Mid Term Review Theme 5 Knowledge for Climate

# INCAH

## Infrastructure Networks Climate Adaptation and Hotspots

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# Table of Contents

# 1 INTRODUCTION

There are still substantial gaps in knowledge on how to make the Netherlands climate proof. Knowledge for Climate (KfC) is a Dutch research program on Adaptation to Climate Change, addressing themes like decision making, climate projections, the built environment and the water system. It should be of benefit for the so-called hotspots, key locations with major climate adaptation challenges, like the Waddenzee, and the ports Rotterdam and Schiphol.

An international review (Koetse and Rietveld, 2009) revealed that in particular in the fields of transport networks and other infrastructures, research on adaptation to climate change has been lagging behind. The KfC program “Infrastructure Networks Climate Adaptation and Hotspots” (INCAH) was developed by a consortium of internationally renowned institutes to produce the required knowledge to assist decision makers in this specific area of infrastructure and networks.

The research focus of the INCAH program is twofold: firstly, on the expected impacts of climate change on the operation of infrastructures; secondly, on integrative approaches to address timely adaptation and transformation of infrastructures for climate adaptation hotspots of the Netherlands. The focal hotspot for testing and application of the INCAH knowledge is the Rotterdam Rijnmond-region - although the developed knowledge will be applicable more broadly.

This midterm report is a preview of the results, halfway the project. It introduces the project background and how the research approach was implemented during the first years of work. We present the first results of the project and look forward towards the expected conclusions and their use. As requested by the KfC board, a self-assessment is provided along several dimensions: the working and external connectedness of the program; its scientific excellence and its expected social impact. The report is built up along these lines. Chapter 2 provides an introduction to the INCAH program and the consortium. Chapter 3 describes and evaluates the research approach. Chapter 4-6 develop the self-assessment along the lines of connectedness, scientific quality and societal impact. We summarize and deliver our midterm conclusions in Chapter 7.

# 2 INCAH VISION AND MISSION

## 2.1 Vision on the research theme

Infrastructures are the backbones of our society. Citizens, companies and government have come to rely on and expect uninterrupted availability of electricity, water, ICT and transport networks. Road, railroad and shipping infrastructure represent the vital link between farmers, the food industry and consumers; water, road, rail and air transport enable affordable, reliable and timely logistics for industrial operators, traders, retailers and commuters. Water infrastructure is crucial to maintain safety and public health, sustain intensive horticulture, industrial manufacture and power generation (e.g. drinking water, waste water and water for cooling).

Since infrastructures are vital to society, climate change calls for timely adaptation and transformation of our on-surface and sub-surface infrastructures and networks. Many infrastructure providers and administrators are struggling, however: how to deal with the effects, what new investments and maintenance strategies should they decide on, how to keep the network accessible, and which prevention measures to take? Especially when extreme weather events occur more frequently, this affects the functionality of the drinking water and mobility networks, railroad services or energy provision systems. In the Netherlands we must prepare for climate change and anticipate on a higher North sea level, more hot and dry summers, a low Rhine and Meuse, water loads in summer but autumn surges, and more frequent and intense (thunder)storms, snow and rainfall. But where to begin the preparation, when to anticipate to climate change and how to do this? What knowledge, facts or predictions should we use? And how to deal with uncertainty? In short, the management of infrastructure is a complex issue because of the interconnection between infrastructure networks, their broader connections with society and the uncertainties of the effects.

The last decade has seen a shift in the research community from an exclusive focus on the role of infrastructures in climate change mitigation towards a recognition of potential vulnerabilities and the need for adaptation. This shift is reflected in numerous studies focusing on infrastructures such as water, electricity and transport (e.g. Decicco and Mark, 1998, Hor et al, 2005, Krishen 2008, Koetse and Rietveld 2009, Hunt 2011, van Vliet 2012). Studies such as these represent an important step towards understanding the potential infrastructure impacts of climate change and developing suitable strategies for dealing with them. At the same time, these few research projects that have studied the effects of climate change to infrastructure and networks also conclude that there are still huge uncertainties in valuing the damages caused by weather extremes to transportation systems, which are determined by system delimitations, consideration of extremes as well as by data uncertainties. (TRB, 2012). These huge uncertainties do not make decision making more easy, as already noted in early reports on climate change effects on transportation (TRB, 2008).

The current body of research is limited in two ways. Firstly, with only a few notable exceptions (e.g. Krishen 2008, Hunt 2011), the existing literature addresses impacts and adaptation strategies relevant for different types of infrastructures separately. This approach disregards potential commonalities, connections and interdependencies between systems, and it misses a potential opportunity for developing a coherent governance for infrastructure adaptation processes. Secondly, existing literature tends to focus on the *micro* level (e.g. impacts on individual infrastructure components) and the *macro/landscape* level (e.g. effects on the natural systems surrounding infrastructures) (Chappin and Lei, 2012). These focal areas leave a gap at the *meso* level - the level at which the technical and social elements of infrastructures interact with one another, and at which component impacts may propagate into network-wide failures.

## 2.2 Mission and research questions

The mission of INCAH is to provide strategic and scientifically underpinned intelligence on the interconnection between climate change, hotspots, infrastructures and governance for adaptation. The focus is on rail transport, road transport, energy and drinking water networks. INCAH aims to determine the relevant effects of climate change on infrastructures and the impacts on the operation, availability and productivity of infrastructures. Meanwhile we would answer the question how to deal with these impacts in relationship with avoiding congestion, service interruption, system breakdown or even systemic crisis through reinforcing effects rippling through interconnected infrastructures. What policies, strategies and governance do we need to adapt infrastructure networks and make our economic hotspots robust and resilient to climate change? The research gap we will try to close is to connect structural failure to network failure to economic impact.

## 2.3 The INCAH consortium

The research is carried out by the INCAH consortium. This consortium includes

- TNO (NL Organization for Applied Scientific Research), program coordinator, responsible for system integration, stakeholder process. Specialists in the field of infrastructure technology, transport modelling and network design.
- Delft University of Technology (TU Delft), Faculty of Technology, Policy and Management. Specialists in infrastructure systems, agent based modelling and robustness of electricity and traffic networks.
- VU University Amsterdam (VU), The Department of Spatial Economics. Environmental, transport and land use economics, economic analysis of climate change adaptation measures and strategies.
- Deltares, independent institute for applied research and specialist advice in the field of water, soil and the subsurface in The Netherlands. Focus on relation between subsurface construction and flood risk management.
- KWR (Watercycle Research Institute), the Dutch research and knowledge institute for the entire water cycle, covering the fields of water supply, sanitation, and water management.

The consortium was composed in a way that all partners have a strong own specialism, with well-respected positions in international scientific circles and an established track record in research projects. In addition, all partners are capable of working in a cross-disciplinary fashion, with programs bridging the specialism of at least two partners. As the following chapter will show, this combination is important for successfully completing the INCAH program.

# 3 RESEARCH APPROACH

## 3.1 Research drives

Our approach is built along four lines of research that we believe are instrumental to develop sound and integrative (i.e. multi-modal, multi-commodity, multi-user) climate adaptation strategies. These lines of research do not so much concern the disciplinary angles, but rather the multidisciplinary research  lines that need to develop to promote development of climate adaptation for infrastructures and networks. They include:

- Integrated modelling,
- Adoption of a systems perspective,
- Development of adaptive policy making,
- Bridging the gap between research and practice

As will be explained further in the text, the consortium partners develop these lines from their own sectorial specialism. We elaborate on these 4 research lines below and discuss how these are embedded in the program in the ensuing subsections.

**Integrated modelling**

Getting to grips with the effects of climate change on infrastructure and to underpin adaptation strategies represents a formidable challenge. We believe underpinning actors' decisions in response to climate change multidisciplinary models and simulations of infrastructure operation and development that may span days to several decades are needed.

Such models must be built upon state-of-the-art knowledge on physical infrastructure components, their behaviour in a changing physical environment and potential failure due to gradual deterioration. Furthermore, the operational failure of transport networks due to extreme weather must be elucidated and represented. Economic effects of these failures or breakdowns and trade-offs in decision making must be modeled to determine the societal impacts.

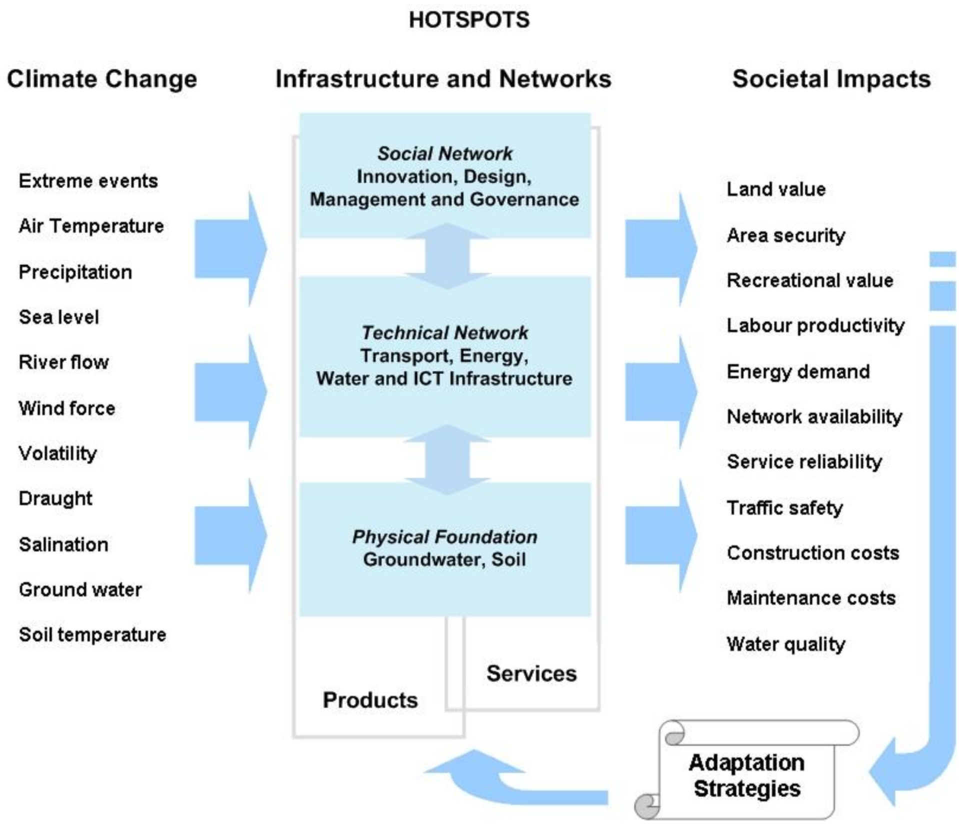


*Figure 1: Scope of INCAH (Infrastructure Networks Climate Adaptation and Hotspots)*

Integrating models of technical and social subsystems allows the simulation of infrastructure development, stability, operation, resilience and socio-economic performance. Investigating the effects of climate scenarios, tipping points of infrastructure performance can be determined. Adaptation by quick-fixes using proven technology, innovation and renewal of assets can be tested and interconnected networks (ICT/energy, energy/transport) may be simulated (see figure 1).

Thus, INCAH's integrated modelling will allow one to play-out the consequences of climate change, quick-fixes and determine whether they are indeed 'no-regret' and match long-term adaptation strategy and lead to increased infrastructure resilience and sustained performance.

**System perspective**

The INCAH program adopts a socio-technical system perspective (Figure 2). Socio-technical systems are technical networks operated, used, maintained and developed by a social network of actors in the civil society, the private commercial and public sector (e.g. Nikolic et al., 2009). They are a an assemblage of tangible (physical) and intangible (knowledge) assets that must be created, operated, maintained and renewed. This socio-technical system is, inter alia, driven by incidents and changes in its external world,  among which is climate change.

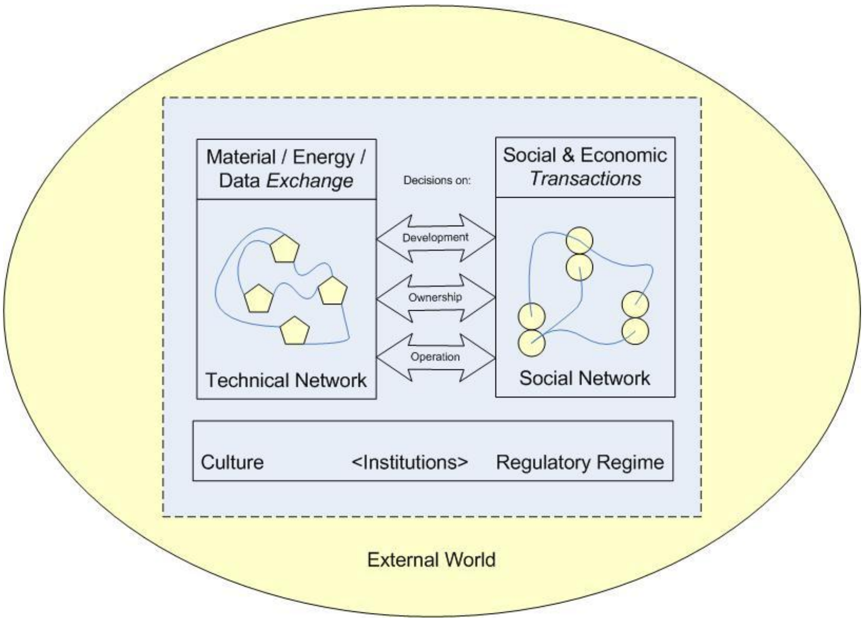


*Figure 2: Socio-technical systems perspective (from Dijkema and Basson, 2009)*

Transport, energy and drinking water networks in or around hotspots can be seen to comprise a technical network that is controlled by a network of stakeholders. This socio-technical network must live in a physical and societal environment. Climate change related weather change is one type of event that occurs in the landscape next to exogenous events on economy, nature and cultural change.  In the societal environment a change in culture, institutions, policy and regulation govern the behaviour and decision-making of stakeholders and the formal and informal rules they abide to. As part of the project we developed a fitting socio-technical system diagram (figure 3).

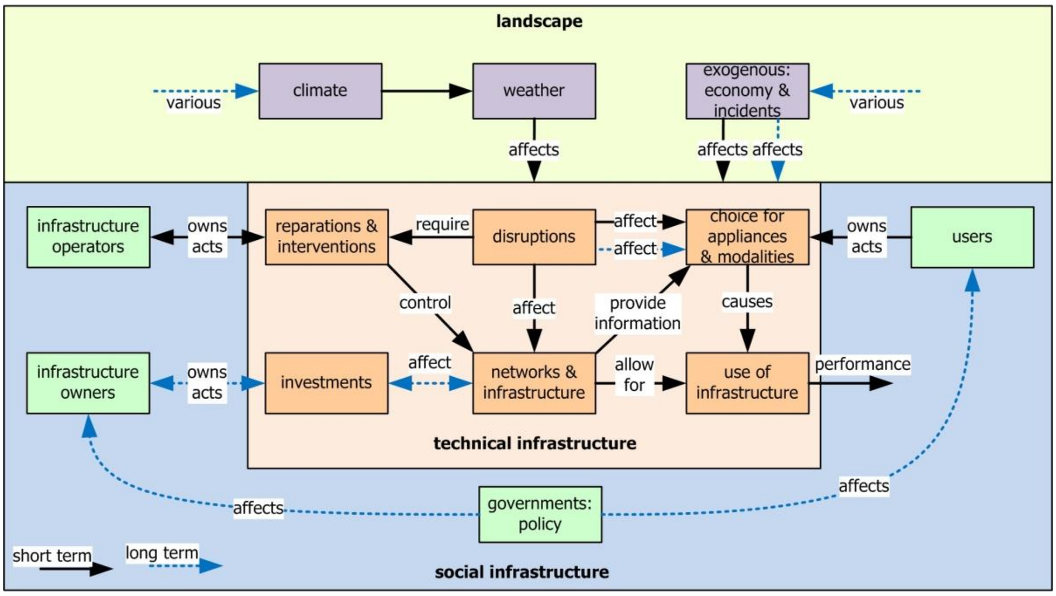


*Figure 3: Socio-technical systems (Maas, 2012, Chappin, 2012)*

The main purpose of the framework is to support integration of a variety of domains, e.g.:

- Technical and engineering know-how on the technical components of the infrastructure networks, which requires geotechnical, civil and mechanical engineering knowledge, hydraulics and sanitation.
- The robustness of the technical networks, the long-term evolution of the network and asset management. This requires system and network theory, system modelling and simulation theory, knowledge management, artificial intelligence and policy and management science.
- Socio-economic performance of technical networks subject to climate change are the focus in work package on socio-economics. This work will be grounded in transport economics, general-equilibrium modelling and cost/benefit analysis.

All projects will address existing transport, energy or water networks of relevance to the hotspots. This implies domain knowledge and expertise on transport, energy and water must be incorporated.

**Adaptive Policy Making**

Of special relevance is the uncertainty on climate change effects, both concerning its locale as well as its magnitude: our climate is a system that exhibits chaotic behaviour. Weather patterns and temperature are expected to change in the long run. One way of dealing with inherent uncertainty is by making use of scenarios. However, probabilities of occurrence cannot be attached to scenarios. This calls for adaptive approaches to infrastructure investments where flexibility is an important element. It is this type of adaptive approaches that will be considered in the present program.

The Dutch Council for transport and networks has published an advice on climate adaptation for infrastructure (Raad voor Verkeer en Waterstaat, 2009), which is built on adaptive governance (Rahman et al, 2008). This approach is based on adaptive management, which is a structured, iterative process of optimal decision making in the face of uncertainty, aiming to reduce uncertainty over time via system monitoring. Adaptive management should be used not only to change a system, but also to learn about the system (Holling 1978). Because adaptive management is based on a learning process, it improves long - run management outcomes.

According to Allan and Stankey (2009) the challenge in using the adaptive management approach lies in finding the correct balance between a strategic and tactical level; gaining knowledge to improve management in the future and achieving the best short - term outcome based on current knowledge. Adaptive infrastructure management requires a thorough understanding of the infrastructure system and input of a multi-disciplinary and multi-perspective group of stakeholders, enabling policy makers to define productive adaptation strategies and setting up a learning process. Indeed, the mitigation and adaptation measures can be contra productive, and cost effectiveness of decisions asks for windows of opportunity (Kingdon, 1984) in the 'normal' infrastructure management decisions. And planning and policy should be flexible to incorporate uncertainties and unpredictability.

**Bridging the gap between research and practice**

Climate and weather conditions cannot be regarded to be stable, especially when considering long term investment characteristics. It requires a flexible policy and planning, capable of evaluation and midterm changes when circumstances are changing (immediately). It also demands for new approaches to connect short term interventions with long term objectives. Thus, flexibility is not only an attribute of the physical system, but also part of the social and governance system. This implies consequences for policy making and decision making process and for the institutional arrangements of public and private and societal networks.

Hischemöller and Hoppe (2001) describe these type of decision making as an unstructured policy problem, because values are at stake and there is no consensus on the knowledge to be used to solve the problem. A lot of policy problems fall in this category. Cuppen emphasizes the need for a stakeholder dialogue in unstructured problems in order to enrich the policy process with new perspectives, knowledge and values (Cuppen, 2009). She defined this as an organized meeting of stakeholders with different perspectives, knowledge and backgrounds, who would otherwise not meet (or not all together), structured to a greater or lesser extent by means of specific methods, tools or techniques (Cuppen, 2009). Hajer et al instigate a deliberative, collaborative and practice based way of producing knowledge with scientists, policy makers and practitioners. (Hajer and Wagenaar, 2003).

Due to all uncertainties on the future of climate change and the dynamics in climate change the involved stakeholders all have different perspectives, and they have their own aims and values. Because of little consensus about knowledge involved a collaborative knowledge production it is necessary to gain negotiated knowledge.

## 3.2 Program outline

INCAH consists of four work packages (WP's). Availability and quality of infrastructure is addressed by considering the structural and functional performance characteristics of infrastructure components (WP2). A second work package focuses on the performance and robustness of infrastructure networks (WP3). The economic tools for decision making are developed in a third work package (WP4). These work packages comprise the core of the research work done in the program. In each of these work packages, the research carried out combines scientific analysis, exploration and modelling with the setup and completion of case studies on national, regional and local transport, water and energy infrastructures. To increase the relevance and utilization of the work, the experience and insights gained in these work packages are combined in an integrative work package (WP1), where adaptation strategies will be developed for the Netherlands.

The integrative work package has a focus on knowledge management, scientific and stakeholder dialogue and integrating the results of the WP's in a system model with adaptation strategies. Initially, WP1 has provided a reality-check: which infrastructure networks are affected by what climate change by involvement of stakeholders? The nature and magnitude of climate change on design and operation of infrastructure has been assessed and the consequences for adaptation and governance explored.

The system model integrates and uses the results and insights from all WP's; via iteration these improvements will provide greater resolution and reliability. Interfacing with WP2, 3 and 4, performance changes in infrastructure networks will be elucidated. Applying the work to the main hotspot Rotterdam-Rijnmond leads to specific insights and conclusions on the impact of climate change, what adaptations are required and how these can be realized. Both PhD's, postdocs and researchers are involved in the programme (Table 1).

*Table 1: Staff involved in the INCAH programme*

| | Theme 5: per work package | | | | Total |
|---|---|---|---|---|---|
| | WP1 | WP2 | WP3 | WP4 | |
| PhD | 1 | | 2 | 1 | 4 |
| Postdoc | | 1 | 2 | 1 | 4 |
| Researchers | 3 | 18 | 3 | 2 | 26 |

In all projects, there is a strong emphasis on modelling, and the projects in WP3 and 4 bridge technical network aspects and social network aspects. This not only requires interfacing knowledge from a variety of disciplines, but preferably also linking technical models with models of stakeholder behaviour subject to various economic conditions and regulatory regimes. This requires formalization and structuring of domain and case study specific knowledge. The synthesis project of WP3 will use our system decomposition method to facilitate the social process of model-building, and develop a common language that in principle will allow connecting models and the underlying knowledge. This is done in concert with WP1, where the link is made to integrate all knowledge into a system model that facilitates communication with the hotspots and other stakeholders.

## 3.3 Research questions

The central questions addressed within INCAH are:

- What are relevant effects of climate change on infrastructures?
- To what extent do these effects threaten the safe, sound, reliable operation of infrastructures, their availability and socio-economic productivity?
- How can we avoid congestion, service interruption, system breakdown or even systemic crisis through reinforcing effects rippling through interconnected infrastructures?
- Through what policies, strategies and governance can we adapt infrastructure networks and make our economic hot-spots robust and resilient to climate change?

Below we give more explicit research questions per workpackage.

WP1 is an integrated work package that aims to transform the knowledge from several disciplines into valuable strategies for hotspots. The main challenges are:

1) to develop a productive dialogue between researchers and practitioners. It is not only about expert knowledge but also creating new knowledge in the boundaries of disciplines, domains and actors. This enhances the ability to respond to a world with new (climatological) dynamics.
2) to create adaptive capacity. The adaptive capacity enables the social systems to change itself and to adapt to new circumstances, without significant loss of productivity, efficiency or functionality. This capacity prevents lock-in because more options are open and available.
3) to integrate the knowledge between disciplines by using system models. System models will elaborate, assemble and structure existing and new knowledge.

WP2 revolves around the theme “How may sub-surface conditions change and affect physical infrastructure?”. Sea level and river load rise may work their way to influence infrastructures via changing sub-surface conditions and slowly wreak havoc on roads, railroads, pipelines and power cables. Ground water pressure, salinity and temperature can lead to accelerated corrosion, weakening of pipes, cables and their joints. Soil stability and contact may change and eventually cause local structural collapse or land-sliding of on-surface infrastructure. Building on hydraulic and geotechnical engineering it will be investigated. What effects can be expected? What may be their consequences?  By what measures can they be prevented or neutralized? The most relevant aspects for the hotspots appear to be the effect of drought and higher soil temperature on pipe integrity and drinking water quality, possibly changing groundwater tables affect soil stability, pipelines and cables and infrastructure foundations, and flooding of (rail)roads and tunnels.

The central theme in WP3 is Network Robustness and Adaptation. This theme is addressed for road transport and electricity networks exploring operation, asset management and long-term network development. Modelling and simulation is used to help hotspots and other stakeholders, improving policy development and decision making. The work package consists of four connected subprojects, each with a specific focus and research question:

1) Short-term adaptation: how to make existing road infrastructure networks robust to effects of climate change? Network resilience is determined by the existing structure and design and fixed short-term. Modern asset management, intelligent infrastructure control and user guidance may increase robustness, prevent congestion and allow traffic to flow, possibly at reduced capacity. Network transport models will be adapted and used to explore effects of climate change induced events and adaptation strategies.
2) Long-term adaptation – resilient networks: how can we develop climate change resilient infrastructure networks? With time, infrastructure hubs, links and network structure change. Resilience and robustness can be built in at the network level to reduce the effect of single points of failure. Agent-based models of infrastructure development and growth will be extended to represent system resilience to climate change induced single- or multiple points of failure (Davis et al., 2009).
3) Adaptation – a life-cycle perspective: Using asset management, a life-cycle perspective will be adopted in modelling decisions on infrastructure modification, maintenance and extensions. Real options theory will be used to develop models to help analyse the effects of decisions today or next year to adaptation long-term, to contribute to the goal of “no-regret” decisions but also “no-regret delay”.
4) Adaptation and interconnection: What is the vulnerability of interconnected networks and what options for adaptation exist? A regionally focused impact assessment will explore possible cascades of failure, which affect the operation of transport and energy networks.  accessibility and capacity for passengers and goods transhipment using models on the network effects of extreme weather.

The main research question addressed in WP4 deals with the economic theme. Economic information on the impact of climate variability and extremes is of great relevance for policy makers, because they want to avoid both overshooting and undershooting in their adaptation policies. For this purpose it is not only important to know the costs of adaptive measures, but also the benefits. The main problem addressed in this WP is a lack of knowledge on the size of the damages that may occur as a result of the impact of climate change on infrastructures. Our analysis concerns a monetization of the impacts of climate change on the physical networks (transport and electricity) and on the reliability and usability of these networks, given uncertain futures, using information from WP’s 1-3 and external sources.  In addition, further economic impacts on transport and electricity network related industries will be addressed. The main questions are:

1) What are the socio-economic effects of climate change via changes in the reliability and usability of transport and electricity infrastructure and via the physical infrastructure in the hotspot regions
2) What are potential flexibility oriented adaptation approaches?

## 3.4 Self-assessment of the research approach and program

In this section we provide an overall assessment of the status of the program and a detailed overview of the main achievements by work package and type of activity (exploration / theory building / design orientation / integration).

Our overall assessment of the research progress is that individual topic areas are proceeding well despite a late start. Integration between subject areas is underway and supported by a positive attitude of and growing co-operation with the stakeholders. Yet, the individual topics need to arrive at a maturity stage where combination is possible and results can be presented at the level of interacting infrastructures. Below we elaborate these points further.

INCAH is half-way in the planning period. The past two years the focus has been on getting each of the projects going. The slow start of the project (almost a year after the start date as originally scheduled in the KfC program at the time of tendering) was mostly due to administrative procedures and recruitment difficulties. Also, trust and commitment from the stakeholders or “hotspots” needed to be built up from the beginning, which took time. By now, however, the individual projects are well underway and are producing outputs, mostly focused on the inventory building, primary problem analysis and the research frameworks. Connection and integration is beginning to emerge at the work package level. Coordinated framing at the program level has been relatively loose, as the insight into the strongest and most relevant links are still emerging. Nevertheless, a number of conclusions can already be drawn as to the benefit of the chosen system approach. These concern the perceived effectiveness of the approach so far and the progress made according to the systems framework. The main function of the system approach so far is that it has helped us to identify, together with stakeholders, the multi-infrastructure system challenges. These were laid down in a joint paper which was recently submitted for Regional Environmental Change.

As can be seen from Table 2, there is quite a diversity of case studies, individual infrastructures addressed. Case study work addresses road transport, rail, drinking water and electricity; for each of these infrastructures, the research covers the network (WP 3 and 4) as well as individual physical elements (WP 2 and 4).

*Table 2 Overview of work per WP across 4 types of activities*

| Activity type/ WP | (A) Exploration, inventory | (B) Theory, Modelling | (C ) Design Space | (D) Integrative Framework |
|---|---|---|---|---|
| 1 | Stakeholder workshops; review | | | In use and in development |
| 2 | Inventory of resilience of transport and | Modification of soil-mechanics / geodetic models | Advanced sub-surface elements design (e.g. | Co-develop to liaise with knowledge on |

| | | | | |
|---|---|---|---|---|
| | drinking water networks | | tunnels) | physical infrastructure |
| 3 | Inventory of threats and consequences; Relation transport infra, users and ICT | Dutch High-Voltage grid; Road network Rotterdam RAM for asset management | Explore long-term network development & use of asset management | Co-develop using socio-technical systems approach |
| 4 | Analysis of climate effects on rail and road infrastructure. Power plants and cooling water | (Societal) Cost-Benefit analysis. Data mining and analysis | Dealing with uncertainty, options for adaptation, cost-benefit perspective | Co-develop w.r.t. assessment and distribution of costs and benefits |

We elaborate on the cells in the table below.

- The activities type (A) lead to structural and functional performance indicators of infrastructure components and an understanding of robustness and resilience of infrastructure networks. For electricity networks, this has been framed as a set of attractors (Bollinger et al., 2012). For sub-surface drinking water and road infrastructure, an inventory and assessment of the concept of resilience has been completed. With respect to the economic assessment, work was completed on Dutch rail transport and electricity generation, using large data sets that record the operation on these systems, and combining these with weather data. A preliminary “reality-check” is taking shape, also to focus the modelling efforts: “which infrastructure networks are affected by what climate change?” and “what is known, or the consensus, on what is to be expected, with respect to the nature and magnitude of climate change on infrastructure” has been qualitatively assessed. Currently, through modelling and simulation, impacts are further detailed. The research is leading to qualitative knowledge and quantitative exploration, to be presented to the stakeholders to discuss the consequences for adaptation and governance.
- As indicated, in WP2, 3 and 4 much work already has been done on modelling (Type (B) activity). A first pass on the knowledge, scope and possibilities of modelling has been completed (e.g. Bollinger et al. 2011 and 2012). A series of first generation models was developed that allow us to investigate the effect of climate change on infrastructure through simulation. Our scientific peers confirm that this work is needed and original, especially where it concerns the meso-level multi-disciplinary modelling approach, addressing infrastructures as socio-technical systems.
- Type (C) activities are only commencing, as they rest on the foundations laid by type (A) and (B) activities. Work already has begun to applying some of the modelling work to a case study for Rotterdam-Rijnmond. Work on the electricity grid currently is focused on the national high-voltage grid. Insights and models will however also be used to complete a regional case that should leads to hotspot specific insights and conclusions on the impact of climate change, what adaptation is required and through what incentives more robust an resilient networks can be developed.
- Type (D) activity is primarily undertaken in the integrative WP1, but as this rests on the other WP’s, therein also integrative work has started. Working from the focus on knowledge management, through scientific and stakeholder dialogue the program work has been framed in a single system model or framework (Maas, 2012).

# 4 CONNECTIONS

## 4.1 Connection between INCAH-themes

The consortium consists of complementary research organizations. The universities in the consortium are uniquely focused on scientific excellence; the applied research institutes bridge the gap between scientific knowledge and application in practice and policy making. These connections were made explicit at the outset of the project during the kick-off conference; see table 3.

*Table 3: Connection between work packages*

| **Work packages** | | | | **Description of connection between work packages** |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | |
| | 2.2 and 2.4 | | | Water safety risks with regard to the stability of dikes |
| | 2.2, 2.3 and 2.4 | 3.4 | | RAM-modelling |
| | | 3.2 | 3.2 | Electricity networks |
| | | 3.3 | 4.1 | Comparison of road versus rail<br>Common use of data |
| 1 | | 3.1 | | Development of socio-technical system<br>Governance approach in uncertainties |
| | 2.2 and 2.4 | 3.3 | 4.2 | Real options methodology |
| | 2.2 | 3.3 | | Disturbances on road networks, effects and probabilities |
| 1 | 2.2 | 3.3 | | Vulnerability analyses of the road network |
| | 2.3 | 3.2 | | Agent based modelling for drinking water system |

The work package leaders have regular meetings in which they address and discuss research focus for case studies, decisions on stakeholder interactions, propositions for FP7, Cost and other calls, and interlinkages within the work packages, the programme and Knowledge for Climate.
In relationship with the interest of hotspot Rotterdam-Rijnmond and Rijkswaterstaat in robustness of road infrastructure a strong connection has been made through WP3.3 and several other projects. These connection is effectuated in a common workshop with WP2.2 on a vulnerability analyses, a joint paper with WP4.3 on adaptation strategies for electricity networks, a common use of data bases on road transport and incidents for WP3.3 and WP 4.1 and an exchange of office accommodation between WP3 and WP4.

## 4.2 Other KfC Programs

Co-operation with the other themes of Knowledge for Climate is organized via the platform function in WP1 and develops along the following lines.

Theme 4 (Climate Proof Cities): As the participating hotspot Rotterdam is interested in case studies in a strongly urbanized area, co-operation with theme 4 is important. At the proposal stage, the two programs have shown to be complementary; however, during the course of the project, further communication has not been so close so far to anticipate the emergence of double work or lacunae on the way. At this moment we do not see double work. We do see lacunae, due to the unexploited area of knowledge development. When we have to define adaptation strategies one of the elements would be how new infrastructural solutions will need to be harmonized with other urban concerns in the area of health care, public safety and quality of life.

We attended workshops to identify issues and links for the "cross-cutting" thematic programs 6-8 (Decision Support Instruments, Governance and Climate Projections). Interfacing issues included :

- Uncertainty whether climate projections would become available in time and at sufficient level of detail for INCAH (Theme 6).
- Need to align work on addressing institutional aspects of capturing the value of robustness in new business models of public and private actors (Theme 7).
- Sharing definitions and modelling conventions concerning cost-benefit analysis and agent based modelling, to maintain consistency of conclusions at the KfC program level (Theme 8).

## 4.3 International cooperation

To our knowledge there is little research internationally on climate change adaptation for infrastructure networks that takes a socio-technical system perspective, as adopted in the INCAH project. We have committed 12 international institutes working in this area and organize the co-operation with exchanges, conferences and collaboration in other projects.

- Through the special session on Infrastructures and Climate Change at the 2012 Planet Under Pressure conference, the INCAH-sessions at the 2012 CESUN conference, participation in the Industrial Society for Industrial Ecology conference and Adaptation Futures 2012 we have worked on establishing an emerging network of academics engaged in infrastructure adaptation research. Notably a link has been forged with University of Oxford Environmental Change institute led by Prof. Jim Hall (UK Infrastructure Transitions Research Consortium: Long term dynamics of interdependent infrastructure systems).
- The PhD-candidate in WP1 is involved in the MUSIC project of the Department of Urban Studies and Planning at MIT. MUSIC is the MIT-USGS Science Impact Collaborative, and this PhD student is investigating how groups of decision-makers and other stakeholders can be assembled to consider streams of infrastructure-related decisions that are impacted by the risks and uncertainty associated with climate change. He uses the work of MIT, and the Consensus Building Institute and their partner organizations to on planning approaches to define a serious game helping the decision making process.
- The PhD candidate in WP3.2 spent 2 months at the York Centre for Complex Systems Analysis (YCCSA) and the Stockholm Environmental Institute in York (SEI-Y) at the University of York, UK, for the purpose of sharing knowledge and expertise with respect to agent-based modelling of climate change adaptation and mitigation. Related to the KIC Climate TNO has actively participated in an international meeting at Schiphol about 'mainports as cities' and contributed with a system perspective.
- The development of a procedure for an impact assessment of climate change on engineered slopes for infrastructure is an essential tool for the Dutch Delta program and programs as Flood Control and Flood Probe. Generated knowledge is shared among researchers and developed

code is used across applications. These results from INCAH have been brought in the call from the framework for European Cooperation in Science and Technology (COST) to address the “Impact of climate change on engineered slopes for infrastructure”. In cooperation with the Newcastle University and researcher form other European countries this group will develop collective understanding, share techniques, facilities and data, and work jointly in disseminating results across the EU and to asset owners. Ultimately, the proposed COST action will enable infrastructure asset owners to make evidence based investment and adaptation decisions to improve resilience and safety.

At the project level, INCAH researchers contribute to or are participate in the EU-FP7 projects ECCONET (focus on inland waterway transport and related sectors), WEATHER (Weather Extremes: Assessment of Impacts on Transport Systems and Hazards for European Regions), EWENT (Extreme Weather impacts on European Networks of Transport), RIMAROCC (risk management for roads in a changing climate). Other initiatives that benefit from the INCAH knowledge are a recent proposal for the Transnational Road Research Programme of CEDR (Conference of European Directors of Roads), and the Dutch research programme Duurzame Bereikbare Randstad (Sustainable and Accessible Randstad - DBR), that contains one project on asset management in relationship with climate change.

## 4.4 Stakeholders

The stakeholders are described briefly below with their specific interest in the INCAH programme.

- The main “hotspot” stakeholder of INCAH is the region Rotterdam-Rijnmond. This region forms a substantial part of the economically most important area in the Netherlands: the Randstad (the area in the triangle Amsterdam – Rotterdam – Utrecht). Rotterdam is located in a coastal region, in a river delta and below sea-level. This make this city relatively vulnerable to climate events such as flooding. The combination of being important from an economic perspective and vulnerable from a climate perspective emphasizes the relevance of taking this area as the geographical scope of the program.
- Rijkswaterstaat (Dutch Road and Waterways Authority): one of the most important objectives is to determine what are the main risks of climate change and to install these in their asset management approach.
- Rotterdam Rijnmond, the most important hotspot in INCAH, is setting up an adaptation strategy for climate change on topics like the built environment, drinking water supply, water protection and on mobility.
- STOWA, as a foundation for Applied Water Research that coordinates and commissions research on behalf of a large number of local water administrations, has a specific interest for the research in INCAH on the consequences of climate change resulting in droughts and periods of heavy precipitation for embankments. In the INCAH project STOWA makes data of measurements on peat dikes available and participates in an advisory group for this aspect of the research in INCAH.
- TenneT is the Dutch and German Electricity Transmission System Operator (TSO). They have the responsibility for operating and maintaining the high-voltage grid (380, 220, 150 and 110 kiloVolts). They have a profound interest in development of robust, resilient networks, and exploring strategies to arrive at no-regret decisions and affordable and acceptable investments.
- ProRail (The Dutch railways infrastructure authority) has collaborated with INCAH researchers in the context of a study on the effects of weather on rail disruptions in the Netherlands. The Dutch

railway network is one of the busiest ones in the European Union, sensitive to disruptions and its performance is subject to continuous scrutiny by the public and government officials.

- NS (the Dutch rail service company) has developed the programme High Quality Rail (Hoogwaardig Spoor) with a horizon in 2020. For the longer term, towards 2030 and further, a thorough analysis of the rail capacity should be made. Not only the higher rain and snow intensity should be analysed, but also more and heavy lightning, more frequent extreme weather circumstances and combinations.
- Waternet (water service company in Amsterdam) is responsible for the delivery of high quality drinking water. INCAH is the first project that is looking to the pipeline infrastructure for the drinking water system, which could influence the delivery and transport of drinking water.

Stakeholder involvement has evolved during the course of the project from an emphasis on the impact of climate changes, into an emphasis on measures and adaptation strategies and an emphasis on applicability and implementation of these strategies within their own organizations. The involvement of these stakeholders has been organized through different channels and on various levels of scale:

- Through a newsletter, to inform stakeholders and a wider range of interest groups, on the progress, on interesting INCAH and other reports, on forth coming conferences and events.
- Through stakeholder workshops, in which stakeholders contribute to research questions and reflect on the applicability of the results in practice on a program level. The first conference with stakeholders took place in May 2011 (after a first kick off) and focused on the impact of climate changes on infrastructures. The second conference took place in February 2012 and has shifted towards a definition of required results. For the second half of the programme we will redesign the stakeholder involvement, based on needs of both researchers and practitioners.
- Through a steering group of stakeholders, consisting of the main core stakeholders, representatives of the Ministry of Transport and Ministry of Economic Affairs, and representative of the hotspot Rotterdam-Rijnmond.
- Through the individual case studies, researchers will contact the stakeholders on a less organized basis with requests for information and data on their infrastructures. In order to fulfill the initial central research questions, input from stakeholders in terms of data and information is crucial to the program's success.

## 4.5 Self-assessment: connected!

Connection is, as explained in the vision of the research approach, one of the main elements in our program. Our assessment  is that currently sound connections exists between disciplines, within the work packages and the projects, between researchers and other stakeholders, on all levels and in different ways.

The use of a system model has structured the dialogue and has helped the policy makers acting in different infrastructure networks ('systems') to learn from each other and to translate feasible solutions in one system to another infrastructure system. The first workshop was very helpful in explaining the work to the stakeholders and to the researchers mutually. Presenting posters of each project helped a lot in getting to learn each other's language. As a consequence of better understanding the stakeholders keep raising new challenges and questions.

So far, much of the energy in developing connection was spent on developing the multi-infrastructure framework and strengthening the linkages with the national and regional stakeholders, from government and industry. Climate change is not on their list of short term priorities, and securing their buy-in in the project has taken much time. The challenge for the next two years is to build out the co-operation with the international partners and advance the dialogue on the state of knowledge about climate adaptation strategies for infrastructures and networks.

# 5 SCIENTIFIC EXCELLENCE

## 5.1 Scientific output

For the assessment of the physical infrastructure we developed a methodology that offers a structured process to consider the effects of climate change on infrastructure. In addition, this project is mathematically challenging by considering so called tail dependencies. The methodology is based on the resilience of the considered infrastructure system for climate change. Comparing the resilience with the climate scenarios leads to valuable insight for policy making. One question of interest is, at which point in time will the tipping points (that is, when the system can no longer deal with climate change in terms of reliability, availability, maintainability and/or safety) occur and when will current policies no longer be applicable?

For the drinking water infrastructure the effect of climate change on the integrity of drinking water distribution systems has been examined, based on historical failure data of drinking water distribution systems. The most commonly observed effect of climate parameters on pipe failure is an increased pipe failure during winter and late summer. These effects can be attributed to (1) large temperature differences between pipe and soil causing thermal stresses, and (2) periods of drought causing differential settlements. In this project we have developed an analogous approach that uses soil differential settlements induced by climate change to predict stresses in pipes. Based on available data on drinking water distribution pipe failures occurring in the supply areas, correlated to KNMI weather data analysis have been performed. For some pipe materials, a slight to moderate increase of the failure frequency with temperature and/or rainfall deficit has been observed.

To assess the consequences of droughts and periods of heavy precipitation for embankments a new analysis procedure has been developed. The procedure couples an agro-meteorological model based on the Penmann - Monteith expression to a groundwater flow model based on Dupuit's approximation. This approach results in an application, for peat dikes, that gives robust results and is computationally efficient. The application had been validated through calculation of extreme water table positions and related stability under wet and dry conditions and comparing these with measurements. Climate change will alter the boundary conditions and a tipping point analysis shows that the dike, used in the validation, fails if the evapotranspiration increases by a factor two.

We have partially filled in the “adaptation-of-infrastructure knowledge gap” that was documented by Koetse and Rietveld (2009).The qualitative literature overview for the electricity network provides a typology of electricity infrastructure impacts, adaptation strategies and their economic costs and benefits.

For the railway system an in-depth analysis has been carried out on a long term database of infrastructure related disturbances. The potential role of climate change is studied by means of the contribution of extreme weather conditions to the number of disturbances. We find that the contribution of extreme weather to infrastructure disturbances is underestimated in the expert judgments of personnel working in the field. We also analyse the broader consequences of extreme weather on delays and cancelations of trains as experienced by travellers and find that the effects run mainly via infrastructure, and to a lesser extent via the vehicles. These are important inputs for improvement of incident management in the rail sector.

For inland water transport a link has been established with the international ECCONET project that addresses the impact of climate change on inland water transport in the Rhine and Danube river basins. The meteorological and hydrological models used lead to the conclusion that the year to year variation in water levels will dominate. Structural changes increasing the probability of long periods with low water levels are not yet clearly visible during the period up to 2050. It is only for the period after 2070 that low water problems may become problematic. Given the lifetime of ships this suggests that the trend of increasing ship sizes will continue and that water management measures should give priority to ensuring that it addresses present water level variations sufficiently, rather than that it should anticipate climate change related problems.

Costs and benefits of adaptation strategies are explored by means of real options analysis. This methodology is based on the principle that if the expected net benefits of investment are currently insufficient, adaptation can be postponed. Since investment is irreversible and the degree of climate change and its impacts are highly uncertain, waiting to adapt can be optimal. In other words, waiting has positive value because it allows decision makers to limit the downside risk of adaptation (e.g. building a redundant dike). In a case study of climate impacts in the electricity sector we indeed find that such a wait-and-see strategy is justified. At the same time, climate change induced events may lead to irreversible loss of human lives, land and infrastructure. In that case, waiting actually carries a negative value and adaptation might be subject to the precautionary principle, which states that one should invest rather sooner than later. With the aim of supporting the discourse on infrastructure adaptation, this program has introduced a framework for infrastructure climate adaptation. Key to this framework is that (1) infrastructures are interdependent; (2) infrastructures contain networks of both technical and social nodes and links, each of them containing various components; (3) the technical and social components of infrastructures need to be discussed together in a systematic manner; and (4) the governance of this system as a whole needs to be considered.

Our preliminary, but main conclusion, is that the short term economic damages of climate change are likely minor. Over the longer term and in some sectors the effects are potentially large. They are best countered by an adaptive strategy: preparing for measures, and only activating them when needed. We emphasize that this tentative conclusion is based on two projects only: one project based on the economic costs of delayed and cancelled trains for railway passengers and another project which focuses on the economic costs of avoiding disruptions in energy production.

## 5.2 Valorization and scientific results presentation

The scientific results are presented at several international conferences and published in research reports and high quality, peer reviewed scientific journals, both in the climate field and the infrastructure/networks field. We mention in particular the ‘Journal of Transport Economics and Policy’, ‘Transportation Research’ parts A, B, D and the Journal of Geotechnical and Environmental Engineering. We have good opportunities publishing in climate journals via an accepted abstract for

Regional Environmental Change (REC). Recent articles in Nature Climate were related to climate change and water scarcity for electricity production, on which we can built forward. This strengthen the researchers to write an article for this journal that is a target journal in the Knowledge for Climate program.

The international exposure will further be extended through the collaboration with our international partners and by international research projects during forthcoming years. Examples are ECCONET (Effects of Climate Change On the inland waterway Networks), ECTRI (European Consortium of Transport Research Institutes), the GRA (Global Research Alliance, about 45000 researchers), COST (Intergovernmental framework for European Cooperation in Science and Technology), ELGIP (European Large Geotechnical Institutes Platform), TRB (Transportation Research Board), PIARC (The World Road Association), ISSMGE (International Society for Soil Mechanics and geotechnical engineering), and the Dutch CROW (National Information and Technology Platform for Transport, Infrastructure and Public Space), CUR (Civieltechnisch Centrum Uitvoering Research en Regelgeving) and COB (Centrum OndergrondsBouwen).

Outcomes for specific infrastructure or network types will be presented in specialist media for the Dutch clients of this work. Also publications in more general media like regional and national newspapers and broadcasts on radio and TV are expedient.

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## 5.4 Self-assessment on scientific excellence

Literature research has shown that the empirical and theoretical analysis of adaptation is a bourgeoning field within climate change research. The review article of Koetse and Rietveld (2009) on transport and climate change adaptation in Transportation Research D has been the most downloaded article for more than two years, indicating that the team is addressing a domain for which much attention exists. The paper was the result of a research program preceding the present one (Climate changes spatial planning preceded Knowledge for Climate). Thus, it can be argued that the study of climate change adaptation needs for infrastructure is still in its early stages.

Researchers within the different work packages have written a substantial number of papers on various aspects (e.g. engineering, economic) of infrastructure adaptation. Many papers written by PhD students and postdoctoral researchers have been presented at international conferences and some papers have been submitted or are in preparation to be submitted to respected scientific journals. We view these developments as promising and expect many more papers to be written, especially now that the PhD students and postdocs have obtained substantial domain knowledge to operate at the relevant research frontier(s) in their fields. For example, INCAH researchers have recently written a paper on climate change and disruptions of electricity supply, which is the outcome of a collaboration with researchers from Wageningen University and a follow-up to a paper recently published in Nature Climate Change.

Opportunities for international cooperation have not yet been fully exploited. Recently, ties with other KfC Themes have been strengthened (in particular in the areas of Governance and Decision Support Tools) and in other areas potential partners have been identified. Continuous effort in this area will ensure a more productive research environment, likely improving the quality of our output.

It is our ambition to publish our scientific work in very high ranked scientific journals. The consortium meetings and bilateral cooperative projects give opportunities to achieve higher qualities by ample time for comments on each other's work. We intend to make use of these opportunities even more in the second phase,

# 6 SOCIETAL IMPACT

## 6.1 Societal outputs

The main questions from stakeholders are related to the design of infrastructure, required investments and maintenance strategies. Currently, the possible implications of climate change are not sufficiently part of infrastructure planning processes. There is little knowledge at why this is needed and how it could be done. The outcomes of INCAH should be adopted shortly in the main infrastructure programs. As the technical life span of infrastructures is approximately 50 years, in the coming decade will see a peaking of maintenance and replacement activities. This decade, therefore, marks a unique opportunity to combine necessary refurbishments with a new, forward looking redesign that takes into account climate change concerns. This project contributes to the agenda setting in this area by involving stakeholders and addressing their needs. Table 5 provides an overview of the changes in awareness by discussing the topic of climate adaptation and infrastructure networks.

*Table 5: Issues of main stakeholders of INCAH*

<table>
<tr><td>Rail</td><td>Road</td><td>Electricity</td><td>Drinking water</td></tr>
<tr><td>Adaptation strategy is a multi-actor problem</td><td>New design parameters and historical data for asset management</td><td>Second order effect of disruption of electricity network (e.g. on ICT)</td><td>The same effects on drainage or urban heat system.</td></tr>
<tr><td colspan="2">Disruptions to rail-road networks and thus adaptation strategies involves those in road networks.</td><td></td><td>Is it still cost effective to realize 100% availability of drinking water</td></tr>
</table>

Some preliminary conclusions are the following (not to be cited yet[1]). Economic damages associated with climate change can be significant. However, systemic effects rooted in technological failure (structural integrity) appear to be minor. At the same time, more focused research is needed to assess specific risks for individual, possibly systems critical segments (such as, for example, the identification of use of IPE blocks used for road foundations). But even with constructions unaffected, the impact of changes in operating conditions (water level changes, extreme weather) on the functional performance of the system can be potentially large. Due to the many dependencies between infrastructures, the connected system is vulnerable to climate change and adoption measures may be needed. Individual infrastructures should develop strategies and strengthen their

[1] We emphasize that this conclusion is based on two projects only (other projects are still work in progress): we have finished one project based on the economic costs of delayed and cancelled trains for railway passengers and another project which focuses on the economic costs of avoiding disruptions in energy production. At this stage the main policy advice focuses on avoiding overinvestment. The other projects, which focus on the same issues but in completely different sectors, may provide us with another conclusion.

control room capabilities to deal with uncertain events. When effects are potentially large, an adaptive strategy is recommended, meaning that responses should be prepared and delayed until the environmental conditions require action. Strategies such as collaborative adaptive management, scenario planning, systems thinking and stakeholder engagement can support decision makers to navigate this context and effectively guide adaptation processes, both within and across infrastructures.

The risks and uncertainty climate change poses to infrastructure planning will challenge the technical skill of designers and engineers as they strive to increase the robustness and/or flexibility of projects. These risks and uncertainties will also stress traditional decision-making procedures, as conventional methods for making decisions based on widely trusted models or forecasts of the future, which have often been seen to be objective, will no longer be sufficient. The degree of uncertainty is becoming increasingly great, and the subjective nature of decisions around such concepts as risk tolerance is becoming clearer. An effective response is to make these decisions transparent, engaging stakeholders in the decision-making process via boundary organizations that grapple with socio-technical questions in concert with the experts that conduct analysis. INCAH provided a preliminary overview so far and give some brief examples what such boundary organizations should look like and how they should function. This will inherently depend on the infrastructure in question.

The societal results will help policy makers to set priorities. In combination with a comprehensive set of short-term and long-term adaptation measures, adaptation strategies can be formulated and a roadmap for actions and timing will be developed. The results out of the projects so far includes:

- A list of climate adaptation measures for drinking water distribution systems helping the policy maker to get an overview
- In the Flood Protection Program large scale assessment take place. The assessment of embankments can be carried out following a procedure developed and tested by INCAH, allowing for the use of a stochastic approach.
- The adaptation measures to prevent from winter (snow) disruptions are dependent on activities of multi-stakeholders and is strongly connected to accountability. The organization of information supply can be supported using agent-based models.
- An interactive vulnerability analysis of the urban infrastructure network will help the multidisciplinary problem solving within a municipality on the short term and will expose the expected vulnerability related to more and extreme weather circumstances.
- Since the electricity sector plays a key role in many questions related to both climate change mitigation and energy security, an analysis of its vulnerability to climate change leads to new insights into these areas as well. For example, whereas certain energy technologies are better suited to decarbonize electricity systems, they might be more vulnerable to changes in climatic conditions, which should be taken into account when determining the generation mix.

Expected outcomes include:

- optimal timing of adaptation for power plants that are vulnerable to climate change, based on an estimation of expected costs of climate change for these power plants.
- insights how rapid and how volatile should climatic conditions be expected to change in order to warrant e.g. retrofitting of existing infrastructure

- information on relevant tipping point indicators (e.g. frequency of extreme frost) concerning climate changes, that are relevant for scheduling maintenance and investment decisions.

Summarized, the research program is providing the stakeholders involved in planning, design, maintenance, and/ or operation of infrastructures, both on national and on regional levels, with both qualitative and quantitative information on threats and risks that infrastructure systems are facing. It has increased the awareness at policy and private levels. It will establish the urgency of adaptation measures in view of the costs and benefits involved. In the end the program will result in a better understanding of infrastructure vulnerability related to climate change.

## 6.2 Knowledge transfer and valorization

We discuss three directions of transfer below: research, design and policy.

In the research arena, our aim is to develop INCAH from a national program towards an international center of excellence. As INCAH is only a first (though necessary) stepping stone for this, substantial support is required from research funds that fall outside the reach of Knowledge for Climate. With a view to the increasing co-operation between national and European institutes (the EIT, the Joint programming Initiatives and the KIC's) the consortium will strengthen linkages with the international partners around INCAH, and participate in various supplementary research initiatives. The international corporation is described in chapter 3.3. In addition to knowledge dissemination within the scientific community, we emphasize the translation of the scientific results into practical applications and support the implementation of adaptation measures and strategies. The knowledge institutes TNO, Deltares and KWR play a key role in this process, each from their own expertise. They will disseminate research results through their existing networks and collaborations with various stakeholders, to bridge the gap between science and practice.

For the design and maintenance of infrastructure systems, through the participation of the main authorities for road and rail infrastructure development and maintenance, new concepts and design strategies will be developed that can be followed up by focused R&D and implementation. At this stage in the project and by learning that research on effects of climate change on infrastructure is just in the beginning, we have no contacts with private companies in this area, other than our INCAH stakeholders.

For policy makers, the climate adaptation agenda is very changeable and sensitive to actual and local political programs. The opportunities for raising the robustness of our infrastructure networks are abundant however, even without high additional costs. At the same time, few policy circles have adopted this agenda yet in the objectives and strategies of their organizations. Raising the awareness among potential stakeholders, beyond those already involved, will be a major challenge of INCAH, with a high expected pay-off. In contrast to daily policy making, access is easier towards strategic or think tank policy advice. Members of the VU team have been the key contributors to the coming IPCC report for the section on climate change impacts on inland waterways. Together with the TU Delft staff they also contributed to the report Witte Zwanen, Zwarte Zwanen, issued by the Raad voor de Leefomgeving (Advisory council for the Environment), in which the theme of adaptation to climate change in the infrastructure domain has been addressed for the first time. The council makes a plea for an adaptation test with respect to climate change in the case of investment decisions in the infrastructure domain. A similar contribution was provided to a study of Kennisinstituut voor Mobiliteitsbeleid (KiM, knowledge institute for mobility policy).

## 6.3 Self assessment: Societal Impact

As research is still only halfway, it is quite early to judge the societal impact of the program. The tangible impacts so far have been mostly in the area of awareness raising. Our expectations are that the project will, within the right economic environment, generate planning and investment efforts that would otherwise not have been made. Economic arguments for investment will be made to convince stakeholders of a need to improve our ability to deal with structural changes, increasing uncertainties and more frequent extreme events. Research into the dependencies between infrastructures, the explored linkages between risk of failure and asset management and the insights into very specific infrastructural issues, will feed the agenda of policy makers and infrastructure managers.

The first two years of the project have confirmed that the process of transfer of scientific results to stakeholders has to be designed specifically to overcome differences in methodological knowledge. In this respect, the interactive mode of operation in the workshops in WP1 has proven to be a right choice. At the same time, the use of agent-based modelling (ABM) and real options (RO) analysis in respectively WP3 and WP4 has led to some difficulties in explaining and motivating research results to stakeholders with a low readiness to explore the many unknowns. For most private stakeholders, investments in climate adaptation have low priority, especially in view of the current economic crisis. On the upside, the awareness of our stakeholders and their knowledge of climate change phenomena has improved considerably. Besides its long term importance, it is also recognized that our research provides new tools to deal with extreme weather phenomena that do cause nuisance every time, whether invoked by climate change or not.

So far, it must be said, the readiness of many stakeholders to invest in climate adaptation is low. Due to recent changes in political orientation and the economic crisis, policy makers have hesitated to adopt an agenda that tackles sustainability issues. National policy on climate change has seen its focus reduced to flood risk, with shrinking budgets and commitment to the adaptation agenda (which, as an action plan, did exist at the national level). At the regional and local level, there have been mild exploration efforts of the magnitude of the problem on the short term, leading to the conclusion that no new major actions are necessary. The climate for developing climate adaptation measures is less favourable than it was at the start of the project. However, as weather variations will remain and economic crises will hopefully pass, we expect that by the end of the project stakeholders will be more willing to convert the new insights into action.

# 7 CONCLUSIONS

The INCAH project had a slow start due to recruitment problems but in the meantime it is well on track, both in terms of projects of individual PhDs and postdocs and in terms of integrating activities.

Some highlights of the results thus far are:

- We partially filled the “adaptation-of-infrastructure knowledge gap” (Koetse and Rietveld, 2009).The literature overview for the electricity network provides a typology of infrastructure impacts, adaptation strategies and their costs and benefits.
- We developed a methodology for resilience assessment of the physical infrastructure under climate change uncertainties, that considers tail dependencies. A case study for road infrastructure is developed to apply the model.
- For certain networks (for example inland water transport) the conclusion is that there is an adaptation deficit: priority should be given to making these networks robust under present climate conditions rather than anticipating climate change related problems.
- Analysis of the railway system identifies relations between weather events and disturbances and reveals that the contribution of extreme weather to infrastructure disturbances is underestimated in the expert judgments of personnel working in the field.
- A new analysis procedure was developed to assess the consequences of droughts and periods of heavy precipitation for embankments. It combines an agro-meteorological model to a groundwater flow model.
- Pipe failures are most common during winter and late summer. For some pipe materials, an increase in the failure frequency with temperature and/or rainfall deficit can be observed.
- The short term economic damages of climate change are likely minor. Over the longer term and in some sectors the effects are potentially large. They are best countered by an adaptive strategy: preparing for measures, and only activating them when needed.

It is our ambition to deepen and broaden our work during the second stage of INCAH. The most important challenges relate to linking the various network domains in order to understand better the possible domino effects. In particular the joint analysis of various transport modes and the electricity network is a major theme  that is both intellectually challenging and has high policy relevance.

One of the promising aspects of INCAH is the broad disciplinary coverage. Individual researchers have already found each other and various bilateral and multilateral cooperation activities have started. Joint work by team members with for example backgrounds in engineering and economics has the potential to lead to high quality applications of welfare analysis that would remain infertile without such a multidisciplinary combination.

The overall direction of INCAH during the second half of the programme will be to continue to extend our engagement with the outside world, including our international reach and our co-operation with the stakeholders. The investment of the past years in raising awareness and establishing firm working relations should pay off, leading to a successful completion in 2014. The dissemination and transfer of our results has already begun through the interactive workshops, the stakeholder case studies and scientific conferences, allowing us to aim for high impact publications.

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# 9 ANNEXES

## 9.1 ANNEX A: FACTS AND FIGURES

### Consortium T5 – Infrastructure and networks

| | |
|---|---|
| Theme 5 | Infrastructure Networks Climate Adaptation and Hotspots –Researching the Interconnections, Exploring Adaptation |
| Title (short) | INCAH |
| Duration | 1 January 2010 – 31 December 2014 |
| Consortium leader | Prof. Dr. Ir. L.A. Tavasszy (TNO) |
| Financial officer | Kees Bouman (TNO & thema)<br>Nellie Slaats (KWR)<br>Peter Lode (Deltares)<br>M. Nijhof - Van der Struik (VU)<br>B.N.(Benito) Minnella (TUDelft) |
| Communication officer | Tsjitske Groen (TNO) & Nadine Croes (TNO) |
| Project coordinator KfC | Monique Slegers |
| Consortium partners | ▽ TNO Delft<br>▽ Delft University of Technology<br>▽ VU University Amsterdam<br>▽ Deltares Delft<br>▽ KWR Watercycle Research Institute Nieuwegein<br>▽ Australian Commonwealth Scientific and Industrial Research Organisation North Ryde<br>▽ Joint Research Centre (JRC) Ispra<br>▽ Southern Cross University Tweed Heads<br>▽ Purdue University School of Aeronautics & Astronautics West Lafayette<br>▽ Louvain School of Management FUCam Louvain-la-Neuve<br>▽ Massachusetts Institute of Technology and United States Geological Survey<br>▽ University of Michigan Center for Sustainable Systems<br>▽ Tottori University and Arid Land Research Center Koyama-Minami<br>▽ Swedish Geotechnical institute Linköping<br>▽ Fraunhofer Institute for Systems and Innovation Research ISI Karlsruhe |

| | | | | |
|---|---|---|---|---|
| Website | http://knowledgeforclimate.climateresearchnetherlands.nl/infrastructureandnetworks | | | |
| Finance | **Initial**[1] | | **Actual prognosis** | |
| | Minimum total budget | € 3.300.000 | Total budget[2] | € 3.300.000 |
| | Maximum KfC subsidy | € 1.850.000 | KfC subsidy[2] | € 1.938.667 |
| | Minimum matching | € 1.450.000 | Matching knowledge institutes (own contribution) | € 1.086.333 |
| | | | External matching[3] | € 275.000 |
| Steering board | ▽ Ben Immers (chairman)<br>▽ Arjan Kapteijns (I&M)<br>▽ Rik Timens (EL&I)<br>▽ Jan Peter van der Hoek (Waternet)<br>▽ Marco Ludeking (RWS)<br>▽ Monique Slegers (KfC)<br>▽ Hetty van Rhijn-Stumphuis (dS+V) | | | |

**Structure of the theme**

| Theme 5 | | | |
|---|---|---|---|
| Work package 5.1 | Work package 5.2 | Work package 5.3 | Work package 5.4 |
| 5.1.1 | 5.2.1 | 5.3.1 | 5.4.1 |
| | 5.2.2 | 5.3.2 | 5.4.2 |
| | 5.2.3 | 5.3.3 | 5.4.3 |
| | 5.2.4 | 5.3.4 | |

**Organization of the work packages**

| Work package 5.1 | Building adaptation strategies for infrastructures and networks |
|---|---|
| Wp leader | Ir. N. Maas |
| Duration | April 2010 – February 2014 |
| Project 5.1.1 | Integration of knowledge towards adaptation strategies |
| Project leader | Ir. N. Maas |
| Duration | 4 years and 3 months, April 2010 – February 2014 |
| Other project members | Drs. T. Groen (researcher)<br>Drs. A.F.L. Slob (researcher)<br>T. Schenk, MSc. (PhD) |

| | |
|---|---|
| | R. Massink (researcher) |

| **Work package 5.2** | **Climate proofness of physical infrastructure** |
|---|---|
| Wp leader | Ir. H.T. Sman |
| Duration | 4 years, April 2010 – February 2014 |
| Project 5.2.1 | Hotspots: climate effects and adaptation measures on physical infrastructures |
| Project leader | Drs. A. Hartman |
| Duration | 4 years, April 2010 – February 2014 |
| Other project members | Ir. H.T. Sman (researcher)<br>Ir. J. van Ruijven (researcher)<br>Ir. T. Bles (researcher) |
| Project 5.2.2 | Quantification of climate effects and measures for rail, roads and tunnels |
| Project leader | Ir. W. van Kanten – Roos |
| Duration | 4 years, April 2010 – February 2014 |
| Other project members | Prof. ir. A.W.C.M. Vrouwenvelder (researcher)<br>Dr.ir. M.S. de Wit (researcher)<br>Dr. O. Morales Napoles (researcher)<br>Ir. J.N. Huibregtse (researcher)<br>Ir. R.M.L. Nelisse (researcher)<br>J.Jochemsen (researcher) |
| Project 5.2.3 | Effects of climate change on subsurface pipe infrastructure |
| Project leader | Dr. Ir. J.H.G. Vreeburg |
| Duration | 2 years, June 2010 – February 2014 |
| Other project members | Dr. D. Danciu (postdoc)<br>R. Beuken, MSc. (researcher)<br>Ing. G.A.M. Mesman (researcher)<br>Dr.ir. E.J.M. Blokker (researcher)<br>Drs. P.G.G. Slaats (researcher)<br>Dr. ir. P. van Thienen (researcher)<br>Dr. ir. B.A. Wols (researcher)<br>Ir. I.N. Vloerbergh |
| Project 5.2.4 | Subsoil effects due to climate changes |
| Project leader | Dr. ir. J.M. van Esch |
| Duration | 4 years, April 2010 – February 2014 |
| Other project | Dr. ir. E.J. den Haan (researcher) |

| | |
|---|---|
| members | Dr. C. Zwanenburg (researcher) |
| | |
| **Work package 5.3** | **Infrastructure Network Robustness and Adaptation** |
| Wp leader | Dr. Ir. G.P.J. Dijkema |
| Duration | 4 years and 3 months, April 2010 – February 2014 |
| Project 5.3.1 | Towards Design principles and development of climate proof infrastructure and networks |
| Project leader | Dr. Ir. G.P.J. Dijkema |
| Duration | 2 years, April 2010 – March 2013 |
| Other project members | Dr. Ir. I. Nikolic (researcher)<br>Dr. E.J.L. Chappin (postdoc)<br>Chris Davis (researcher) |
| Project 5.3.2 | Modelling infrastructure robustness and network failure – assessing climate risks |
| Project leader | Dr. Ir. G.P.J. Dijkema |
| Duration | 2 years, April 2010 – March 2013 |
| Other project members | Dr. M. Snelder (postdoc) |
| Project 5.3.3 | Agent-Based Modelling of long-term development of transport and energy infrastructure networks |
| Project leader | Dr. Ir. I. Nikolic |
| Duration | 4 years, April 2010 – February 2014 |
| Other project members | L.A. Bollinger, MSc. (PhD) |
| Project 5.3.4 | Asset management for adaptation to climate change |
| Project leader | Dr. Ir. P.M. Herder |
| Duration | 4 years, April 2010 – February 2014 |
| Other project members | S. Biramdipathi (PhD) |

| | |
|---|---|
| **Work package 5.4** | **Socio-economic effects of climate change on mainports and on urban infrastructure networks** |
| Wp leader | Prof. dr. P. Rietveld |
| Duration | 4 years and 3 months, April 2010 – February 2014 |

| | |
|---|---|
| Project 5.4.1 | Socio-economic effects of changes in reliability/usability of land based transport infrastructure in the hotspot regions due to climate change |
| Project leader | Prof. dr. P. Rietveld |
| Duration | 4 years, April 2010 – February 2014 |
| Other project members | Dr. J.N. van Ommeren (researcher)<br>Y. Xia, MSc. (PhD)<br>M. Adler (PhD) |
| Project 5.4.2 | Socio-economic effects of changes in reliability/usability of electricity infrastructure in the hotspot region due to climate change |
| Project leader | Prof. dr. P. Rietveld |
| Duration | 3 years and 6 months, October 2010 – February 2014 |
| Other project members | Dr. C. Bogmans (postdoc) |
| Project 5.4.3 | Socio-economic effects of flexibility oriented adaptation approaches |
| Project leader | Prof. dr. P. Rietveld |
| Duration | 3 years and 6 months, October 2010 – February 2014 |
| Other project members | Dr. C. Bogmans (postdoc) |

| | Theme 5 – per work package | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | Tot. |
| PhD | 1 | | 2 | 1 | 4 |
| Postdoc | | 1 | 2 | 1 | 4 |
| Researcher | 3 | 18 | 3 | 2 | 26 |

**PhD candidates/promovendi**

| name | University | project code |
|---|---|---|
| T. Schenk, MSc. | MIT | 5.1.1 |
| L.A. Bollinger, MSc. | TU Delft | 5.3.3 |
| M. Adler . | VU Amsterdam | 5.4.1 |
| S. Biramdipathi | TU Delft | 5.3.4 |

**postdocs**

| name | University | project code |
|---|---|---|

| | | |
|---|---|---|
| Dr. D. Danciu | KWR | 5.2.3 |
| Dr. E.J.L. Chappin | TU Delft | 5.3.1 |
| Dr. M. Snelder | TNO / TU Delft | 5.3.2 |
| Dr. C. Bogmans | VU Amsterdam | 5.4.2 & 5.4.3 |
| | | |

**researchers**

| Name | University | project code |
|---|---|---|
| Ir. N. Maas | TNO | WP5.1; 5.1.1 |
| Drs. T. Groen | TNO | 5.1.1 |
| Drs. A.F.L. Slob | TNO | 5.1.1 |
| Drs. R. Massink | TNO | 5.1.1 |
| Ir. J. Jochemsen | TNO | 5.1.1. en 5.2.2 |
| Ir. H.T. Sman | Deltares | WP5.2; 5.2.1 |
| Drs. J.W.M. Salemans | Deltares | 5.2.1 |
| Ir. J. van Ruijven | Deltares | 5.2.1 |
| Ir. T. Bles | Deltares | 5.2.1 |
| Drs. A. Hartman | Deltares | 5.2.1 |
| Ir. W. van Kanten – Roos | TNO | 5.2.2 |
| Prof. ir. A.W.C.M. Vrouwenvelder | TNO | 5.2.2 |
| Dr.ir. M.S. de Wit | TNO | 5.2.2 |
| Dr. O. Morales Napoles | TNO | 5.2.2 |
| Ir. J.N. Huibregtse | TNO | 5.2.2 |
| Ir. R.M.L. Nelisse | TNO | 5.2.2 |
| Dr. Ir. J.H.G. Vreeburg | KWR | 5.2.3 |
| R. Beuken, MSc. | KWR | 5.2.3 |
| Ing. G.A.M. Mesman | KWR | 5.2.3 |
| Dr.ir. E.J.M. Blokker | KWR | 5.2.3 |
| Drs. P.G.G. Slaats | KWR | 5.2.3 |
| Dr.ir. P. van Thienen | KWR | 5.2.3 |
| Dr.ir. B.A. Wols | KWR | 5.2.3 |
| Ir. I.N. Vloerbergh | KWR | 5.2.3 |
| Dr.ir. E.J. den Haan | Deltares | 5.2.4 |
| Dr. C. Zwanenburg | Deltares | 5.2.4 |

| | | |
|---|---|---|
| Dr.ir. G.P.J. Dijkema | TU Delft | WP5.3; 5.3.1; 5.3.2 |
| Dr.ir. I. Nikolic | TU Delft | 5.3.3 en 5.3.1. |
| Dr. C. Davis | TU Delft | 5.3.1 |
| Prof.dr.ir. P.M. Herder | TU Delft | 5.3.4 |
| Prof. dr. P. Rietveld | VU Amsterdam | WP5.4; 5.4.1; 5.4.2; 5.4.3 |
| Dr. J.N. van Ommeren | VU Amsterdam | 5.4.1 |
| | | |

**PPO (project publication officers)**

| name | Affiliation | work package / project code |
|---|---|---|
| L.A. (Andrew) Bollinger | TU Delft | |
| T. Groen | TNO | |
| N. Croes | TNO | |

**Matching projects (cofinancieringsprojecten)***

1. ECCONET - Effects of Climate Change On the inland waterway Networks (Transport & mobility: T&M, Leuven, Belgium)

**Adjacent projects (aanpalende projecten)**

1. Reliable Transport Systems (VU Amsterdam, Department of Spatial Economics)
2. Rimarocc - Risk Management for Roads in a Changing Climate (Swedish Geotechnical Institute)
3. Climate proof Areas – Interreg IVB (Province of Zeeland)
4. Building blocks asset management (KWR Water Cycle Research Institute)
5. Sensible Sewer Rehabilitation (Waternet)
6. Mechanisms of loose deposits' microbiota effect on the quality of chlorinated distribution systems (Laboratiorio Nacional de Engenharia Civil: LNEC, Portugal)
7. Communities and Climate Change (Massachusetts institute of Technology (MIT) i.c.w. USGS and TNO)
8. Climate and water (TNO)
9. Towards robust infrastructure networks (TNO)
10. Climate and Environmental change and Sustainable Accessibility of the Randstad (Utrecht University)
11. Research programme on next generation infrastructures, 2008-2012 (TU Delft / NGI)
12. Government funded initiative on natural gas infrastructure, 2010-2015 (Energy Delta Gas Research (EDGaR)

**Cofinancieringsprojecten dienen goedgekeurd te worden voordat ze opgenomen kunnen worden als cofinanciering. Alleen goedgekeurde cofinancieringsprojecten komen in dit overzicht te staan.*

**Key publications of the consortium (max. 5). For complete list check the website**

- Bollinger, L.A., Dijkema, G.P.J. and Nikolic, I. Resilience of Electricity Infrastructures to Climate

Change.  Adaptation Futures 2012, Tucson, USA, 30 May 2012.

- Bhamidipati, S., Telli van der Lei, Paulien Herder (2012): From mitigation to adaptation in asset management for climate change: a literature review, accepted for 7th World Congress on Engineering Asset Management (WCEAM), Korea,  October 8-10, 2012
- Chappin, E. J. L. & van der Lei, T. (2012), Modelling the adaptation of infrastructures to prevent the effects of climate change – an overview of existing literature, in 'Third International Engineering Systems Symposium – Design and Governance in Engineering Systems – Roots, Trunk, Blossoms', Delft, 18-20 June 2012
- Dijkema,G.P.J., L.A. Bollinger, M. Snelder, C.W.J. Bogmans, E.J.L. Chappin,I. Nikolic Infrastructure Networks, Climate Adaptation and Hotspots - Researching the Interconnections, Exploring Adaptation, *Planet Under Pressure 2012*, London.
- Maas N. (2012) Modelling as knowledge brokerage Instruments, in 'Third International Engineering Systems Symposium – Design and Governance in Engineering Systems – Roots, Trunk, Blossoms', Delft, 18-20 June 2012

## 9.2 ANNEX B: PROGRAMME STRUCTURE and WORK PACKAGE DESCRIPTION

| work packages (short title) | projects (short title) |
|---|---|
| 1 Building adaptation strategies for infrastructures and networks | 1 Building adaptation strategies for infrastructures and networks |
| 2 Climate proofness of physical infrastructure | 1 Design of physical infrastructures (integrative)<br>2 Quantified effects for rail, roads and tunnels<br>3 Effects on subsurface pipe infrastructure<br>4 Subsoil effects due to climate changes |
| 3 Infrastructure network robustness and adaptation | 1 Design of climate proof networks (integrative)<br>2 Modelling failure to assess climate risks<br>3 ABM for transport and energy networks<br>4 Asset management for climate adaptation |
| 4 Socio-economic effects of climate change | 1 Economic impacts of adaptation for transport networks<br>2 Economic impacts of adaptation for electricity networks<br>3 Economic impacts of flexible adaptation approaches<br>4 Costs and benefits of adaptation (integrative) |

| Work package | Title | Description |
|---|---|---|
| **INCAH** | Infrastructure Networks Climate Adaptation and Hotspots – Researching the Interconnections, Exploring Adaptation | INCAH's main research questions (MRQ) are<br>- What are relevant effects of climate change on infrastructures?<br>- To what extent do these effects threaten the safe, sound, reliable operation of infrastructures, their availability and socio-economic productivity?<br>- How can we avoid congestion, service interruption, system breakdown or even systemic crisis through reinforcing effects rippling through interconnected infrastructures?<br>- Through what policies, strategies and governance can we adapt infrastructure networks and make our economic hot-spots robust and resilient to climate change? |
| **WP1** | Building adaptation strategies for infrastructures and networks | This WP is about "how to integrate and valorize the knowledge from WP2-4" by creation of a platform for dialogue between researchers and practitioners, development of a systems model to assemble and structures existing and new knowledge, compilation of flexible adaptation strategies. WP1 addresses all INCAH MRQ's, and specifically:<br>- What - technical, organizational and economic - measures ameliorate system robustness? |

| | | |
|---|---|---|
| | | - What governance, financial, spatial conditions foster implementation of these measures?<br>- How to support decision-making – a roadmap: what measures to implement when? |
| **WP2** | Climate proofness of physical infrastructure | The main research challenges in this WP are<br>- to gain insight in type and magnitude of the effects of changing climate factors on physical infrastructure components<br>- to investigate changing subsoil behaviour in a changing climate.<br>- to determine and quantify vulnerabilities and effects on infrastructure integrity and quality<br>- to conclude with adequate adaptation measures (for hotspots) |
| **WP2.1** | Design of physical infrastructure | This project elaborates these questions for the Schiphol and Rotterdam infrahubs |
| **WP2.2** | Quantifies effects for rail, roads and tunnels | Project analyses the effects on existing roads, railways and tunnels and explores adaptation measures for a required level of functionality and for climate proof design. |
| **WP2.3** | Effects on subsurface pipe infrastructure | This project focuses on drinking water and sewerage pipeline infrastructure |
| **WP2.4** | Subsoil effects due to climate change | This project is about climate change working through subsoil to effect infrastructure, analyses what climate changes effect the physical conditions of subsoil and what associated loads on soils can be determined. How do soils then behave, are they robust and how to quantify this and what effects on infrastructures can be attributed to subsoil behaviour? |
| **WP3** | Infrastructure Network Robustness and Adaptation | WP3 its main questions are:<br>- “what are the sensitivities of transport, ICT and energy infrastructure to climate change; how may climate change affect infrastructure robustness (system integrity, operation, safety, reliability etc.)”<br>- “what asset management and design of infrastructure networks provide short term robustness and long-term resilience to climate change,”<br>- “under what (policy, regulatory) conditions and incentives may such systems emerge. |
| **WP3.1** | Design of climate proof networks | This project liaises with WP1 and synthesizes WP3’s main questions |
| **WP3.2** | Modelling failure to assess climate risks | This is concerned with “how can road and energy networks be made more robust against the effects of climate change” and “how to model climate events and associated network failure over time, while taking into account network design and learning?” In concert with WP1 and WP2 it will be analysed “what currently are the most vulnerable components of transport and energy networks with respect to failure caused by extreme climate events.” |

| | | |
|---|---|---|
| **WP3.3** | ABM for transport and energy networks | main question is “how to construct agent-based models of infrastructure evolution that provide sufficient resolution and reliability to represent the effect of climate change?” How to model relevant actor behaviour and the dominant factors that shape infrastructure networks and make it possible to explore effects of adaptation strategies by simulation? |
| **WP3.4** | Asset management for climate adaptation | The main research question of this project is “how can we incorporate the required robustness of our infrastructures regarding climate change into the asset management of our (physical) infrastructures?” |
| **WP4** | Socio-economic effects of climate change on mainports and on urban infrastructure networks | Main research questions in WP4 are:<br>- What are the socio-economic effects of climate change via changes in the reliability and usability of transport and electricity infrastructures and via the physical infrastructure in the hotspot regions<br>- What are potential flexibility-oriented adaptation approaches? |
| **WP4.1** | Economic impacts of adaptation for transport networks | The research question is “what costs are associated with transport infrastructure damage and associated reduction in the reliability and usability of (1) the road and railway transport networks for travellers of Schiphol airport (2) of the road, railway and waterway corridors for freight transport to and from the Port of Rotterdam. |
| **WP4.2** | Economic impacts of adaptation for electricity networks | This project will analyse the electricity infrastructure on the local-and Randstad level due to climate change |
| **WP4.3** | Economic impacts of flexible adaptation approaches | This focuses on the benefits and costs of a flexible infrastructure adaptation strategy for specific cases in the Schiphol and Rotterdam hotspot regions. |

| WP1 Building Adaptation Strategies for infrastructure and Networks |
| --- |
| National and regional adaptation policies are aimed to make the spatial organization of the Netherlands (or a specific region) robust to climate change. This research program contributes to this goal thereby adopting a demand driven approach, which means that institutions in 'the field' (the stakeholders) deliver input in this program by means of (research) cases. This guarantees that the eventually developed adaptation strategies (in WP1) will satisfy the stakeholders' knowledge needs. The formulated adaptation strategies will then contribute to a climate robust spatial arrangement of the Netherlands.<br>In the integrative WP1, the focus is on knowledge management, scientific and stakeholder dialogue and representing the program results by integrating all WP results in a system model and adaptation strategies. Initially, WP1 will provide a reality-check: which infrastructure networks are affected by what climate change? The nature and magnitude of climate change on design and operation of infrastructure will be assessed and the consequences for adaptation and governance explored.<br>The system model will be built and integrated using results and insights from all WP's; via iteration these will be improved to provide greater resolution and reliability. Interfacing with WP2, 3 and 4, performance changes in infrastructure networks will be elucidated. The work will provide input for governance, and policy and regulatory incentives for climate resilient infrastructure will be developed and analysed. WP1 applies the scientific work to case studies and to the hotspot Rotterdam-Rijnmond.<br>This integrative project mainly has three activities:<br>-organisation of the dialogue between researchers and practice<br>- development of a system model<br>- defining adaptation strategies.<br>By defining the system model together with the stakeholders we will contribute in the development of a common language and each other perspective. The system model will help to compare the several infrastructure system and to see the overlap in possible adaptation strategies. WP1 will bring together the different perspectives to climate change and infrastructure, related to WP 2, 3 and 4. |
| **WP2.1 Climate effects and adaptation measures on physical infrastructures** |
| In project 1, the relationships between climate change and its consequences for the physical infrastructure has been assessed in a qualitative manner, partly based on the insights and knowledge obtained in the more specialized projects 2.2 to 2.4. This knowledge is qualitatively scaled to an overall picture of the impact on infrastructure networks is obtained. The aim is to obtain an overview of the vulnerabilities and the robustness of the system as a whole. This has been examined in the pilot "Botlek case". |
| **WP2.2 Quantification of climate effects and measures for rail, roads and tunnels** |
| During this project a literature study was performed from which an overview of relevant climate effects was deduced. In addition it was concluded that hardly any quantified information on climate change and the effects on infrastructure are available. The next step was therefore to develop a methodology to quantify climate change effects in infrastructure from which measures and/or adaptation strategies could be derived. This method, including one test case is described in a report.<br>The method is based on the resilience of the considered infrastructure system for climate change. Comparing the resilience with the climate scenarios leads to valuable insight for policy making. One question of interest is, at which point in time will the tipping points (that is, when the system can no longer deal with climate change in terms of reliability, availability, maintainability and/or safety) occur and when will current policies no longer be applicable? In this case an alternative set of measures should be selected and implemented. Due to the uncertainties in the climate change scenarios, the derived tipping points are not deterministic but rather modelled through probabilistic techniques.<br>From the previous mentioned literature study, it followed that flooding of tunnels might be considered as an important effect of climate change, due to an expected increase of intensity of rain. As a test case, the methodology is therefore applied to study the effects of flooding due to precipitation in a fictitious tunnel. In order to model climate change effects on precipitation, KNMI data for rain duration and intensity are used. |

Previous research has indicated the importance of considering tail dependence when modelling effects of climate change. Therefore, from the KNMI data parameters of a bivariate copula with tail dependence are computed. After that, the resilience of the tunnel system is obtained by modelling a typical layout, and testing this system for various combinations of rain duration, rain intensity (obtained from the conditional copula) and tunnel components configurations.

The plan is to apply the methodology to two additional test cases. One possibility is to define a test case from the results of a workshop organized in Rotterdam in February 2012. This workshop was a cooperation between project 2.2 and project 3.2. During this workshop critical, in terms of vulnerable to extreme weather conditions, parts of the road network in Rotterdam were identified.In order to implement the methodology in the road authority operations insight is needed how road authorities and other stakeholders make decisions under uncertain circumstances. Todd Schenk (PhD at MIT) is performing research to this topic. From these results conclusions concerning implementation of methodologies to support decision making under uncertain circumstances might be drawn. We will review how our methodology can be adapted based on these conclusions. In addition, stakeholders will be consulted to review the methodology in their practical use.

From scientific perspective, the developed methodology offers a structured process to consider the effects of climate change on infrastructure. In addition, this project is mathematically challenging by considering so called tail dependencies. From societal point of view, this methodology can contribute to a climate robust road network in terms of reliability, availability, maintainability and safety.

## WP2.3 Effects of climate change on subsurface pipe infrastructure

Literature reviews have been made on 1) historical failure data of drinking water distribution systems, 2) failure mechanisms of pipes and joints, 3) mechanical and statistical models to predict future failure rates. These reveal the effect of climate on the integrity of drinking water distribution systems worldwide. The most commonly observed effect of climate parameters on pipe failure in literature is an increased pipe failure during winter and late summer. These effects can be attributed to large temperature differences between pipe and soil causing high thermal stresses, and periods of drought causing differential settlements.

We have analysed the sensitivity of pipe failure rates on climate parameters in The Netherlands from historical data. Since a few years all drinking water distribution pipe failures occurring in the supply areas of about half of the Dutch drinking water companies are stored in a central database called USTORE. These failure data were correlated to KNMI weather data. For some pipe materials, a slight to moderate increase of the failure frequency with temperature and/or rainfall deficit has been observed.

Semi-analytical models from the literature to estimate the stresses in pipes induced by soil displacements were evaluated. These models, based upon Winkler type models, are often used to predict the effect of tunneling underneath pipes. We have developed an analogous approach that uses soil differential settlements induced by climate change to predict stresses in pipes.

From societal perspective we have assembled an overview of possible adaptation measures to climate change for drinking water distribution systems.

The developed numerical model was applied to the Botlek area. Based upon the expected soil differential settlements (determined by Deltares) in this area, it was calculated that only a small increase in stresses is to be expected in the drinking water transport pipes.

## WP2.4 Effects of climate change on engineered slopes

Climate change may result in a reduction of integrity and reliability of engineered slopes in general and can even lead to failure of the soil structure due to pore pressure changes. The failure of a peat dike in the very dry summer of 2003 at Wilnis in the Netherlands (Figure 1.1) illustrates the effect of meteorological conditions on the integrity of a slope. This failure caused no casualties, however the damage was about twenty million euros and since climatic change may cause droughts to occur more often the safety level of the 7000 km of peat dikes in the Netherlands has to be secured. The Knowledge for Climate program of the Dutch Ministry of Infrastructure and Environment therefore supports research into the behaviour of these engineered slopes under changing conditions as the underlying processes are insufficiently known. Results from this research will lead to more efficient and more effective advice for maintenance, remediation and adaptation measurements. The presented research aims at a better description of the flow process in engineered slopes, like road embankments, flood defenses and embankment dams.

## WP3 Infrastructure Network Robustness and Adaptation

The aim of this project therefore is to bring together knowledge on climate-change-robust infrastructure development and design and to develop a coherent framework for understanding and modelling infrastructure adaptation to climate change. Therein the focus is on the design and management of infrastructure systems and networks.

This project aims to develop network models to analyse and design network robustness and test adaptation strategies for the hotspots. The project will address at least two cases: one on a road transport network around a hotspot and one on energy infrastructure, while in both cases ICT infrastructure will be addressed. The specific case scope definition will be aligned with the work done in WP2 and WP4.

The central research questions addressed in this work package and project are 1) "what are the sensitivities of transport, ICT and energy infrastructure to climate change; how may climate change affect infrastructure robustness (system integrity, operation, safety, reliability etc.)" 2) "what management and design of infrastructure networks provide short term robustness and long-term resilience to climate change," and 3) "under what (policy, regulatory) conditions and incentives may such systems emerge."

## WP3.1 Design of climate proof networks

This project is set up as a synthesis project. To address the three central questions, a systemic, integrative and connecting framework will be developed for the analysis, understanding and modelling of infrastructure network adaptation to climate change. To this end, a socio-technical systems perspective will be adopted and adhered to.

Integrating and the projects in WP3

Adopting a socio-technical systems perspective, in the project the impact assessment of climate change  the insights and results from (WP1 and WP2) will be used as a starting point for the analysis and development of network models to analyse and design network robustness and test short-term adaptation strategies for the hotspots (Snelder, Tavasszy, Immers, vZuylen 2008). An inventory and comparison of suitable modelling approaches will be made, and it will be explored where combination of modelling approaches is worthwhile and feasible.

Regular meetings have been held to ensure exchange of knowledge and ideas between the researchers involved. Now that in project 3.2 and 3.3 first prototype models and applications have been developed, the real integration work has started (v.d. Lei and Chappin, 2012).

## WP3.2 Modelling failure to assess climate risks

We need to identify the parts of existing infrastructures that are most sensitive to these severe climate events, in order to focus our attention and energy into securing them in advance. Identification must be done at a component level of these infrastructures, taking onto consideration local geographical and climate conditions.  Once we understand the current state of the network, we need to explore the likely development scenarios, and evaluate how these developments will perform under (worsening) stress. We need to understand how learning that results from operation and adaptation of these infrastructures at the local level can be used to evolve more robust system overall.  Many measures (related to network design, infrastructure design, information provision, routing and route guidance, incident management etc.) can be taken to make road and energy networks more resistant against disturbances. In this project, apart from road or power plant design, we address the network design question – which network structures provide additional robustness and resilience against single or multiple node or hub failures?

The central research questions addressed in this project therefore are 1) is how road and energy networks can be made more robust against the effects of climate changes.

1. What are currently the most vulnerable components of transport and energy networks with respect to failure caused by extreme climate events?

2. Given the models of network evolution, described in project 3, how can we model systematic climate events driven network failure over time, taking learning by stakeholders and improved network design into consideration?

**WP3.3**

The aim of this project is to develop agent-based models that enable exploring the effect of climate change and adaptation by simulation of the long-term development of transport and energy infrastructure networks subject to a variety of scenarios.

While we know we can construct agent-based models of infrastructure evolution (Nikolic, 2009; Chappin et al. 2009), it remains unknown whether these provide sufficient resolution and reliability to represent the effect of climate change. In addition, it is unknown how to suitably represent the behaviour of actors and link these to climate change behaviour. Furthermore, we need a suitable representation of adaptation strategies to allow the comparative simulation.

These will be the central questions addressed: we will elucidate the dominant factors that shape infrastructure networks, how climate change as a stressor relates to these and develop an approach to explore the possible effect adaptation strategy.

Two literature reviews have been completed, one on infrastructures and climate change, a second on modelling approaches. A first model simulating the Dutch electricity grid and the effect  climate events thereupon has been completed. Network representations and data have been built and data is being stored in http://enipedia.tudelft.nl.

**WP3.4**

Asset management is a scientific (management) domain in development. Presently, it is both art and science. The aim of this project is to bring to the table asset managers expertise and questions related to climate change, its effect and possible responses. The objective is to improve our understanding of and somehow incorporate climate change adaptation into asset management, and develop first models to elucidate the drawbacks and benefits of such approaches.

The central research question addressed is “How can we incorporate the required robustness of our infrastructures regarding climate change into the asset management of our (physical) infrastructures? “

Only in 2011 we finally selected and contracted a qualified PhD researcher. As a consequence, this project has effectively started march 2012. To date, literature study and first small case studies have been addressed. The scope of the work will be somewhat reduced, to allow additional time and effort spent on projects 3.1, 3.2 and WP1.

| WP4.1 |
| --- |
| This WP has four parts: (1) The effects of weather on rail disruptions in the Netherlands, (2) Weather and disruptions of road transport (3) Weather and cycling and (4). Economic implications of weather predictions for the transport sector<br>Project 1: The effects of weather on rail disruptions in the Netherlands<br>In this project, we have concluded that there is little or no literature about the effect of weather conditions on rail disruptions. For this reason, we have examined the effect of weather conditions on disruptions as registered by Prorail during a period of about 10 years. We find a strong effect of weather conditions on disruptions, which is much stronger than reported by experts on the tracks which report whether or not a disruption is weather-related. It has also been shown that there are strong effects of weather conditions on the number of delayed and cancelled trains. In addition, we have been able to decompose the effect of weather on the number of delayed and cancelled trains into the effect through disturbances of infrastructure and the direct effect. We show that certain types of bad weather (e.g. snow) affect performance of the train operator mainly indirectly, so through the weather effect on infrastructure disturbances, rather than directly. In general, the welfare losses of bad weather conditions are rather minor. This is in line with our finding that the welfare losses for passengers confronted with increased cancellations of trains and decreased punctuality in the Netherlands due to one standard deviation increase in infrastructure disruptions are only about €0.35 per day per passenger implying welfare losses of about €80 million per year.<br>Project 2: Weather and disruptions of road transport<br>The PhD student started to work with the data from Rijkswaterstaat about the influence of weather disturbances on the road. This will be linked with data about incident management in order to see to what extent incident management must be very based on the weather conditions. We have started to cooperate with TNO.<br>Project 3: Weather and cycling (casus Rotterdam)<br>We received now the data from the municipality Rotterdam to analyse the effect of weather conditions on bicycling for a number of locations for each hour for a period of about 10 years. We are also interested to see to what extent bicycling depends on introduction of paid parking, strikes, fuel prices etc. The first analysis shows strong results for weather, but more detailed analysis is needed.<br>Project 4: Economic implications of weather forecasts for the transport sector<br>We have now good contacts with the Dutch Meteorological Institute KNMI in order to receive data about weather forecast and their effect on household and firm decisions regarding mobility. So, we aim to do what extent forecasts change behaviour of actors. This is a first step to determine the economic value of an accurate weather forecast. This project has not started yet. |
| **WP4.2** |
| The second theme focuses on the socio-economic effects of climate change impacts on infrastructure, with an emphasis on vulnerable assets in the electricity sector. Flexible adaptation strategies that deal with these impacts also constitute an important research topic. The study of these strategies takes place by the application of cost-benefit analysis to case studies, but work in progress also includes novel theoretical models that aims to elucidate in detail the basic trade-offs that influence decision making in the context of adaptation.<br>Project 1. Reliability and vulnerability of electricity supply in the context of climate change. In this project the reliability and vulnerability of electricity supply in the context of climate change is studied; a qualitative literature overview of infrastructure impacts and possible adaptation strategies is provided. Typologies are categorized across technologies (e.g. renewable, non-renewable) and stakeholders (e.g. producers, consumers). There is also a quantification of economic costs for certain types of infrastructure. Potential effects of uncertainty regarding climate change on stakeholder behaviour are also discussed. In contrast to previous work in the literature, this project provides for a true economic assessment of climate change impacts in the electricity sector.<br>Project 2. Optimal climate change adaptation of thermal power plants. Worldwide more than 70% of electricity supply is generated in so-called thermal power plants. These power plants are very much reliant on |

cooling water from fresh water bodies for their continuous operation. As explored in a growing number of studies in the literature, climate change might lead to a steady deterioration of hydrological conditions. As a consequence, effective production capacity is reduced, thereby threatening the continuous supply of electricity in modern market economies. In this paper we add to the literature by combining insights from economics and state-of-the-art hydrological models to estimate the expected costs of climate change for a representative selection of EU thermal power plants. In addition, by making use of real options analysis we explore the optimal timing of investment in cooling towers, a feasible but as of yet unexplored adaptation strategy.

Project 3. Optimal adaptation with subjective risk perceptions (please do not cite ). Optimal adaptation is studied in a theoretical model where the costs of climate change are associated with stochastic occurrence of extreme events (e.g. natural hazard, extreme weather event, oil spill, earthquake, environmental disaster). In contrast to previous papers, it is assumed that decision makers are endowed with subjective risk perceptions. First, we assume that decision makers ex-ante overestimate (underestimate) the occurrence of high (low) probability, low (high) impact events. Second, catastrophic events not only impose direct costs on society, but they might also ex-post change the perception of future risks, which could either mitigate or increase the expected damages from future events. The method of dynamic programming is employed to analysis the dynamics of adaptation under these assumptions.

Project 4. Real option analysis in network settings (please do not cite ). Deferral of adaptation investments can be efficient if they are costly and irreversible and if there is a substantial degree of uncertainty regarding their expected benefits. Problems of this nature are even more complex in networks because network-based adaptation strategies are likely to be characterized by a large number of different, but interdependent options. These options might be interdependent both from a spatial point of view as well as an intertemporal perspective. Preliminary analysis in the literature indicates that the value of flexible investment strategies is likely to be even higher than usual. A numerical scheme to analyse such networks of options is developed and applied to a high-scale interpretation of the Dutch electricity network to study a yet to be determined investment problem.

**WP4.3**

tbd

## 9.3 ANNEX C: HOTSPOTS and CASE STUDIES

| Hotspots and stakeholders | Contribution | Case studies |
|---|---|---|
| Rotterdam | 75 kE | Botlek Area<br>Development of adaptation strategy for hotspot Rotterdam |
| | | Cycling in the city |
| Haaglanden | 0 kE | |
| NS | 0 kE | Disturbances in rail transport |
| ProRail | 12 kE (in kind) | Disturbances in rail transport |
| TenneT | 12 kE (in kind) | High voltage electricity network |
| RWS | 200 kE | Robust networks<br>Incidents and traffic disturbances |
| RWS-Zuid Holland | 32 kE (in kind) | Development of Adaptation strategy for hotspot Rotterdam |
| Waternet | | |
| STOWA | 50 kE | |

## 9.4 ANNEX D: PUBLICATIONS AND COMMUNICATION ACTIVITIES

| PUBLICATIONS | |
|---|---|
| **a. Boek (Book)** | |
| Chmieliauskas, A.; Chappin, E.; Davis, C.; Nikolic, I. & Dijkema, G. (2012), *New Methods for Analysis of Systems-of-Systems and Policy: The Power of Systems Theory,Crowd Sourcing and Data Management*, in Adrian V. Gheorghe, ed., 'System of Systems', Intech, | TUD |
| Sabir, M., Ommeren, J.N. van, Koetse, M.J. & Rietveld, P. (2010). Weather and travel time of public transport trips: an empirical study for the Netherlands. In M. Givoni & D. Banister (Eds.), *Integrated transport: from policy to practice* (pp. 275-288). Abingdon, Oxon: Routledge | VU |
| **b. Brochure (Brochure)** | |
| INCAH brochure | TNO |
| **c. Eindrapport van project (Final project report)** | |
| - | |
| **d. Persbericht** | |
| - | |
| **e. Project factsheet (Project factsheet)** | |
| - | |
| **f. Nieuwsbrief van project (Project newsletter)** | |
| Editors, Publicatie datum, Titel, Naam van serie, Totaal aantal pagina's, Status | Projectpartner(s) |
| Groen, T., Tavasszy, November 2010 | TNO |
| Maas, N., T. Groen, Mei 2012, nieuwsbrief INCAH, 4 p. (verzonden) | TNO |
| Maas N., N. Croes, Juli 2012, Nieuwsbrief INCAH, 4 p. (verzonden) | TNO |
| **g. Populair artikel over wetenschap (Popular article about science)** | |
| TNO Magazine, Climate research at TNO, among which is INCAH<br><br>TBM Quarterly, Jaargang X, nr. 2: L.A. Bollinger, “Klimaatverandering en elektriciteitsnetwerken”; G.P.J. Dijkema, “Nederland voorbereiden op klimaatverandering” | TNO |
| **h. Poster** | |
| Posters from all INCAH projects, used in first stakeholder workshop in May 2011 | All consortium members |
| Bollinger, L.A., Climate change and energy infrastructures – Balancing mitigation and adaptation, IGS-SENSE Conference 2011. | TU Delft |

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|---|---|
| Bollinger, L.A., Growing climate-resilient energy infrastructures, UKERC Summer School 2011. | TU Delft |
| **i. Proceedings** | |
| Bhamidipati, S., Telli van der Lei, Paulien Herder (2012): From mitigation to adaptation in asset management for climate change: a literature review, accepted for 7th World Congress on Engineering Asset Management (WCEAM), Korea, October 8-10, 2012 | TU Delft |
| Bollinger, L.A. Balancing the demands of climate change adaptation and mitigation in energy infrastructures – a modeling framework. Proceedings of the IGS-SENSE Conference 2011. In print. | TU Delft |
| Bollinger, L.A. and Dijkema, G.P.J. Resilience of Energy Infrastructures to Climate Change. 3rd International Engineering Systems Symposium (CESUN 2012), Delft, Netherlands, 20 June 2012. | TU Delft |
| Bollinger, L.A., Dijkema, G.P.J. and Nikolic, I. Resilience of Electricity Infrastructures to Climate Change. Adaptation Futures 2012, Tucson, USA, 30 May 2012. | TU Delft |
| Bollinger, L.A., A modeling framework for supporting the development of climate-resilient energy systems in the Netherlands. ISIE 2011, San Francisco, 8 June 2011 | TU Delft |
| Chappin, E. J. L. & van der Lei, T. (2012), Modeling the adaptation of infrastructures to prevent the effects of climate change – an overview of existing literature, in 'Third International Engineering Systems Symposium – Design and Governance in Engineering Systems – Roots, Trunk, Blossoms' | TU Delft |
| Maas N. (2012) Modeling as knowledge brokerage Instruments, in 'Third International Engineering Systems Symposium – Design and Governance in Engineering Systems – Roots, Trunk, Blossoms', Delft, 18-20 June 2012 | TNO |
| **j. Presentatie (Presentation)** | |
| Adaptive Policy Making, inleidende presentatie stakeholderworkshop op 17 en 18 mei. | TNO |
| Nelisse, M., “Klimaatbestendige tunnels”, Dag ondergronds bouwen 17 juni 2011 | TNO |
| Bollinger, L.A.. A modeling framework for supporting the development of climate-resilient energy systems in the Netherlands. ISIE 2011, 8 Juni 2011. | TU Delft |
| G.P.J. Dijkema, L.A. Bollinger, M. Snelder, C.W.J. Bogmans, E.J.L. Chappin, I. Nikolic Infrastructure Networks, Climate Adaptation and Hotspots - Researching the Interconnections, Exploring Adaptation, Planet Under Pressure 2012, London (also presented at Keio University, SDM, Tokyo, Japan, August 2012). | TU Delft |
| Maas, N. Regional adaptation strategies for Mobility, Resilient Cities, ICLEI conference, Bonn, 12 – 15 May 2012 | TNO |

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|---|---|
| Bollinger, L.A. Presentation of  a poster at the UK Energy Research Council (UKERC) Summer School, University of Warwick, on the developed agent-based model, November 2011 | TU Delft |
| Bollinger, L.A., Paper submission and poster presentation at the IGS-SENSE Resilient Societies Conference, at the University of Twente, October 2011 | TU Delft |
| **k. Proefschift (PhD thesis)** | |
| - | |
| **l. Rapport (Report)** | |
| Huibregtse, E., Nelisse, M, Kanten, W. van, Wit, S. de (2012), Inventory of climate change effects on infrastructure TNO rapport TNO-034-DTM-2010-04986 | TNO |
| Huibregtse, E., Kanten, W. van, Nelisse, M. (2012), INCAH – Resilience analysis, draft TNO report | TNO |
| Esch, dr.ir. J. van, ir. H.T. Sman, "Impact of climate change on engineered slopes for infrastructure; computer model", Deltares report, draft dec 2011, ref. 1201351-008. | Deltares |
| Bollinger, L.A. Evolving climate-resilient energy infrastructures - A proof-of-concept model. Draft (2012). http://wiki.tudelft.nl/pub/Main/AndrewBollinger/Proof_of_concept_model_summary.pdf | TU Delft |
| **m. Wetenschappelijk artikel (Scientific paper)** | |
| Xia, Y, J.N. van Ommeren, P. Rietveld, W. Verhagen (2012), WEATHER, disruptions and the railway sector (draft) | VU |
| Expected 2012: L.A. Bollinger, C. West, I. Nikolic, G.P.J. Dijkema, C. Topi and J. Timmis. Integrated assessment of climate change – surveying the advantages of agent-based modeling (submitted for review 2012) | TU Delft |
| **n. Wetenschappelijk artikel peer reviewed (Scientific paper peer reviewed)** | |
| Bollinger et al, Climate adaptation of infrastructure networks: lessons from the energy, transport and water sector, special issue Climate Adaptation of Regional Environmental Change (accepted abstract) | TUD, VU, KWR, TNO |
| Expected 2012: L.A. Bollinger, C. West, I. Nikolic, G.P.J. Dijkema, C. Topi and J. Timmis. Integrated assessment of climate change – surveying the advantages of agent-based modeling. | TU Delft |
| Jonkeren, O.E., Demirel, E., Ommeren, J.N. van & Rietveld, P. (2010). Endogenous transport prices and trade imbalances. *Journal of Economic Geography, 4* (feb.), 1-19. | VU |
| Rietveld, P. (2010). Publiek en privaat initiatief bij klimaatadaptatie. *Beleid en Maatschappij, 37*, 29-43. | VU |

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|---|---|
| Chmieliauskas, A.; Chappin, E.; Davis, C.; Nikolic, I. & Dijkema, G. (2012), New Methods for Analysis of Systems-of-Systems and Policy: The Power of Systems Theory,Crowd Sourcing and Data Management, in Adrian V. Gheorghe, ed., 'System of Systems', Intech | |

| COMMUNICATION ACTIVITIES | |
|---|---|
| **a. Workshops** | |
| Stakeholder Kick Off, September 2010 | TNO |
| First stakeholder workshop, May 2011 | TNO |
| Second stakeholder workshop, February 2012 | TNO |
| Vulnerability Analysis Workshop, February 2012 with hotspot Rotterdam | TNO |
| **b. Steering Groups** | |
| Steering Group meeting, January 2011 | TNO |
| Steering gGroup meeting, November 2011 | TNO |
| Steering Group meeting, February 2012 | TNO |
| Steering Group meeting, June 2012 | TNO |
| **c. Consortium Meetings** | |
| Project Kick off, September 2010 | TNO |
| First Consortium meeting, May 2011 | TNO |
| Second Consortium meeting, February 2012 | TNO |
| WP3 / WP1 Research meeting June 2012 | TU Delft, TNO |
| Regular WP3 – Researchers meetings 2010, 2011, 2012 | TU Delft |
| **d. Stakeholder Meetings** | |
| Presentation RAS Team Rotterdam, March 2012 | TNO |
| TenneT meetings 2011, 2012 | TUD |
| Several bilateral meeting with stakeholders | projectpartners |