East straightened valleys. Also the spatial distribution of flood and mudflow/landslide events shows a plausible reflection of the topographic conditions.

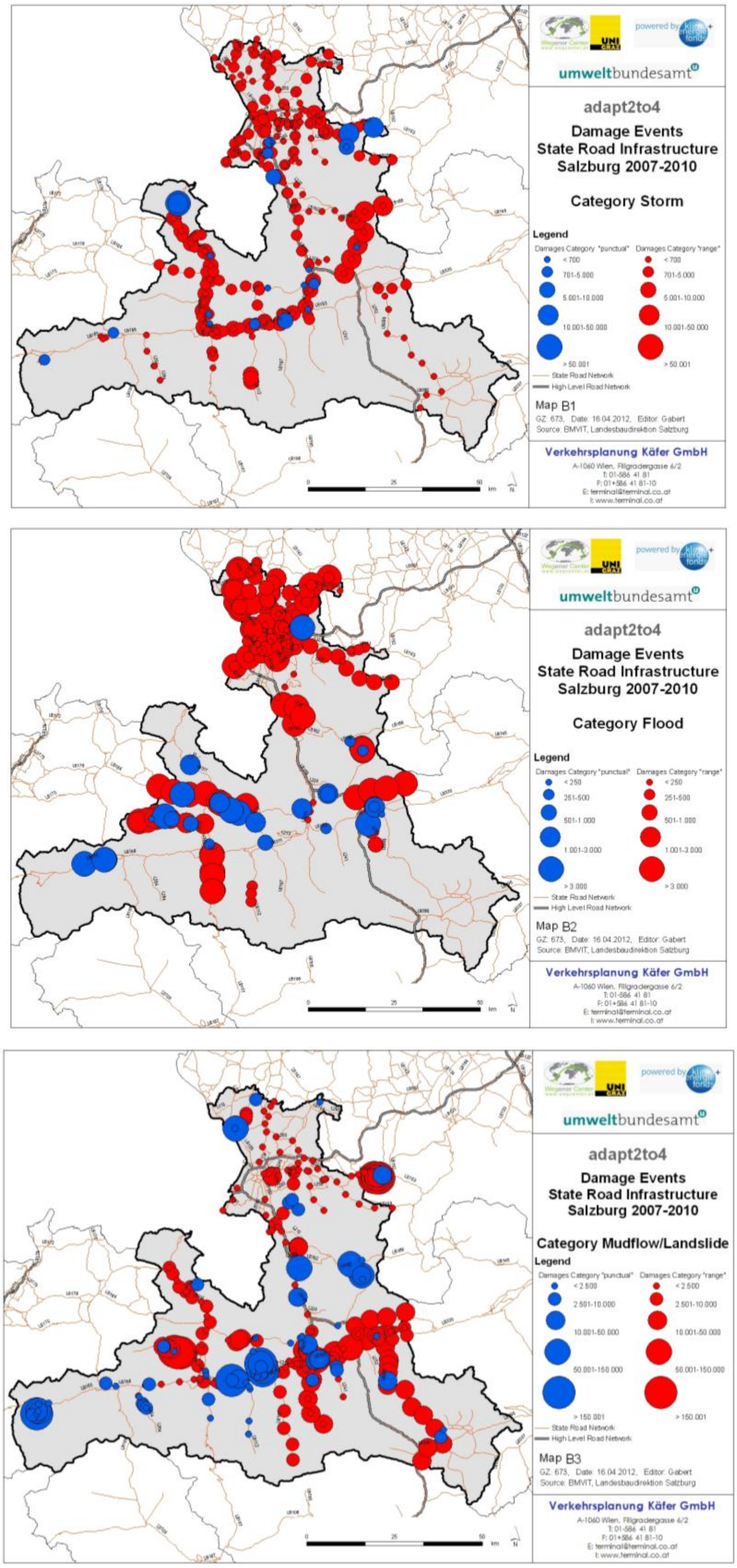

Figure 3: Storm, mudflow and landslide damage costs for secondary roads in Salzburg 2007-2010

Data source: Amt der Salzburger Landesregierung (2012)

Assessment of climate indices for transport infrastructure

Figure 4 exemplarily visualizes the seasonal climate change signals for heavy precipitation days in the Prealps in Styria. The climate change results indicate that for all subregions in Salzburg and Styria and all seasons the mean precipitation intensity as well as the mean frequency of heavy precipitation days will increase. Especially heavy precipitation events show strong positive climate change signals in all seasons but summer with increases up to ~ 45% in winter in parts of Styria (Riedelland). Regarding the uncertainty of the provided signals there is a tendency in the 5^{th} and 95^{th} percentile numbers that the entire distribution is rather positively shaped (also compare Figure 3, where in most months the majority of the entire distribution indicates a positive climate change signal) supporting the conclusion of a probable increase in mean as well as heavy precipitation events.

Similar results can be found in almost all precipitation indices, also in the number of consecutive dry days, which supports the fact that in future more intensive precipitation will occur on less wet days. Regarding temperature indicators, the number of frost days decreases with nearly no uncertainty in future due to the well known global warming.

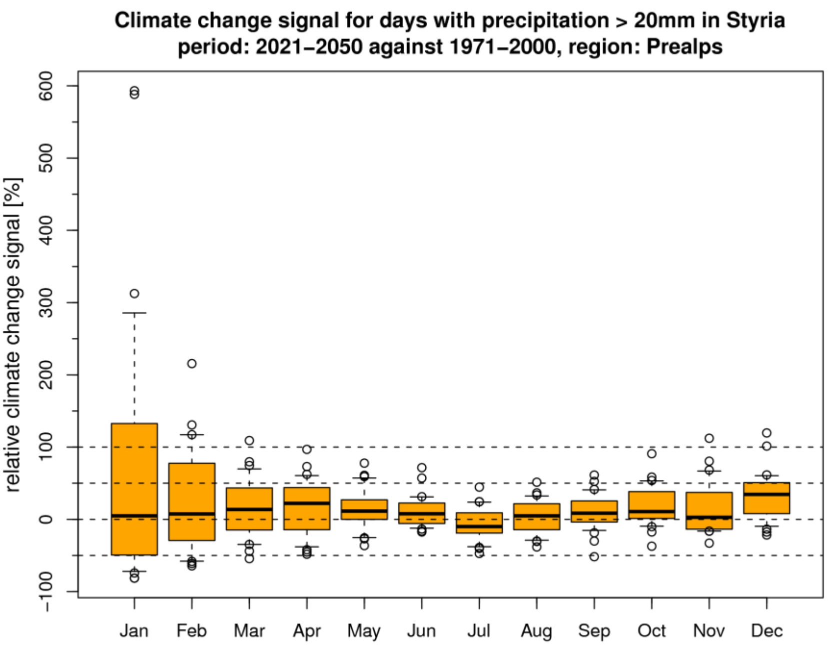

Figure 4: Monthly climate change signal and its associated uncertainty range from an ensemble of RCMs between 1971-2000 and 2021-2050 for days with more precipitation than 20 mm/d in the sub-region of Riedelland in Styria.

The horizontal bold line indicates the mean climate change signal, the yellow box limits the range between the 25th and 75th percentile, the whiskers indicate the respective 5th and 95th percentile of the climate change signals.

Estimated current and future climate change impacts for road infrastructure (WP2)

Upscaling damage costs as reported in Figure 2 (for the secondary road network) to the entire Austrian road network (primary, secondary and tertiary roads) leads to average annual cost of 18 million euros for the period 1981-2010. For details of the methodology, see section C.6 below.

Comparing these results to results gained in comparative studies for the Alpine regions in Europe (within the EU project WEATHER; Doll and Sieber, 2011), reveals that adapt2to4 cost estimates are lower: Applying the WEATHER results to Austria for the period 2000-2010, yields average annual cost of 47 million euros for road and 16 million euros for rail. The lower figures obtained in this project are due to the fact that precipitation increases in some regions while it declines in others leading to an overall smaller effect for Austria in total; second, the damage cost registry data provides costs of repair whereas undetected or unrepaired costs are not included. Finally, WEATHER takes into account not only damage to transport infrastructure but also to vehicles and to operation (time costs).

The average annual damage costs for Austria are estimated to increase from € 18.4 million in the base period (1981-2010) to € 26.8 in 2016-2045 and to € 38.3 million in 2036-2065. As costs per damage event are assumed to increase over time, there is thus a much larger difference in damage costs than there is in damage days between period 2016-2045 and 2036-2065. While the number of damage events increases by 7% in the first period, costs increase by 46% because both exposed values and maintenance costs per km of destroyed road are assumed to be higher in the future. Moreover, while the increase in damage costs in the second period is more than twice as strong as the increase in the first period, the increase in damage days is smaller.

Figure 5 compares damage costs for the total Austrian road network for different socio-economic developments (reference, diminishing and enhancing assumption on network expansion) and due to climate change (baseline without climate change and mid-range climate change). For each future period, costs for both – the baseline without climate change and with mid-range climate change – are very similar. When road expansion is doubled as compared to the reference socioeconomic assumption ("enhancing" socioeconomic assumption), direct sector impact costs increase to € 28 million in the first period and to € 42 million in the second. When instead road expansion is completely stopped ("diminishing" socioeconomic assumption), damages are smaller than in the reference specification. Thus, according to this analysis, the main damage trigger is road network expansion and hence the increase in the exposed values.

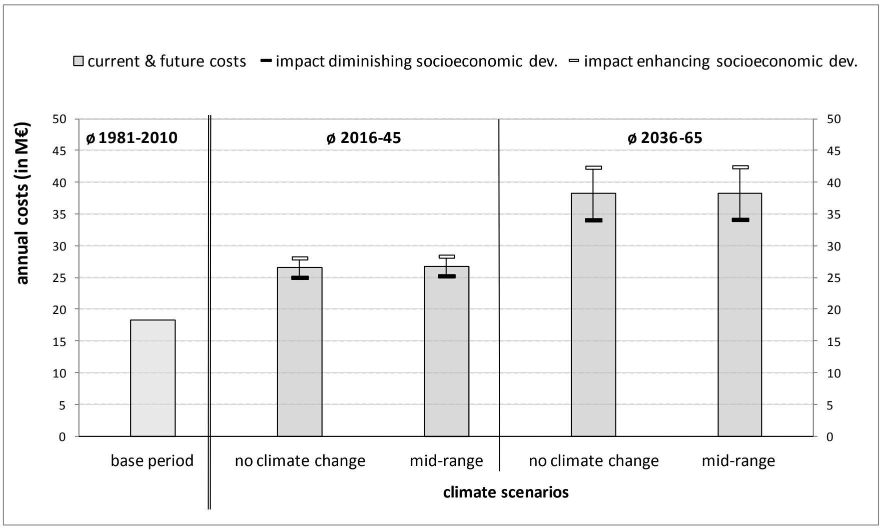

Figure 5: Average annual weather and climate triggered damage costs for the total Austrian road network arising from socioeconomic development and climate change (in M€)

Notes: "impact enhancing": Annual growth in road network as in period 1981-2010; "impact diminishing": no growth in road network (fixed at size of 2010).

Macroeconomic assessment of climate change impacts and adaptation in land transport (WP3&4)

Before presenting the macroeconomic results, we start with a sectoral breakdown of costs and benefits of climate change impacts and adaptation. In this assessment, we do not only consider damage costs to transport infrastructure, but also damages to vehicles and operation. We therefore use the results of the second approach based on the WEATHER data (Doll and Sieber, 2011).

Based on plausible assumptions about damage reduction potentials (DRP, see section C.6 for details) the costs and benefits of adaptation are taken into account according to Table 1. In the road transport sectors, the costs after adaptation are nearly the same as the direct impact costs, meaning that there is no clear benefit from adaptation on the sectoral level. Regarding the rail sectors the costs after adaptation are much lower than the direct impact costs without adaptation. Aggregating the road and rail sectors we see costs without adaptation of 65 million euros (M €) and of 53 M € with adaptation, thus a benefit from adaptation of 12 M €. Note that this breakdown depends strongly on the chosen assumptions for the damage reduction potential.

Table 1: Cost and benefit breakdown of direct impacts and adaptation for the road and rail transport sectors in Austria (without economic indirect feedback effects).

	costs [million euros]		
	road sectors	**rail sectors**	**road & rail**
Direct impact costs w/o adaptation	46.73	18.38	65.11
Impact reduction by adaptation	-27.71	-12.16	-39.87
Residual impact costs	19.01	6.22	25.24
Adaptation costs	+26.84	+1.27	+28.12
Costs after adaptation	45.86	7.50	53.35

Data source: own calculation based on Enei et al. (2011)

Regarding the macroeconomic effects of climate change impacts we evaluate the effects on GDP and welfare relative to the benchmark equilibrium of the CGE model without climate change. The red bars in Figure 6 show the changes of GDP (left) and welfare (right) from impacts occurring in the road and rail sectors separately and when combined. In the combined case annual GDP is by -142 M € (-0.05%) lower than without impacts. Welfare loss adds up to -163 M € p.a. (-0.08%) and is thus even stronger than GDP loss. The negative effects on GDP and welfare emerge by more than 95% from damaged infrastructure and the resulting higher depreciation and capital demands. Thus, we find that direct damage costs more than double due to sectoral interconnectedness.

Adding adaptation measures induces further costs but also reduce the damage costs of climate change according to the respective damage reduction potential. The corresponding blue bars in Figure 6 can be interpreted as residual macroeconomic impact after adaptation. For GDP as well as for welfare, the losses are always smaller in the adaptation case (blue bars are always shorter than red bars). In the combined adaptation case GDP and welfare losses are by 0.02% and 0.05% lower compared to the benchmark equilibrium. The green bars in Figure show the difference between the impact scenario and the adaptation scenario and therefore give the net effect of adaptation in terms of GDP and welfare. In all cases a net benefit is generated by adaptation: GDP losses are therefore reduced by 55% and welfare losses by 34%.

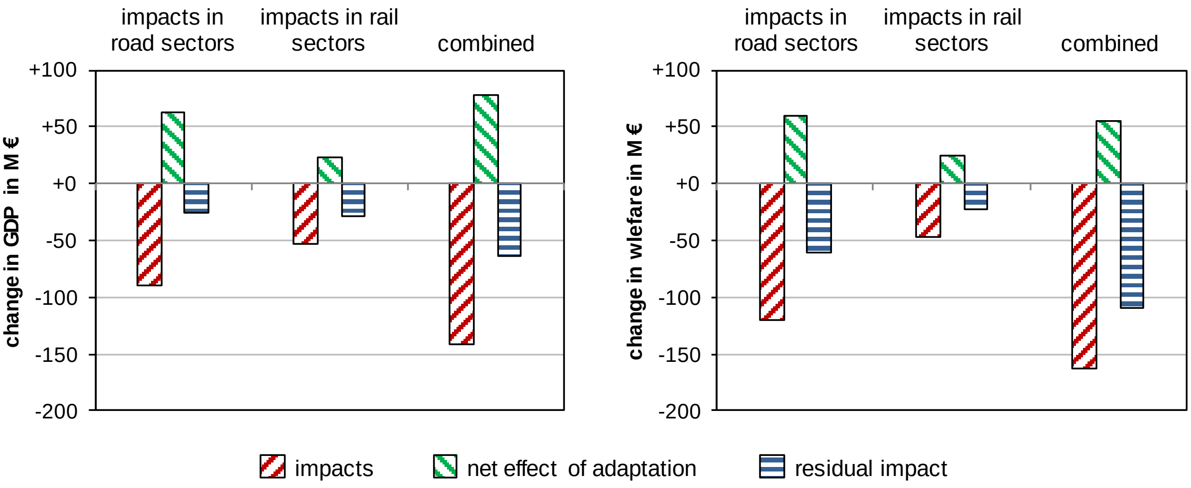

Figure 6: Changes of GDP and welfare without and with adaptation to climate change in the road and rail transport sectors in M € relative to the benchmark equilibrium (including indirect feedback effects).

Note: The following adaptation measures were included: enlargement of drainage system, intensification of vegetation management, improvement of early warning systems, more frequent visual inspection, expansion of avalanche and torrent protection.

Multi-criteria assessment of adaptation options (WP4&5)

In a first step, the stakeholders were asked on the degree of implementation of the adaptation options and to name the options that are central for them. 12 stakeholders participated in this round. 32 of 49 adaptation measures were seen as central for the adaptation in the transport sector. The adaptation option named most frequently by the stakeholders was 'adaptation of the risk zone maps' (14%), followed by 'installation of a national landslide hazard map', 'improvement of communication plans in case of hazards' and 'flood protection'.

In the second step of the MCA, 12 measures were evaluated and compared by six experts in detail. These measures were grouped into four categories to ease comparison (see Figure 7). While all four groups score equally well regarding environmental and social impacts, there are more pronounced differences regarding importance, cost effectiveness and value added (as a measure of economic activity). While general protection measures and supervision are seen as less important, high priority is seen for technical measures and incentives and information measures. Moreover, measures which tend to involve high investment costs also may lead to positive effects on value added. In contrast, low cost measures such as planning and zoning instruments are regarded as more flexible while technical measures and general protection measures are seen as less flexible and more prone to maladaptation.

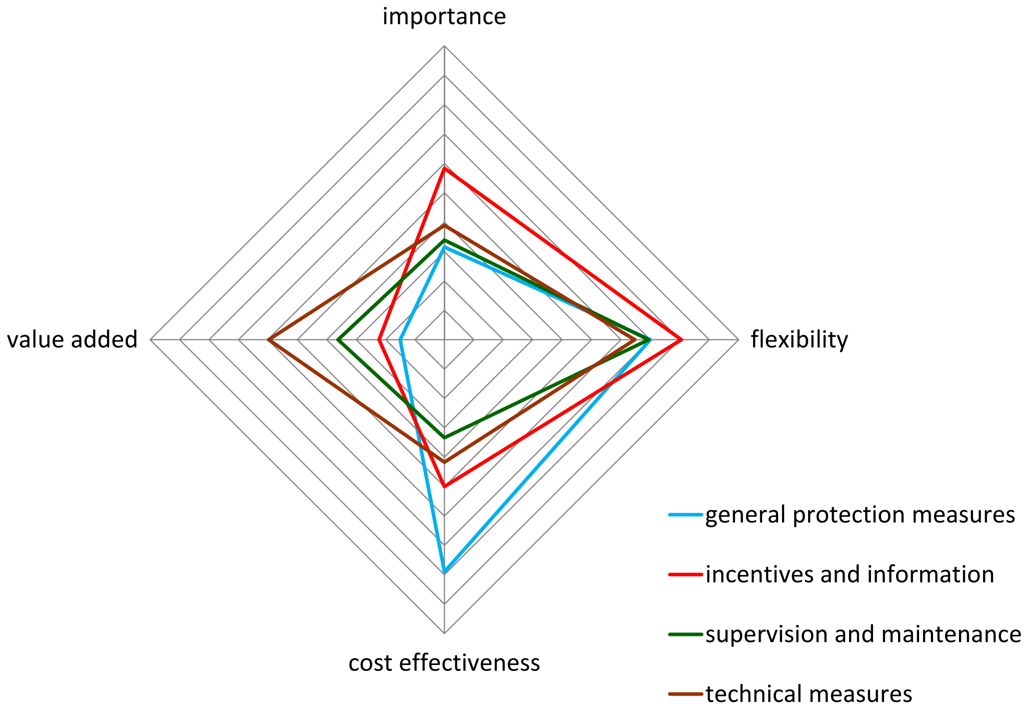

Figure 7: MCA results for four subgroups*

Note: Value range: between 0 and 1

An adaptation schedule for Austrian transport infrastructure (WP4)

The 'Adaptation Schedule' developed within adapt2to4 suggests tools to tackle climate impacts by detecting the main risks for Austria's street infrastructure (program 1), it then comes up with concrete suggestions on how to attenuate further exposition of infrastructure (program 2) and furthermore describes measures to mainstream adaptation into road maintenance and construction (program 3). The importance of mainstreaming in new construction is underlined by the fact that traffic infrastructures are long-lasting constructions and so exposed to climate change throughout forthcoming decades.

All those measures fulfill the criterion for early action and early value for money (cf. Watkiss & Hunt 2011), which is: addressing the adaptation deficit and implement no-regret measures.

The second part of the adaptation schedule focuses on (partly cost-intensive) measures addressing the current, but even more future/long-term risks. While program 4 is built on the damage inventory and analysis, which was performed in the project (cf. WP1) and thus highlights measures to stabilize slopes and protect streets from mass movements respectively, program 5 focusses on measures to retrofit and adapt bridges as they are Achilles heels for climate risks for the transport infrastructure. The final program 6 recommends two very controversial and cost-intensive measures: de-settlement and deconstruction of access roads to alpine valleys and building of redundancies for arterial connections. Both measures are cost-intensive and highly questionable for many other reasons then economically: Additional roads for example might be beneficial for attenuating indirect effects from service interruptions as they create more time-efficient detours, but in fact they expose additional street km to direct damaging impacts (cost for repair and additional maintenance) of climate change. Deconstruction and de-settlement imply ethical considerations as well as a human withdrawal from certain Alpine areas, with the impacts of the latter still subject to further research and potentially very much different from valley to valley. Cf. a graphical overview on the adaptation schedule (Figure 8).

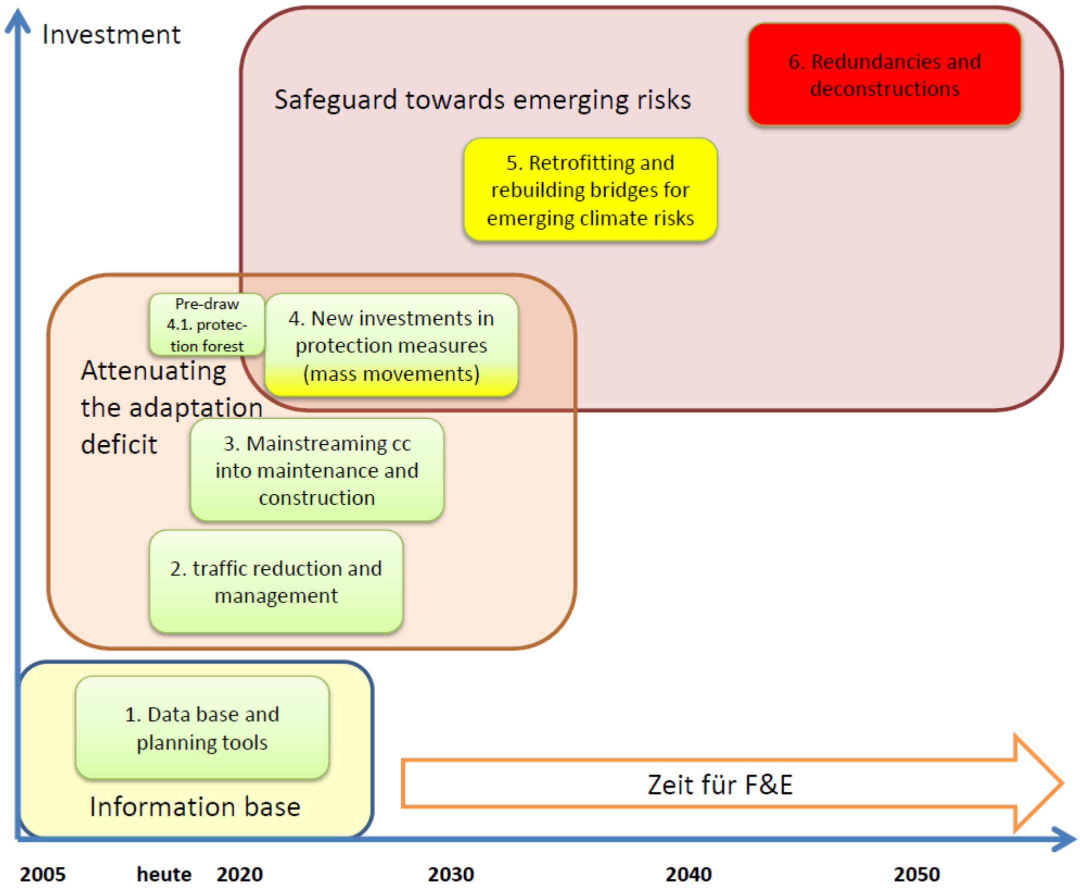

Figure 8: Adaptation phasing for the Austrian road network infrastructure depicting the sequences and parallel timings of the schedules' six programs.

5 Conclusions and recommendations / Schlussfolgerungen und Empfehlungen

- In future, weather and climate related damages to road infrastructure in Austria are primarily precipitation triggered (leading to flooding, landslides and mudflows)
- Compared to temperature trends, results for precipitation involve larger uncertainties both across regions as well as across climate scenarios. According to model simulations, there is a tendency to higher frequencies of high precipitation events (less uncertainty for small-scaled convective events while more uncertain for large-scale advective precipitation over several days).The majority of current impact costs to road and rail transport is due to infrastructure damages, not damages to vehicles and users
  Regarding weather related damages to road infrastructure in Austria, future damages increase both due to climate change as well as socioeconomic change (expansion of the road network), which is why a crucial planning of new road sections is crucial and the project developed suggestions, which factors to carefully check.
- The macroeconomic costs of climate change impacts to road and rail infrastructure are twice as high as the sectoral costs because of the strong cross-sectoral linkages
- Adaptation measures can reduce the damage potential, but also lead to costs. As a consequence, climate change damage effects on GDP can be more than halved by implementing adaptation while the welfare effect is reduced only by a third.
- In addition to economic effects, also non-economic factors like flexibility or importance affect decision making on climate change adaptation. Often, decisions on adaptation measures involve trade-offs among competing goals.
- An adaptation roadmap for transport infrastructure was devised consisting of three phases: first focusing on detecting main risks for Austria's road network, then to attenuate further exposure of infrastructure, and finally reduce the existing adaptation deficit while mainstreaming adaptation into road maintenance and construction. Altogether 25 measures were proposed and structured in six programs.

5. Outlook

- Publications out of the project will be submitted to journals
- Within the ACRP-project PACINAS on public expenditures for adaptation in Austria, one case study will also deal with transport infrastructure
- A guidance document will be provided regarding collection of damage cost data at provincial level (to increase consistency of data)
- A further exchange with transport infrastructure operators is necessary to exploit the potential for applying the proposed adaptation measures. This process should be coupled with the implementation process of the Austrian national adaptation strategy. Yet, the risk perception is very different among transport infrastructure operators. Due to different vulnerability settings, action should focus on the secondary road network in the first place.

C) Project details / Projektdetails

6 Methodology / Methodik

Regional climate scenarios: Derivation of climate indices for transport infrastructure

Within WP2 meteorological indicators, which trigger the occurrence of railway and road infrastructure damaging events in the study regions Salzburg and Styria were analyzed. For this purpose, a literature review as well as a damage event correlation analysis on damage cost and meteorological data was performed. Concerning the former, related projects as CLAVIER (www.clavier-eu.org), STARDEX http://www.cru.uea.ac.uk/projects/stardex/), ARNICA (http://www.lgp.cnrs-bellevue.fr/arnica/summary.html) or EWENT (http://ewent.vtt.fi/) as well as reviews on meteorological thresholds definitions as given in http://rainfallthresholds.irpi.cnr.it/ were screened and their outcomes summarized in an index library. Furthermore, expert knowledge was consulted complementarily. Concerning the latter, meteorological records for minimum, maximum and mean temperature, precipitation amount, snow pressure and wind speed from the Austrian Meteorological Service (ZAMG) and the Hydrological Service (HZB) corresponding to railway and road damaging events were analyzed between 2007 and 2011 for their triggering potential in Salzburg and Styria. For this purpose the damaging events were classified into small and medium scale flood, mud flood/landslide, snow pressure/avalanche and then qualitatively clustered into damaging sub-regions.

In order to provide tailored regional climate scenarios for milestone M2.1, 24 regional climate models (RCMs, Giorgi and Meanrs, 1991) from the projects ENSEMBLES (van der Linden and Mitchell, 2009) and reclip:century (Loibl et al., 2011) were used in this study. These RCMs were all based on the A1B emission scenario between 2001 and 2050 (Nakicenovic et al., 2000) and on observed greenhouse gas emissions from 1961 to 2000. Since even high resolution regional climate models are still too coarse for direct application in local climate change impact studies (Mearns et al., 2003), and since they are known to feature considerable errors, particularly regarding precipitation and their extremes (e.g., Suklitsch et al., 2010; Jacob et al. 2007), empirical-statistical error correction and downscaling methods (DECMs; Themeßl et al., 2011; Déqué, 2007) were implemented on daily basis in adapt2to4. The here proposed error correction method was furthermore already proofed to be able to generate new extremes in future (compare Themeßl et al., 2012), comparably to those simulated by the RCM. This fact also increases QM's credibility for the application of future scenarios where e.g. in the case of air temperature new extremes are likely to occur due to global warming.

For the purpose of error correction, especially in the context of correcting extreme events from RCMs long term observational data were needed. Although the Austrian Meteorological Service (ZAMG) provides daily records from a fairly dense observational stations network in Austria (~ 300 measuring stations at the moment), on daily scale many stations are incomplete in their time line or exhibit significant inhomogenities due to e.g. station replacements. The quality of the data furthermore is different depending on the considered parameter. I.e daily wind data cannot be taken for further into account for skillful analysis for many observational stations within Austria (Krenn et al., 2011). Thus, it was decided jointly by the project consortium to use a 1 km gridded observational network for temperature and precipitation in Austria (Beck et al., 2009) for the correction purpose. The decision, however, implicated the advantages of high spatial resolution for mean temperature and precipitation amount as well as their derived extreme indices and accepted that minimum, maximum temperature and wind speed as well as their related indices could not be considered for further future scenario investigations. However, this limitation is only a minor disadvantage for the project, since precipitation events are responsible for the majority of the costly damaging events which was derived from preliminary correlation analysis between observational station records and insurance data for different sectoral damages provided by the Munich Reinsurance company for entire Austria. In return, daily snow data (not planned in the original proposal) for all 24 regional climate models have been calculated and were used for the assessment of suitable indices for triggering future damaging events.

Table 2 lists those indicators which were analyzed by adatapt2to4 due to their triggering potential for railway and road damages in respect to climate change up to 2050.

Table 2: List of indicators and their definition used for adapt2to4.

Indicator Abbreviation	Indicator description	Unit	*Unit of abs. difference and of the historical records*
days237	number of days with tmean > 23.7°C on at least 3 consecutive days	%	days
tzero	number of days with -1.2°C < tmean < +1.4°C	%	days
frost	number of days at which tmean is < -10°C	%	days
tmean	daily mean temperature	°C	°C
cdd	average number of consecutive days with precipitation = 0mm	%	days
prec20	number of days with at least 20mm precipitation	%	days
prec50	number of days with at least 50mm precipitation	%	days
2daysrr25	number of days with at least 25mm precipitation on two consecutive days	%	days
sdii	mean precipitation on all days with precipitation > 1mm	%	mm/Tag
pmean	daily mean precipitation	%	mm/Tag
snowfall10	number of days with snowfall > 10cm	%	days
snow	mean depth of snow	%	m

Seasonal as well as monthly absolute and relative climate change signals for the considered indicators as well as their uncertainty ranges, represented by the 5th and 95th percentile of all 24 RCMs, were calculated.

Climate change impact cost assessment for transport infrastructure

To identify the scope to cope with or adapt to near-term climate change, the analysis of highly disaggregated data on observed damages and responses and the involvement of stakeholders (regional, national; private, public) were crucial elements of analysis. The impact and adaptation assessment combines GIS-based data analysis to derive estimates of occurred and future (scenario based) climate change impacts with interviews and focus groups to delineate immediate adaptation options and their estimated costs.

At the start of the project, there was no consistent database available for weather or climate induced damages on road infrastructure at the national level. Therefore, available data of physical impacts on road infrastructure (damage data) was gathered. This data is recorded and administrated at the provincial level, so the responsible provincial bureaus were contacted. For four provinces of Austria (Styria, Salzburg, Tirol and Vorarlberg) road damage data (number, date, location and trigger of events and arising direct damages/costs) could be collected and consolidated with respect to the type of event.

The collected data had to be processed in order to build a consistent GIS data base. In a first step, inapplicable data (insufficient information, not assignable, not concerning road infrastructure etc.) has been eliminated from the data basis. Subsequent, a unique ID number has been assigned to each event. Generally, there are two types regarding geo-referencing: "punctual" and "range". Punctual means that a damage event occurred at a certain location. These punctual events are geo-referenced as a single point in the GIS database and identified by 3-digit ID. "Range" indicates a damage event relating to a certain section of the street network. Such damage events are geo-referenced using an initial and an end point. In case of longer distances a point each 5 kilometer (considering the digital elevation model where appropriate) was set. "Range" damages are identified by a 4-digit ID. As basis for geo-referencing a road network graph representing the high level street network provided by the Federal Ministry of Transport BMVIT was used. This graph has been manually completed for relevant minor roads.

Eight damage categories were thus defined: avalanche, flood, hail, mudflow & landslide, rockfall, snow pressure, storm and mix (events which are not clearly attributable). To integrate the available damage data with climate and GIS data, certain minimum requirements for every set of damage data must be fulfilled (availability of information on date of event (e.g. 01.02.2005), type of event (e.g. landslide), spot (waypoint or section of a road) and direct damage costs in €). The available data were filtered with respect to these criteria. Moreover, damage prevention measures (= pro-active adaptation measures) were separated from direct damage costs (costs to reestablish the pre-event state of infrastructure assets).

The evaluation of current damages comprised five steps: the estimation of an impact function based on past damage cost data. This was done for the damage data described above for the secondary road network in the province of Styria, as data quality of the other provinces was insufficient for such an estimation procedure (too few observations). The impact function is a quadratic function which relates daily precipitation to the probability for a damage event of € 30,000 or higher (per day and NUTS-3 region). The second step required the application of this impact function to precipitation data for all NUTS-3 regions in Austria, both for past precipitation data (1980-2010) and for the mid-range climate scenario (periods 2016-2045 and 2036-2065). In a third step, damage estimates were scaled up from the secondary to the total road network. In a final step, physical impacts (events with damage potential of € 30,000 or higher per day and NUTS-3 region) were translated into costs and aggregated to province, then scaled up to national level. For more details on methodology and results, see the supplementary material to Bednar-Friedl et al. (2015).

<u>Collection of adaptation options for transport sector</u>

Based on a comprehensive literature review, climate change impacts on the transport sector have been assessed and summarized. The impacts are differentiated by transport mode (rail and road), by climate change effect (temperature extremes, heavy rainfall etc.) and by type of impact (physical infrastructure or the operating performance of the system). Parallel to the analysis of damage costs, adaptation options for road and rail infrastructure were reviewed.

Within the process of data collection, interviews with stakeholders for road and rail infrastructure were conducted both on the quality and type of data and on experiences and expert estimates on weather-related damages in their particular region and on the relevance of different adaptation options identified in the literature. Table 3 gives an overview of green, soft and grey adaptation measures relevant for transport infrastructure. Yet, costs for adaptation options are hardly available, except for some types like avalanche protection. In the remainder of the project, the focus was put on policy-driven adaptation options only, as information on market-driven adaptation is even harder to obtain because even insurance instruments are currently only under discussion but not available yet.

Table 3: Green, soft and grey adaptation options in the transport infrastructure sector

	Green adaptation	Soft adaptation	Grey adaptation
Description of adaptation options	'Green' adaptation is commonly low-cost and low-regret adaptation since it supports, maintains or extends existing ecosystem services. A further plus are frequent synergies with mitigation efforts. In most cases, 'green' adaptation implies foresight and thus proactive action. In fact, most of the measures are meant to be implemented before excessive damages have occurred. If 'green' measures are implemented as reactive measures for the transport sector, their most obvious disadvantage however might be the long handling time before positive/protective effects happen.	The advantage of 'green' and 'soft' adaptation is that it is non-invasive, low-cost and usually without implications for ecosystems (occasionally ecosystems profit from 'green' or 'soft' measures).	'Grey' adaptation to climate change in the traffic sector is already most common and deals normally with proactive as well as reactive investments on flood and avalanche protection and slope stability. Investments for grey adaptation are usually high, and the impacts on ecosystems can be massive.
Examples	• afforestration or reforestration of protection forests (e.g. to retain mass movements and avalanches) • low-tillage for better soil erosion control • permeable pavements to strengthen urban groundwater recharge • reverse sealed areas upstream to increase infiltration • additional wetlands upstream (and maintainance of existing ones)	• flood zoning • establishment of (upstream) water retention areas (e.g. renaturation of wetlands)early warning systems for floods and mass movements • alternatives to allow for modal switches for all arterial connections • infrastructure for inter- and multi-modal traffic to allow for fast modal shifts for loading units	• galleries • tunnels • flooding damns • nets against rock fall • protection fences and walls • aisles to protect from windfalls

A report on 'adapted futures' was set up by the project team, which contains a rough assessment on the factors that determine vulnerability of transport infrastructure. The picture is complex (see Table 1 in the Appendix) and can be clustered in following criteria for the determination of vulnerability patterns for direct impacts: (i) the amount of vulnerable roads especially in terms of exposure towards mass movements, flooding and (less important) storm events; (ii) Existing (adaptation) protection measures like management of protection forests, slope stability and flood protection programs and retrofitting of roads after damaging events; and (iii) GDP growth determining a good part of the discounting we may apply to damages and losses of public infrastructure stocks.

Given the fact that transport infrastructure is a core service for society and economy, the indirect damages and costs caused by service interruptions may even exceed the direct costs. The control of indirect costs is determined by (i) the possibility to bypass interrupted parts of the network via bypass roads or mode switches (e.g. from road to rail or vice versa); (ii) how much interregional exchange of commodities or upstream products is necessary for production and how far away the production is from the consumer market i.e. how much the industrial chain is relying on transport services; and (iii) the number of commuters who rely on transport services and loose time, if service is interrupted (and while for the direct infrastructural damages, GDP growth leads to future discounting on the damages of infrastructures, GDP growth leads to higher values for 'loss-of-time' and thus to higher indirect costs for a growing economy). These results complete Milestone M 2.3 (Policy visions for adapted futures).

Economy-wide assessment of adaptation benefits and costs: CGE modelling

While the relevant scale for adaptation is, unlike for mitigation, regional (sub-national), there is still need to consolidate adaptation needs at the aggregate level. This is why CGE models have been used to assess adaptation needs and costs within the wider economy (e.g. de Bruin et al., 2009; Bosello et al., 2009; Richard and Nicholls, 2009). De Bruin et al. (2009) work with AD-DICE and AD-RICE outputs, which are modified version of the Dynamic Integrated model for Climate and the Economy (DICE; Nordhaus, 1994; Nordhaus, 2007) and its regional counterpart (RICE; Nordhaus and Yang, 1996; Nordhaus and Boyer, 2000) by incorporating reactive adaptation as a policy/decision variable. There is no sectoral assessment of adaptation, i.e. impact and adaptation functions are parameterised to a single climate measure (temperature). Bosello et al. (2009) work with AD-WITCH, which is an Integrated Assessment Model (IAM) in CGE format with different world regions that has been developed for the joint analysis of adaptation and mitigation. The model uses a damage function which separates adaptation costs and residual damages, and it distinguishes between market-driven and policy-driven adaptation (proactive, reactive, and knowledge adaptation). A CGE is used also within the PESETA project (Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis; Richard and Nicholls, 2009) to assess the wider economic effects of coastal adaptation on the European economy. The assessment of macro effects of (publicly funded) adaptation builds on the outputs of a bottom-up impact and adaptation cost assessment study for coastal zones (using the DIVA model; Nicholls, 2007).

In the present project, we refined a national-scale CGE model (Bachner et al. 2015) to compare the direct and indirect costs of climate change impact and adaptation (private, public) for transport infrastructure. As a first step, we agreed on sectoral coverage in the model, created the required Input Output table based on industries/activities (not commodities) from the respective make and use tables (STAT 2012) and aggregated the Austrian Input Output table for 2008 accordingly. Based on the ÖNACE classification, we distinguish five transport and mobility sectors (t&m1-5); with the central sector investigated thereof is t&m2 (land transport). Construction activities (sector c&b) are important for considering restoration costs for damaged infrastructure. For details on the model, see Bachner (2015).

To set up and integrate impact functions, the data set generated in WP2 covers only damages to the secondary road network, but not effects on transport services and rail. We therefore followed a different approach here by using results from a European study (Doll and Sieber, 2010) and downscaled them to Austria. See Bachner (2015) for details.

Regarding adaptation we were able to integrate the costs and benefits of the following technical and planned adaptation measures:

- Enlargement of drainage system capacities alongside roads and rails by +20% (based on Altvater et al., 2012)
- Intensification of vegetation management next to roads and rails by 20% (ACA, 2013).
- Improvement of early warning systems by installation of additional hydrological stations
- Doubling in the frequency of visual road inspection (ACA, 2013)
- Expansion of the Austrian torrent and avalanche protection agency by +50%; the latter being a more general measure which protects road and rail transport systems (besides other non-transport infrastructure)

Comparison of adaptation options and development of evaluation framework for policy support

Building on a multi criteria decision framework within the StartClim project SALDO (Bednar-Friedl et al. 2011), we conducted a multi criteria analysis (MCA) on adaptation options for Austrian road and rail transport. MCA is a popular framework for decision support in adaptation planning (e.g. De Bruin et al., 2009).

Within a two-step survey stakeholders from the public sector (on different regional levels like ministries, provincial governments, disaster management etc.) had to evaluate climate change adaptation options. They first decided on the adaptation options that are central in their view and the current state of implementation of these options. Second, the subset of most relevant adaptation measures was evaluated by the criteria urgency, importance, environment and social consequences, flexibility, economic performance and macroeconomic effects. For the assessment, the measures were grouped by transport planning aspects into the categories ‚general protection measures' (e.g. flood protection, spatial planning), ‚incentives and information' (e.g. national damage data base, risk mapping), ‚supervision and maintenance' (e.g. vegetation management) and ‚technical measures' (e.g. heat-resistant pavement, drainage systems). By using the MCA method an evaluation could be conducted for the individual measures as well as for groups of measures. For details, see Wolkinger et al. (2014).

Decision support for public and private entities (Task 4.3, EEA)

Adapt2to4's WP4 deals with policy support i.e. how the results of the projects can be fed into concrete next steps on the implementation of adaptation measures. Report **R4.1** has emerged into an 'adaptation framework' that was also presented and discussed at the final workshop on Sep 29 2014 and is presented in brief in the following (cf. König et al. 2014 for details). In a review report, Eisenack et al. (2011) analyzed 60 journal articles and reports on climate change adaptation in transport. Besides the fact that research on transport sector adaptation is still in its infancy, many measures focus on the 'rolling equipment' and not on transport infrastructure (cf. Doll et al. 2011). This gap is to be filled in order to compensate for the existing damage structure and thus the visible adaptation deficit as well as adapting to a changing climate and particularly extreme weather regime – especially in countries with a complex terrain such as Austria.

7 Work and time schedule / Arbeits- und Zeitplan

WP1: Cross-Sectoral Survey of Climate Change Impacts and Adaptation Costs **M1.1**:Complete picture about relevant projects and literature (month 6) **M1.2:** Cross-sectoral impact and adaptation cost assessment completed (month 9) **R1.1:** Commented list of pertinent projects (month 3) **R1.2:** Commented matrix of key methods and results (month 6) **R1.3:** Matrix of climate-sensitive economic sectors in Austria with sector-wise impact/potential damage and adaptation cost assessments (month 9)
WP2: Identification of Impacts, Adaptation Measures and Costs for Transport and Building Infrastructure in Austria **M2.1:** Availability and usability of climate scenarios for impact analysis (month 12) **M2.2:** Impact assessment for transport infrastructure completed (month 18) **M2.3:** Policy visions on 'adapted futures' available (month 18) **R2.1:** List of market-driven adaptation options/costs (month 17) **R2.2:** List of policy-driven adaptation options/costs (month 17) **R2.3:** Report on politically feasible adaptation pathways ('adapted futures') (month 18)
WP3: National Adaptation Cost Assessment for Infrastructure **M3.1:** Integration of adaptation technologies and costs in CGE model and model refinement (integration of bottom-up and top-down) (month 36) **M3.2:** A set of different scenarios for the adaptation process in infrastructure available (month 30) **M3.3:** Availability of model for economic assessment of micro-founded and technology based sector-specific adaptation costs and their sectoral feedback effects, macro and welfare implications in the Austrian economy (month 36) **R3.1:** Technical Report on national adaptation cost assessment for transport infrastructure in Austria (month 40)
WP4: Evaluation of Adaptation Options under Uncertainty **M4.1:** Evaluation framework including national cost assessment and further criteria for a prioritisation of measures/policies in Austria available (month 36) **M4.2:** Macroeconomic assessment of adaptation options completed (month 40) **R4.1:** Benchmark report on preferred adaptation measures serving as policy decision support (for practical part of NAS) (month 40) **R4.2:** Benchmark report on preferred policy options serving as policy decision support (for strategic part of NAS) (month 40)
WP5: Project Management and Coordination **M5.1:** Kick-off workshop accomplished (month 1) **M5.2:** Stakeholder & expert workshop to discuss preliminary results accomplished (month 25) **M5.3**: Presentation of final results (month 42) **M5.4:** Discussion of approaches and results with international partners (month 3, 12, 18, 22, 28, 36, 42) **R5.1:** Interim reports to funding institutions (month 12, 24) **R5.2:** Publication of suitable preliminary results (month 42) **R5.3:** Final report (including scientific papers) (month 42)

8 Publications and dissemination activities / Publikationen und Disseminierungsaktivitäten

Publications (Journals, books, reports)

Bachner, G. (2015), Land Transport Systems under Climate Change: A Macroeconomic Assessment of Adaptation Measures for the Case of Austria, Graz Economic Papers 2015-01, University of Graz, Department of Economics.

Bednar-Friedl, B., Wolkinger, B., König, M., Offenthaler, I., Bachner, G., Leitner, M., Formayer, H. (2015), Chapter 9 Transport and Mobility, in: Steininger, K., König, M., Bednar-Friedl, B., Kranzl, L., Loibl, W., Prettenthaler, F. (eds.) (2015), Economic Evaluation of Climate Change Impacts. Development of a Cross-Sectoral Framework and Results for Austria. Springer, Berlin (R 3.1)

Wolkinger, B., Laurien, F., Bednar-Friedl, B. (2014), Anpassungsoptionen für Österreichs Straßen- und Schienenverkehr: Ergebnisse einer Multi-Kriterien-Analyse, Wissenschaftlicher Bericht 64-2014, Wegener Center für Klima und Globalen Wandel, Universität Graz, ISBN 978-3-9503918-1-7.

König, M., Wolkinger, B., Bednar-Friedl, B., Felderer, A. (2014), Ein Anpassungsfahrplan für die Österreichische Straßenverkehrsinfrastruktur, REPORT REP-0495, Umweltbundesamt, Wien.

König, M., Doll, C., Offenthaler, I., Felderer, A. (foreseen for 2015): Foresight planning of road alignments and protection of existing road network with respect to weather-triggered damages and service interruptions. Draft working paper.

List of presentations

Hasse, C., König, M. (2014), Shaping national adaptation strategies with economic tools: Possibilities and limitations based on experiences in Germany and Austria Third International Climate Change Adaptation Conference – Adaptation Futures 2014 , Fortolezza, Brazil, May 12-16 2014. http://adaptationfutures2014.ccst.inpe.br/wp-content/uploads/2014/05/PROGRAMA%C3%87%C3%83O.pdf.

Bednar-Friedl, B., Climate Change impacts to the Austrian road network by 2030 and 2050: A macroeconomic assessment, Environmental and Resource Economics Seminar, University of Manchester, March 19, 2014.

Hasse, C., König, M., Bednar-Friedl, B. Shaping national adaptation with economic tools and assessments: For which fields of adaptation action could it work and at which scale? CIRCLE 2 SHARE Workshop on Cross-sectoral Vulnerability, Risk and Economic Assessments of Climate Change Impacts – What is needed for adaptation strategies?, Berlin, Germany, February 11, 2014.

Truhetz, H. (2014), Klimatischer Veränderungen in der Steiermark – Was erwartet uns in den nächsten Jahren?, Diskussionsveranstaltung Bio Ernte Steiermark, Judenburg, Austria, February, 2014.

Truhetz, H. (2013), Womit die Klimaforschung in die Zukunft schaut, Informationsveranstaltung Achtung Forschung, Universität Graz, Austria, November 16, 2013.

Martin König, Olivia Koland, Brigitte Wolkinger, Discussion of WP2 methodology at Workshop on "Economic Aspects of Climate Change", Umweltbundesamt/Berlin, Jan 19, 2012. (with Clemens Hasse, Umweltbundesamt D),

Bednar-Friedl B., Bürgel J., Felderer A., Fürst B., Gobiet A., Heinrich G., Hölzl M., Käfer A., König M., Koland O., Steininger K., Truhetz H., Wolkinger B. adapt2to4 –Kosten der Anpassung: eine (nicht nur) ökonomische Abschätzung zur Maßnahmenpriorisierung und politischen Weichenstellung in einer +2°C/+4°C-Welt, ACRP-Forum, Klimafolgenforschung in Österreich: Aktuelle Projekte im Überblick", Museumsquartier, Vienna, May 17-18, 2011.

Bednar-Friedl B., Bürgel J., Felderer A., Fürst B., Gobiet A., Heinrich G., Hölzl M., Käfer A., König M., Koland O., Steininger K., Truhetz H., Wolkinger B. adapt2to4 –Kosten der Anpassung: eine (nicht nur) ökonomische Abschätzung zur Maßnahmenpriorisierung und politischen

Weichenstellung in einer +2°C/+4°C-Welt, EGC Workshop, University of Graz, Oct 10, 2011.

List of external workshops

Within the project, two workshops were organized:

- Themen-Tag Klimawandel: Wie verwundbar sind die steirischen Regionen? Fokus: Klimawandelkosten am Beispiel Verkehrsinfrastruktur, 10 Apr 2013, Land Steiermark, Graz.
- Anpassung des Verkehrssystems an den Klimawandel. Ergebnis-Workshop im Rahmen des ACRP-Projekts adapt2to4, 29. September 2014, Umweltbundesamt, Wien.

Media coverage:

- Wie lassen sich die Straßen für den Klimawandel wappnen? Österreichische Forscher haben neue Maßnahmen erarbeitet. Die Presse, 12.12.2014, http://diepresse.com/home/science/forschungsfrage/4618245/Wie-lassen-sich-die-Strassen-fur-den-Klimawandel-wappnen
- Project overview to KLIEN brochure "ACRP in essence" (forthcoming January 2015)
- Web publication on expert workshop: www.klimwandelanpassung.at/kwa_adapt2to4 and http://www.umweltbundesamt.at/aktuell/publikationen/publikationssuche/publikationsdetail/?pub_id=2087

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Bachner, G. (2015), Land Transport Systems under Climate Change: A Macroeconomic Assessment of Adaptation Measures for the Case of Austria, Graz Economic Papers 16-2015, University of Graz, Department of Economics.

Bednar-Friedl, B., Koland, O., König, M., Raab, J. (2011): Die gesellschaftlichen Kosten von Anpassung: Ansätze für eine Bewertung von Anpassungsoptionen (SALDO). Endbericht von StartClim2010.C in StartClim2010: Anpassung an den Klimawandel: Weitere Beiträge zur Erstellung einer Anpassungsstrategie für Österreich, Auftraggeber: BMLFUW, BMWF, BMWFJ, ÖBF

Bednar-Friedl, B., Wolkinger, B., König, M., Bachner, G., Formayer, H., Offenthaler, I., Leitner, M. (2015). Transport. In: Steininger, K., König, M., Bednar-Friedl, B., Kranzl, L., Prettenthaler, F. (ed.), Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria. Springer, Berlin.

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