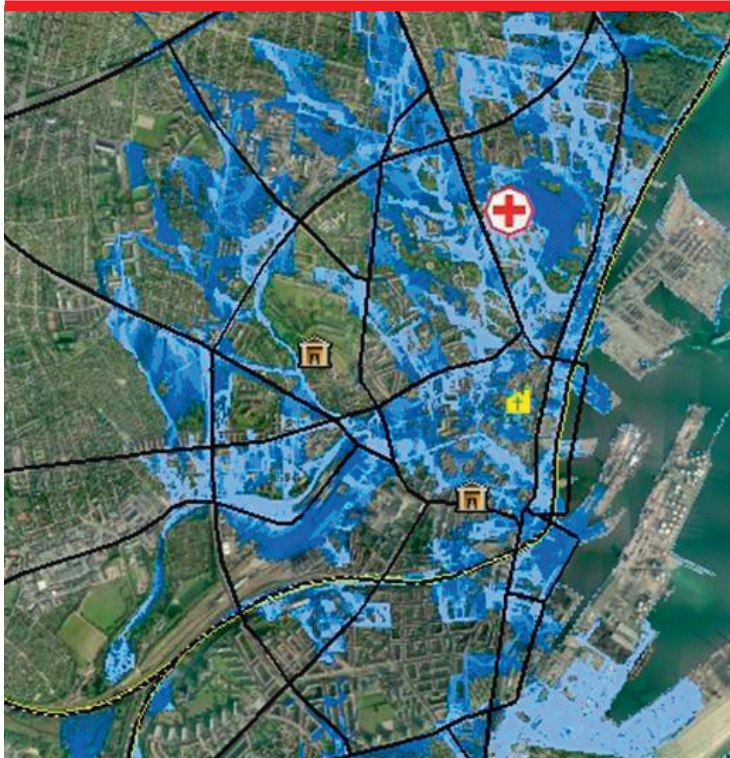# Methodological framework, analytical tool and database for the assessment of climate change impacts, adaptation and vulnerability in Denmark

Report 11.2012

DTU Management Engineering

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Coordination Unit for Research in Climate Change Adaptation

DTU Management Engineering
Department of Management Engineering

Data Sheet

Preface

This report was prepared at the request of and funded by the Coordination Unit for Research in Climate Change Adaptation (KFT).

The report is a milestone of the project titled "*Udvikling af metodisk ramme for dansk analytisk værktøj og database over klimasårbarhed og klimatilpasning", funded by KFT*. The project is one of seven initiatives proposed by KFT for 2012. The methodology report includes definitions of major concepts, an outline of an analytical structure, a presentation of models and their applicability, and the results of case studies.

The work presented in this report draws on intensive research collaboration with several Danish universities and Centres of Excellence, including DMI, GEUS, DHI, Aarhus University, Copenhagen University, and DTU. Work carried out by our research partners has been co-funded by a number of different sponsors, including KFT and the Danish Strategic Research Council.

The flood hazard maps presented in this report constitute the first preliminary results of on-going methodological and analysis development in mapping potential impacts in relation to flooding from extreme precipitation in the city of Aarhus. For all purposes the Aarhus flood maps presented in this report should be considered work-in-progress. The analysis was conducted by DHI as part of the DSF project Centre for Regional Change of the Earth System (CRES).

Contents

1. Introduction

This report provides a short introduction to a methodological and modelling framework that can be used to assess climate risks and adaptation options. The framework has been developed in a Danish context as part of an on-going collaboration between Danish universities and other research institutions in research projects as well as in the context of the Coordination Unit for Danish Research in Climate Change Adaptation (KFT).

In the following the major focus is how integrated assessments of climate change adaptation related to decision making can be structured and established through linking of data, modelling tools and conceptual models from various disciplines including climatology, ecology, hydrology, agricultures sciences, energy systems, urban systems, economics, sociology, etc.. Obviously, it is not possible to be comprehensive within such a broad field, and hence the present manuscript aims at providing an overview of linkages and analytical structures that are particularly illustrating related to specific case studies in the urban and rural areas.

The described system follows a bottom up approach, which implies that the idea is to support context specific assessments of areas, which are expected to be particularly vulnerable to climate change impacts (hotspots). Such assessments, while being specific, also have a strong generic methodological element, and a major aim of the paper is to develop and apply this element.

Application of an approach for detailed context specific assessments as in the present context is extremely demanding in terms of data access, and it has therefore been a major part of the work to retrieve relevant data sets and to establish a proper database related to the included Danish case examples. The complexities in data access are manifold and include the multidisciplinary character of the data, formatting problems, property rights, and commercial issues. Being part of a several research projects has helped to overcome many of these barriers, but it also means that some of the data and modelling tools mentioned herein are not freely available to the public. This hindrance is unfortunate, as these tools could be highly interesting for broader use by, e.g. stakeholders and local governments.

2. Scope of the report

The report is presenting a general methodological framework and an analytical tool that can be used to assess climate change impacts, vulnerabilities, and adaptation options in Denmark. The report includes definitions of major concepts, outlines an analytical structure, identify models and applications, and finally present case study results based on the approach.

The scope of the framework is on the provision of policy relevant information where climate change impact data and potential adaptation options and costs can be assessed in an integrated manner. There are marked differences as to how data will be used in relation to different climate change impacts and adaptation studies in a sectorial or geographical scope. The analytical tool and the data system presented in this report reflects the scope of on-going research projects including CRES (Centre of Regional Change in the Earth System) and RiskChange (Risk Based Design in a Changing Climate), both funded by DSF (Det Strategiske Forskningsråd). This means that the system in no manner may be considered comprehensive in covering all relevant areas and sectors for Danish climate change adaptation analysis.

The final part of the report presents the results of a case study on flood impacts from extreme precipitation in the city centre of Aarhus. This case study highlights key methodological issues and

documents the requirements for data integration and further development of analytical tools including detailed climate models, impact models and tools for socioeconomic analysis.

3. Climate change vulnerability, risk and adaptation

The published literature on climate change impacts and adaptation offer various definitions of risk and vulnerabilities. In many cases they are designed in order to reflect specific issues of policy relevance within the area. At the same time, very comprehensive and integrated concepts are suggested, that take several cross sectorial and interdisciplinary aspects into consideration, which often leads to rather complicated approaches. In the following we propose a specific methodological framework that may be used to develop and apply a bottom up based integrated assessment tool. The concept definitions and analytical structure will reflect the aim to support climate risks assessment as support to decision making on adaptation options.

A key focus of climate change impacts and adaptation studies is to determine the vulnerability of a system, and to propose decision making to support the development of effective adaptation strategies to reduce vulnerability. According to the *Intergovernmental Panel on Climate Change - Working Group II (2007)* "Vulnerability to climate change is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity".

A full implementation of this vulnerability concept in comprehensive studies is likely to prove extremely demanding if a broad range of climate sensitive sectors are to be covered, and even then it will remain to be determined how valuable it is to establish such detailed overviews of vulnerabilities. The present approach is to address vulnerabilities as a broader screening exercise, which as a first qualitative step is used to select areas for in depth adaptation analysis.

Following the definition of vulnerability, proper adaptation strategies should aim at reducing vulnerabilities related to specific climate risks, and assessments should therefore focus on how climate change affects natural and human systems, determination of physical, social, and economic consequences, and thereby measure climate change risks. Following that, adaptation strategies aim at balancing potential risk reduction and adaptation costs.

Climate change risks are here defined as the consequence of a climate event times the probability of the event.

4. Framework for integrated climate change impact and adaptation analysis

A generic structure for generating technical information for climate change adaptation is illustrated in Figure 1. This figure demonstrates how information about the climate system, impacts, and related costs may support decision making. The approach for generating information can be structured into five different analytical steps:

- Climate and socioeconomic projections
- Impact assessment
- Mapping of physical impacts
- Risk and adaptation costs assessment
- Decision support

Each of the five steps is discussed in detail below.
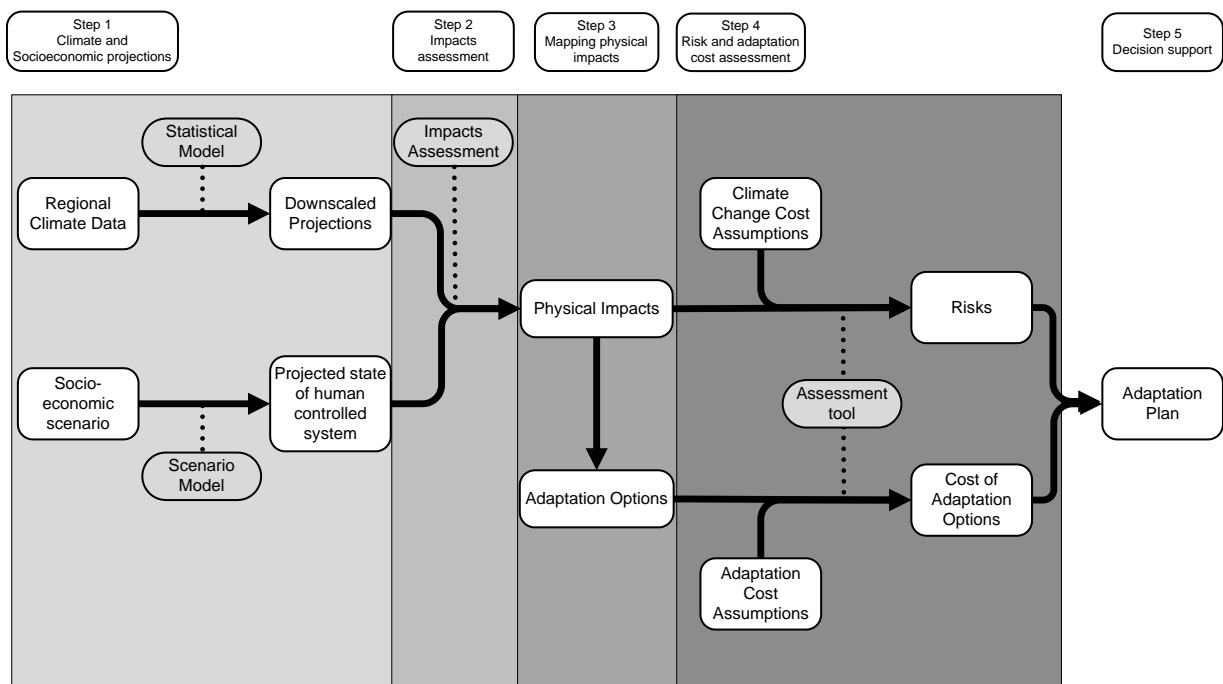
Figure 1: Generic structure for providing information for decision support in relation to climate change adaptation.

Climate and socioeconomic projections

In this step, various possible scenarios are created for future conditions. Typically, we will have two classes of scenarios:

1. A reference scenario (where current trends are projected into the future)
2. A climate change scenario (where additional forcing from a changing climate is considered)

The Reference scenario

From Figure 1, there are *at least* two dimensions in developing a reference scenario: the physical climatic projections and the socioeconomic projections. The reference scenario projects the likelihood for unchanged climatic conditions (including the probability for extreme weather events) into the future, as well as serves to establish a plausible storyline for future socioeconomic conditions. There may be several reference scenarios developed in order to conduct sensitivity analyses on different parameter values to determine which are the most important to target for further study in order to reduce uncertainty.

Physical parameters (e.g., temperature and precipitation) are predicted using climate models or earth system models. In some cases, such as urban flooding, detailed precipitation data are necessary. Typically, output from coarse resolution (global or regional) climate models must be statistically downscaled to a finer spatial resolution. This can be one of the challenging aspects of this step, and the distribution of local climate parameters (such as precipitation) is potentially highly uncertain.

The reference case also aims at projecting socioeconomic activities in the area of interest. In order to subsequently link climate impacts and socioeconomic activities, it will often be relevant to develop a geographical representation of the activities, which is not directly built into the structure of economic modelling tools. The socioeconomic scenario may also include estimates for the uncertainty bounds for the historic data and projected scenarios, or have important assumptions noted in the projections as determined from a sensitivity analysis.

The Climate change scenario

The climate change scenario is based on outputs from climate models or earth system models. Depending on the time frame considered for the adaptation options, climate change projections will be strongly conditioned on different emission scenarios (see, for example Intergovernmental Panel on Climate Change., Working Group 3, 2000 for further discussion). Since 2000 the SRES family of emission scenarios have been used almost exclusively, these scenarios are, however, presently being replaced by a new family of scenarios called the Representative Concentration Pathways (RCP).

If the relevant time horizon for a specific purpose is the "near future" (i.e. up to 2050), there is not much difference in the predicted climate parameters across various climate change scenarios; the difference in the scenarios due to emissions is seen exclusively on longer time scales (towards 2100 and beyond). Thus, for assessments of climate change impacts using the longer time horizon, it may be necessary to consider multiple climate change scenarios, as no inherent probability have been asserted to the underlying emission scenarios.

The two different scenarios (reference vs. climate change) allow us to discern how climate change affects individual parameters and will lead to a better understanding of the impacts in the next step. Often, it will be necessary to determine the probability distribution of climate parameters in order to determine how climate change affects the probability of events with different levels of severity. In Figure 2, we have a hypothetical physical climate parameter whose value is normally distributed with a specific mean (μ) and standard deviation (σ). In this example, climate change causes the distribution to change, with both an increase in the mean ($\mu+\alpha$) and standard deviation ($\sigma+\beta$). Thus, climate change increases the probability of a more extreme event, because the distribution is shifted to the right (increase in the parameter mean) and the distribution has heavier tails (increase in the parameter standard deviation). For some parameters, the shape of the distribution would likely be single-tailed,

with climate change shifting the distribution such that the tail is heavier. The climate scenario could also affect the skew or kurtosis of the distribution, which could also increase the probability of an extreme event occurring.
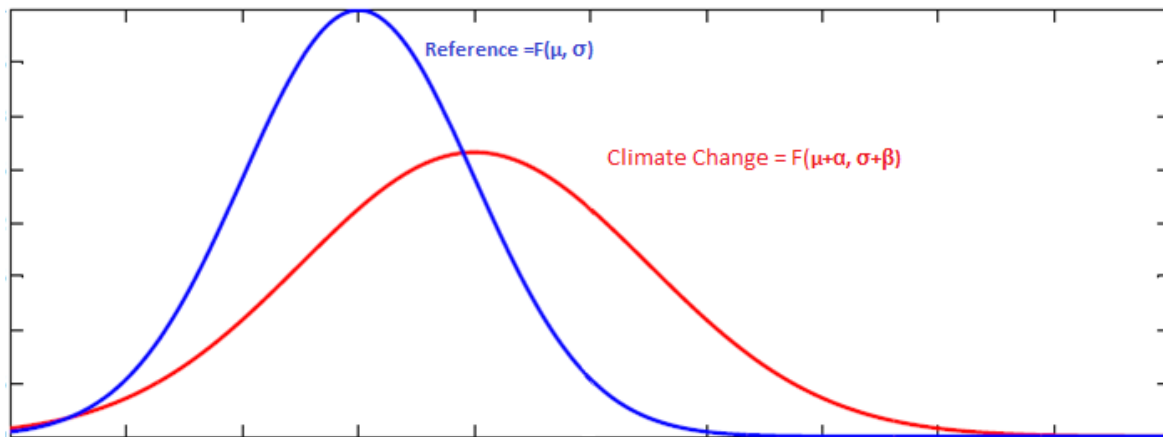

Figure 2: Hypothetical example of the distribution of a climate parameter in both a reference and climate change scenario

Impact assessment

Using data from, say, regional climate models, coupled with a socioeconomic scenario (that can include municipal zoning, structures, or agricultural land use), the impact assessment determines the facets of the urban or rural (the first often employing a downscaling of the climate model data) system that could be impacted by the future climate. The output of this process is a list of physical impacts, their severity, and the likelihood of occurrence. Already in the selection of focal impacts to measure, there is a clear link to decision making, since the geographical scope and the investigated impacts are to reflect major priorities and issues of concern by different stakeholders (see the section on Decision support for more details).

As risk can be defined as the probability and severity of the impact multiplied by a cost value (either intrinsic or monetary), it is important that the units of analysis for the impacts are quantitative. This opens up possibilities for many different types of metrics and indicators to determine the level of the impact. Thus, there is some subjectivity in determining what the boundaries to the system are, which impacts are included, how they are measured, and what threshold defines an impact.

Mapping physical impacts

From the impacts assessment, the next step is to denote and map the physical impacts. To do this, it is necessary to clearly define the geographic boundaries of the impacts. To the extent possible, the boundaries should be defined in a way where the impacts reflect legal and political governance seen from a decision making perspective. In a Danish context relevant governance boundaries are municipalities, regions or national.

Mapping the physical impacts will give a better understanding of the linkages between the impacts. Thus, there is an additional dimension where the impacts can take the form of a network of causal chains. For example, increased probability of extreme precipitation events could lead to more runoff and nutrient leaching into stream catchments. This in turn can lead to eutrophic conditions in lakes,

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and consequently lead to loss of aquatic biodiversity. In urban areas, for example, power line damage may increase the risk of fire which would lead to property damage.

For rural areas, mapping the physical impacts can be done within a Geographical Information System (GIS), and dedicated spatially explicit agricultural and land cover models. Because topography, hydrology, and pedology are spatially explicit information and as they are essential inputs to the analysis models, it follows that the impacts will also be defined spatially. When modelling sediment and nutrient flows, the scale of analysis will typically be a catchment or watershed.

The urban system can also be modelled using a GIS. As for rural areas this requires the application of a combination of spatially explicit hydrological and land use/land cover models. In mapping the physical impacts from flooding from extreme precipitation events of different levels of severity (different return periods), hazard maps showing the extent of flooding from the individual precipitation events are created using a pipe flow model and an surface flow model (such as MIKE URBAN & FLOOD[1], models used to simulate water drainage in sewer systems and related overland flow). Combining the hazard map with a geographical representation showing the assets of interest within the urban area will provide a detailed map of the expected physical damage categories. Identifying the assets potentially affected is essential in performing the next step: risk and adaptation cost assessment.

Risk and adaptation cost assessment

Decisions about climate change adaptation rely on technical information about the risks of climate change compared with the costs of mitigating the risks through adaptation. Climate risk, as defined in this report is the probability multiplied by the consequence of an event. The probability can be expressed in terms of either a return time or an annual probability. For phenomena that are expected to become increasingly likely, such as extreme precipitation, it may be more illuminating to plot this in terms of annual probability, since return time assumes a constant probability of occurrence though time. Moreover, annual probabilities are more conducive to this analysis, since the annual probability is the multiplicand in the risk calculation.

The next step is to assess the various adaptation options in terms of their cost, and how well do they perform in reducing the risk from extreme climate events. It is also important to note any other potential benefits from specific actions, and as with the risks, whether or not a specific monetary value can be assigned.

Not all costs are straightforward to monetize. For example, flooding can destroy homes and the cost of this impact can be determined by the homes' replacement values. The impacts on physical assets are the easier to value since they are related to the market and a cost can be associated with handling the damages. Climate change and extreme climate events can also impact human health. Health impacts in terms of injuries and mortality are often represented by standard economic valuation approaches in terms of the value of a statistical life (VSL) (Murphy and Topel, 2006), but it can be argued that there are specific health impact aspects that are not fully represented by monetary values. Thus it might be informative both to supply monetary and non-monetary information about health impacts and injuries related to a climate extremes.

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[1] Hydrological models provided by DHI. http://www.dhisoftware.com/.

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It is particularly difficult to provide information about the value of natural and historical heritage and other values related to recreational areas, since these "assets" are not related to markets and cannot be totally replaced if they negatively affected. There are a number of economic techniques that can be used to estimate monetary value in these areas, but as with health impacts it can be argued that such values do not fully represent the assets and monetary information should be supplemented with physical descriptions. Hence, adaptation options that prevent these impacts will have a value that is much more difficult to quantify specifically (parameter uncertainty).

Nevertheless, the comparison of the costs of adaptation versus the climate risks can avoid some climate change impact valuation problems. For instance, it may be possible to identify adaptation options that have a lower cost than what is included in the integrated assessment of climate risks, considering that these risks only represent part of the climate change consequences. It can also be argued that in some cases, it can be worth spending more on climate change adaptation than what is included in a risk assessment, for example, if we adhere to the precautionary principle.

Decision support

The climate and socioeconomic projections, impact assessment, mapping and risk and adaptation assessment finally feed into the last analytical step Decision Support, where the total "balance" of evidence of expected climate change consequences is going to be balanced in relation to costs and other impacts of implementing adaptation options. More formally, all impacts are here considered jointly in a decision making framework, which can be thought of as an objective function for measuring adaptation options, where the arguments in the function should reflect social perspectives as well as various private stakeholder interests.

As previously emphasised in the Impact assessment section, the final analytical step on Decision support has a lot of implications for previous analytical steps, since decision support is demanding very specific information based on, what is relevant to stakeholders and society. It is therefore recommended to organise an ongoing interaction between the decision support component and other analytical steps right from the beginning of adaptation assessments. Examples of key feedbacks from decision support to other analytical steps are:

- Screening of vulnerabilities and selection of areas for in depth adaptation analysis.
- Selection of focal climate impact areas to assess.
- Consideration of values and measurement units for different climate impacts in relation to physical assets, health, ecosystems, historical heritage etc.
- Risk aversion attitudes.
- Uncertainties.
- Equity aspects.

A number of these aspects can be addressed in specific studies on preferences, perceptions, values, and stakeholder priorities.

5. Danish Integrated Assessment System (DIAS)

The generic analytical structure described above has been implemented in a Danish integrated database and analytical tool. This system will be introduced below.

The scope of the system may briefly be described by highlighting a few key examples of policy relevant questions that have guided the development. These include:

- Which climate risks are particularly important to various stakeholders recognizing preferences, risk attitudes, and the relationship to decision making.
- Adaptation options related to flooding in urban areas including technical measures, behaviour, and responses by the private sector.
- Adaptation options in urban areas related to hot spells and health including urban structures and health support to elderly people.
- Adaptation options related to ecosystems e.g. in relation to agriculture and the Water Framework Directive.
- Critical infrastructure including harbours, bridges, and roads.
- Agricultural investments e.g. related to husbandry.
- Water conflicts related to groundwater demand.
- Land use structure in agriculture and forestry given climate change impacts and adaptation.
- Biodiversity impacts of changed temperature in freshwater systems, relationship to agricultural land use, and other human systems.
- Urban development, demands for nature conservation areas, and the relationship to adaptation options in cities and the open land.

Despite differences in focus and modelling tools for studies related to different policy relevant questions as those mentioned above, the Danish integrated assessment system (DIAS) for climate adaptation studies has been developed in order to support different research groups and other experts to share data and modelling results given the understanding, that the multidisciplinary character of the work demands such a structured approach to collaboration.

The system at its present stage of development includes data on climate, land use, ground water resources, soil types, special ecosystems, critical infrastructure, population, income, buildings, historical heritage, infrastructure, traffic, industry, and social institutions in a GIS system for Denmark. The variety of studies that can benefit from adapting a data and modelling framework as the DIAS also need to be supported by different sector specific detailed models as for example climate models, storm surge models, groundwater models, drainage system models, flood models, agricultural crop models, ecosystem water models, and various cost and social impact assessment tools. These models and analytical tools are available at Danish universities and other climate change centres of excellence. DIAS draws on a subset of data developed by these institutions, and in itself constitute an excellent platform for facilitating a sharing of data and study outputs and a possible framework, where they can feed into the common GIS system for Denmark.

The DIAS structure is shown in Figure 3 below. It should be noticed that present elements included reflect present data availability, and that the system will be further developed in the future.
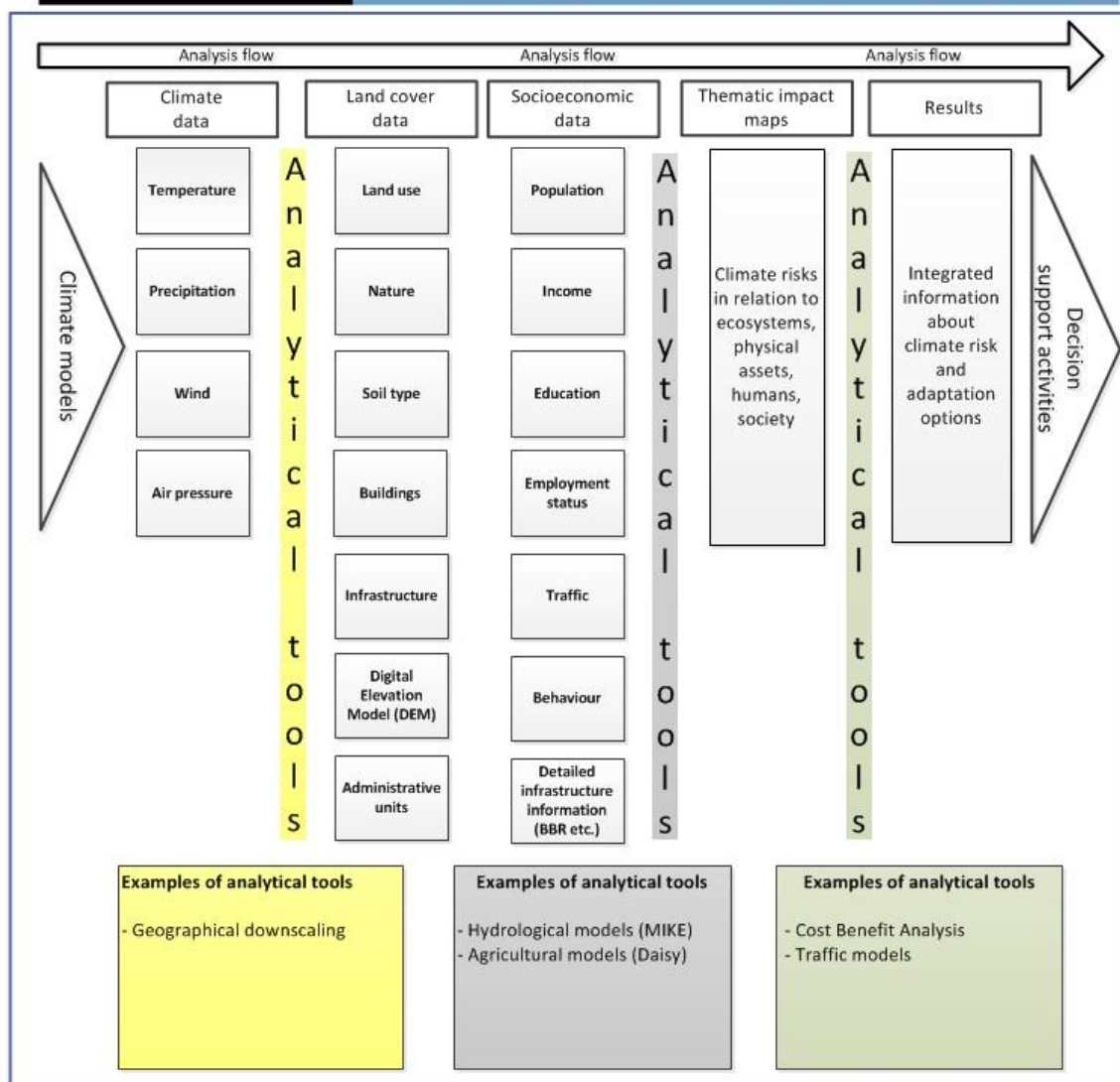
Figure 3: Analytical structure and major elements of the DIAS

As is illustrated in Figure 3 DIAS is structured around five analytical elements. These are:

- Climate data: Temperature, precipitation, wind, air pressure etc.
- Land cover data: Land use activities, buildings, infrastructure, protected nature areas, administrative units, elevation data etc.
- Socioeconomic data: Population, income, employment, education, traffic, behaviour etc.
- Thematic impact maps: Climate risks in relation to ecosystems, physical assets, humans, society etc.
- Results: Integrated information about climate risk and adaptation options.

These five columns represent a progression in the assessment moving from left to the right towards the final conclusions on potential climate change adaptation options, which can be used in relation to further decision support activities.

The emphasis of the assessment system is on different analysis tools as highlighted by the three coloured columns in figure 3. The first group of analysis tools (yellow column) links climate

modelling data with land cover data. The tools here include various climate data downscaling methods and models. The next step is to link climate specific land data and socioeconomic data, which serve as input to assessments of climate change impacts. Climate impacts are assessed with analytical tools like flood models, hydrological models, ecosystems models, agricultural models, health models etc., and the output of these models in DIAS can be various physical impact maps. An example of such an impact map is shown in Figure 4 which shows a flood map for the city of Aarhus based on modelling performed by DHI in MIKE Urban and MIKE Flood surface and sub-surface hydrological models.

The final step is to assess climate change risks and adaptation options based on the physical impacts that are identified from the impact maps. There are many complicated issues related to preferences and valuation of impacts involved in this step, and it is recommended that these issues are explicitly addressed, when standard analytical approaches such as cost benefit analysis and /or Multi Criteria Analysis (MCA) apply. Some of the complicated valuation issues in the Aarhus case are illustrated in Figure 5. Figure 5 highlights that in the case of flooding risks in Aarhus, various physical, human and historical values are at risk including building damages, health risks to children, and 1000 year old churches. Risk attitudes and preferences matter a lot here in assessing adaptation options and costs and should be considered specifically in the integrated assessment.
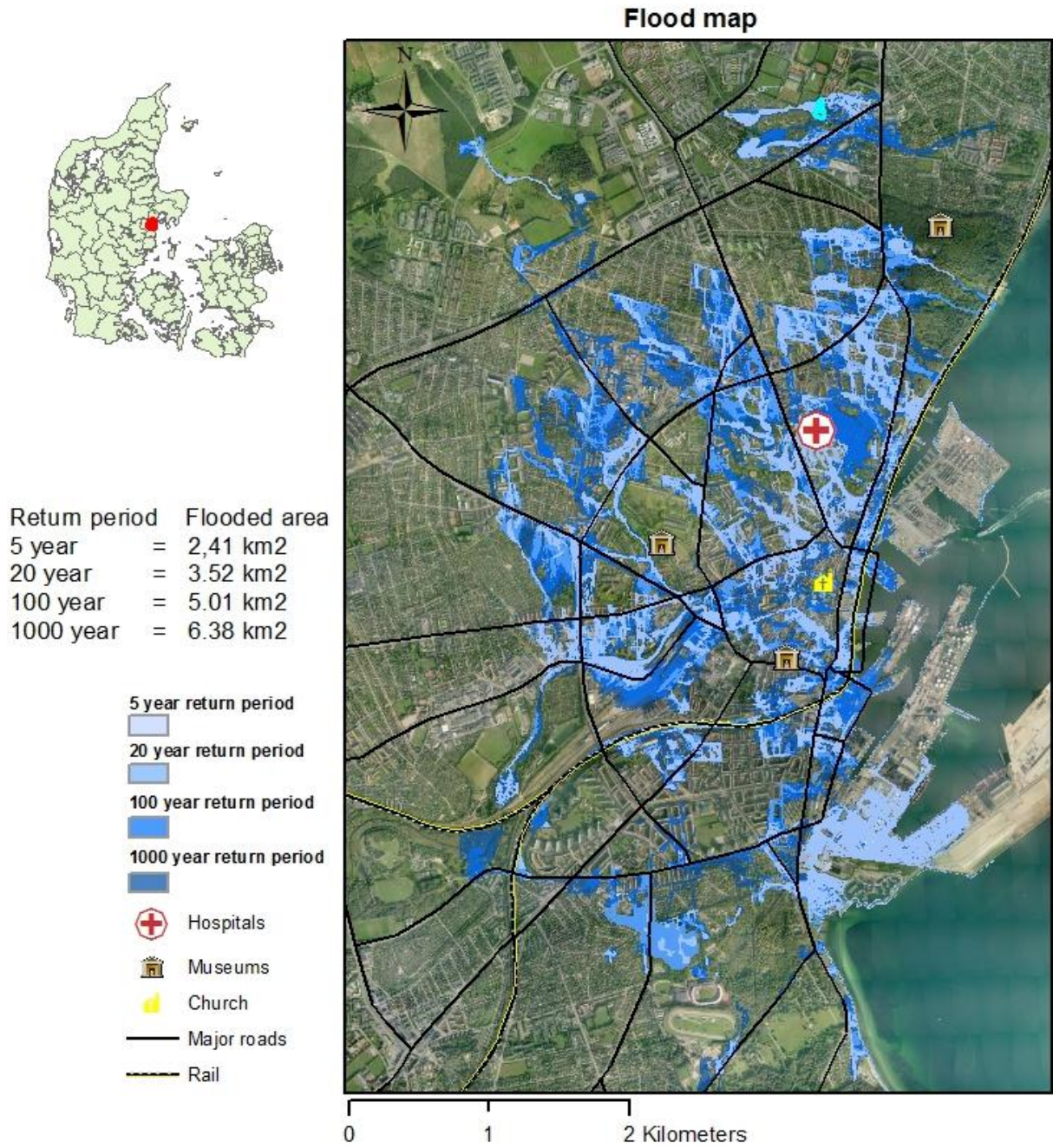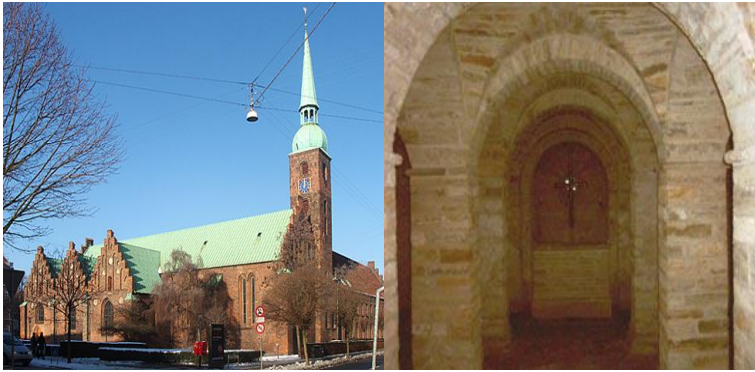
Figure 4: Flooding map of Aarhus during extreme rainfall with different return periods

Baroque Organ: Largest Church Organ in DK

Viking Museum:
Archaeological Site

Kindergarten:
Health Impacts

Figure 5: Examples of complicated valuation areas in Aarhus

6. Data inventory

This section presents and identifies the accessibility of relevant data for integrated assessment of vulnerability, exposure and risk towards the impacts of climate extremes. Historical climate data is publically available for the period 1950-2012 as an output of the EU project ENSEMBLES (van der Linden P., and J.F.B. Mitchell 2009). Climate projections for Denmark are hosted by DMI. A major part of the land cover and socioeconomic data is freely available for all public institutions (including universities) through the KMS governmental data agreement (http://www.kms.dk/Indgangefor/Saerligtforstaten/). All KMS data is available for download on the KMS ftp server (ftp://ftp.kms.dk/). Thematic impact maps are NOT publically available; however some of these may assessed by contacting the institutions responsible for conducting the analysis and producing the maps. Additionally some institutions provide webGIS solutions including dynamic interfaces where thematic impacts maps can be explored (http://www.klimatilpasning.dk/da-DK/service/vaerktoejer/Sider/Forside.aspx). Detailed information about relevant data is provided in the following table.

	Description	Temp. coverage	Geogr. coverage	Temp. resolution	Spatial resolution	Data format	Access
Historical climate data							
Temperature	Min, mean and max temp	1950-2012	Europe	Daily	0.25 degree	NetCDF	Open http://eca.knmi.nl/download/ensembles/download.php
Precipitation	Mean precipitation	1950-2012	Europe	Daily	0.25 degree	NetCDF	Open http://eca.knmi.nl/download/ensembles/download.php
Sea level pressure	Mean sea level pressure	1950-2012	Europe	Daily	0.25 degree	NetCDF	Open http://eca.knmi.nl/download/ensembles/download.php
Climate change data							
Temperature	Min, mean and max temp	2021-2050 and 2071- 2100. 1961-1990 reference period	Denmark	Monthly, seasonal and annual	25km	NetCDF	Developed by DMI for Klimatilpasning.dk Contact: Martin Olesen
Precipitation	Mean precipitation	2021-2050 and 2071- 2100.	Denmark	Monthly, seasonal and annual	25km	NetCDF	Developed by DMI for

		1961-1990 reference period					Klimatilpasning.dk Contact: Martin Olesen
Wind	Max wind	2021-2050, 1961-1990 reference period	Denmark	Monthly, seasonal and annual	25km	NetCDF	Developed by DMI for Klimatilpasning.dk Contact: Martin Olesen

Land cover data

Orthophoto	Aerial photography	2004-2010	Denmark	-	10-40cm	GIS server	KMS governmental agreement. Contact: KMS
Land use	Compilation of several thematic maps. > 500 LU classes, primarily rural classes (agriculture/forest types)	2012	Denmark	-	10 m	Raster file (ArcGIS)	DMU, developed for KFT 2012. Contact: Gregor Levin (DMU)
Buildings	Point layer with all buildings in DK	2010	Denmark	-	Point layer	Shape file (ArcGIS)	KMS governmental agreement. Contact: KMS
Churches	Point layer with all churches in DK	2010	Denmark	-	Point layer	Shape file (ArcGIS)	KMS governmental agreement. Contact: KMS
Hospitals	Point layer with all hospitals in DK	2010	Denmark	-	Point layer	Shape file (ArcGIS)	KMS governmental agreement. Contact: KMS
Roads	All roads	2010	Denmark and southern Sweden	-	Polyline layer	Shape file (ArcGIS)	KMS governmental agreement. Contact: KMS
Administrative units	Parish, municipality and region etc.	2010	Denmark	-	Polygon layer	Shape file (ArcGIS)	KMS governmental agreement. Contact: KMS

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Digital elevation model (DEM)	Digital Elevation Model. Due to the total data size (109GB) the DEM is divided into multiple files (653).	2010	Denmark	-	1.6 m	Ascii (import to ArcGis)	KMS governmental agreement. Contact: KMS
Soil type	DJF data – 8 soil types	Based on mapping from 1975-1979	Denmark	-	Polygon layer	Shape file (ArcGIS)	Cost: 4000 kr. Contact: Mogens Humlekrog Greve, DJF
Protected areas	Includes both nature, culture, buildings etc.	2010	Denmark	-	Polygon layer	Shape file (ArcGIS)	Danmarks miljøportal http://kort.arealinfo.dk/
Groundwater	Areas of special drinking water interests	2010	Denmark	-	Polygon layer	Shape file (ArcGIS)	Danmarks miljøportal http://kort.arealinfo.dk/
Nature and wildlife reserves	Wildlife reserves established under the Law on hunting and wildlife management in order to protect and nurture populations of wild birds and mammals	2010	Denmark	-	Polygon layer	Shape file (ArcGIS)	Danmarks miljøportal http://kort.arealinfo.dk/
Soil contamination	Areas where the activities on the site or activities in other areas may have been a source of contamination on the site	2010	Denmark	-	Polygon layer	Shape file (ArcGIS)	Danmarks miljøportal http://kort.arealinfo.dk/

Municipal planning	Kommuneplaner and lokalplaner – adopted and proposals.	2010	Denmark	-	Polygon layer	Shape file (ArcGIS)	http://www.plansystemdk.dk/Se/
Agriculture	MVJ, Natura2000, SFL, phosphorus, nitrogen etc.	2010	Denmark	-	Polygon layer	Shape file (ArcGIS)	Danmarks miljøportal http://kort.arealinfo.dk/
Natura 2000	EF habitat area, Ramsar and EF bird protection area	2010	Denmark	-	Polygon layer	Shape file (ArcGIS)	Danmarks miljøportal http://kort.arealinfo.dk/
Protected natural areas	Protected nature and waterways	2010	Denmark	-	Polygon layer	Shape file (ArcGIS)	Danmarks miljøportal http://kort.arealinfo.dk/
Mining areas	Areas of raw materials	2010	Denmark	-	Polygon layer	Shape file (ArcGIS)	Danmarks miljøportal http://kort.arealinfo.dk/
Socioeconomic data							
Population	Number of persons according to age	2012	Denmark	Annually	Parish level	Table data combined with the administrative units Shape file (ArcGIS)	Statistics Denmark
Country of origin	Number of persons according to country of origin and nationality	2012	Denmark	Annually	Municipality level	Table data combined with the administrative units	Statistics Denmark

						Shape file (ArcGIS)	
Life expectancy	Average life expectancy	2011	Denmark	Annually	Municipality level	Table data combined with the administrative units Shape file (ArcGIS)	Statistics Denmark
Income	Personal and family income	2012	Denmark	Annually	Municipality level	Table data combined with the administrative units Shape file (ArcGIS)	Statistics Denmark
Socioeconomic status	Employed, unemployed, retired etc.	2012	Denmark	Annually	Municipality level	Table data combined with the administrative units Shape file (ArcGIS)	Statistics Denmark
Traffic data	Avg. number of cars passing specific road sections per day.	Updated annually for most road sections.	Denmark	Annually	Potentially all public roads in Denmark	Shape file (ArcGIS) Table data added to the road section polyline layer. This is done using the join tool in GIS.	Data available for all roads sections as table data through vejman.dk (the Danish Road directorate). Most municipalities have data as a GIS layer and it may be possible to gain access through the individual

							municipalities.
Thematic impact maps							
Flooding maps	Surface water levels in relation to extreme rainfall events with various return periods	Return periods: 5-1000year events.	City of Aarhus	-	10 meter	Raster data	Prepared by DHI for DSF project. Contact: Henrik Madsen, DHI
Flooding maps	Surface water levels in relation to extreme rainfall events with various return periods. The various scenarios are presented in the Climate Adaptation plan of the municipality of Copenhagen (2012)	Return periods: 20 and 100 year return period and 100 year return period in 2100 (with climate change). More return periods should be available.	City of Copenhagen	-	2 meter	Raster data	Prepared by COWI for the Municipality of Copenhagen. Contact: Jan Rasmussen, municipality of Copenhagen
Climate groundwater maps	Climate effects on hydrology and groundwater levels	Changes in groundwater levels and groundwater recharge in 2021-2050 as compared to the reference period 1961-1990	Denmark	-	500 meter	Raster data	Prepared by GEUS for KFT. Contact: Louise Grøndahl, Naturstyrelsen - Miljøministeriet

7. Vulnerability and exposure to climate change

As pointed out in previous sections, climate change vulnerability indicators can be used as a screening tool for selecting areas that should undergo a more detailed assessment of climate risks and adaptation options (section 3 and 4). Vulnerability is treated as a key indicator of particular high risk areas, and we have argued that the vulnerability assessment is a rather general entrance to the more detailed risk and adaptation analysis, which is outlined in more detail in section 4.

In the following our focus in the choice of vulnerability indicators will be how extreme events could influence society. This is in spite of the most commonly used denominators of climate change, which are the recent and expected future change in global average air temperature and annual mean precipitation. However, although changes in the average climate are seemingly much easier and more certain to project as compared to the changes in probability, distribution and severity of extreme events, long term changes in average biophysical/climatic parameters are often not very important in terms of asserting the impacts of climate change on the anthropogenic and natural environments. Rather in a climate impacts assessment and or vulnerability study, changes in climate variability and the associated occurrences of extreme events becomes much more important since the human and natural environment (which more often than not are also affected by human settlements, agriculture etc.) are often not very resilient towards the impacts of extreme events. The degree of resilience towards the impacts of extremes is site specific property and varies substantially in time and space. This must be considered when assessing potential impacts of climate extremes.

The severity of a climate extreme is frequently not solely related to the extremes themselves but is rather the consequence of a combination of the extreme event and the exposure and vulnerability of the affected area. **Exposure** can here be defined as the presence of people, ecosystem services and resources, infrastructure or economic, social or cultural assets in the area potentially affected. **Vulnerability** refers to predisposition to be adversely affected (Cardona & Van Aalst 2012).

In the following, different types of key vulnerability indicators in relation to the impacts of climate extremes will be highlighted.

Vulnerability indicators

Important vulnerability indicators in relation to impact assessment of climate extremes can be divided into the following types: Physical indicators, social/health indicators, environmental and economic indicators. The vulnerability indicators emphasized in this section should not be interpreted as being a complete list useful for measuring vulnerability towards any thinkable climate extreme, however they represent the most important ones in a Danish context, and primarily in relation to flooding, heat waves and storm surges.

It is important to recognize, that individual vulnerability indicators are not equally important and local expert knowledge is often needed in order to evaluate the significance of each individual indicator based on the local/regional characteristics of the case area. In some cases, it might also be valuable to normalize the different data values to create a single vulnerability index in order to identify vulnerability hot-spots. Different methods are suitable for combining information from several criteria to create a single index including Multi Criteria Analysis (MCA)(Alexander 2011). MCA enables the inclusion and quantitative comparison of different types of criteria, e.g. number of elders in an area

may be compared with the total length of the road network or traffic loads to create a final index. As the impacts of climate change are expected to vary significantly in different regions the included vulnerability data should preferably have a geographic dimension as it enables spatial analysis and comparison with for instance downscaled projections of climate variables or flood simulation data. It should here be mentioned that the accessibility to data with a geographical dimension is often limited (physical or economic access) which can be a severe constraint to performing a comprehensive vulnerability analysis.

Physical indicators

The physical dimension deals with the direct and indirect effects of the physical impacts of a climate extreme. In relation to urban flooding in Denmark this includes damage to buildings, roads, railways, critical infrastructure (government buildings, hospitals, energy production and supply units, communication infrastructure etc.) and tourist relevant buildings. Direct effects can be defined as the actual damage to any given asset while indirect effects are the secondary consequences of the physical impact. Examples of secondary effect include the "costs" related to the extra time needed to evacuate people, or for people to get to work, when roads are flooded. If tourist relevant buildings, e.g. the Little Mermaid in Copenhagen, is affected the secondary effects includes the loss of income as a consequence of less tourists visiting in the aftermath of a climate extreme.

Useful physical indicators include buildings, roads, railways, government buildings, tourist related buildings, historical buildings, critical infrastructure, nursing homes, kinder gardens, schools etc.

Social/Health indicators

The social dimension considers specific population groups who differ with respect to age, income, employment conditions, education level, gender or origin. The different social indicators are included in order to describe the level of human welfare in a given area and can potentially express the level of social integration and mental and physical health within a given area. In relation to extreme event impact assessments, in particular flooding and heat waves, the included indicators may be used as proxies for the fragility of an area, and are therefore useful to include in a vulnerability study.

Vulnerable population groups include elders and children, due to the weakness of their physical and sometimes mental condition. This is the case both in relation to flooding and heat waves.

Employment rate is another social indicator which may contain information on the vulnerability of an area towards the impacts of a climate extreme, in particular urban flooding. Unemployed groups often have fewer savings and lower access to financial support to buffer them against the impact of a climate extreme. Consequently employment is correlated with less vulnerable conditions.

Access to services and funding in a pre- and post-disaster phase may be influenced by cultural and language barriers and points to the inclusion of population origin in the social vulnerability dimension. In this case native speakers are considered to be less vulnerable as compared to immigrants (Alexander 2011).

In relation to health impacts, floods are usually associated with an increased risk of infections and direct contact with contaminated water (cleaning up of flooded basements, roads etc.) is a common source of infection in relation to urban flooding events (Alexander 2011).

Environmental indicators

The environmental dimension deals with the vulnerability and fragility of the biophysical systems and their functions and services for humans and biodiversity.

Rivers, lakes, wetlands, forests and other pristine natural areas are rich in species and provide important services for human consumption and as recreational areas, especially in relation to agriculture and water supply. Ecosystem functioning may be affected severely by climate extremes, both in relation to their role as habitat for a wide range of species and as a provider of services for human wellbeing. Common impacts of climate extremes on ecosystems in Denmark include forest damage, habitat loss/fragmentation, river overflows, coastal and inland erosion, soil loss, increased flow of nutrients to natural waterways, increased occurrences of eutrophication, general water quality impacts. Relevant examples of environmental vulnerability indicators include information on the location and functioning of rivers, lakes, wetlands, forests and other natural areas.

Economic indicators

The economic dimension deals with the cost related to the potential damage and/or the disruption of the systems productive capacity as a result of the impact of a climate extreme. The first category covers the costs of repairing/rebuilding the affected areas and infrastructure, and includes repairing of roads, buildings (residential and industry) and other infrastructure, and replacing damaged or lost assets. The second category is related to the degree to which the systems productive capacity is affected by the climate extreme. This includes the cost of lost working time due to traffic delays where roads are flooded, lost working time where parents have to stay at home to watch their children in areas where kindergartens/schools are affected and the loss of production interruption where industry and agriculture are affected.

Useful indicators in relation to the economic dimension include the location of residential and commercial buildings, public service facilities (e.g. hospitals, kindergartens, nursing homes etc.), building of historical or cultural value, industry, agriculture, roads and other critical infrastructure. Furthermore information on road specific traffic volumes, number of children in kindergartens, area specific income and industry turnover can be useful in assessing the potential disruption of an areas productive capacity and/or monetary loss related to the impact of a climate extreme.

8. Case example - Integrated impact assessment of flooding from extreme rainfall in Aarhus

Introduction

The objective of the following case example is to demonstrate the usefulness of the methodology implemented by DIAS for integrated assessment of climate change exposure, vulnerability, impacts and adaptation. For this purpose an integrated assessment of the impacts of urban flooding from extreme rainfall was carried out for the city of Aarhus. Aarhus was chosen to serve as a case area as it is one of the focal areas of DSF projects CRES and Risk Change, hereby enabling us easy access to the data and models required to complete a detailed impact assessment analysis.

Scope

The impacts considered in the assessment are not to be considered exhaustive, however, they represent some of the major impact areas, both in relation to direct monetary costs and risk aversion and preferences in relation to urban flooding. Considering the latter is important as many of the impacts may not be straightforward to calculate in terms on monetary values as they depend on the risk aversion attitudes of various stakeholders which may vary considerably between individuals. Examples of impact areas where risk aversion attitudes are of major importance include health impacts, environmental impacts and the loss of irreplaceable cultural, historical, religious and symbolic assets.

The impacts considered in the analysis include the following:

- Infrastructure
  - Residential buildings
  - Industrial and commercial buildings
  - Basements
  - Roads
- Transportation
  - Delays
  - Trips avoided
- Health
  - Injuries and deaths
  - illness
- Other
  - Historical and cultural values
  - Symbolic and religious values

Impact assessment

As a consequence of the geographical characteristics of the impacts of flooding from an extreme rainfall event (flooding is obviously not evenly distributed geographically but varies as a result of topography, water collection systems etc.) the major part of the impact analysis was carried out using a GIS (Geographic Information System). A major challenge in relation to this is the collection of and

access to relevant datasets with a geographic dimension. The utilized datasets for the current analysis include:

<u>Climate data</u>
- Precipitation data

<u>Land cover data</u>
- Buildings
- Basements
- Roads

<u>Socioeconomic data</u>
- Traffic data
- Google maps travel time estimates
- Population
  - Age distribution (parish data)

<u>Other</u>
- Churches
- Museums

Impact assessment procedure

<u>Infrastructure</u>
In order to estimate the direct monetary impact of flooding from extreme rainfall on infrastructure (residential, industrial and commercial buildings, basements and roads) flood hazard maps showing the maximum surface water level for extreme precipitation events with different return periods (from 5 year-1000 year return periods) was combined with a unit cost for each asset impacted by flooding. The extent of flooding for the different precipitation events was calculated using the MIKE Urban/MIKE Flood software package (MIKE by DHI). In order to calculate the number of flooded buildings for the different return periods an impact model was created in Model builder in ArcGIS overlaying the flood hazard map with information on the location of the different types of infrastructure included in the impact analysis.

For the damage cost estimate of **buildings** a unit cost of 500,000 DKK was multiplied with the total number of buildings inundated by more than 20cm of surface water (Zhou et al. 2012).

For the impact assessment of flooded buildings flooding damage costs for **basements** was calculated on the basis of flood hazard maps combined with a unit cost and a water level threshold for where the unit cost applies. For basements a unit cost of 25,000 DKK was applied for all basements located in areas with > 0.3 cm of surface water (Zhou et al. 2012).

Road damage during flooding from extreme rainfall was calculated using a similar approach as for buildings and basements. A GIS model was developed to calculate the length of road network inundated by > 20 cm of surface water. A unit cost of 3,400,000 DKK was applied to account for repairing/cleaning 1 km of flooded road. The unit cost is based on the findings of the WEATHER project (Doll & Sieber 2011) which is funded under the 7th framework program of the European Commission. From the synthesis of literature findings from this project an asset damage cost of

450.336 €/km was estimated. This corresponds to unit cost of approx. 3,400,000 Dkk per km of flooded road.

<u>Traffic</u>
Flooding impacts on traffic is divided into two distinctive categories: **Traffic delays** and **avoided trips** due to roads being inundated.

To assess **traffic delays**, roads inundated with more than 15 cm of water were mapped. In order to get an estimate of the total traffic volumes on an average working day, traffic data for the major roads within the city of Aarhus was included in the analysis. Combining the flood hazard maps with the road specific traffic data allows for an estimate of the total amount of traffic affected by the inundated roads. The actual delay due to flooding is then calculated based on the assumption that the total delay in Aarhus is equal to the summarized difference in travel time (and choosing alternate routes) between travel times at rush hour and the travel times at times with no congestion. Thus the extra travel time (delay) is calculated by multiplying the averaged difference in travel time for the major routes going in and out of Aarhus by the number of persons travelling to and from Aarhus on an average day. Google Maps was used to estimate the daily variation in travel time between the outer ring road and the center of Aarhus for every hour of the day. Furthermore, roads are assumed to be flooded for an entire day. The time period in which the roads are flooded is assumed constant and does not vary with the severity (return period) of the extreme precipitation event.

In order to calculate the **trips avoided** due to several roads being inundated it is assumed that the number of vehicles traveling is reduced by the proportion of residential areas that are flooded during a given extreme event. In other words, if there is flooding at a residence, we assume that the inhabitants will not travel. This corresponds to a 5 % - 29 % decrease in traffic for extreme precipitation events with return periods of 5-1000 year. For the current cost assessment roads are considered flooded for 24hrs (one day) and the Value Of Time (VOT) applied is 80 DKK/hour. It is further assumed than none of the people having to avoid travelling are able to perform their work tasks from home. As a result there is a cost of 600 DKK ((7.5 hours * 80 DKK/hour * 1 day (duration of flood)) associated with every person having to stay at home due to flooding.

<u>Health</u>
Health impacts are divided into two distinct impact categories; **physical health impacts** (injuries and deaths) and **illness related impacts**.

The procedure for estimating the **physical health impacts** from a flooding event are adapted from the methodology developed by Penning-Rowsell et al. 2005. This approach employs the water depth, maximum velocity, anticipated debris loads, housing type, warning systems and location of vulnerable population in order to calculate the impact of flooding. In relation to flooding from extreme precipitation vulnerable population groups include children (< 5 years of age) and elderly (above 70 years of age). The cost of relative disutility as presented in table 1 are used to estimate the total monetary impact of flooding on physical health conditions. From table 1 it is seen that fatalities related to extreme precipitation are associated with a cost of 41,760,000 DKK.

Severity	Fraction of VSL (Value of Statistical Life)	Cost/injury (DKK)	Share of physical impact severity in Aarhus case
Minor	0,2 %	83,520	50 %
Moderate	1,6 %	647,280	35 %
Serious	5,8 %	2,401,200	13 %
Severe	18,8 %	7,830,000	3 %
Critical	16,3 %	31,842,000	0 %
Fatal	100 %	41,760,000	0 %

Table 1: Cost of relative disutility by injury severity level. Adopted from Murphy & Topel 2006

Illness related health impacts are calculated on the basis of the estimated number of persons exposed to surface water during flooding from extreme precipitation. In combining the calculated number of flooded basements (GIS overlay model) with a factor of 1.7 person/basement it is possible to estimate the total number of persons exposed to flooding during extreme precipitation events with varying severity (Zhou et al. 2012). The total number of exposed persons is then combined with a unit cost of 6687 DKK in order to estimate to total monetary impact of flooding on illness related health conditions.

Damage category	Unit cost	Surface water threshold (cm)
Buildings	500.000 DKK/house	20
Basements	25.000 DKK/basement	0.3
Roads	3.400.000 DKK/km	20
Traffic	80 DKK/hour	15
Health – physical	987.624 DKK/injury	see Penning-Rowsell et al 2005
Health – Illness	6687 DKK/exposed person	0.3

Table 2: Damage categories, unit costs and surface water threshold applied for the economic assessment of flooding damage costs from extreme precipitation.

Other

It is particularly difficult to provide information on the values of cultural, religious and historical heritage and other values related to recreational areas, since these "assets" are not related to markets and cannot be totally replaced if they are negatively affected. Aarhus the Cathedral is an example of such an asset. The monetary value of the numerous frescos (1300-1500) and the largest Baroque church organ in Denmark, both situated within the cathedral, may be very difficult to estimate and different people may have very different opinions (risk aversion attitudes) towards the importance of preserving such assets. Therefore in the current analysis the economic impacts of flooding on these assets have NOT been quantified. However, it is noticeable that the cathedral is situated in an area which is going to be inundated during floods with a return period of > 20 years (see Figure 4). See the illustration below for information on other assets in Aarhus which may be difficult to valuate.

Infrastructure impacts

Figure 6 and 7 show the results of the impact analysis of flooding from extreme precipitation on buildings and basements in Aarhus. Buildings within the Aarhus city area (residential, commercial and industrial) are represented by a red colour and showing the actual extent of each building (left map in Figure 6). The left map in Figure 6 also depicts the flooding extent and maximum surface water level (m) during an extreme precipitation event with a return period of 100 years. The maximum surface water level increases with the darkness of the blue colour and various from < 1cm to above 5m. The right map in Figure 6 shows the buildings which are going to be flooded by more than 20 cm of surface water during an extreme precipitation event with a 100 year return period. Figure 7 show the total number of buildings and basements flooded during extreme precipitation events with varying severity. The assessment is performed for flooding from extreme precipitation with return periods of 5-1000 years. The corresponding numbers of building and basements which can be expected to be affected by flooding are 216-650 buildings and 689-1923 basements.
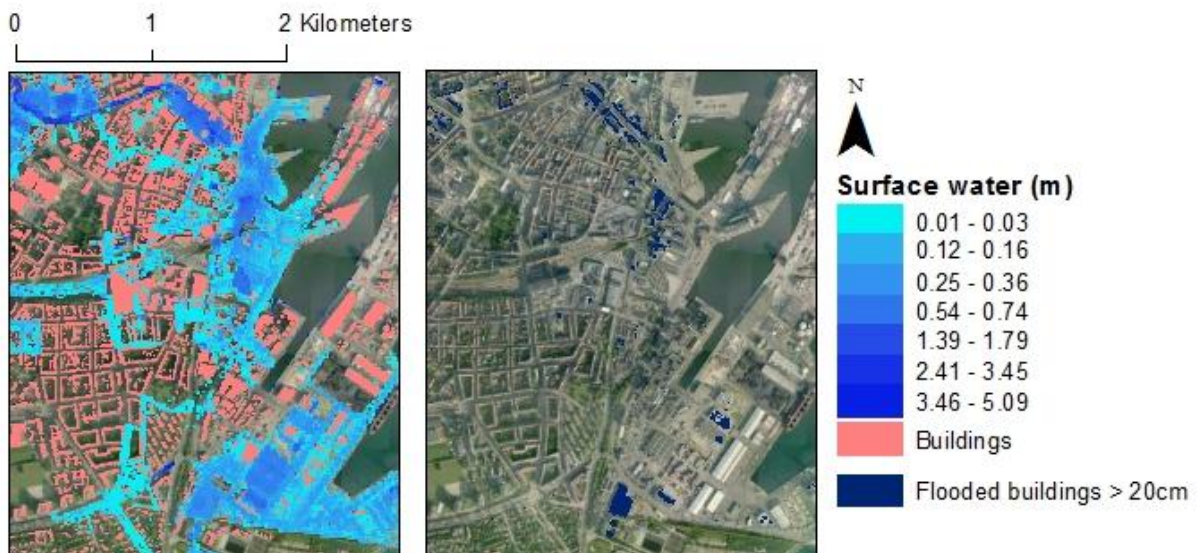

Figure 6: Flooded buildings in Aarhus during extreme precipitation with a return period of 100 years.
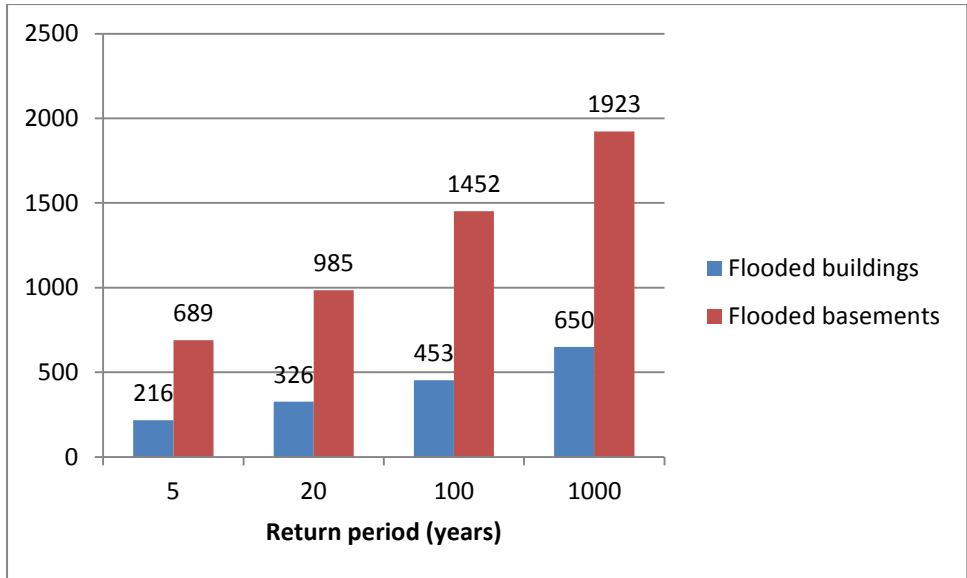
Figure 7: Number of buildings and basements flooded due to flooding from extreme precipitation events with various return periods.

Figure 8 and Figure 9 present the results of the analysis of the flooding impacts on roads. Figure 8 (left map) shows the location of major roads within the Aarhus city centre area. The modelled maximum flood extent and surface water depth during a precipitation event with a 100 year return period is overlaid the road layer and base map. On the right map in Figure 8 the road sections which are expected to be flooded with more than 20 cm of surface water are highlighted in red. From Figure 9 it is seen that 0,7 km – 4,5 km of road is expected to be flooded as a consequence of extreme precipitation events with return periods of 5-1000 years.

Figure 8: Road sections flooded during a 100 year extreme rainfall event.
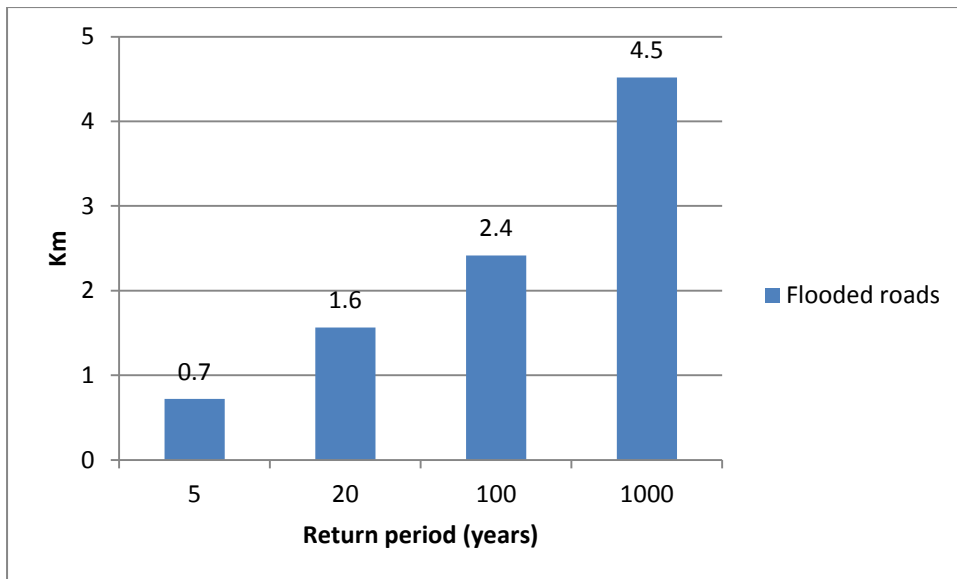
Figure 9: Road sections flooded due to flooding from extreme precipitation events with various return periods.

Traffic impacts

The results of the impact assessment of flooding on traffic are highlighted in Figure 10. The impact is divided into two distinctive categories; **traffic delays** and **lost working time** due to avoided trips. The former refers to the extra time needed to transport from A to B due to additional congestion and/or having to select a non-optimal route while the latter considers the cost (time loss) of not being able to perform the normal work tasks. The results of the analysis indicate that the cost of lost working time is far greater than the cost of traffic delays. From Figure 10 it is seen that the impacts of flooding from extreme precipitation on traffic delays and lost working time amounts to 31.000-23.000 hours and 128.000-473.000 hours respectively. Furthermore it is seen that the cost of lost working time becomes more important than traffic delays as the severity of the extreme event increases (cost of delay decreases with increasing return period and vice versa for lost working time). However, this is not surprisingly as the total travel time (and traffic), and therefore also the potential traffic delay, decreases as the flood extent increases. Notice that the share of trips avoided due to flooding is considered equal to the share of the residential area affected by flooding.
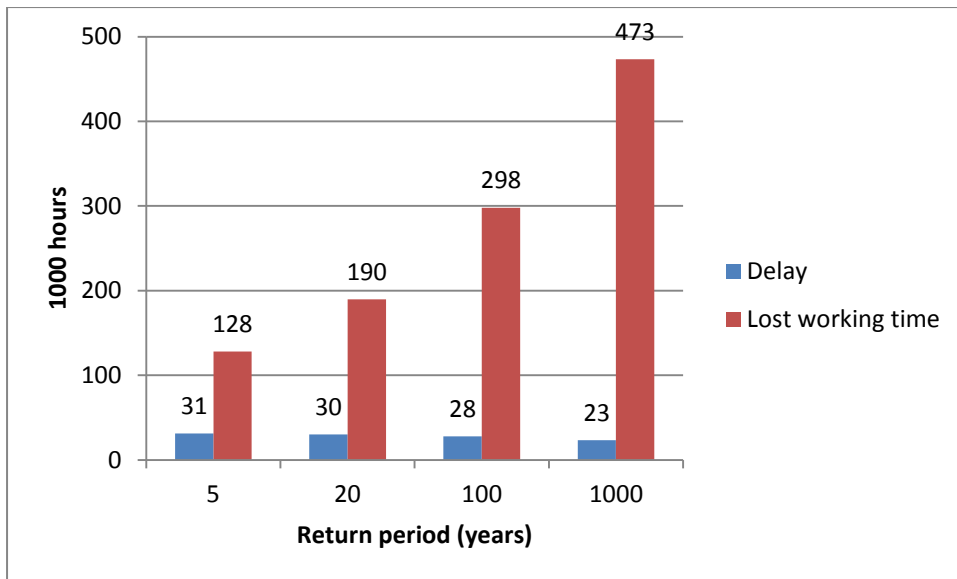
31

Figure 10: Traffic impacts of flooding from extreme precipitation with various return periods.

Health impacts

Figure 11 and Figure 12 present the overall results of the impact assessment on health. From Figure 11 it is seen that the municipality of Aarhus should expect 1-8 injuries in relation to flooding from extreme precipitation with return periods of 5-1000 year. The outcome of the analysis further showed that fatalities should **not** be expected as a direct result of a flooding event from extreme precipitation. Figure 12 shows the total number of persons potentially affected by illness related impacts during and/or in the aftermath of a flood from extreme precipitation.
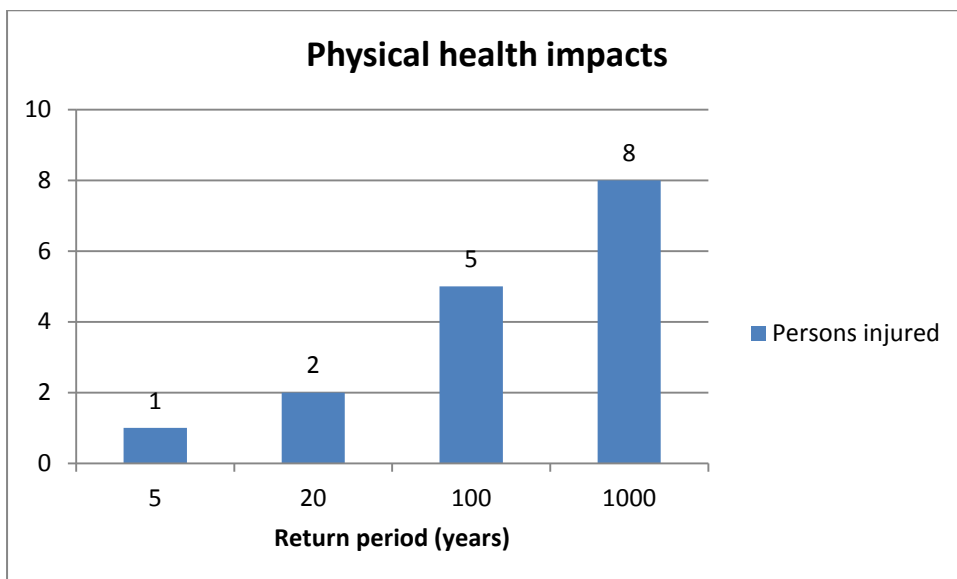

Figure 11: Number of injuries in Aarhus city centre due to flooding from extreme precipitation with various return periods.
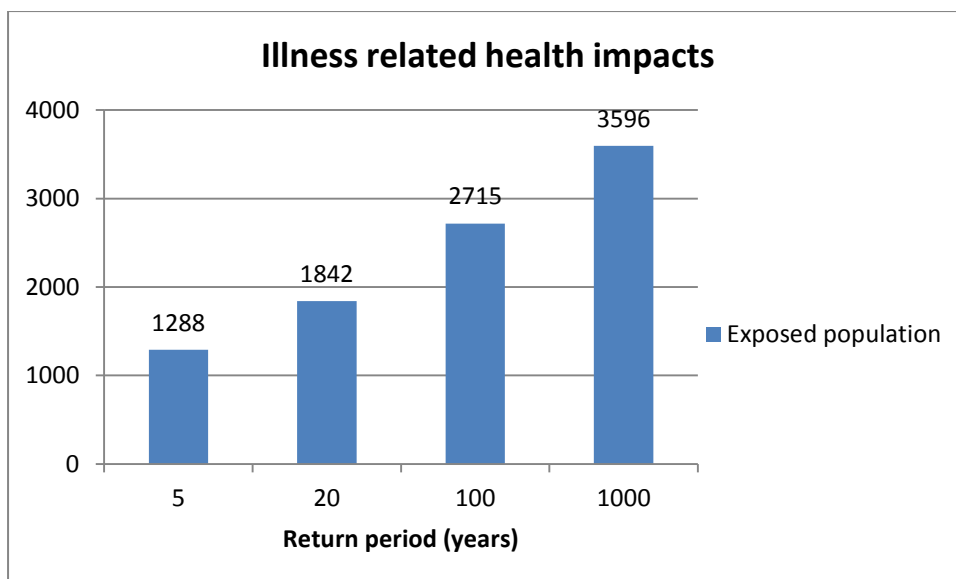
Figure 12: Number of persons exposed to surface water from flooding in Aarhus city centre during extreme precipitation events with various return periods.

Overall results of the integrated assessment

The result of the economic dimension of the integrated impact assessment is presented in Figure 13, showing the cost summary. From here it is seen that the largest costs of flooding are related to those of repairing buildings and replacing lost or broken assets within buildings. Road damage and the cost of lost working time were likewise found to be of importance in relation to urban flooding in Aarhus. On the other hand the cost of health impacts and traffic delays were found to be of minor importance from an economic point of view. From the outcome integrated impact assessment it can be seen that the total cost of flooding from extreme precipitation in Aarhus city centre amounts to 150 – 460 million DKK dependent on the severity of the extreme precipitation event. It should here be noticed that risk aversion factors and various stakeholder preferences have not been included in determining the cost of flooding for the different impact areas. The cost summary as presented above rely solely on simple calculations of unit costs (as found in the literature) and the modelled severity of flooding from extreme precipitation events with varying severity. Considering various stakeholder preferences may potentially alter the importance of the different impact categories significantly.
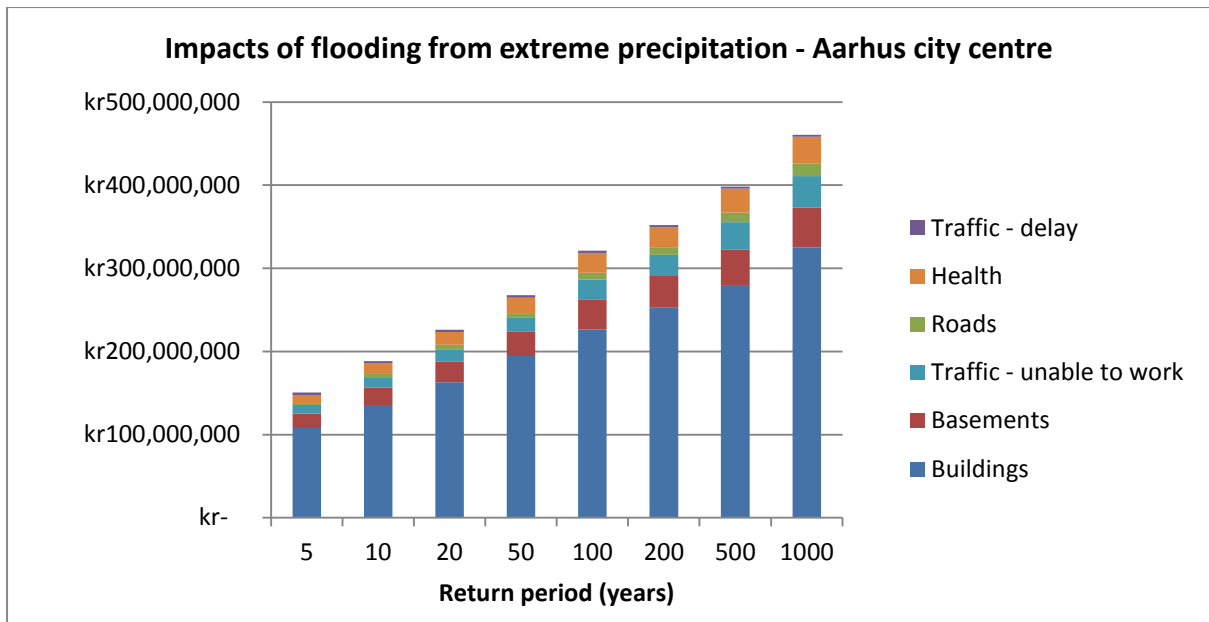
Figure 13: Cost summary – Impacts of flooding in Aarhus city centre from extreme precipitation with return periods of 5-1000 years.

9. Conclusions and perspectives

In this report we provide recommendations about how more consistent studies and data can be provided based on available modelling tools and data for integrated assessment of climate change risks and adaptation options. It is concluded that integrated assessments within this area requires the use of a wide range of data and models in order to cover the full chain of elements including climate modelling, impact, risks, costs, social issues, and decision making. As an outcome of this activity a comprehensive data and modelling tool named Danish Integrated Assessment System (DIAS) has been developed, this may be used by researchers within the field.

DIAS has been implemented and tested in a case study on urban flooding caused by extreme precipitation in Aarhus, and this study highlights the usefulness of integrating data, models, and methods from several disciplines into a common framework. DIAS is an attempt to describe such a framework with regards to integrated analysis of climate impacts and adaptation.

The final product of the DTU KFT project "Tool for Vulnerability analysis" is NOT a user friendly Climate Adaptation tool ready for various types of analysis that may directly be used by decision makers and consultant on their own. Rather developed methodology and collected/available data can serve as a starting point for case specific analyses. For this reason alone this work should very much be viewed as an attempt to coordinate research, data and models outputs between different research institutes from various disciplines.

It is unquestionable that there is a future need to integrate information for areas not yet included, and it is very likely that such efforts will depend on research projects conducted in different climate change adaptation areas and sectors in Denmark.

10.   References

Alexander, D., 2011. Methods for the Improvement of Vulnerability Assessment in Europe - Handbook of Vulnerability Assessment in Europe.

Cardona, O. & Van Aalst, M., 2012. IPCC SREX Chapter 2: Determinants of Risk - Exposure and Vulnerability.

Doll, C. & Sieber, N., 2011. *Weather - Assessment of Impacts on Transport Systems and Hazards for European Regions: Deliverable 2 - Transport Sector Vulnerability - Annex 3 Vulnerability Assessment for Road Transport*,

Intergovernmental Panel on Climate Change. Working Group II., 2007. *Climate Change 2007 : impacts, adaptation and vulnerability : working group II contribution to the Fourth Assessment Report of the IPCC*, Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change., Working Group 3, 2000. Special Report on Emission Scenarios (SRES).

Murphy, K.M. & Topel, R.H., 2006. The Value of Health and Longevity. *Journal of Political Economy*, 114(5), pp.871–904.

Penning-Rowsell, E. et al., 2005. Estimating injury and loss of life in Floods: A Deterministic Framework. *Natural Hazards*, 2005(36), pp.43–64.

van der Linden P. and J.F.B. Mitchell (eds.) 2009: ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK. 160pp.

Zhou, Q. et al., 2012. Framework for economic pluvial flood risk assessment considering climate change effects and adaptation benefits. *Journal of Hydrology*, 414-415, pp.539–549.

This report provides a short introduction to a methodological and modelling framework that can be used to assess climate risks and adaptation options. The framework has been developed in a Danish context as part of an on-going collaboration between Danish universities and other research institutions in research projects as well as in the context of the Coordination Unit for Danish Research in Climate Change Adaptation (KFT).

A major focus is how integrated assessments of climate change adaptation related to decision making can be structured and established through linking of data, modelling tools and conceptual models from various disciplines including climatology, ecology, hydrology, agricultures sciences, energy systems, urban systems, economics, sociology, etc.. Obviously, it is not possible to be comprehensive within such a broad field, and hence the present manuscript aims at providing an overview of linkages and analytical structures that are particularly illustrating related to specific case studies in the urban and rural areas.