Adaptation Measures in the EU: Policies, Costs, and Economic Assessment

"Climate Proofing" of key EU policies

In co-operation with

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Report details

This report is a deliverable for the project "*Climate Proofing" of key EU policies – short term actions.*

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Executive Summary

The aim of this report was to identify the most appropriate measures on the EU level to address different threats. A final selection of measures to be assessed with a view to their costs and economic, social and environmental impacts was agreed at the first interim meeting with the Commission. Measures already part of EU wide assessment projects were no part of the assessment.

In a first step (chapter 3) key policy areas have been screened to identify adaptation measures. The aim of this section was twofold. To screen the EU key policy areas with a specific focus on policy areas where currently no or little adaptation efforts have been made (e.g. energy, transport and agriculture policies) regarding their ability to deal with climate change impacts (= climate proofing).

Adaptation should not be performed decoupled from existing policies (e.g. legislation, funding systems). Thus, relevant instruments in place for the key policy areas mentioned above have been reviewed in the first step to understand to what extent adaptation considerations are already addressed in the existing policy framework.

To address different threats, existing policies have been proofed to be partly insufficient to handle the adaptation needs and thus, the inclusion of new measures into existing policies was required. Based on the review of existing measures suitable for climate change adaptation in key policies and interviews with EC key representatives, further measures necessary to respond to the impacts of climate change as well as adjustments of existing measures have been identified, also considering possible supportive actions for "climate proofing" (i.e. through elaborating guidelines, establishing funding provisions). These measures have been described in detail (e.g. aim and objective, responsibilities, time frame). The compilation of adaptation measures was built on a comprehensive literature review.

The outcome was a matrix of measures indicating the EU policy areas vis-à-vis corresponding measures. While not going into detail on the way of implementation, the outcome of chapter 3 included a first assessment of whether accompanying measures can be established to support "climate proofing" of existing EU legislation (e.g. guidelines, funding instruments) or whether legislative adjustments and new instruments would need to be implemented. A final selection of measures agreed with the Commission was further processed in terms of costing (chapter 4) and the assessment of impacts (chapter 5).

These two chapters have been performed in close connection to each other: The costing of key measures was fed into the assessment of economic impacts and costs/benefits, while the assessment of social and environmental impacts was introduced into the costing section to the extent that these can be expressed in monetary values.

The assessment did not only consider the adaptation effects of measures, expressed in terms of reduced vulnerability and net impacts, but also other criteria, e.g. those distinguished by the UNECE (2009) have been taken into account in a qualitative fashion

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1 Introduction and aim of the report

The **aim** of this report is to ascertain **priority concerns for further action** through opposing current EU efforts to different threats and **suggest complementary options** (cf. chapter 3) for the following four sectors:

- Energy
- Transport infrastructure
- Urban areas and
- Agriculture

A final selection of most appropriate measures that address major threats has been assessed with a view to their costs and economic, social and environmental impacts (cf. chapter 4 and 5). Measures already sufficiently covered by EU wide assessment projects or other relevant studies/projects will be clearly referenced but not further analysed in this report.

2 Methodology

2.1 Policy screening and identification of adaptation measures

In order to suggest appropriate measures that best address different threats, the following approach was used:

- Step 1: In-depth analysis of current EU policies for each of the four sectors addressed in this report (energy, infrastructure and transport, urban areas, agriculture)
    - Detailed analysis of **current EU policy efforts** based on investigations for each sub-sector (identifying direct references to climate change impacts and adaptation)
    - Creation of an **impact table** with additional information from literature research for each sub-sector

For each sub-sector (e.g. in case of infrastructure and transport: rail, road etc.):

- Step 2: Gap analysis assessing current EU policies and their projected effects to address major climatic risks
    - **Comparison** of current EU policy efforts vis-à-vis major threats identified
    - Identification of **threats** that are at present **not or not sufficiently addressed by EU action**
- Step 3: Exploration of possible adaptation measures for the sub-sector
    - Compilation of measures based on **literature research** and **expert judgment** (in regard to EU competency):

(i) analysing existing work done on adaptation measures
(ii) screening relevant EU projects focusing on adaptation measures
(iii) analysing national adaptation strategies and Good-Practice-Examples

- **Categorization of measures** (based on Impact Assessment accompanying the White Paper on Adaptation):

  A. Technical measures
  B. Regulation and standards
  C. Capacity building
  D. Communication/Awareness raising
  E. Guidelines
  F. EU financing scheme

➲ Step 4: Exploration of policy options for the EU level for the sub-sector

Step 4a:

- Analysis of **existing policies** in regard to explore possibilities for mainstreaming adaptation:

  (i) sector-specific policies (e.g. transport)
  (ii) sub-sector-specific policies (e.g. rail, road, aviation, shipping)
  (iii) sector-related policies (e.g. GNSS Applications)

- Highlighting "**entry points**" for adaptation

- Suggestions for **mainstreaming adaptation** in existing policies by taking up adaptation measures collected in Step 3

Step 4b:

- Developing options for **additional policy action**

➲ Step 5: Suggestion for the selection of key measures to be further assessed in terms of costing and impacts (chapter 4 and 5)

The final selection of key measures has been discussed on July 4th with DG CLIMA and representatives from DG MOVE and DG AGRI. In order to get more detailed feedback summary tables of all potential measures have been distributed within the Commission. As a basis for the selection of key measures to be further assessed an estimate for each measure has been enquired along the following criteria: (i) Urgency with respect to already existing threats, (ii) Practicability for implementation on relevant timescales, (iii) Robustness under a range of likely future projections, (iv) EU relevance and potential market failure. Feedback has been included into the revision of the sector analysis and led to a selection of key measures for further assessment under chapter 4 and 5.

2.2 Costing of key measures

In chapter 4, the key adaptation measures identified earlier in chapter 5 are analysed in depth regarding their costs. Therefore, in general the following approach has been pursued. Additional topic-specific aspects of the methodology are described in the respective sections in chapter 4.

<u>For each selected sector:</u>

- Step 1: Perform a literature review on bottom-up case studies focusing on adaptation costs. The following aspects are collected:
    - Regional coverage
    - smallest spatial unit
    - underlying CC scenarios
    - time frames
    - important assumptions
    - adaptation measures
    - all information on adaptation costs
    - important cost drivers
    - peer reviewed or not
- Step 2: Extraction of important cost information:
    - e.g. unit costs per km / inhabitant / km^2 / city
    - calculate costs in €/yr
    - comparison of unit costs from different sources
- Step 3: Transfer of unit costs to EU-level
    - dependent on data availability: either on MS-level or on NUTS2-level
    - as far as feasible: taking account of cost drivers and differences in unit costs in Europe
    - partly, experts have been interviewed for confirmation of parameter assumptions and additional needed cost information
- Step 4: Cost-sharing
    - rough indication of relevant actor who has to bear the costs, given the current legislation (public or private, private households or firms)

2.3 Assessment of economic, social and environmental impacts of key measures

For the adaptation measures identified in chapter 3 a general impact assessment was provided. As part of the impact assessment the benefits of the adaptation measures were analysed and cost-benefit ratios were estimated.

- Step 1: Literature review on relevant studies which focus on impacts of adaptation measures, special focus on studies with estimation of benefit aspects
    - Analysis of literature with focus on adaptation -> impacts of adapation measures, especially benefits (estimated benefit components with basic conditions, e.g. climate scenario, timeline, etc.)
- Step 2: Conducting Impact assessment along the established criteria set

- Criteria set contains four criteria categories: Basic information, Effectiveness, Efficiency, Side effects
- Sub-categories (described in the following table) were analysed on the basis of the literature review:

Compiled Criteria-Set for Impact Assessment

Criteria	Sub-criteria	Explanation of sub-criteria
Basic information		
	Policy area	With which policy area is the measure associated?
	Type of measure	Does the measure support adaptation in terms of reducing impacts, reducing exposure, enhancing resilience and adaptive capacity (including increasing awareness of adaptation needs and options), or enhancing opportunities?
Effectiveness of adaptation		
Relevance		
	Relevance of the measure	How important is the climate change threat addressed by the measure? (What economic values, ecosystem functions and socio-cultural values are at stake, and to what extent are they affected by climate change impacts? Is there an indication of overriding public interest, e.g. critical infrastructures, public health)
	Avoided damage	What portion of the targeted potential damages can be avoided by implementing the measure?
	Windfall profit	Would or at which part would private stakeholders implement the measure autonomously?
	Dynamic incentive	Does the measure initiate further activities for adaptation to climate change?
	Scope of effect	At which spatial level does the measure have an effect?
Urgency		
	Timescale	At what timescale does action need to be taken?
	Time-lag	How long is the time-lag between implementation of the adaptation measure and the effect of the measure?
	Timeframe for measure (lifetime)	What is the timeframe during which the measure will have an effect?
Interactions between adaptation measures		
	Interactions	Does the measure affect other sectors or agents in terms of their adaptive capacity?
Flexibility		
	Regret/no-regret	Does the measure contribute to overall sustainable development, alleviate already existing problems and bring benefits for other social, environmental or economic objectives than adaptation?

	Scenario-variability	Is the measure effective under different climate scenarios and different socio-economic scenarios?
	Potential for adjustments	Can adjustments be made later if conditions change again or if changes are different from those expected today?
Efficiency/ costs and benefits		
	Cost/benefit-ratio	How high are the benefits of the measure relative to the costs? Are the costs justified by the benefits
	Administrative burden	What are the costs of the administrative implementation of the measure?
Side effects		
Economic side effects		
	Effect on innovation and competitive advantage	Does the measure give an incentive for innovation / can it deliver a competitive advantage for the EU economy?
	Effect on employment	Does the measure have effects on employment?
Environmental effects		
	Synergies with climate mitigation	Does the measure create synergies with mitigation (i.e. reduce GHG emissions or enhance GHG sequestration)?
	Positive effects on biological diversity	Does the measure have positive or negative effects on the conservation of biological diversity (other than directly intended as an adaptation effect)?
	Positive effects on other environmental pressures	Does the measure alleviate or exacerbate other environmental pressures?
Socio-economic effects		
	Distributional impacts	What are the impacts on different social or economic groups, are there expected impacts on particularly vulnerable groups?
	Effects on well-being and quality of life	Does the measure enhance well-being and quality of life (e.g. in the urban environment)?
	Stakeholder involvement	How does the measure enable or restrict stakeholder involvement and public participation in decision-making processes?

➲ Step 3: Analyses of benefits of the adaptation measures (as part of impact assessment)

- Overview of existing benefit components
- Estimation of quantitative benefit parts: benefit under climate change scenarios, transfer of information for different EU countries (dependent on data availability different assumptions for country adjustments necessary)
- Analysis of qualitative benefits

- Establishing of cost-benefit-ratios, together with cost data from chapter 4.

3 Screen key policy areas and identify adaptation measures

3.1 Energy

3.1.1 Analysis of current EU policies towards climate change adaptation efforts

For chapter 3, energy policies potential climate change impacts for this sector have been assessed.

The following overview provides insights if or how climate impacts and risks are addressed in existing policies for the energy sector. It can be concluded that adaptation is not at all mentioned in directives, regulations or standards for the energy sector. The only general references to climate change adaptation so far can be found at the level of green papers (cf. below).

EC directives, regulations and decisions on fossil fuels are not depicted below since not tackled here in terms of adaptation. A quick screening of related policies also did not show any references to adaptation.

With respect to cohesion policy, pertinent funding schemes might become accessible for adaptation measures in the energy sector.

Focus on Networks:

- **Regulation (EC) No 67/2010 of the European Parliament and of the Council of 30 November 2009 laying down general rules for the granting of Community financial aid in the field of trans-European networks**[1]

  No reference to adaptation

- **Regulation (EC) No 680/2007 of the European Parliament and of the Council of 20 June 2007 laying down general rules for the granting of Community financial aid in the field of the trans-European transport and energy networks (TEN Financial Regulation)**[2]

  No reference to adaptation

- **Decision No 1364/2006/EC of the European Parliament and of the Council of 6 September 2006 laying down guidelines for trans-European energy networks**[3]

  No reference to adaptation

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[1] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:027:0020:0032:EN:PDF.

[2] http://tentea.ec.europa.eu/download/legal_framework/8__regulation_6802007.pdf.

[3] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:262:0001:0001:EN:PDF.

- **Green Paper on a secure, sustainable and competitive energy network (COM(2008) 782)**[4]
  Addresses adaptation:
  - p8: *Related to this, the implications of climate change for Europe's energy networks, for example the positioning of plants, power lines and pipelines, need to be taken into account.*
- **Commission regulation (EU) 838/2010 and 774/2010 on transmission charging**[5]

  No reference to adaptation

- **Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity**[6]

  No reference to adaptation

- **Regulation (EC) No 714/2009 of the European Parliament and of the Council of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity**[7]

  No reference to adaptation

- **Directive 2005/89/EC of the European Parliament and of the Council of 18 January 2006 concerning measures to safeguard security of electricity supply and infrastructure investment**[8]

  No reference to adaptation

- **REGULATION (EC) No 713/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 establishing an Agency for the Cooperation of Energy Regulators**[9]

  No reference to adaptation

Focus on Supply:

- **Green Paper on a sustainable, competitive and secure energy (COM(2006) 105)**[10]
  Addresses different demand patterns where European citizens have to adapt:

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[4] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0782:FIN:EN:PDF.

[5] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:250:0005:0011:EN:PDF and http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:233:0001:0006:EN:PDF.

[6] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:211:0055:0093:EN:PDF.

[7] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:211:0015:0035:EN:PDF.

[8] http://www.energy.eu/directives/l_03320060204en00220027.pdf.

[9] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:211:0001:0014:EN:PDF.

[10] http://europa.eu/documents/comm/green_papers/pdf/com2006_105_en.pdf.

- ➲ p4: *Access to energy is fundamental to the daily lives of every European. Our citizens are affected by higher prices, threats to the security of energy supply and* *__changes to Europe's climate__*.
- ➲ And in general terms at p5: *Sustainable development. How can a common European energy strategy* *__best address climate change__* [not clear if adaptation is meant here]*, balancing the objectives of environmental protection, competitiveness and security of supply? What further action is required at Community level to achieve existing targets? Are further targets appropriate? How should we provide a longer term secure and predictable investment framework for the further development of clean and renewable energy sources in the EU?*

- **Council Regulation (EU, Euratom) No 617/2010 of 24 June 2010 concerning the notification to the Commission of investment projects in energy infrastructure within the European Union[11]**

  No reference to adaptation

- **Directive 94/22/EC of the European Parliament and of the Council of 30 May 1994 on the conditions for granting and using authorizations for the prospection, exploration and production of hydrocarbons[12]**

  No reference to adaptation

- **Regulation (EC) No 663/2009 of the European Parliament and of the Council of 13 July 2009 establishing a programme to aid economic recovery by granting Community financial assistance to projects in the field of energy[13]**

  No reference to adaptation, but establishing important funding mechanisms that my become relevant for adaptation (cf. part 3)

- **Regulation (EU) No 1233/2010 of the European Parliament and of the Council of 15 December 2010 amending Regulation (EC) No 663/2009 establishing a programme to aid economic recovery by granting Community financial assistance to projects in the field of energy[14]**

  No reference to adaptation

- **Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources[15]**

  No reference to adaptation

General:

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[11] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:180:0007:0014:EN:PDF.

[12] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2010:157:0002:0004:EN:PDF.

[13] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:200:0031:0045:EN:PDF.

[14] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:346:0005:0010:EN:PDF.

[15] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF.

- **Fifth report on economic, social and territorial cohesion[16]**

  Reference to vulnerability (p118ff); direct reference to climate change adaptation!

  ➲ p30: *To improve financial engineering instruments within Cohesion Policy, a number of measures could be examined:*
  extend both the scope and scale of financial engineering instruments: in terms of scope, to encompass new activities (e.g. sustainable urban transport, research and development, energy, local development, lifelong learning or mobility actions, climate change and environment, ICT and broadband); in terms of scale, to combine interest subsidies with loan capital or other forms of repayable financing.

  ➲ *p192: A budget of some EUR 92 billion was allocated to the EAFRD for 2007-2013... This was increased by EUR 4,4 billion in 2009, in part by reducing the amount available under the first pillar, in order to reinforce expenditure on climate change, ...”*

  ➲ *p192: Reference to EC White paper on adaptation*

- **Conclusions of the fifth report on economic, social and territorial cohesion: the future of cohesion policy (2010 642, finale)**17

  Reference to climate change

  ➲ *p2: “As indicated in the EU budget review2, in particular progress needs to be made in the following key areas: concentrating resources on the Europe 2020 objectives and targets; committing Member States to implementing the reforms needed for the policy to be effective; and improving the effectiveness of the policy with an increased focus on results. The explicit linkage of cohesion policy and Europe 2020 provides a real opportunity: to continue helping the poorer regions of the EU catch up, to facilitate coordination between EU policies, and to develop cohesion policy into a leading enabler of growth, also in qualitative terms, for the whole of the EU, while addressing societal challenges such as ageing and climate change”.*

➲ **COUNCIL REGULATION (EC) No 2012/2002 of 11 November 2002 establishing the European Union Solidarity Fund[18]**

No direct reference

➲ **COMMUNICATION FROM THE COMMISSION: Trans-European networks: Towards an integrated approach {SEC(2007) 374}[19]**

No direct reference

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[16] http://ec.europa.eu/regional_policy/sources/docoffic/official/reports/cohesion5/index_en.cfm.

[17] http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/EN/genaff/119400.pdf.

[18] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:311:0003:0008:EN:PDF.

[19] http://ec.europa.eu/ten/transport/legislation/doc/com_2007_0135_sec_0374_en.pdf.

3.1.2 Gap analysis

Distribution and transmission networks (including storage)

The climate-related demands on the electricity distribution networks are triggered by the following issues:

1. Direct climatic pressures as depicted in the impact table above
2. Demand peaks e.g. for more frequent heat waves (as indirect impact on the distribution network)
3. The EU goal to promote renewable energy (overall share of 20% until 2020, cf. directive 2009/28/EC) which means less reliable base loads and more variable peaks in energy production (as impact of climate mitigation policy on the distribution network)
4. Overall change in demand patterns due to e.g. population migration, change in tourism (as indirect impact of climate change on the distribution network)

The gap analysis for the existing policies can be summarized as follows:

The term 'tackling climate change' (or similar) is referred to in many regulations, directives and the two green papers on secure, sustainable and competitive energy and energy network. In fact, this refers solely to mitigation efforts, but not to responsive measures urgently needed to enhance climate change resilience for distribution and subsequently securing supply.

Energy supply (including demand)

The supply of energy and the climate vulnerabilities thereof to which adaptation measures have to be put in place in order to respond and secure reliable supply are:

1. Direct climatic pressures on supply facilities as depicted in the impact table above
2. Altered demand peaks e.g. due to more frequent heat waves or due to more electric devices in consumer's hands (all of which have to be met by supply i.e. the energy production mix envisaged by the EU and MS)
3. The EU goal to promote renewable energy (overall share of 20% until 2020, cf. directive 2009/28/EC) which faces less reliable base loads and more variable peaks in electricity energy production that are not easily adjustable - also due to the climate-induced changing demand patterns
4. Overall change in demand patterns due to e.g. population migration, change in tourism (as indirect impact of climate change on the distribution network)

The gap analysis for the existing policies can be summarized as follows:

The term 'tackling climate change' (or similar) is referred to in many regulations, directives and the two green papers on secure, sustainable and competitive energy and energy networks. In fact, this refers solely to mitigation efforts, but not to responsive measures urgently needed to enhance climate change resilience for distribution and subsequently securing supply.

The urgent need to tackle climate adaptation becomes visible when looking at the yet most common (and most important in terms of share of the total energy supply) renewable energy sources: these are the completely climate dependant sources provided by wind, running water and solar irradiation.

We have excluded biomass energy and agrofuel from our analysis due to the following facts:

- Biomass and agrofuel should be regarded as part of the agriculture/forestry sector, since their production and vulnerability towards climate change is highly driven by agriculture policy (e.g. subsidies or directives concerning mandatory share of agrofuel in diesel and gasoline)
- The potential of especially (1st generation) agrofuel to support the 20/20/20 goals is currently highly controversial and thus an extension of at least agrofuel production is questionable
- Biomass and agrofuel production compete with food production. Higher food prices might also - purely market-based - lead to decreasing production and supply of biomass and especially agrofuel

3.1.3 The components of the energy system

To get a coherent overview on climate impacts and recommended responses, it is useful to distinguish between four parts of the energy system:

- **supply** (including all energy production types)
- **energy networks (transmission and distribution)**
- **demand** (with the consumer responding to climate change by demanding additional/less energy)
- **storage** (as new envisaged part of the energy system especially responding to the needs of expanding the share of renewables that are less suitable for base load)

Thus, the elaboration on adaptation measures is divided in two parts:

A. ***Distribution and transmission networks*** (which will include measures for ***storage*** as part of the adaptation measures package) and for which the EU has a high political responsibility through the TEN-E and coherence policy;

B. ***Energy supply*** (which will include measures for ***demand*** reduction/management as smaller part for the adaptation measures package).

A. Distribution and transmission networks (including storage)

1. Impact Table:

The impact table provides a summary on climatic pressures and resulting risks for the energy distribution networks.

The following chapters refer basically to the distribution and transmission of electricity, since climate impacts on the gas distribution network seem much less demanding and thus manageable by system operators.

Table 3-1: Impact Table distribution and transmission networks

Type	Climatic pressures	Risk	Time frame of expected impact	Area mainly affected
Primarily electrical transmission networks	Extreme high temperatures	Decreased network capacity	Medium negative (2025) to extreme negative (2080)	EU-wide
	Snow, icing, storms	Increased chances on damages to energy networks/blackout	Medium negative to low positive (2050)	NW-EU
Primarily electrical distribution networks	Heavy precipitation	Mass movements (landslides, mud- and debris flows) causing damages	Time frame, magnitudes and frequencies uncertain	Especially mountain-ous regions
Primarily Transmission networks (oil and gas)	Melting permafrost	Ties of gas pipelines in permafrozen ground cause technical problems (this is touching only arctic supply pipelines and not the East-West gas pipelines, since the latter ones are not grounded in permafrost)	Low for 2025 and gradually increasing	Arctic Eurasia
Primarily Storage and Distribution	Higher temperatures	Reduced throughput capacity in gas pipelines		
	Storms in connection with high tides and SLR	Threats to refineries and coastal pipelines due to SLR/high tide/storms	Low for 2025 and gradually increasing	EU-wide

2. Exploration of possible adaptation measures

Adaptation measures for the electricity distribution and transmission network responding to climate change impacts still have a very thin base of available literature. NAS of EU members states include adaptation in the energy sector - at least in 9 of the so far 12 existing NAS -, but put emphasis on the supply side and build upon the specifics of countries' energy supply mix and its vulnerabilities. Thus, scaling up of national experiences to EU level implies major constraints - especially for energy networks.

Nevertheless, the EU has already instruments in place to integrate national networks into a pan-European network, which allows for mainstreaming measures as described below mainly into the following instruments:

- the Strategic Energy Technology (SET) plan including the European Energy Grid Initiative (EEGI)
- the European Network for Transmission System Operators (ENTSO) and
- the European Distribution System Operators for Smart Grids (EDSO-SG)
- the very recent setup of the Agency for the Cooperation of Energy Regulators (ACER)

The measures are grouped using categories based on the Impact Assessment accompanying the White Paper on Adaptation (COM 2009).

Note: In our review, we have included storage measures as one part of the solution to climate-proof the distribution of (electrical) energy.

A. Technical measures

1 Climate-proof the grid *(cf. measure 13-15)* by

a. **Transmission:** Installing additional network capacities with special focus on volatile base load countries and regions with high potential and future dependence on non-base load capable renewable energy sources ((e.g. North Africa -> Solar Energy (cf. DESERTEC) or North Sea (offshore wind parks) (cf. ENTSOE 2010)) [This measure refers to smart grid activities already taking place (cf. e.g. EDSO-SG) which yet do not take into account the threats climate change is posing to the security of supply through the stepwise implementation of the renewable energy goals]

b. **Transmission:** Installing additional network capacities with special regard on countries and regions with storage potential (e.g. Norway -> currently solely pumped storage units) (cf. ENTSOE 2010)[Yet, water pumping storage capacities have the highest efficiency]

c. **Distribution:** Making stronger use of electrical railway network to further decentralize the distribution and transmission network *(cf. measure 12)* [This measure would allow for a cost-efficient support of additional distribution capacities urgently needed while decentralizing energy supply with small-scaled facilities]

2 **Transmission:** Detect vulnerability hot spots (Williamson 2009) e.g. in the overhead transmission networks *(cf. measure 16 and 18)* towards monitoring of

a. Mass movements

b. Storms

c. Floods

d. Overheating *(cf. measure 10)*

3 **Transmission:** Install underground cables at vulnerability hot spots [expensive, according to ZEW, costs may exceed 10times the costs of ordinary overhead

transmission, also the conductivity of underground cables is limited due to fast warming and additional cooling facilities needed]

4 **Transmission:** Expand aisles through forests to the degree necessary [controversial, but in some explicitly storm-exposed regions possibly unavoidable]

5 **Transmission/Distribution** (depending on the scope of the measure): Put slope stability measures into place (protective forests or technical measures)

6 **Transmission/Distribution:** Set up an early warning system (Williamson et al. 2009 and Ebinger 2011 et al.) for energy shortcuts due to

   a. High demand (e.g. during heat waves or cold spells -> overheating of the network due to overuse)

   b. Extreme events (storm, icing, hail) or periods (droughts -> low hydropower and usually also wind power, heat waves -> overheating of the transmission cables due to high temperatures)
   (cf. measure 16)

Storage:

7 Install new storage facilities (pumped storage units) especially in regions with volatile base load (Ibrahim et al. 2008)

8 Explore potential of other storage methods (e.g. H_2 or CH_4) to build up in parallel to expanding renewable energy share (Ibrahim et al. 2008, URS 2010)

9 Mid-term: Make use and maintain existing gas distribution network for CH_4 transmission and storage, once SABATIER process ('solar fuel', or other biochemical methods) reach industrial application/marketability [currently research is progressing fast on new methods for electrolysis and methanising H_2 to CH_4]

B. Standards and regulations

Transmission:

10 Higher standards for overhead transmission cables with respect to increasing demands by climate change (e.g. temperature increase) and energy demands (overheating) *(cf. measure 2.d)*

11 Empower ACER to disentangle the distribution and transmission network and foster competition of transmission system operators leading to enhanced investments in the energy distribution and transmission networks [most of these measures have to be financed by power suppliers/TSOs and should not be subject to public spending, only co-funding as put forward in *measures 21-23*]

12 Foster standards in power transmission to further enable electrified railway networks to be used for decentralized distribution *(cf. measure 1.c)*

C. Capacity building *(cf. measures 1-6)*

13 **Transmission:** Foster strong cooperation with the European Transmission Operators via ENTSO-E (mandated by internal energy market directive 2009/72/EC) to climate-proof the transmission network

14 **Transmission:** Enhance cooperation of ENTSO-E with small electricity producers to climate-proof the transmission network by better connecting decentralized energy supply facilities to the network

15 **Transmission/Distribution:** Foster the cooperation among the European Electricity Grid Initiative (EEGI), EDSO-SG (the European DSO Association for smart grids), the grids R&D Roadmap 2010-2018 and ENTSO-E's R&D activities towards European smart grid solutions that are not only capable to optimize supply and demand issues but also to allow for emergency switches ('detours for transmission') of the network in case of local/regional disruptions caused by meteorological extreme events

D. Communication/Awareness raising

16 **Transmission/Distribution:** Provide information like impact/vulnerability maps and good practice examples (Ebinger et al. 2011) and easy access to information to ENTSO, EDSO and all energy producers (e.g. communicate results from research projects such as AEOLUS to the wind power producers)*(cf. measure 2)*

17 **Transmission/Distribution:** Take care for adaptation to be taken into account in further integration (Ebinger et al. 2011) of the national networks into a pan-European one i.e. mainstream adaptation into further proceedings of ENTSO, EDSO, ACER, EEGI and the execution of the SET plan

E. Guidelines

18 **Transmission/Distribution:** Develop check list and guidance for TSOs and DSOs to assess vulnerability and possible adaptation options *(cf. measure 2)*

19 **Transmission/Distribution:** Develop guidelines for setting up pan-European early warning systems for energy shortcuts *(cf. measure 6)*

F. EU financing scheme

20 Increase funding within EU RTD funding schemes for the following most crucial parts

a. **Storage:** Electricity Storage systems and methods

b. **Transmission:** New material for transmission cables

c. **Transmission/Distribution:** Smart grids managing new demand patterns, system operations after disruptions and larger share of renewable energy

21 **Transmission:** Use MBI like tax reduction to create incentives for TSOs to invest in further climate-proofed networking capacities (note: this is a classic no-regret measure, since these investments have to be placed anyway)

22 **Transmission/Distribution:** Use EC-EIB initiative 'EU Sustainable Energy Financing Initiative' and the Marguerite equity fund (led by EIB) to mainstream adaptation into funded projects

23 **Transmission:** Use Cohesion Funds to support large-scale energy adaptation projects

3. Exploration of adaptation options for the EU level

The current energy networks policy is framed by the TEN-E as well as the internal energy market policy which leave responsibilities for maintenance of the energy networks mainly to the transmission and distributions system operators and thus also partly to the members states whenever the companies are in public ownership. However, setting up a true pan-European energy network puts additional responsibilities to EU level and empowers TEN-E and internal energy market policies, where among other issues the need to climate proof energy networks should be put in the focus of discussions.

Thus, we have explored possibilities for adjustments of existing policies for mainstreaming adaptation (cf. A). The suggestions take up the adaptation measures presented under section 2 in terms of options for corresponding policy actions (according references are given in brackets to each suggestion).

In addition, further policy options advisable to respond to identified climatic risks and pressures have been investigated (cf. B).

A. Suggestions for adjustments in existing policies

- **Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity**

(5) „A secure supply of electricity is of vital importance for the development of European society, the implementation of a sustainable climate change policy, and the fostering of competitiveness within the internal market. To that end, cross-border interconnections should be further developed in order to secure the supply of all energy sources at the most competitive prices to consumers and industry within the Community."

Suggestion: Add: "Cross-border interconnections can also serve as an adaptation measure to extreme events causing interruptions of national transmission networks by reducing the risk of long lasting blackouts. Extreme events are expected to become more frequent and intense due to climate change." *(addresses measure 17)*

Art. 12 (c): Tasks of transmission system operators:

"Each transmission system operator shall be responsible for:

contributing to security of supply through adequate transmission capacity and system reliability"

Suggestion: Add: "For the latter, risks posed by climate change for the existing network components shall be taken into account, in particular towards meteorological extreme events including associated mass movements." *(addresses measure 17)*

- **Directive 2005/89/EC of the European Parliament and of the Council of 18 January 2006 concerning measures to safeguard security of electricity supply and infrastructure investment**

(15) „Transmission and distribution system operators need an appropriate and stable regulatory framework for investment, and for maintenance and renewal of the networks."

Suggestion: Add […]"while additional stresses are put on the TSO by climate change, which are

a. Direct impacts onto the network via increasing temperatures and more extreme events
b. Different demand patterns induced by more frequent heat waves
c. Higher share of renewable energy putting more volatility on the network." *(addresses measures 16 and 18)*

Art. 6, 1. "Member States shall establish a regulatory framework that:

(a) provides investment signals for both the transmission and

distribution system network operators to develop their networks in order to meet foreseeable demand from the market; and

(b) facilitates maintenance and, where necessary, renewal of their

networks."

Suggestion: Add: "(c) allows TSOs and DSOs to enhance climate resilience of their infrastructure especially towards projected more frequent and intense extreme events." *(addresses measure 19)*

- **<u>Regulation (EC) No 67/2010 of the European Parliament and of the Council of 30 November 2009 laying down general rules for the granting of Community financial aid in the field of trans-European networks</u>**

Art. 6.4: "Project selection criteria"

"The decision to grant Community aid should also take account of:

(a) the maturity of the project;

(b) the stimulating effect of community intervention on public and private finance;

(c) the soundness of the financial package;

(d) direct or indirect socio-economic effects, in particular on employment;

(e) the environmental consequences."

Suggestion: Add: "(f) the risks of damages to the project by climate change impacts." *(addresses measures 20-23)*

- **<u>REGULATION (EC) No 713/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 establishing an Agency for the Cooperation of Energy Regulators</u>**

(15) "The Agency should contribute to the efforts of enhancing energy security."

Suggestion: Add: […]"by analyzing the additional stresses put onto energy supply and distribution by the higher share of renewable energy as well as the threats for the energy system caused by climate change and shall promote awareness on the need for taking steps to climate-proof the European energy system." *(addresses measures 16)*

In case further policy initiatives are taken on the below mentioned Green Papers, the following suggestions can be given:

- **Green Paper on a secure, sustainable and competitive energy network (COM(2008) 782)** addressing adaptation:
  - ➲ p8: *Related to this, the implications of climate change for Europe's energy networks, for example the positioning of plants, power lines and pipelines, need to be taken into account* [suggestion to add with respect to the White Paper process: "…and steps to adapt the European energy system have to be taken"].
- **Green Paper on a sustainable, competitive and secure energy (COM(2006) 105** addressing different demand patterns while European citizens have to adapt:
  - ➲ P4: *Access to energy is fundamental to the daily lives of every European. Our citizens are affected by higher prices, threats to the security of energy supply and changes to Europe's climate* [suggestion to add with respect to the White Paper process: "causing new energy demand peaks e.g. for air conditioning during heat waves].

And in general terms at p5: *Sustainable development. How can a common European energy strategy best address climate change* [suggestion to add with respect to the White Paper process: "mitigation and adaptation"], *balancing the objectives of environmental protection, competitiveness and security of supply? What further action is required at Community level to achieve existing targets? Are further targets appropriate? How should we provide a longer term secure and predictable investment framework for the further development of clean and renewable energy sources in the EU?*

[*Comment: Suggestions only relevant if a White Paper is foreseen*]

B. Options for additional policy action

- **Commission ENTSOE-E and the climate research community with the adaption of the European electricity network by opening pertinent calls (jointly between DG ENER and DG CLIMA)** *(addresses measures 1-6)*
- **Intensify research on storage methods (DG RTD)** *(addresses measures 7-9)*
- **Set up an annex to** Decision No 1364/2006/EC **which shall provide standards for overhead as well as for underground/undersea transmission cables reflecting the higher demand posed by higher temperatures and demand by consumers particularly during heat waves** *(addresses measure 10)*
- **Set up an Energy System Adaptation Plan funded by the 'EU Sustainable Energy Financing Initiative' and the Marguerite equity fund (in cooperation with the EIB)**

B. Energy supply (including demand)

1. Impact Table:

The impact table below provides a summary on climatic pressures and resulting risks for energy supply in Europe.

Note that in the following chapters we do not refer to biomass and agrofuel (due to strong correlation with forestry and agriculture, cf. text below).

The following renewable energies are not climate sensitive and/or have a very low share in energy production so far: aerothermal, geothermal, hydrothermal, ocean energy (tidal and wave power plants), landfill gas, sewage treatment plant gas, biogases and osmosis power plants. Thus, these (potential) energy supplies have been left aside.

This puts the focus for further assessment on the electrical energy production/supply of the most important types: thermal (fossil fuel+nuclear) as well as renewable energy supplies by water (distinguished in two categories), wind (not distinguishing between offshore and onshore) and solar energy (PV and thermal).

Table 3-2: Impact Table energy supply

Type	Climatic pressures	Risk	Time frame of expected impact	Area mainly affected
Hydropower, large-scale	Decreased glacial run off (mid- to long-term) Extreme low rivers and streams flows during drought periods	Increased chance on shortage of hydropower supply in summer at downstream (pluvial-regime fed) stations	Medium negative (2025; 2080) to high negative (2080)	EU-wide
Hydropower, small scale (upstream/alpine)	Increased glacial run-off in the short run	Loss of "buffer capacities" for summer droughts in the mid and long run due to losses in glacier volumes	Short term: positive, mid- to long term: high negative (with individual glacial volumes, regional climates and thus different time scales)	Mainly Alps and Scandinavia
Solar energy (PV and thermal)	Increasing temperatures -------------------- Cloudiness	Loss in solar cell effectivity due to higher ambient temperatures ---------------------- For some regions with high potential (and existing capacities) a decrease in cloudiness seems	Medium (2050) and long-term (2080) negative -------------- Highly uncertain: medium negative (2025), no	EU-wide ------------- Southern Europe: positive Northern

	-------------------- Solar irradiation	likely ------------------------ Inverse proportional to cloudiness	information for 2080 (depending largely on the uncertain climate parameters irradiation and cloudiness	Europe: negative (highly uncertain)
Thermal power plants (incl. nuclear)	Water temperature increase -------------------- Floods -------------------- Extreme low water flows	Lower CARNOT efficiency due to higher ambient and cooling water temperatures ------------------------ Risk of flood damages due to location of most thermal facilities at water bodies (rivers) ------------------------ Reduced cooling water availability	Medium negative (2025) to extreme negative (2080)	EU-wide
Wind power generation	Storm frequency (not severity, since facilities are capable to handle highest wind speeds) -------------------- Melting inland glaciers and water expansion due to temperature increase	Wind power generation has to be turned down beyond certain wind speed thresholds in order to avoid overheating/overload of distribution systems ------------------------ SLR (only in very few offshore cases and considering high SLR scenarios)	Referring to climate model outputs, future storm frequencies are highly uncertain, but might increase in North and Baltic Sea (where offshore wind power generation is concentrated) --------------- Long term (2080) negative	North Sea and Baltic Sea regions

Reduction of electricity demand by consumer (through self supply of e.g. small PV units)	Higher temperatures	Reduced PV efficiency	Highly uncertain	cf. solar energy
Passive heating (geothermal)	Altering precipitation regime	Fluctuating groundwater levels	Unpredictable	Regions with sensitive aquifers
Energy demand	Higher temperatures	High AC demand in summer; high cooling demand by food industry	Short term medium to long term strong negative (i.e. raise in electricity demand in summer season)	EU-wide
		Low heating demand in winter	Generally positive (for both cf. studies by Dolinar et al. 2010 for Sl, Mirasgedis et al. 2007 for GR and Christenson et al. 2006 for CH)	Southern and Eastern Europe
	Droughts	High energy demand by pumping for irrigation	Low negative	

2. Exploration of possible adaptation measures

Adaptation measures for energy supply have a fairly limited base of available literature while there is plenty of literature available for ways to decrease the demand of energy. This is reflected in the EU policy and the according directives and regulations, where many tackle the energy demand side through labeling, pricing or setting standards. Since all efforts for enhancing energy efficiency or increasing self-supply can also be regarded as adaptation (e.g. to less reliable supply of energy), some (further) ideas are put forward in the following analysis, although the focus will be on the supply of energy, where we see a significant gap in pertinent policies in terms of climate-proofing.

NAS of EU MS include adaptation in energy supply/demand - at least in 9 of the so far 12 existing NAS – although they build upon the specifics of countries' energy supply mix and its vulnerabilities. Nevertheless, some lessons learned from either the NAS itself or associated research projects have been detected.

The measures are grouped using categories based on the Impact Assessment accompanying the White Paper on Adaptation (COM 2009).

Supply:

Water:

1 Technically optimize hydropower plants to more frequent and intense extreme events (droughts, floods, erosion/sedimentation) by e.g. build desilting gates to flush silted reservoirs (Williamson et al. 2009) and adjust upsurge operation (cf. proceedings from Austrian research project DSS_KLIM:EN project)

2 Avoid erosion in hydropower catchments by land management (Williamson 2009)

3 Install additional capacities (if possible) at increasing (glacial) flow regimes, if increases persist longer than the technical lifetime of the plant (Williamson 2009)

Wind:

4 Increase in efficiency of wind turbines towards more variable wind conditions through adjustments of constructions and power control for wind speeds <5m/s and >15m/s (according to Krohn (2009) wind turbines are currently optimized for wind speeds of around 8m/s)

5 Due to the high volatility in wind power generation, combine/connect wind power plants with local storage systems (pumped power units, electrolytical generation of H_2/CH_4 or batteries) to avoid losses due to network overloads

Solar:

6 Enhance efficiency of PV installations by solar tracking

7 Storm- and hailproof PV installations (cf. Ebinger et al. 2011, German NAS 2008)

Thermal:

8 Improve the robustness of mining installations to: i. offshore: storms and SLR and ii. onshore: to both flooding and shortage of water needed for mining operations (Williamson 2009)

9 Site power plants in flood-secure places with sufficient cooling water supply (Williamson 2009)

General:

10 Diversify energy supplies to the degree possible

11 Support integrated approaches tackling energy *and* water supply (coherence, creation of jobs in underdeveloped regions and development aid)

Demand:

Water:

12 Promote water saving technologies that are capable to reduce cooling water demands by thermal power plants (e.g. through reuse or partially closed circles) and if ambient temperature scenarios allow, replace water cooling systems with air cooling (Williamson 2009) *(cf. measure 16)*

Solar:

13 Install decentralized solar-powered air conditioning ('solar cooling'), since energy production of PV units is usually high during heat waves (increased irradiation outweighs high temperatures) to cut demand peaks during heat waves (cf. Ebinger 2011) *(cf. measure 15)*

B. Standards and regulations

14 Set standards for energy efficiency of air conditioning devices

15 Set regulation for air conditioned office buildings to install PV ('solar cooling') *(cf. measure 13)*

16 Set standards for energy efficiency for water pumping (needed for additional irrigation) *(cf. measure 12)*

17 Set up regulation for energy cuts during meteorological extreme events/periods (Ebinger at al. 2011)

C. Capacity building

18 Set up an EU-wide database of hydropower stations and classify them according to their climate sensitivity (e.g. types: pumped storage, power stations with reservoir, river run-off stations; run-off regime: glacial, nival, pluvial with different vulnerabilities)(cf. proceedings from Austrian research project DSS_KLIM:EN)

19 Use regional climate scenarios to explore sites of potential surplus energy production (mainly wind and solar) in forthcoming decades

20 Set up energy-meteorological databases tailoring data needs for the purposes of energy suppliers (e.g. site-specific wind simulations, catchment-specific run-off data, localized solar irradiation data)(cf. Ebinger et al. 2011)

21 Intensify international cooperation in energy policy (cf. SET-Plan) not just with a focus on supply of fossil fuels, but also emphasizing security of energy supply with respect to climate change (the DESERTEC project can serve as nucleus for that)

D. Communication/Awareness raising

22 Set up overviews of envisaged energy mix 2020 of all EU MS as basis for national climate-proofing and assist EU MS in doing so

23 Explore opportunities to build clusters of energy suppliers (maybe via Eurelectric) that are specialized in certain generation of energy and build European networks for e.g. hydropower, wind and solar suppliers on the vulnerability and opportunities of climate change – this could lead to common approaches for Climate Risk Assessment (CRA) and Management (CRM) for power plants either planned or already operated

24 Cooperate with insuring companies for awareness campaigns to include climate change considerations in their risk assessments and in determining insurance premiums

E. Guidelines

25 Develop check list and guidance for energy producers to assess vulnerability, productivity chances and possible adaptation options (cf. measures 16-18)

26 Develop guidelines for setting up pan-European early warning systems and contingency plan for energy shortcuts due to supply disruptions (cf. measure 17)

F. EU financing scheme

27 Raise funding within EU RTD funding schemes for the following most crucial parts

  a. Impacts of extreme events (cf. Tebaldi et al. 2006) and possible abrupt climate change on the energy supply

  b. Dynamics of yet not climate-proofed energy supply (e.g. hydropower, cf. Lehner et al. 2001) under climate change

  c. Harden energy infrastructure and thus raise climate resilience (cf. Pryor & Barthelmie 2010 for wind, URS 2010)

  d. User-oriented data information systems on energy meteorology amended by climate scenarios data information yet provided by e.g. ENSEMBLES)

  e. new forms of generating renewable energy capable to supply base load (e.g. biomass and geothermal)

28 Explore further possibilities to share responsibilities for losses and risks by hedging weather events through the use of financial instruments, e.g. weather derivatives and insurance products to protect against adverse financial effects due to mainly extreme events/periods (cf. Ebinger et al. 2011)

29 Use EC-EIB initiative ‘EU Sustainable Energy Financing Initiative’ and the Marguerite equity fund (led by EIB) to mainstream adaptation into funded projects (cf. recommendations in energy distribution)

30 Use Cohesion Funds to invest in climate proofing energy supply

3. Exploration of adaptation options for the EU level

Our policy recommendations are framed by three major efforts that have to be undertaken when climate-proofing energy supply and demand in Europe:

1. Each MS has to climate proof its envisaged national energy production mix. This has to be done at MS level due to the various differing key energy sources (e.g. nuclear in France, hydropower/biomass in Austria, wind energy in Denmark/Germany) in the member countries (and has already been touched in some NAS), but needs a mutual exchange that has to be coordinated by DG CLIMA/DG ENER. The climate-proofing process will need to be performed for three different time scales:

i. 2020/2025, when in 2020 the goal to have a 20% share of renewable energy in the total energy supply mix enters into force (which requires some additional efforts on climate proofing cf. impact table and possible adaptation measures above),

ii. 2050, when most expected impacts (cf. impact table) have increased - e.g. glacial run-off regimes have vanished to a significant degree and extreme weather events/periods are common; mitigation targets might be high (yet uncertain); and virtually all of today's power plants will have to be replaced due to the end of their lifetime.

iii. For 2080, a strategic vision of a well-adapted *and* carbon-neutral energy production should be envisaged.

2. EU policies on energy efficiency have to respond to the changing demand patters of European citizens, industry and agriculture that are induced by climate change (mainly heat waves and droughts). This needs a concerted action on the energy efficiency of air conditioning (office and private buildings), industrial cooling facilities (especially for the food industry) and pumping systems (in agriculture) as well as on tailor-made energy supply for these demands (e.g. 'solar cooling'). These efforts seem small, but can significantly contribute to cut off critical demand peaks and thus avoid blackouts.

3. Besides the carbon intensity of different sorts of energy supply, EU policies have to account for the water intensity of energy production as well. The competition for freshwater supplies among the energy sector and the water and agriculture sector needs to be reflected in EU policies (e.g. WFD and CAP) since it is likely to increase under conditions of climate change in many parts of Europe (e.g. water scarcity in southern Europe). (Note: These cross-sectoral challenges are not reflected in the following recommendations)

It is surprising though that adaptation of the energy sector is not yet mainstreamed neither in the process of the SET plan implementation nor the Strategic Energy Review since it puts various challenges onto security of energy supply which builds the core pillar of EU energy policy.

Thus, we have explored possibilities for adjustments of existing policies for mainstreaming adaptation (cf. A). The suggestions take up the adaptation measures presented under section 2 in terms of options for corresponding policy actions (according references are given in brackets to each suggestion).

In addition and probably more comprehensive, further policy options advisable to respond to identified climatic risks and pressures have been investigated (cf. B).

A. Suggestions for adjustments in existing policies

- **DIRECTIVE 2010/31 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2010 on the energy performance of buildings and its amendments**

Article (6): New buildings

1. Member States shall take the necessary measures to ensure that new buildings meet the minimum energy performance requirements set in accordance with Article 4.

For new buildings, Member States shall ensure that, before construction starts, the technical, environmental and economic feasibility of high-efficiency alternative systems such as those listed below, if available, is considered and taken into account:

(a) decentralised energy supply systems based on energy from renewable sources;

(b) cogeneration;

(c) district or block heating or cooling, particularly where it is based entirely or partially on energy from renewable sources;

(d) heat pumps.

Suggestion: Add: "(e) 'solar cooling' i.e. air conditioning powered by onsite PV" *(addresses measure 12)*

- **DIRECTIVE 2006/32 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC ("The Energy Services Directive")**

Annex III: Indicative list of examples of eligible energy efficiency improvement measures

Suggestion: Add: "Agriculture sector: energy efficient water pumping devices for irrigation" *(addresses measure 16)*

- **REGULATION (EC) No 106/2008 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 January 2008 on a Community energy-efficiency labelling programme for office equipment (Energy Star)**

Suggestion: Add: "air conditioning devices" and "solar cooling" in the annex c for office equipment product groups (*addresses measure 15*)

- **DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance)**

Article 4: National renewable energy action plans

[1…6]

Suggestion: Add: (7): Member States shall ensure a preliminary vulnerability assessment of the supposed extension of their national renewable energy supplies as laid down in their national renewable energy action plan as well as potential and already executed measures to respond to those vulnerabilities. A comprehensive vulnerability assessment of all Member States` energy supplies shall be carried out until 2015 and will serve the basis for a sectoral energy climate change adaptation plan.

(addresses measures 1-7)

- **REGULATION (EC) No 713/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 establishing an Agency for the Cooperation of Energy Regulators (Text with EEA relevance)**

Article 9: Other tasks

Suggestion: Add:

(3) The Agency shall elaborate on a contingency plan for energy cuts during meteorological extreme events and other disruptions of energy supply caused by natural hazards. *(addresses measure 17)*

- **REGULATION (EC) No 663/2009 establishing a programme to aid economic recovery by granting Community financial assistance to projects in the field of energy**

Article 8: Selection and award criteria under (2)

Suggestion: Add:

(i) the capability to increase the climate resilience of the energy supply system through climate-proofing renewable energy as well as thermal power plants as well as to introduce water saving technologies especially for the cooling purposes of thermal power plants (incl. nuclear). *(addresses measures 1-11 and 13)*

B. Options for additional policy action

- **Use the SET plan and the Strategic Energy Review to address and mainstream adaptation into the further energy policy process by**

    1. Setting up focus groups of energy producers (insurance companies and banks) to exchange on VIA in solar, wind, hydropower and thermal energy production (and mining) and to

    2. Contract research institutions to intersect energy-meteorological data with climate change scenarios and tailor them to

    3. Vulnerability assessments and hot spots maps for all energy supply facilities

    4. Use the vulnerability assessments aggregated and disaggregated (MS level) as DSS for the adequate energy mix until 2020 in order to meet the 20/20/20 goal *(addresses measures 18-24)*

- **Develop check list and guidance for energy producers to assess vulnerability, productivity chances and possible adaptation options** *(addresses measure 25)*

- **Develop guidelines for setting up pan-European early warning systems and contingency plan for energy shortcuts due to supply disruptions** *(addresses measure 26)*

- **Mainstream urgent needs for further research funding on climate-proofing the energy supply chain into** *(addresses measures 27, 29 and 30)*:
    - EU FP-RTD programme "Energy"
    - Cohesion Funds (for demonstration and applied projects)
    - EC-EIB initiatives/funds: Marguerite and EU Sustainable Energy Financing Initiative'
- **Address risk sharing for financial losses due to climate impacts (both losses in energy productivity as well as losses after blackouts) bringing together energy producers and insurance companies** *(addresses measure 28)*
- **Set up a regulation on energy labeling for water pumping devices for irrigation** *(addresses measure 16)*
- **Set up a directive on energy labeling of air conditioning devices in office and private buildings as well as for industrial cooling (e.g. food industry)** *(addresses measures 14 and 15)*

3.2 Infrastructure and Transport

3.2.1 Analysis of current EU policies towards climate change adaptation efforts

For chapter 3 policies and potential climate change impacts have been assessed. The following overview provides insight if or how the climatic risks are addressed in existing policies for infrastructure and transport.

- **Council Regulation (EC) N°1083/2006 laying down general provisions on the European Regional Development Fund, the European Social Fund and the Cohesion Fund and repealing Regulation (EC) No 1260/1999** [20]

No reference to climate change or adaptation

- **Fifth report on economic, social and territorial cohesion**[21]

Reference to vulnerability (p118ff); direct reference to climate change adaptation!

➲ p30: "*To improve financial engineering instruments within Cohesion Policy, a number of measures could be examined:*
extend both the scope and scale of financial engineering instruments: in terms of scope, to encompass new activities (e.g. sustainable urban transport, research and development, energy, local development, lifelong learning or mobility actions, <u>*climate*</u>

[20] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:210:0025:0078:EN:PDF .

[21] http://ec.europa.eu/regional_policy/sources/docoffic/official/reports/cohesion5/index_en.cfm .

change and environment, ICT and broadband); in terms of scale, to combine interest subsidies with loan capital or other forms of repayable financing."

- p192: *"A budget of some EUR 92 billion was allocated to the EAFRD for 2007-2013... This was increased by EUR 4,4 billion in 2009, in part by reducing the amount available under the first pillar, in order to reinforce expenditure on climate change, ..."*
- *p192: Reference to EC White paper on adaptation*

- **Conclusions of the fifth report on economic, social and territorial cohesion: the future of cohesion policy (2010 1348, finale)[22]**

Reference to climate change

- p2: *"As indicated in the EU budget review, in particular progress needs to be made in the following key areas: concentrating resources on the Europe 2020 objectives and targets; committing Member States to implementing the reforms needed for the policy to be effective; and improving the effectiveness of the policy with an increased focus on results. The explicit linkage of cohesion policy and Europe 2020 provides a real opportunity: to continue helping the poorer regions of the EU catch up, to facilitate coordination between EU policies, and to develop cohesion policy into a leading enabler of growth, also in qualitative terms, for the whole of the EU, while addressing societal challenges such as ageing and climate change".*
- *p6.: "To improve financial engineering instruments within cohesion policy, a number of measures could be examined:*
  - o *Extend both the scope and scale of financial engineering instruments: in terms of scope, to encompass new activities (e.g. sustainable urban transport, research and development, energy, local development, lifelong learning or mobility actions, climate change and environment, ICT and broadband); in terms of scale, to combine interest subsidies with loan capital or other forms of repayable financing."*

- **COUNCIL REGULATION (EC) No 2012/2002 of 11 November 2002 establishing the European Union Solidarity Fund[23]**

No reference to climate change or adaptation

- **COMMUNICATION FROM THE COMMISSION: Trans-European networks: Towards an integrated approach {SEC(2007) 374}[24]**

No reference to climate change or adaptation

- **TEN-T Guidelines (661/2010/EC)[25][26]**

No reference to climate change or adaptation; only indirect through SEA

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[22] http://ec.europa.eu/regional_policy/sources/docoffic/official/reports/cohesion5/pdf/conclu_5cr_part1_en.pdf.

[23] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:311:0003:0008:EN:PDF .

[24] http://eur-lex.europa.eu/LexUriServ/site/en/com/2007/com2007_0135en01.pdf.

[25] http://ec.europa.eu/transport/infrastructure/basis_networks/guidelines/guidelines_en.htm.

- **GREEN PAPER TEN-T: A policy review. TOWARDS A BETTER INTEGRATED TRANSEUROPEAN TRANSPORT NETWORK AT THE SERVICE OF THE COMMON TRANSPORT POLICY COM(2009) 44 final[27]**

  Direct reference to climate change adaptation

  ➲ p9: *While seeking to make a noticeable contribution to the Community´s 20/20/20 climate change objective, TEN-T policy should also take account of the need to adapt to the possible consequences of climate change. The vulnerability of the TEN-T to climate change and potential adaptation measures should therefore be assessed, and attention should be given to the question of how to "climate proof" new infrastructure. Furthermore, in order to assess fully environmental impacts of the TEN-T, the requirements set out in the UNECE Protocol on SEA to the ESPOO Convention should be met.*

- **A European strategy on clean and energy efficient vehicles [COM(2010)186** [28]

  No reference to climate change adaptation (focus on mitigation)

  COMMUNICATION FROM THE COMMISSION: Reducing the Climate Change Impact of Aviation[COM(2005) 459[29]

  No reference to climate change adaptation (focus on mitigation)

- **White Paper: Roadmap to a single European Transport Area – Towards a competitive and resource efficient transport system (COM(2011)144)[30]**

  Direct reference to climate change adaptation:

  ➲ *p14: "54.The selection of projects eligible for EU funding must reflect this vision and put greater emphasis on European added value. Co-funded projects should equally reflect the need for infrastructure that minimizes the impact on the environment, that is resilient to the possible impact of climate change and that improves the safety and security of users.*

  ➲ *p. 27: "Ensure that EU-funded transport infrastructure takes into account energy efficiency needs and climate change challenges (climate resilience of the overall infrastructure, refueling/recharging stations for clean vehicles, choosing of construction materials…)."*

  In addition, in the accompanying **Commission Staff Working Document (SEC(2011) 391[31])** *the following references are included:*

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[26] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010D0661:EN:NOT.

[27] http://ec.europa.eu/transport/infrastructure/basis_networks/guidelines/doc/green_paper_en.pdf.

[28] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0186:FIN:EN:PDF.

[29] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0459:FIN:EN:PDF.

[30] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:PDF.

[31] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SEC:2011:0391:FIN:EN:PDF.

- ➲ *p.96: "The efficiency and competitiveness of inland navigation is largely determined by the quality and conditions of the waterway infrastructure, including smaller waterways, where efforts need to focus on the maintenance of the waterways, the upgrading of certain sections to the prevailing standard of the entire waterway link and the extension of the existing network, notably by closing gaps (‘missing links’). The investments need increasingly to take into account the possible effects of climate change which are likely to affect the navigability of the waterways."*
- ➲ *p.102: "Moreover, new projects and infrastructure upgrades will need to be made resilient to foreseen negative impact of climate change such as rising sea level and more extreme weather including floods, droughts and more frequent storms. They will also need to reflect EU legislation on road safety and security*[32]*."*
- ➲ *p.105: " All projects co-financed by the EU (Cohesion, Agricultural and Fisheries Policies) need to contribute to EU energy efficiency and environmental goals and have to be subject to an Environmental Impact Assessment (EIA) or a Strategic Environmental Assessment (SEA) – depending on their nature. Certainty for investors requires further progress towards establishing a workable and effective framework for the environmental impacts of projects, including aspects that are not presently considered, notably the contribution to climate change and climate resilience."*

- **Community strategic Guidelines on cohesion (2006/702/EC)[33]**

  No reference to climate change or adaptation

3.2.2 Gap analysis

In order to identify potential gaps, relevant polices mentioned under chapter I have been assessed in-depth. As a result it can be concluded that most existing transport policies (cf. I), do not explicitly address the climatic pressures (e.g. increase of temperature) and impacts which can be expected in the future as potentially harming transport infrastructure.

The recently published strategy paper (White Paper on Transport) does explicitly address the need for adaptation to climate change in the transport sector and suggests enhancing adaptation by establishing a link to funding mechanism. In addition, a few policies (e.g. Fifth report on economic, social and territorial cohesion) highlight the need for climate change adaptation of transport infrastructure. Other policies include mechanism or technical standards which could be extended in regard to adaptation. In addition, adaptation can be integrated in existing policies dealing with new infrastructure projects (especially those who receive EU funding) to ensure climate-proofed infrastructure. A detailed assessment of possibilities to mainstream adaptation in both transport specific and transport related policies is provided in the following steps.

[32] Directive 2008/96/EC on road infrastructure safety management and Directive 2004/54/EC on minimum requirements for tunnels in the Trans-European Road Network.

[33] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:291:0011:0032:EN:PDF.

Screening relevant policies for the different transport modes (rail, road, shipping, aviation) showed that not all mention the need to address climate change (e.g. in the Communication for Integrated Maritime Policy).

The measures suggested mostly support actions in the field of capacity building (e.g. increase of knowledge, improvement of data and accessibility to data). A few policies propose measures which are also of importance under the headline of climate change adaptation (e.g. Directive on River Information Services to implement information services and to provide information on navigation, water level etc.). Nevertheless, the majority of existing policies analyzed in section I. does not tackle climate change adaptation but might provide entry points to integrate climate change adaptation.

In general, the climatic pressures which need to be addressed with adaptation measures in transport infrastructure can be summarized as follows (pls. check for further information the impact tables for each transport mode):

<u>Short-term action responding to:</u>

- ➲ summer heat, especially in South Europe
- ➲ extreme precipitation, European wide

Nevertheless, decisions concerning long-term investments - such as transport infrastructure with a life-span-time up to 100 years (e.g. major transport routes, bridges, tunnels) – need to take climate change into account already today. Due to the uncertainties in future climate projections, planning new infrastructure should not focus on one single "optimal" solution but should be made more robust to a range of possible climatic changes (Hallegatte 2009). Dessai et al. 2009 states that "robust strategies" perform well (though not necessarily optimally) over a wide range of assumptions about the future.

Account also needs to be taken of the network nature of the transport system. Different elements of the transport infrastructure have varying level of importance for the overall functioning of the transport system: a major hub plays a crucial role in the whole of the aviation network, while a small regional airport not. The ash cloud crisis in April 2010 and the weather-related disruptions towards the end of 2010 have shown that the capacity of the EU transportation system to tolerate and absorb disruption triggered by natural or man-made disasters is not sufficient to fulfil its basic function, which is to ensure a seamless mobility of people and goods. The lessons drawn suggest that, besides obstacles of a more structural nature such as missing links in the transport network and the lack of Single Transport Area, the vulnerability of the EU transport system can be attributed to the inadequate level of preparedness and cooperation between all actors (COM 2011:73 144 final). These lessons learned are also important in regard to enhance the climate change resilience of the transport system.

Thus, in the case of transport infrastructure, multiple-benefits, no-regret and low-regret adaptation options[34] should be favoured with focus on main transport nodes and corridors.

[34] Multiple-benefits options provide synergies with other goals such as mitigation or sustainability; No-regret and low-regret actions are beneficial in all plausible climate futures, such as early warning systems and insurance against floods.

Climate change impacts and in particular adaptation of transport infrastructure is a new field in research and only recently a number of projects have started. Expected outcomes from the following projects might provide some suggestion and advice for further action on the EU level:

- EWENT[35]: Extreme weather events on EU networks of transport (2010-2012; FP7)
- WEATHER[36]: Weather Extremes – Impacts on Transport Systems and Hazards for European Regions (2010-2012; FP7)
- ECCONET[37]: Effects of climate change on the inland waterway networks (2010-2012; FP7)
- PARAmount[38]: imProved Accessibility: Reliability and security of Alpine transport infrastructure related to mountainous hazards in a changing climate (2007-2013; Alpine Space Programme)
- QUANTIFY[39]: Quantifying the Climate Impact of Global and European Transport Systems (2005-2010, FP6)
- FUTURENET[40] (focus on UK, no information on project duration and funds)

3.2.3 Examination of different transport modes

All four transport modes deserve further analysis:

- rail (railways)
- road (roads in general and specific cases of coastal and mountain roads)
- shipping (inland and ocean shipping, ports) and
- aviation (airports).

We focus in the transport sector mainly on climatic pressures for the infrastructure and partly on transport equipment (cf. page 59).

In the following possible adaptation measures and corresponding policy options are presented for each transport mode. Policy options that apply to all transport modes are summarized on p. 73ff.

RAIL infrastructure

1. Impact Table:

The impact table provides a summary on future climatic pressures which may affect the rail infrastructure negatively.

[35] http://virtual.vtt.fi/virtual/ewent/index.htm.

[36] http://www.weather-project.eu/weather/index.php.

[37] http://www.ecconet.eu/.

[38] http://www.paramount-project.eu/index.php.

[39] http://www.pa.op.dlr.de/quantify/.

[40] http://www.arcc-futurenet.org/.

Table 3-3: Impact Table RAIL infrastructure

Climatic pressures	Risk	Time frame of expected impact	Area mainly affected
Summer heat	Rail buckling; material fatigue; increased instability of embankments; overheating of equipment (e.g. engine ventilation, climatization); increase wildfires can damage infrastructure	Medium negative (2025; 2080) to high negative (2080)	Southern Europe medium negative until 2025 and high negative until 2080; West, East and Central EU medium negative until 2080
Winter cold/ice	Ice on trains and catenary	Medium negative (2025; 2080)	Northern Europe, Central Europe
Extreme precipitation	Damage on infrastructure due to flooding and/or landslides; scour to structures; destabilization of embankment	Medium negative (2025) to high negative (2080)	European wide
Extreme storms	Damage on infrastructure such as signals, power cable etc. (e.g. due to falling trees, etc.	No information	No information
	<ins>In general:</ins> reduced safety; increased cost for reparation and maintenance; disruption of “just in time" delivery of goods and passengers		

2. Exploration of possible adaptation measures

For the compilation of possible adaptation measures a comprehensive literature review was carried out (cf. reference list). The information was gathered from work done on adaptation measures (e.g. Nolte 2008) and from relevant research projects focusing on adaptation in rail transport (e.g. ARISSC). The literature on adaptation of transport infrastructure includes a variety of options, while many act on a very generic level (e.g. vegetation management, protection of critical evacuation routes, enhancing drainage systems). In case of aviation, only a few adaptation options could be identified.

Based on expert judgment we present a range of possible adaptation measures addressing those climatic pressures and risks identified for the various transport modes. The measures are grouped using categories based on the Impact Assessment accompanying the White Paper on Adaptation (COM 2009).

A. Technical measures

A1. Measures related to the infrastructure

1 Use materials for new or upgrades of rail infrastructure which better cope with summer heat to prevent track buckling *(cf. measure 15)*

2 Check existing air conditioning systems in trains and adopt them to higher temperature (see summer 2010 in Germany) (Savonis et al. 2008) and humidity *(cf. measure 16)*

3 Improve air conditioning for signals in case of heat waves (Savonis et al. 2008) *(cf. measure 16)*

4 Improve system to warn in case of rail buckling and update dispatch centers, crews and stations (Savonis et al. 2008)

5 Increase in monitoring of land slopes (TRB 2008, Nolte 2008)

6 Install early warning systems which can shut down the train service in case of floods (Lindgren, Jonsson and Carlsson-Kanyama 2009, Nolte 2008)

7 Use sensor technology to track the condition of infrastructure and implement reporting system (The Royal Academy of Engineering 2011)

8 Strengthened earthwork to reduce embankment instability due to moisture fluctuation caused by wetter winters and drier summers (HM Government 2011, Nolte 2008, RSSB 2003) *(cf. measure 17)*

9 Monitoring wind speeds and install wind alarms for overhead line system based on real time monitoring (Nolte 2008) *(cf. measure 18)*

10 Design structures (bridges, signs, overhead cables, etc.) for more turbulent wind conditions (Savonis et al. 2008)

11 Develop rolling stock further to cope with falling ice

A2. Measures related to operation of the services

12 Adjust operation rules (Issue to be specified by CER)

13 Set rules for stopping operation in the case of extreme events and communicate this to the passengers

14 Develop emergency plans to shift passengers to alternative transport modes (e.g. bus).

B. Regulation and standards

15 Higher standards of rail used to prevent track buckling in increased temperatures (HM Government 2011) *(cf. measure 1)*

16 Modify standards for air conditioning systems in trains and for signals to be better adopted to higher temperature *(cf. measures 2 and 3)*

17 Upgrading drainage system to better meet the requirements in case of extreme precipitation (The Royal Academy of Engineering 2011, TRB 2008, Nolte 2008) *(cf. measure 8)*

18 Modify standards for height of dams and flood barriers due to expected increases in rainfall intensity and duration (especially in winter) (ARISSC, Nolte 2008) *(cf. partly measure 9)*

19 Restriction of development in floodplains (TRB 2008)

C. Capacity building

20 Adaptation measures should be incorporated into the routine maintenance processes and the lifecycle replacement of assets in particular rolling stock. Some major infrastructure may require significant investment to meet adaptation requirements; new infrastructure will need to be built consistently with adaptation requirements (The Royal Academy of Engineering 2011)

21 Systematic mapping and monitoring of different types of climate threats, vulnerabilities and their consequences on the existing infrastructure (e.g. development of a Climate-Rail - risk map) should be performed in order to guide the implementation of adaptation measures (Lindgren, Jonsson and Carlsson-Kanyama 2009, ARISCC, Nolte 2008, RSSB 2003). Vulnerability hot spots can be detected in regard to e.g.

   a. Summer heat (overheating)
   b. Floods
   c. Storms
   d. Mass movements

D. Communication/Awareness raising

22 Provide information (e.g. impact maps, good practice examples) and easy access to information to the national railway operators in Europe (e.g. communicate results from research projects such as ARISCC)

23 Development of emergency plans/ crisis management plans in case of heat waves, floods, storms, etc. including replacement modes (Cochran 2009) (see Action 23 of the White Paper on Transport concerning Mobility Continuity Plans)

E. Guidelines

24 Develop check lists for the EU national railway operators to assess vulnerability and possible adaptation options

25 Develop methodologies for climate proofing to rail companies

F. EU financing scheme

26 Integrate funding provisions to EU funding schemes which support specific adaptation options mentioned under A to E

27 Explore tax support mechanisms. Providing tax reductions for certain measures could trigger their uptake by the private sector

3. Exploration of adaptation options for the EU level

Under the current policy framework protecting existing and planned transport infrastructure from the impacts of climate change remains predominantly within Member State responsibility. The White Paper on Adaptation (COM 2009) defines the role of the European Commission mainly in promoting best practice via support for infrastructure development and also in developing standards for construction.

Thus, we have explored possibilities for adjustments of existing policies for mainstreaming adaptation (cf. A). The suggestions take up the adaptation measures presented under section 2 in terms of options for corresponding policy actions (according references are given in brackets to each suggestion). In addition, further policy options advisable to respond to identified climatic risks and pressures have been investigated (cf. B)

A. Suggestions for adjustments in existing policies

In case of rail transport, the EC efforts have concentrated on three major areas which are crucial for developing a strong and competitive rail transport infrastructure: (i) opening rail transport market to competition; (2) improving interoperability and safety of national networks and (3) developing rail transport infrastructure (DG MOVE Website[41], accessed June 2011). Regarding climate change adaptation, policies focusing on the safety of rail networks and on new development of infrastructure are of specific interest.

- **TEN-T Guidelines (661/2010/EC)**

Art. 10.1 "Characteristics of rail network (comprising high-speed rail network and the conventional rail network)."

Art. 10.6 "The rail network shall offer users a high level of quality and safety, by virtue of its continuity and of the gradual implementation of its interoperability, which shall be brought about in particular by technical harmonisation and the ERTMS harmonised command and control system recommended for the European railway network".

Suggestion: To sustain a high level of quality and safety, adaptation measures to a changing climate are essential. Thus, technical measures such as improved material able to cope with higher temperature, improved conditioning systems, monitoring systems, early warning systems, etc. should be taken into account in technical harmonization *(addresses A "Technical measures")*

- **Regulation 1370/2007/EC on public passenger transport services by rail and by road and repealing Council Regulations (EEC) Nos 1191/69 and 1107/70**

Suggestion: Quality targets in relation to public service obligations should reflect the level of adaptation to changing climates in order to maintain high quality transport services. *(addressed partly measure 20)*

- **Community strategic Guidelines on cohesion (2006/702/EC)**

[41] http://ec.europa.eu/transport/road/index_en.htm.

1.1.1, p16: "They should also enhance the creation of an EU-wide interoperable network. Compliance and applications of the interoperability and the fitting of ERTMS (European Rail Traffic Management System) on board and on track should be part of all projects financed where appropriate."

Suggestion: Reference to ERTMS: incorporate adaptation measures into the ERTMS to ensure that climate change impacts are addressed European wide in the train control and command systems. *(addresses measures 2,3, 15 and 16)*

- **Action Plan on GNSS Applications (COM(2010)308)**[42]

The European Commission is committed to 6 priority domains identified in the impact assessment accompanying its Action Plan on GNSS Applications (2010):

• applications for individual handsets and mobile phones (LBS),
• road transport;
• aviation;
• maritime transport ;
• precision agriculture and environment protection;
• civil protection and surveillance.

Suggestion: Extend the application of EGNOS and GALILEO also for rail transport for early warning, monitoring wind speeds, spread of flooding etc. *(addresses measure 5, 6 and 9)*

- **Directive 2004/49/EC on safety on the Community`s railways**[43]

Suggestion: Analyze existing common safety methods and targets in the light of a changing climate. Thus, the European Railway Agency - responsible for technical assistance to implement the Directive - might play a crucial role. *(addresses all measures listed under B "Regulation and standards")*

- **Directive 2008/57/EC on the interoperability of the rail system within the Community**[44]

Art. 23; 3. "The applicant shall submit to the national safety authority a file on the vehicle or type of vehicle and the intended use thereof on the network. The file shall contain the following information:

(d) evidence on technical and operational characteristics that shows that the vehicle is compatible with the infrastructures and fixed installations, including climate conditions, energy supply system, control-command and signaling system, track gauge and infrastructure gauges, maximum permitted axle load and other constraints of the network.

[42] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0308:FIN:EN:PDF.

[43] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:220:0016:0039:EN:PDF.

[44] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:191:0001:0045:EN:PDF.

Suggestion: Add: railway infrastructure should also be assessed due to climate change. *(addresses measure 20)*

- **Technical Specifications for interoperability**[45]

Technical specifications for interoperability (TSIs) mean the specifications by which each subsystem or part of subsystem is covered in order to meet the essential requirements and to ensure the interoperability of the trans-European high speed and conventional rail systems. The European Railway Agency works on drafting the third group of Conventional Rail Technical Specifications for Interoperability concerning Infrastructure, Energy, Locomotives and Passenger rolling stock, and Telematic applications for passenger services. The Agency is also carrying out the revision of TSIs related to Freight wagons, Operation and traffic management, and Noise. Further activities will include revision of earlier adopted TSIs with the aim of extending their scope to the entire European railway network.

Suggestion: Include aspects of climate change in the development or revision process of TSIs. *(addresses A "Technical measures")*

B. Options for additional policy action

- **Open grants for the development of emergency plans** *(addresses measure 18)*
- **Dedicate funds for targeted research** *(addresses measures 22, 23, 24 and 25)*
- **Facilitate exchange of climate change adaptation relevant expertise within the European Railway Agency to be able to provide help to national rail operators, e.g. using ACE for or organizing special events for operators** *(addresses C "Capacity Building")*

ROAD Infrastructure

1. Impact Table

Table 3-4: Impact table ROAD infrastructure

Considered part	Climatic pressures	Risk	Time frame of expected impact	Area mainly affected
Roads (including other infrastructure such as bridges, tunnels etc.) ------------------	Summer heat -------------------	Pavement deterioration and subsidence; melting tarmac; reduced life of asphalt road surfaces (e.g. surface cracks); increase wildfires can damage infrastructure; expansion/buckling of bridges ---------------------------------- Damage on infrastructure	Medium negative (2025; 2080) to high negative (2080) ---------------------	Southern Europe (2025), West, East and Central EU (2080) -----------------

45 http://www.era.europa.eu/CORE-ACTIVITIES/INTEROPERABILITY/Pages/TechnicalSpecifications.aspx.

	Extreme precipitation/ floods ------------------- Extreme storm events	(e.g. pavements, road washout); road submersion; scour to structures; underpass flooding; overstrain drainage systems; risk of landslides; instability of embankments ---------------------------------- Damage on infrastructure; roadside trees/vegetation can block roads <u>In general</u>: speed reduction; road closure or road safety hazards; disruption of "just in time" delivery of goods; welfare losses; higher reparation and maintenance costs	Medium negative (2025) to high negative (2080) --------------------- No information	European wide ----------------- No information
Coastal roads	Sea level rise	<u>Sea level rise, extreme storm events and heavy precipitation</u>:	Medium negative (2080)	European wide
	Extreme storm events	Damage infrastructure due to flooding; coastal erosion; road closure	No information	No information
	Heavy precipitation events		Medium negative (2025) to high negative (2080)	European wide
Mountain road	Permafrost degradation	Decrease of stability; rockfalls; landslides; road closure;	No information	No information
Sewerage system	Heavy precipitation events	Overloaded sewerage system can cause road flooding and water pollution	Medium negative (2025) to high negative (2080)	European wide

<u>2. Exploration of possible adaptation options</u>

<u>A. Technical measures</u>

1 Identify and implement cost-effective means of retrofitting existing infrastructure (e.g. roads, tunnels, bridges) and equipment (in particular buses and coaches) to more extreme climatic conditions (e.g. technical flood protections) (Cochran 2009, HM Government 2011) *(cf. measures 6 to 9 and 11)*

2 Consider sea level rise in the design of long-life structures (Youman 2007)

3 Link road infrastructure with other transportation modes to enhance resilience (Taylor 2011) *(cf. measure 7)*

4 Stipulate monitoring of land slopes and floods (Nolte 2008)

5 Install early warning systems in case of extreme events (e.g. floods, storms) (Knoflacher 2010)

B. Regulation and standards

6 Modify standards for road materials (e.g. pavement, embankments) to be able to cope with higher temperature and extreme precipitation events (Youman 2007) *(cf. measure 1)*

7 Modify technical standards for height of dams and flood barriers due to expected increases in rainfall intensity and duration (Nolte 2008) *(cf. measure 1, 3 and 11)*

8 Upgrade drainage system to better cope with intensive precipitation events (UK's Transport Research Laboratory) *(cf. measure 1)*

9 Design structures (e.g. bridges, anchorage of traffic lights and signs) for more turbulent wind conditions (Savonis et al. 2008, Knoflacher 2010) *(cf. measure 1)*

10 Restrict development in flood-prone areas to major roads (UK's Transport Research Laboratory)

C. Capacity building

11 Increase understanding of how materials react to higher temperature and intensive precipitation and the thresholds at which deterioration or disruption occurs (research) (UK's Transport Research Laboratory, Cochran 2009) *(cf. measures 1 and 7)*

12 Enhance methods of maintenance in order to address extreme fluctuations in temperature

13 Identify the likely risks of climate change for roads (e.g. degradation of permafrost) and the specific areas of vulnerability (UK's Transport Research Laboratory)

14 Identify and prioritize critical network “nodes” for immediate attention and reinforcement (detect vulnerability hot spots) (Cochran 2009)

15 Develop climate change strategies and actions plans for local authorities and operators

16 Provide sea level rise maps (Youman 2007)

17 Recognize current operational practices and approaches to ensure that existing road infrastructure is functioning properly within changing climatic conditions (Cochran 2009, HM Government 2011)

18 Assist State and local governments and private infrastructure providers to incorporate climate change into their long-term capital improvement plans, facility designs, maintenance practices and operations (TRB 2008)

19 Provide advice for reviewing and revising road regulations of Member States and existing incentives with consideration of expected climate changes (HM Government 2011)

D. Communication/Awareness raising

20 Provide information (e.g. vulnerability maps, good practice examples) and easy access to information to the National Ministries of Transport and to operators

21 Create crisis management plans, including replacement modes, secondary itineraries and temporary network shutdowns, in preparation for the potential increase in frequency and intensity of extreme weather events (Knoflacher et al. 2010)

22 Provide real-time communication and information to help manage recovery and emergencies, including providing information about road closures, traffic conditions, alternative routes and early warning systems on adverse weather (Gledhill & Low 2010)

E. Guidelines

23 Develop check lists for vulnerability assessments supporting the National Ministries of Transport

24 Publish guidelines for responsible Ministries and road operators to take climate change into account in connection with construction and operation (HM Government 2011)

F. EU financing scheme

25 Integrate funding provisions to EU funding schemes which support specific adaptation options mentioned under A to E

26 Explore tax support mechanism: provide tax reductions for certain measures could trigger their uptake by the private sector

3. Exploration of adaptation options for the EU level

A. Suggestions for adjustments in existing policies

EU policy objectives for road transport are to promote efficient road freight and passengers transport services, to create fair conditions for competition, to promote and harmonise safer and more environmentally friendly technical standards, to ensure a degree of fiscal and social harmonisation, and to guarantee that road transport rules are applied effectively and without discrimination (DG MOVE Website, accessed in June 2011).

- **Directive 2008/96/EC on road infrastructure safety management**[46]

This directive requires the establishment and implementation of procedures relating to road safety impact assessments, road safety audits, the management of road network safety and safety inspections by the Member States for the trans-European road network, whether they are at the design stage, under construction or in operation.

ANNEX I: ROAD SAFETY IMPACT ASSESSMENT FOR INFRASTRUCTURE PROJECTS

2. Elements to be taken into account:

(f) seasonal and climatic conditions;

ANNEX II: ROAD SAFETY AUDITS FOR INFRASTRUCTURE PROJECTS

[46] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:319:0059:0067:EN:PDF.

1. Criteria at the draft design stage: (a) geographical location (e.g. exposure to landslides, flooding, avalanches), seasonal and climatic conditions and

seismic activity; (f) meteorological conditions;

Suggestion: When carrying out a road safety impact assessment and a road safety audits for infrastructure projects, not only the current climatic conditions should be taken into account, but also information on possible future climatic conditions *(addresses measures 1, 12, 14, 15)*

- **COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS: Towards a European road safety area: policy orientations on road safety 2011-2020**[47]

Following the 3rd road safety action programme, the Commission has published this communication on road safety to provide a general framework, under which concrete action can be taken at European, national, regional or local levels from 2011 until 2020.

➲ *Objective n°6, p.9: Improve emergency and post-inju ries services*

Suggestion: To address objective n°6, the Commission suggests d eveloping a global strategy of action concerning road injuries and first aid. One specific focus should be on first aid in the case of natural disasters such as land slides and heat waves conditions *(addresses measure 22)*.

- **Regulation 1370/2007/EC on public passenger transport services by rail and by road and repealing Council Regulations (EEC) Nos 1191/69 and 1107/70**

Suggestion: Quality targets in relation to public service obligations should reflect the level of adaptation to changing climates in order to maintain high quality transport services *(addresses C "Capacity building")*.

- **Directive 2010/40/EC on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport** [48]

With this directive, the EU aims - inter alia - to establish a European wide multimodal travel information service, a real-time traffic information service and data and procedures for the provision, where possible, of road safety related minimum universal traffic information free of charge to users. These provisions can also be seen as important for adaptation to climate change and address *measures 6 and 23.*

- **TEN-T Guidelines (661/2010/EC)**

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[47] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0389:FIN:EN:PDF.

[48] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:207:0001:0013:EN:PDF.

The TEN-T aims to establish a single, multimodal network that integrates land, sea and air transport networks throughout the EU. This becomes even more important in the face of climate change. Thus, road infrastructure should be linked with other transport modes *(addresses measure 2)* and/or gradually replaced by public transport networks (where possible) *(addresses measure 3)*, both to enhance resilience to a changing climate and to help achieving climate mitigation goals.

- **COMMUNICATION FROM THE COMMISSION TO THE COUNCIL, THE EUROPEAN PARLIAMENT, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Thematic Strategy for Soil Protection [SEC(2006)620] [SEC(2006)1165]**[49]

In regard to a possible increase of flood events due to climate change, the water-retention capacity of soil becomes even more important. Planning and constructing new road infrastructures highly impacts the function of soil and thus a stewardship of available resources is required.

Suggestion: A future Soil Framework Directive should also highlight the function of soil in regard to climate change and emphasis on carefully and soil-saving planning in the case of road infrastructure *(addresses measure 6)*.

B. Options for additional policy action

The responsibility for adjusting regulations and standards (cf. measures B) in road infrastructure (e.g. standards in materials, dimensions) rests mostly with the respective authorities in the Member States. Thus, at the EU level, the scope of action is basically limited to the provision of information on possible climatic changes and to awareness raising for the need of adaptation.

- **Provide guidelines and check lists for adapting road infrastructure to a changing climate** *(addresses E "Guidelines")*
- **Open grants for the development of a better information base needed for climate change adaptation of road infrastructure and provide access to information to responsible Ministries at the national level and to operators** *(addresses C "Capacity building" and D "Communication and awareness raising")*
- **Dedicate funds for targeted research, e.g. to enhance heat resilience of materials and road infrastructure** *(addresses measure 13)*

AVIATION

1. Impact Table

Table 3-5: Impact table aviation

[49] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0231:FIN:EN:PDF.

Considered part	Climatic pressures	Risk	Time frame of expected impact	Area mainly affected
Airports (including runways)	Summer heat	Greater need for ground cooling; degradation of runways and runways foundations; higher density altitudes causing reduced engine combustion efficiency; decrease airport lift and increased runway lengths	Medium negative (2025; 2080) to high negative (2080)	Southern Europe (2025), West, East and Central EU (2080)
	Heavy precipitation events	Flood damage to runways and other infrastructure; water runoff exceeds capacity of drainage system	Medium negative (2025) to high negative (2080)	European wide
	Extreme storms	Wind damage to terminals, navigation, equipment, signage	No information	No information
	Sea level rise	Flooding of runways, out-buildings and access roads <u>In general</u>: interruption and disruption to services supplied and to ground access; periodic airport closures; higher maintenance costs	Medium negative (2080)	European wide

2. Exploration of possible adaptation options

A. Technical measures

1 Build longer runways at high-altitude or hot-weather airports, if feasible (Ang-Olson 2009, Savonis et al. 2008)

2 Update gate-based cooling systems due to temperature increase (Ang-Olson 2009) *(cf. measure 8)*

3 Install redundant systems (e.g. navigation equipments) (Ang-Olson 2009)

4 Install protective structures/dikes to protect runways or raise existing dikes (Ang-Olson 2009, Savonis et al. 2008)

5 Consider sea level rise in the design of long-life structures (Youman 2007)

6 Improve early warning systems in case of extreme events (Savonis et al. 2008)

B. Regulation and standards

7 Modify surface materials of runways to be able to cope with higher temperature and extreme precipitation events (Youman 2007)

8 Modify standards for gate-based cooling systems taking summer heat into account *(cf. measure 2)*

9 Upgrade drainage system to better cope with intensive precipitation events and storm water runoffs (UK's Transport Research Laboratory, Ang-Olson 2009)

10 Design structures (e.g. terminals, navigation equipment, signage) for more turbulent wind conditions (Savonis et al. 2008)

C. Capacity building

11 Assess how temperature increases may affect aircraft takeoff performance capabilities and payload requirements, and address any such increases in the context of current runway utilization and future runway design (Savonis et al. 2008)

12 Identify the critical concerns and screen risks for airports in the light of climate change projections to determine whether, when, and where projected climate changes might be consequential; detect vulnerability hot spots (Savonis et al. 2008)

13 Consider not only vulnerability of the aviation sector but include other related infrastructure, e.g. surface access to airports (Gledhill & Low 2010)

14 Recognize current operational practices and approaches to ensure that existing infrastructure is functioning properly within changing climatic conditions (Cochran 2009, HM Government 2011)

15 Airport infrastructure typically undergoes regular upgrades, replacement and maintenance. Depending on these cycles, introduce adaptation measures to incorporate enhanced levels of resilience according to the latest science (Gledhill & Low 2010)

D. Communication/Awareness raising

16 Provide information (e.g. vulnerability maps, good practice examples) and easy access to information to operators

17 Create crisis management plans, including replacement modes, secondary itineraries and temporary network shutdowns, in preparation for the potential increase in frequency and intensity of extreme weather events

E. Guidelines

18 Publish guidelines for operators to take climate change into account in connection with construction and operation (HM Government 2011)

19 Develop check lists for vulnerability assessments

F. EU financing scheme

20 Invest in research on climate change impacts and adaptation

3. Exploration of adaptation options for the EU level

A. Suggestions for adjustments in existing policies

The European Union objective in air transport is to modernize and adapt the infrastructure to increasing passenger flows, whilst also improving their rights and safety. In order to do this, the Union is working to implement the Single European Sky. Moreover, the introduction of optimum traffic management technologies will enable the challenges related to economic efficiency, safety and respect for the environment to be reconciled (DG MOVE website, accessed in June 2011).

Due to the lack of knowledge in regard to climate change effects and adaptation needs for aviation, we suggest to improve the knowledge base in the first step and to amend policies/create new policies based on this information.

- **Council Regulation (EEC) No 3922/91 of 16 December 1991 on the harmonization of technical requirements and administrative procedures in the field of civil aviation**[50]

This regulation applies to the harmonisation within the European Union (EU) of technical requirements and administrative procedures in the field of civil aviation safety, concerning the operation and maintenance of aircraft and to persons and organisations involved in those tasks.

Suggestion: The EC, assisted by the European Air Safety Agency, shall consider amending the common technical requirements and administrative procedures where such amendments seem necessary by new information from science and technology. The European Air Safety Agency can play a crucial role for the generation of new knowledge on climatic risks and possible adaptation responses as well as for the dissemination, providing evidence base for adjustments of existing technical requirements or administrative procedures in terms of adaptation to climate change *(addresses measures under A "Technical measures", B "Regulation and standards" and C "Capacity building")*

- **Commission Communication of 24 January 2007 to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions entitled "An action plan for airport capacity, efficiency and safety in Europe" [COM (2006) 819]**[51]

In this Communication, the Commission announced five key actions to address the expected "capacity crunch":

- *make better use of existing airport capacity;*
- *develop a consistent approach to air safety operations at airports;*
- *promote "co-modality", the integration and collaboration between modes of transport;*
- *improve the environmental capacity of airports and the planning framework for new airport infrastructure;*
- *develop and implement cost-efficient technological solutions.*

[50] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31991R3922:EN:HTML.

[51] http://ec.europa.eu/transport/air_portal/airports/doc/2007_capacity_en.pdf.

Suggestion: The Communication suggests implementing an Advanced-Surface Movement Guidance and Control Systems (A-SMGCS) throughout European airports. In addition, the SESAR programme will develop new technologies aiming at further increasing the safety and efficiency of airport operations. This system might contribute to improve early warning systems *(addresses measure 6)*

- **Council Regulation (EC) No 219/2007 of 27 February 2007 on the establishment of a Joint Undertaking to develop the new generation European air traffic management system (SESAR)[52]**

The Single European Sky ATM Research (SESAR) Programme is the technological pillar of

the Single European Sky Initiative (SES). SESAR aims at developing the new generation of air traffic management system (ATM) capable of ensuring the safety and fluidity of air transport worldwide over the next 30 years.

Suggestion: SES and SESAR address the need for climate change mitigation and promise to contribute to the targets but do not include the need for improving climate change resilience of management systems. The issue of climate change resilience should be added to the agenda *(addresses measures under A - F)*

B. Options for additional policy action

- **Particularly for aviation, more knowledge about climate change impacts and adaptation is needed. Thus, funds should be opened that aim at enhancing the information base** *(addresses measures under F "EU financing scheme")*

SHIPPING

1. Impact Table

Table 3-6: Impact table shipping

Considered part	Climatic pressures	Risk	Time frame of expected impact	Area mainly affected
Inland shipping	High river flow (e.g. extreme precipitation, snow melt) ---------------------- Low river flow (e.g. drought) ----------------------	Problems for the passage of bridges; speed limitations because of dike instability; some restrictions to the height of vessels ---------------------------------- Strong restrictions to the loading capacity; navigation problems, speed reduction --------------------------------- In general shorter periods of ice cover can be expected; nevertheless	Medium negative (2080) -------------------- Medium negative (2025) to high negative (2080) -------------------- No information	European wide ---------------- South, East and Central Europe; in 2080 also Western Europe ----------------

[52] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:064:0001:0011:EN:PDF.

	Change in ice cover	warm and early winters, followed by a rapid decrease in air temperature, may result in thicker or rougher ice cover formation and thus, lead to ice jams, damage to navigation signs and infrastructure (e.g. locks) In general: disruption of "just in time" delivery of goods; stop of inland shipping; welfare losses		No information
Maritime transport	Sea level rise	Navigability could be affected by changes in sedimentation rates and location of shoals (TRP 2008); more frequent closure	Medium negative (2080)	European wide
	Change in sea conditions	More severe storms and extreme waves might affect ships (DNV 2009[53])	No information	No information
	Less days below freezing	Reduce problems with ice accumulation on vessels, decks, riggings and docks; occurrence of dangerous ice fog (TRB 2008)	Medium positive (2080)	European wide
	Reduced sea ice	Improved access; longer shipping seasons; new shipping routes (TRP 2008)	Summer sea ice could completely disappear in the Arctic Ocean somewhere between 2013 and 2040[54]	No information
Ports	Extreme storm events	Storms, sea level rise and floods/landslide may cause: Devastation of infrastructure; interruptions and bottlenecks in the flow of products through ports	Storms: no information	No information
	Sea level rise		Sea level rise: medium negative (2080)	European wide
	Floods/landslide		Floods/land-slide: medium negative (2025)	European wide

[53] http://www.dnv.com/press_area/press_releases/2009/designchangesneededforextremestormpredictions.asp.

[54] WWF, Climate change: faster, stronger, sooner, A European Update of climate science, 20 October 2008.

		to high negative (2080)	
	In general: disruption of "just in time" delivery of goods; welfare losses; increased cost for reparation and maintenance		

2. Exploration of possible adaptation options

A. Technical measures

1 Improve or develop monitoring system, e.g. for river depth information or sea level rise (van der Toorn 2010, ECCONET 2011)

2 Improve weather forecast systems (UK's Transport Research Laboratory)

3 Consider sea level rise in the navigation and design of long-life structures (e.g. dock and wharfs) and retrofit facilities (Savonis et. al 2008, Youman 2007) *(cf. measure 10)*

4 Consider climate change conditions in the design procedures of ships (DNV 2009)

5 Install protective structures/dikes or raise existing dikes to protect ports (Ang-Olson 2009, Savonis et al. 2008)

6 Elevate bridges and other structures (Savonis et al. 2008) *(cf. measure 10)*

7 Find alternate navigation routes (van der Toorn 2010)

B. Regulation and standards

8 Regulate the number and weight of barges in case of low river discharge (van der Toorn 2010)

9 Modify technical standards for height of dams and flood barriers due to expected increases in rainfall intensity and sea level rise (Nolte 2008)

10 Design harbor infrastructure (e.g. docks, wharves, terminals) stronger to protect it from storm surge and wave damage (Savonis et. al 2008) *(cf. measures 3 and 6)*

C. Capacity building

11 Carry out risk-analysis for ports by simulating different scenarios of likely impact to identify how vulnerable a port is to such risks (detect vulnerability hot spots) (Becker et al. 2011)

12 Address climate change in existing management plans such as port strategic plan, and in the operational practices and approaches (Becker et al. 2011)

13 Produce sea level rise maps (Youman 2007)

14 Increase understanding of climate change and Waterborne transport by providing funding for research

D. Communication/Awareness raising

15 Provide information (e.g. vulnerability maps, good practice examples) and easy access to information to operators

16 Create crisis management plans, including replacement modes, secondary itineraries and temporary network shutdowns, in preparation for the potential increase in frequency and intensity of extreme weather events

E. Guidelines

17 Publish guidelines for operators to take climate change into account in connection with construction and operation (HM Government 2011)

18 Develop check lists for vulnerability assessments

F. EU financing scheme

19 Invest in innovative fleet management (e.g. vessels with smaller draft, extra buoyancy, etc.)

3. Exploration of adaptation options for the EU level

A. Suggestions for adjustments in existing policies

The European Commission aims to promote and strengthen the competitive position of the inland waterway transport in the transport system, and to facilitate its integration into the intermodal logistic chain. The EU is committed to breathing new life into the sector, particularly through the Naiades Action Programme. This programme provides one entry point for integration of adaptation in inland shipping.

In regard to maritime transport, the European Commission's objective is to protect Europe with very strict safety rules preventing sub-standard shipping, reducing the risk of serious maritime accidents and minimizing the environmental impact of maritime transport. In addition, the EC works against issues such as piracy and terrorism threats as well as for concerns in the social dimension focusing on passengers (e.g. ensure safety) and seafarers (e.g. health issues, professional qualifications). Thus, adaptation in the field of maritime transport can be mainly integrated in existing EU policies focusing on safety rules.

- **Commission Communication - Strategic goals and recommendations for the EU's maritime transport policy until 2018 [COM(2009) 008 final][55]**

[55] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0008:FIN:EN:PDF.

This Communication defines the main strategic objectives of the European maritime transport policy until 2018 and recommends actions to increase the competitiveness and environmental performance of this sector.

4.2. Maritime transport safety:

– Revise the mandate and the functioning of the European Maritime Safety Agency, in order to further enhance the technical and scientific assistance it can give to the Member States and the Commission.

Suggestion: The European Maritime Safety Agency (EMSA) was established, inter alia, to provide support and advice to the EC but also to its Member States (e.g. in technical questions regarding ship safety, Port State control). The EMSA collaborates with many stakeholders and thus could play an important role in disseminating information regarding climate change and adaptation *(addresses measures 14, 16, 17, 18 and 19)*.

4.2. Maritime transport safety:

In that context, devote special attention to the challenges posed by extreme navigation conditions, such as ice, as well as the constantly increasing size of vessels. Appropriate ice navigation and construction standards and assistance requirements (ice-breakers) should apply in respect of all vessels operating in the more exposed sea areas.

Suggestion: Ice navigation is mentioned as one case of extreme navigation conditions. Due to climate change, sea level rise could be expected and thus, appropriate navigation and construction standards are needed. *(addresses measure 3)*

- **Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions of 10 October 2007 on an Integrated Maritime Policy for the European Union [COM(2007) 575 final56**

The prime objective of an integrated maritime policy for the EU is to maximise sustainable use of the oceans and seas while enabling growth of the maritime economy and coastal regions. In order to ensure the competitiveness, safety and security of the sector, the European Commission commits – among others – to create a strategy to alleviate the consequences of climate change in coastal regions. Thus, the Communication highlights the need for a strategy *to mitigate the effects of Climate Change on coastal regions* (cf. p3), *to launch pilot actions to adapt to climate change in coastal zones* (p10), and *to support research to predict, mitigate and adapt to the effects of climate change on maritime activities, the marine environment, coastal zones and*

[56] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0575:FIN:EN:PDF.

islands (p12). In addition, the Commission will take steps towards a European Marine Observation and Data Network, and promote the multi-dimensional mapping of Member States' waters, in order to improve access to high quality data.

Suggestion: The Communication already addresses the need for adaptation and thus, several measures suggested in section 2 *(addresses measure 1, 12, 13, 14).* These options should be gradually concretized in line with new research results.

- **Communication from the Commission to the European Parliament and the Council of 8 September 2010 – Marine knowledge 2020 marine data and observation for smart and sustainable growth final)57**

This Communication proposes an action plan from 2011-2013 intended to improve the use of scientific knowledge through a more coordinated approach to marine data collecting and assembly. The Communication suggests building on existing initiatives such as INSPIRE, EMODnet, WISE-marine (component of SEIS) and GMES and proposes to improve existing instruments in order to enhance their effect.

Suggestion: So far, specific data requirements in regard to climate change impacts and adaptation are not mentioned but could be included in the action plan. In addition, the data could provide a valuable information base for risk analyses, sea level maps, monitoring systems etc. *(addresses measure 12, 14, 16).*

- **Directive 2005/44/EC on harmonised river information services (RIS) on inland waterways in the Community [Official Journal L 255, 30.9.2005]58 &Commission Regulation (EC) No 414/2007 of 13 March 2007 concerning the technical guidelines for the planning, implementation and operational use of river information services (RIS)5960**

The River Information Services (RIS) concept is aimed at the implementation of information services in order to support the planning and management of traffic and transport operations. The Directive aims at a Europe-wide framework for the implementation of the RIS concept in order to ensure compatibility and interoperability between current and new RIS systems at European level and to achieve effective interaction between different information services on waterways. In order to ensure harmonised and interoperable implementation of RIS, guidelines and technical specifications were established in 2007.

Suggestion: Some of the information provided within RIS is also important in regard to adaptation to climate change (e.g. fairway information, navigation support, transport logistic). Nevertheless, the current version of the RIS Guideline does not touch upon the issue of climate change. Thus, when updating the RIS Guidelines, the existing system should be

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[57] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:0461:FIN:EN:PDF.

[58] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:255:0152:0159:EN:PDF.

[59] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:105:0001:0034:EN:PDF.

[60] http://www.ris.eu/home.

analysed in regard of possible impacts of climate change and – if necessary – adapted to be climate proofed *(addresses measure 1, 2, 6, 8).*

- **NAIADES Action Programme (2006-2013)61**

In January 2006, the multi-annual NAIADES Action Programme which aims at promoting inland waterway transport (IWT) in Europe was launched. It sets the frame for a comprehensive IWT policy by focusing on five strategic interdependent areas - among other - on infrastructure.

Suggestion: In the follow-up to the current action programme, adaptation to IWT should be considered. By 2013 results from the EWENT-7.FP can be expected and thus will provide a knowledge base to build on appropriate adaptation measures *(addresses F "EU Financial scheme")*

B. Options for additional policy action

- **Based on enhanced knowledge, adjust regulation and standards for long-life structures (e.g. dock, wharfs, bridges, dams) and/or retrofit existing facilities to meet requirements of a changing climate** *(addresses A "Technical measures" and B "Regulation and standards")*
- **Provide guidelines and check lists for addressing climate change in shipping** *(addresses E "Guidelines")*
- **Open grants for more research on impacts and possible adaptation measures in the field of infrastructure** *(addresses measure in "Capacity Building")* **as well as on innovative fleet management** *(addresses measure 20)*

Policies relevant for all transport modes

- **Council Regulation (EC) N°1083/2006 laying down general provisions on the European Regional Development Fund, the European Social Fund and the Cohesion Fund and repealing Regulation (EC) No 1260/1999[62]**

Art. 40*: "The Member State or the managing authority shall provide the Commission with the following information on major projects: (e) a cost-benefit analysis, including a risk assessment and the foreseeable impact on the sector concerned and on the socio-economic situation of the Member State and/or the region…".*

Suggestion: Reference to risk assessment: could additionally request a systematic mapping of different types of climate threats, vulnerabilities and consequences for new projects *(addresses C "Capacity building" in all transport modes)*

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[61] http://ec.europa.eu/transport/inland/promotion/naiades_en.htm.

[62] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:210:0025:0078:EN:PDF.

- **Conclusions of the fifth report on economic, social and territorial cohesion: the future of cohesion policy (2010 1348, finale)**[63]

p6.: "To improve financial engineering instruments within cohesion policy, a number of measures could be examined: Extend both the scope and scale of financial engineering instruments: in terms of scope, to encompass new activities (e.g. sustainable urban transport, research and development, energy, local development, lifelong learning or mobility actions, climate change and environment, ICT and broadband); in terms of scale, to combine interest subsidies with loan capital or other forms of repayable financing."

Suggestion: Add a reference to climate robust transport infrastructure *(addresses measure A-E in all transport modes)*

- **TEN-T Guidelines (661/2010/EC)**

Suggestion: Include in objectives of trans-European transport network, that the network is resilient to a changing climate. *(addresses C "Capacity building" in all transport modes)*

Suggestion: Concrete methodologies and guidelines for climate proofing could be incorporated into the TEN-T guidelines (COM 2009). *(addresses E "Guidelines" in all transport modes)*

- **White Paper: Roadmap to a single European Transport Area – Towards a completive and resource efficient transport system (Com 2011)**[64]

This White Paper highlights the need for adaptation to climate change and has included direct references to enhance the resilience of transport infrastructure.

Suggestion: The general policy objective of this initiative is to define a long-term strategy that would transform the EU transport system into a sustainable system by 2050. This general objective aims to decrease the greenhouse gases and thus focuses mainly on the issue of mitigation. Without a doubt on the importance of this goal, we suggest broadening the objectives to aspects of climate resilience in the field of transport infrastructure. In addition, transport research should also include aspects of climate change robustness. *(addresses C "Capacity building" in all transport modes)*

➲ **COUNCIL REGULATION (EC) No 2012/2002 of 11 November 2002 establishing the European Union Solidarity Fund**[65]

The floods in Germany, Austria, the Czech Republic and France in the summer of 2002 caused serious human and material damage. To enable itself to respond to such situations or to similar cases of major natural disasters (e.g. storms, fires, with serious repercussions on living conditions in a rapid, efficient and flexible manner to urgent situations, the Community has established a Solidarity Fund. Intended to finance measures alleviating non-

[63] http://ec.europa.eu/regional_policy/sources/docoffic/official/reports/cohesion5/pdf/conclu_5cr_part1_en.pdf.

[64] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:PDF.

65 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:311:0003:0008:EN:PDF.

insurable damage in principle, the urgent actions eligible for the Fund are for example the immediate restoration to working order of infrastructure in the fields of transport.

Suggestion: Weather-related natural catastrophes are occurring more and more frequently and causing an increasing amount of damage (Munich RE 2010). Thus, one can expect that the annual budget of one billion euro might be not sufficient in future. *(addresses "EU financing scheme" in all transport modes)*

In addition, a reference to climate change adaptation can be included such as requirements for enhancing the climate resilience (e.g. install early warning system, prepare emergency plans) when reconstructing the transport infrastructure.

- **Cohesion Fund**[66]

The Cohesion Fund aims to strengthen the economic and social cohesion of the Community through the balanced financing of projects, technically and financially independent project stages and groups of projects forming a coherent whole, in the fields of the environment and trans-European transport infrastructure networks.

Cohesion Policy investments in transport between 2007 and 2013 will be concentrated in the Convergence regions. It is split as follows:
(Source: http://ec.europa.eu/regional_policy/themes/transport/index_en.htm)

- TEN-T projects across all transport modes will receive €38 billion (11% of the total of cohesion policy investments). About half of that will be allocated to road infrastructure and the remainder to rail.
- Overall almost €41 billion (12% of the total) will be available for road infrastructure, including TEN-T and national, regional and local roads.

- For rail infrastructure, a total of €23.6 billion (6.8%) will be spent, including TEN-T projects.
- Other allocations include: urban transport: €8.1 billion (2.3%), ports and inland waterways: €4.1 billion (1.2%), multimodal transport and intelligent transport systems: €3.3 billion (1%); airports: €1.9 billion (0.5%).

Suggestion: Concrete methodologies and guidelines for climate proofing could be incorporated into the Cohesion Fund (COM 2009).

- **Marco Polo Programme**[67]

Marco Polo aims to ease road congestion and its attendant pollution by promoting a switch to greener transport modes for European freight traffic such as railways, sea-routes and inland waterways.

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[66] http://europa.eu/legislation_summaries/regional_policy/provisions_and_instruments/l60018_en.htm.

[67] http://ec.europa.eu/transport/marcopolo/about/index_en.htm.

Suggestion: In addition to fund the improvement of the environmental performance of the transport system, the Programme should also include funding of actions which aim at increasing robustness towards climatic change.

- **COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS: A Community approach on the prevention of natural and man-made disasters SEC(2009)202**[68]

With this communication the EC aims to provide a comprehensive approach to disaster prevent at the EU level and sets out the first step towards a Community strategy for the prevention of natural and man-made disaster.

The Prevention Communication proposes to focus action at EU-level on three areas:

1. Developing knowledge-based prevention policies (e.g. inventory of information on disasters, spreading best practices; developing guidelines on hazard/risk mapping, encouraging research activities,
2. Linking actors and policies throughout the disaster management cycle (e.g. training and awareness-raising; Reinforcing early warning tools)
3. Improving the effectiveness of existing financial and legislative instruments (e.g. efficient targeting of Community funding)

Suggestion: All these proposed measures are also of high importance under the heading of climate change adaptation in general, but also in the transport sector. The issue of climate change adaptation should be incorporated strongly in the planned EC strategy *(addresses C, D and E in all transport modes).*

- **Council Regulation (EC) No 680/2007 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL laying down general rules for the granting of Community financial aid in the field of trans-European networks**:

  Art. 5 (2) Selection of projects[69]

Suggestion: Add as further criteria: - Adaptation measures foreseen to respond to changing climatic conditions.

Recommendations for further adaptation actions in the transport sector on the EU Policy level
1 Establish additional grants to support research in the field of climate change impacts on the transport sector (especially on aviation) and possible adaptation options. More knowledge particularly necessary to be able to suggest concrete amendments in standards and regulation.

[68] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0082:FIN:EN:PDF.

[69] http://tentea.ec.europa.eu/download/legal_framework/8__regulation_6802007.pdf.

2 Integrate the need for adaptation in TEN-T Guidelines and provide support by developing climate change adaptation guidance for the transport sector

3 Facilitate European Transport Agencies (European Maritime Safety Agency, European Aviation Safety Agency, European Railway Agency and Trans-European Transport Network Executive Agency) as information platform and desk in regard to questions on climate change

4 Provide information and access to information to Member States and transport operators (e.g. through the Adaptation Clearing House for Europe)

3.3 Urban areas

3.3.1 Analysis of current EU policies towards climate change adaptation efforts

For chapter 3 policies and potential climate change impacts have been assessed. The following overview provides insight if or how the climatic risks are addressed in existing policies for urban areas.

Urban specific/related:

- **Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - Mainstreaming sustainable development into EU policies : 2009 Review of the European Union Strategy for Sustainable Development (COM (2009) 400 final)[70]**

Reference to climate change and clean energy, also referring to the White Paper on Adapting to Climate Change; further, adaptation to climate change is mentioned to be considered as one point with regard to the monitoring of the strategy.

- **Urban guide – the urban dimension in European Union policies 2010[71][72]**
  No direct reference to adaptation, climate change (as a world-wide challenge) is seen as one of the thematic priorities related to urban issues
- **Communication "Cohesion policy and cities: the urban contribution to growth and jobs in the regions" (COM (2006) 385 final)[73]**

[70] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52009DC0400:EN:NOT.

[71] http://ec.europa.eu/regional_policy/sources/docgener/guides/urban/pdf/urbanguide1_en.pdf.

[72] http://ec.europa.eu/regional_policy/sources/docgener/guides/urban/pdf/urbanguide2_en.pdf.

[73] http://ec.europa.eu/regional_policy/consultation/urban/com_2006_0385_en.pdf.

No direct reference – linkage to the URBACT[74] Programme (European exchange and learning programme to promote sustainable urban development)

- **Orientation paper on future Cohesion Policy[75]**

  Reference to climate change - the necessity to incur high investment outlays to fight climate change and Cohesion policy investments should be climate proofed

- **Communication "The Strategy on the Urban Environment" (COM (2005) 718 final)[76]**

  Reference to adaptation

  ➲ p4: *the Strategy will ultimately contribute to improve the quality of the urban environment, making cities more attractive and healthier places to live, work and invest in, and reduce the adverse environmental impact of cities on the wider environment, for instance as regards climate change.*

  ➲ p8: *Urban areas have an important role to play in both adapting to climate change and mitigating greenhouse gas emissions. Urban areas are vulnerable to the consequences of climate change such as flooding, heat waves, more frequent and severe water shortages. Integrated urban management plans should incorporate measures to limit environmental risk to enable urban areas to deal better with such changes.*

- **Communication "Green paper on the Urban Environment" (COM (90)218 final, 28.6.1990)[77]**

  No direct reference

Buildings (including pole related constructions)

- **EU Energy performance of Buildings Directive (2010/31/EU)[78]**

  No direct reference – reference to climate change and the fulfillment of Kyoto aims

  ➲ p9 (Art 8.1): *technical building systems: adjustment and improvement of technical building systems like heating-, hot water-, air-conditioning- and cooling systems as combination of such systems*

  ➲ p9 (Art 9.1): *development of national plans for increasing the number of nearly zero-energy buildings*

- **COMMISSION RECOMMENDATION (2003): on the implementation and use of Eurocodes for construction works and structural construction products, C(2003) 4639), (2003/887/EC)[79]**

  No direct reference

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[74] http://urbact.eu/.

[75] http://ec.europa.eu/regional_policy/newsroom/pdf/pawel_samecki_orientation_paper.pdf.

[76] http://ec.europa.eu/environment/urban/pdf/com_2005_0718_en.pdf.

[77] http://ec.europa.eu/environment/urban/pdf/com90218final_en.pdf.

[78] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF.

[79] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:332:0062:0063:en:PDF.

Communication infrastructure

- **Common regulatory framework for electronic communications networks and services (2009/140/EC)[80]**

  No direct reference

Human health and air quality

- **White paper (2007): Together for Health: A Strategic Approach for the EU 2008 – 2013 (COM (2007) 630 final)[81]**

  Direct reference to adaptation

  ➲ p9: *Health aspects on adaptation to climate change (Commission)*

  ➲ p3: *Climate change is causing new communicable disease patterns. It is a core part of the Community's role in health to coordinate and respond rapidly to health threats globally and to enhance the EC's and third countries' capacities to do so.*

  ➲ p8: *Action is also needed on emerging health threats such as those linked to climate change, to address its potential impact on public health and healthcare systems.*

- **EU Health Programme[82][83]**

  No direct reference

- **Communication: A European Environment and Health Strategy (Com (2003) 338 final)[84]**

  No direct reference

- **EU Ambient Air quality and cleaner air Directive[85]**
  No reference to climate change, but to air quality

  ➲ p10 (Chapter IV, Art23): *Air quality plan: if the levels of pollutants in ambient air exceed any limit value or target value, establishment of this plan in order to achieve the related limit value or target value.*

  ➲ p10 (Chapter IV, Art 24): *Short term action plan: if there is a risk that the levels of pollutants will exceed one or more of the alert thresholds, establishment of action plans indicating the measures to be taken in the short term in order to reduce the risk or duration of such an exceedance.*

Urban transport

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[80] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:337:0037:0069:EN:PDF.

[81] http://ec.europa.eu/health/ph_overview/Documents/strategy_wp_en.pdf.

[82] http://ec.europa.eu/eahc/.

[83] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:301:0003:0013:EN:PDF.

[84] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2003:0338:FIN:EN:PDF.

[85] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:EN:PDF.

- **<u>Green paper – Towards a new culture for urban mobility (SEC (2007 1209)</u>**[86]
  No direct reference – reference to climate change and the reduction of greenhouse gas emissions
  - ➲ p8: *environmental conditions are still not satisfactory: local authorities are facing serious problems to meet the requirements on air quality, such as the limits of particulates and nitrogen oxides in ambient air. These have a negative impact on public health.*
- **<u>Communication “Action plan on urban mobility” (SEC (2009 1211/1212)87</u>**
  No direct reference – reference to climate change and the EU overall strategy to combat climate change and to promote an integral approach linking energy and climate change with transport.

3.3.2 Gap analysis

In order to identify potential gaps, policies mentioned under chapter I have been assessed in-depth.

As a result it can be concluded that existing policies (cf. I) related to **urban built environment and open spaces** do not explicitly address the climatic pressures (e.g. increase of temperature) and impacts which can be expected in the future as potentially harming urban built environment. Nevertheless, a few policies (e.g. floods directive) highlight the need to integrate possible impacts due to climate change into the respective plans (flood risk management plans). In addition, adaptation can be integrated in the revision of the currently developed plans, especially those who receive EU support for the plan developments or its realization (e.g. Cohesion funds) to ensure climate-proofed built urban environments.

Existing policies (cf. I) related to urban **buildings (including pole related construction)** do not explicitly address the climatic pressures (e.g. increase of temperature, storms, salt water intrusion) and expected future impacts. Nevertheless, a few policies (e.g. energy performance of buildings directive) highlight the need to focus on mitigation and the relation to the fulfillment of the Kyoto 2℃ target. In addi tion, adaptation can be integrated in the Eurocodes[88] of buildings (Commission Recommendation on Eurocodes[89]) as well as into the design of new urban development.

With regard to **communication infrastructure (incl. energy supply)** no explicit policies (cf. I) could be identified. Nevertheless, a few policies (e.g. transport, energy) highlight the need to integrate possible impacts due to climate change into the respective plans and projects. In addition, adaptation can be integrated in the revision of the currently developed

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[86] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0551:FIN:EN:PDF.

[87] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0490:FIN:EN:PDF.

[88] The Eurocodes are a set of unified international codes of practice for designing buildings and civil engineering structures, which will eventually replace national codes.

[89] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:332:0062:0063:en:PDF.

plans and projects, especially those who receive EU support for its development or its realization (e.g. Cohesion funds) to ensure climate-proofed communication infrastructure.

Policies (cf. I) related to **human health and air quality** do not explicitly address the climatic pressures (e.g. increase of temperature, droughts) and impacts which can be expected in the future as potentially harming human health and air quality. Nevertheless, a few policies (e.g. air quality directive, Staff working document, accompanying the White Paper on Adaptation – Human, Animal and Plant Health Impacts of Climate Change[90]) highlight the need to integrate possible impacts due to climate change into the respective systems and plans (e.g. Heat Health Warning System, environmental health information systems, air quality plan and short term action plan). In addition, adaptation can be integrated in the revision of programmes, especially those who receive EU support for the project or initiative (e.g. EU Health Programme). (cf. 4 Exploration of adaptation options for the EU level).

Relating to **urban transport** existing policies (cf. I) do explicitly address climate change as impacts that will cause dramatic shifts in global eco-systems and urgent action is required to keep impacts to a manageable level. A few European initiatives (e.g. Green paper – Towards a new culture for urban mobility and Communication "Action plan on urban mobility"[91][92]) highlight the need to integrate possible impacts due to climate change into the respective urban transport modes and (e.g. urban mobility actions). In addition, adaptation can be integrated in the revision of programmes, especially those who receive EU support for the project or initiative (e.g. CIVITAS Initiative[93]) and recommendations (e.g. Europe at a crossroads – The need for sustainable transport[94]).

An assessment of all above mentioned policy options is provided in the following steps.

3.3.3 Examination of different components of urban areas

We have identified five parts of urban areas for our analysis: built environment (roads, sidewalks, infrastructure) and open spaces (including green spaces), buildings (including pole related constructions), communication infrastructure (incl. energy supply), human health and air quality and urban transport.

Built environment and open spaces

1. Impact Table:

Table 3-7: Impact table built environment and open spaces

[90] http://ec.europa.eu/health/ph_threats/climate/docs/com_2009-147_en.pdf.

[91] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0490:FIN:EN:PDF.

[92] http://ec.europa.eu/transport/urban/urban_mobility/doc/2009_apum_citizens_summary_en.pdf.

[93] http://www.civitas-initiative.eu/main.phtml?lan=en.

[94] http://ec.europa.eu/publications/booklets/move/39/en.pdf.

The impact table provides a summary on future climatic pressures which may affect the Built environment and open spaces negatively.

Type	Climatic pressures	Risk	Time frame of expected impact	Area mainly affected
Built environment (e.g. paved areas like roads, infrastructures) and open spaces (incl. Green areas)	Temperature increase and heat waves	Droughts - increase of the heat island effect	Medium negative to extreme negative	2025: Southern, Eastern EU 2080: Northern EU, Southern, Eastern, Central EU
	Floods	Damage to infrastructure due to flooding, property at risk due to location	Medium negative (2025;2080) to high negative (2080)	2025: Northern, Western 2080: Eastern, Southern, Northern, Western, Central
	Heavy precipitation events (extreme flash floods)	Heavy water run-off	Medium negative (2025;2080) to high negative (2080)	2025: Southern, Western 2080: Eastern, Southern, Northern, Western, Central
	Sea level rise and flooding due to storm surge	Rising sea level can affect not only the built environment but also water availability and quality. Salt water intrusion	Medium negative to extreme negative	2025: Southern, Western, Northern EU 2080: Southern, Western, Northern EU
	Extreme storms, strong winds	Damages, increase of maintenance cost	Small to medium impacts	European wide

2. Exploration of possible adaptation measures

For the compilation of possible adaptation measures a comprehensive literature review was carried out (cf. reference list). The information was gathered from work done on Urban Regions including adaptation options (e.g. Schauser 2010)[95] and from relevant research

[95] http://acm.eionet.europa.eu/reports/docs/ETCACC_TP_2010_12_Urban_CC_Vuln_Adapt.pdf.

projects and policies focusing on vulnerability and adaptation in urban regions. The literature on adaptation for urban built environment includes a variety of options, while many act on a very generic level (e.g. increase open space areas, emergency plans, and integrated transnational water management). Thus, based on expert judgment we present a range of possible adaptation measures addressing those climatic pressures and risks identified for the urban built environments (cf. 1). The measures are grouped using categories based on the Impact Assessment accompanying the White Paper on Adaptation (COM 2009).

A. Technical measures

1 Preserve and enhance existing areas of green space (e.g. private gardens, public spaces, streets) to adapt to increasing temperatures - biophysical features of green space in urban areas, through the provision of cooler microclimates (e.g. providing shade and evaporative cooling, drought-resistant plantings, porous surfacing) and reduction of surface water runoff (e.g. by decreasing rainwater runoff through interception, storage and infiltration) (Gill 2007, ASCCUE Project[96]); All green spaces help urban areas adapt to the impacts of climate change, there is evidence that open spaces within towns and cities, rather than green belt might be more effective (Climate Change and Urban Green Spaces[97]); more green and blue infrastructure are needed and mechanisms foreseen for cooling (blue infrastructure, trees, heat resistant plants, porous surfacing) and ventilation for public spaces including squares (EEA Report 5/2009 – Ensuring quality of life in Europe´s cities and towns[98]) *(cf. measures 6 and 7)*

2 Consider green space provision to increase water storage. There is significant potential to utilize sustainable urban drainage (SUDS) techniques, such as creating swales, infiltration, detention and retention ponds in parks (Mansell, 2003; CIRIA, 2000)

3 Improve flood risk management measures via precaution (space provision – restrictions for developments; build provision (adaptation of existing built environment, e.g. porous surfacing[99]) and hard measures (dikes, walls, retention basins) (The FloodResilienCity, 2010). Optimize flooding pathways and give room to the river (The FloodResilienCity, 2010[100]) and modify evacuation plans and evacuation routes and additional construct dikes in vulnerable regions in order to reduce damages (de Bruin 2007) *(cf. measure 8)*

4 Increase, upgrade and enlarge of drainage system capacity and integrated drainage, especially for new developments and drainage strategies to better meet the requirements in case of expected increase of extreme precipitation (Gill 2008). As a basis, climate

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96 http://www.sed.manchester.ac.uk/research/cure/research/asccue/publications.htm.

97 http://www.cchangeproject.org/r-nav/65.jsp.

98 http://www.eea.europa.eu/publications/quality-of-life-in-Europes-cities-and-towns.

99 http://www.griffith.edu.au/__data/assets/pdf_file/0004/275107/urp-rp32-matthews-2011.pdf.

100 Project FloodResilientCities, 2010; http://www.floodresiliencity.eu.

change projections have to be integrated into existing tools like modeling software for urban drainage.

5 Secure areas for water storage (retention systems or basins) - the availability of temporary storm-water retention areas or “emergency water ways” is important to reduce the occurrence of urban drainage floods (Hasse 2010)

B. Regulation and standards

6 Guide the development and renewal of green and blue infrastructure through local regulations at the city or regional level (GRaBS project); Strategic planning is required, at a local scale these include the modification of surface properties, for example ‘cool roofs’, ‘green roofs’ and ‘cool pavements’. Planting trees and vegetation and the creation of green spaces to enhance evaporation and shading are other options, as temperatures in and around green spaces can be several degrees lower than their surroundings (heat wave plan for England 2010[101]) *(cf. measure 1)*

7 Climate proof new developments in the Growth Areas and introduce functional green infrastructure during the development process (Gill 2007); Adapt external spaces via shading, planting for dryer summers, green and blue spaces to reduce the urban heat island effect – relation to built environment, especially in new urban development’s or redevelopments (Gething, 2010[102], Southampton – Low Carbon City 2011-2020, part 2103, heat wave plan for England 2010) *(cf. measure 1)*

8 Modify standards for height of dams and flood barriers due to expected increases in rainfall intensity and duration (especially in winter) *(cf. measure 3)*

9 Retreat and give up land to reduce damage caused by flooding events (de Bruin 2007), additional restrict development in floodplains and reassess the potential of flooding (Flood risk management, Spatial Planning provisions)

10 Develop joint adaptation action plans in vulnerable urban areas with clearly assigned responsibilities for all participating parties (GRaBS project[104])

C. Capacity building

11 Support transnational knowledge and good practice exchange on adaptation to climate change using green and blue infrastructure in urban areas (GRaBS project), diverse good

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[101] http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_116029.pdf.

[102] http://www.innovateuk.org/_assets/pdf/other-publications/tsb-climatechangereport-0510_final1.pdf.

[103] http://www.grabs-eu.org/downloads/Part%202%20-%20The%20Low%20Carbon%20City%20Strategy.pdf.

[104] http://www.grabs-eu.org/membersArea/files/Database_Final_no_hyperlinks.pdf.

practices improve cross-border learning and the planning and implementation of certain measures, e.g. via Eurocities[105]

D. Communication/Awareness raising

12 Provide information (e.g. impact maps, good practice examples) and easy access to information about the causes and consequences of climate change (EEA Report 5/2009 – Ensuring quality of life in Europe´s cities and towns[106])

13 Develop emergency plans/ crisis management plans in case of heat waves, floods, storms, etc. including replacement modes

14 Transnational meetings between politicians and technical experts of cities to benefit from each other's knowledge, experiences and best practice (The FloodResilienCity, 2010; EEA Report 5/2009; GRaBS project) - e.g. via Eurocities

E. Guidelines

15 Develop methodologies and checklists for climate proofing urban area (including vulnerability assessment and possible adaptation options), e.g. like for the Netherlands (Building the Netherlands Climate Proof: Urban Areas, Deltares 2010[107])

F. EU financing scheme

16 Integrate funding provisions to EU funding schemes (Life, Cohesion policy and European Territorial Cooperation) which support specific adaptation measures mentioned under A to E for urban areas

17 Explore tax support mechanisms. Providing tax reductions for certain measures could trigger their uptake by the private sector (e.g. water suppliers, waste water managers, land owners)

3. Exploration of adaptation options for the EU level

Under the current policy framework related to built environment and open spaces impacts of climate change remain predominantly within Member States, mostly at the regional and municipal (city) responsibility. The White Paper on Adaptation (COM 2009) only identifies urban areas as one of the most vulnerable regions in Europe. It does not define the role of the European Commission with regard to urban areas though.

Thus, we have explored possibilities for adjustments of existing policies for mainstreaming adaptation (cf. A). The suggestions take up the adaptation measures presented under

105 http://www.eurocities.eu/main.php.

106 http://www.eea.europa.eu/publications/quality-of-life-in-Europes-cities-and-towns.

107 http://www.deltares.nl/en/expertise/101145/urban-land-and-water-management/1076557.

section 2 in terms of options for corresponding policy actions (according references are given in brackets to most suggestions).

A. Suggestions for adjustments in existing policies

- **EU Floods Directive**

p1 (§4): Directive, does not take into account the future changes in the risk of flooding as a result of climate change

p2 (§14): The elements of flood risk management plans should be periodically reviewed and if necessary updated, taking into account the likely impacts of climate change on the occurrence of floods

p7 (Chapter VIII, Art. 14, §4): The likely impact of climate change on the occurrence of floods shall be taken into account in the reviews of the preliminary flood risk assessment (starting in Dec. 2018) as well as in the review of the flood risk management plan(s)

Suggestion: Reference to risk of flooding could additionally request to address climate change into risk of flooding and into the review of flood risk management plans as a must to adapt urban areas and especially new developments to a changing climate *(addresses measures 3, 4, 5, 8, 9, 13 and 16)*

- **Communication "The Strategy on the Urban Environment" (COM (2005) 718 final)**

p8: Urban areas have an important role to play in both adapting to climate change and mitigating greenhouse gas emissions. Urban areas are vulnerable to the consequences of climate change such as flooding, heat waves, more frequent and severe water shortages. Integrated urban management plans should incorporate measures to limit environmental risk to enable urban areas to deal better with such changes.

Suggestion: Reference to integrated urban management plans: incorporate adaptation measures into the integrated urban management plans to ensure that climate change impacts are addressed European wide in cities and towns. *(addresses measures 1, 2, 6, 7, 10 11 and 12)*

- **Communication "Cohesion policy and cities: the urban contribution to growth and jobs in the regions" (COM (2006) 385 final)**

Related to the previous point "Making our cities attractive and sustainable":

p27: LIFE funds and the urban environment - The programme supports pilot projects in cities that develop new technologies, policy approaches, methods and instruments for urban environmental management, in line with the Thematic Strategy on the urban environment. For example, in 2005 LIFE supported Elefsina 2020, a project to regenerate this environmentally degraded port and city in Greece. LIFE+ has a total budget of €2 billion for the 2007-2013 period.

Cohesion policy funding for urban areas - Between 2007 and 2013, around €30 billion will be spent on urban projects within region policy programmes. In addition to the policy's financing *for infrastructure and people-based actions, the European Territorial Cooperation objective (formerly "INTERREG") can be used by cities to develop joint cross-border or transnational projects.*

The Commission also provides special support for cities to work together through the URBACT programme, which is a European exchange and learning programme promoting sustainable urban development. In the current programming period URBACT offered financial support to 289 cities participating in 44 different projects. The programme enables cities to jointly develop solutions to major urban challenges, reaffirming the key role they play in facing increasingly complex societal changes.

Suggestion: Concrete formulation of adaptation needs into the future cohesion policy, which will be stronger focusing on the urban dimension. Only measures like green and grey infrastructures that improve the resilience of urban areas against impacts of a changing climate shall be funded in the upcoming Cohesion Fund (COM 2006). Like suggested in the orientation paper on future Cohesion Policy[108], Cohesion policy investments should be climate proofed. Competitiveness measures will need to take into account constraints and opportunities of a low carbon economy. *(addresses measures 16 and 17)*

In case further policy initiatives are taken on the below mentioned Green Paper, the following suggestion can be given:

- **Green paper – Towards a new culture for urban mobility (SEC (2007 1209) and Communication "Action plan on urban mobility" (SEC (2009 1211/1212)**

Suggestion: Reference to urban mobility: programs and projects shall include elements of adapting the current and future transport modes to a changing climate and promote an integral approach linking energy and climate change with transport *(addresses measures 15, 16 and 17)*

[*Comment: Suggestions only relevant if a White Paper is foreseen*]

Buildings (including pole related constructions)

<u>1. Impact Table</u>

Table 3-8: Impact table buildings

The impact table provides a summary on future climatic pressures which may affect buildings (including pole related constructions) negatively.

Type	Climatic pressures	Risk	Time frame of expected impact	Area mainly affected
Buildings (including pole related constructions)	Temperature increase and heat waves --------------	Decrease of comfort ------------------------------	Medium negative (2025) to high negative (2080) ------------------------	European wide ----------------

[108] http://ec.europa.eu/regional_policy/newsroom/pdf/pawel_samecki_orientation_paper.pdf.

	Heavy precipitation events (extreme flash floods)	Possible infiltration of water into buildings	Medium negative (2025;2080) to high negative (2080)	2025: Southern, Western 2080: Eastern, Southern, Northern, Western, Central
	Storms and storm-waters	Damages, destruction, flooding	Small impacts	European wide
	Salt water intrusion	Deterioration of facades, statues, monuments	Medium negative to extreme negative	2025: Southern, Western, Northern EU 2080: Southern, Western, Northern EU

2. Exploration of possible adaptation measures

For the compilation of possible adaptation measures a comprehensive literature review was carried out (cf. reference list). The information was gathered from work done on adaptation measures (e.g. Roaf 2005, Gething 2010) and from relevant research projects focusing on adaptation of buildings (e.g. Prometheus Project[109] aims at helping the building sector adapt to the challenges of climate change). The literature on adaptation for building in urban areas includes a few options, while many act on a very generic level (e.g. shut the internal blinds, solar shading, adjust the air-conditioning, certain building types, passive techniques). Thus, based on expert judgment we present a range of possible adaptation measures addressing those climatic pressures and risks identified for buildings in urban areas (cf. 1). The measures are grouped using categories based on the Impact Assessment accompanying the White Paper on Adaptation (COM 2009).

A. Technical measures

1 Develop rooftop gardens, which decrease fluctuations due to air flow through the roof and therefore, help to control interior temperature (Achieving Urban Climate Adaptation in Europe and Central Asia, 2009[110]) *(cf. measure 6)*

2 Provide adequate protection in extreme weather such as temperature increase or storms (e.g. using staking boards to adapt to storms) through clever design and building types (Roaf 2005[111]) *(cf. measures 6 and 8)*

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[109] http://centres.exeter.ac.uk/cee/prometheus/.

[110] http://siteresources.worldbank.org/ECAEXT/Resources/258598-1243892418318/Cities_Climate_Adaptation.pdf.

3 Assess the opportunity to store rainwater at high level of buildings to provide water for non-portable uses (e.g. WC flushing) and thus reduce the effects of related flooding events (Gething, 2010)

4 Increase the number of green roofs largely. Green roofs have big benefits like biodiversity as well as water management. They attenuate the run-off from storm events and locking up some of it so it doesn't get to the sewerage system. They slow down rainfall from reached piped systems, especially in terms of the effects climate change might have on rainfall patterns (Matthews, 2011[112])

5 Implement hard measures to reduce the risk of salt water intrusion (e.g. coastal defenses, canals to regulate the ground water level and sheet pill cut off walls) and coastal zone management plans in urban regions

B. Regulation and standards

6 Adapt building regulations and building codes to include enough cushion for extreme events (e.g. storms and related flooding, salt water intrusion) like green roofs and stable building foundations (Roaf 2005) Adapt building codes for heat waves like the regulation of height of the buildings, the building density and the kind of trees to be planted along the streets (Heat-waves: risks and responses, WHO, 2005[113]) *(cf. measures 1 and 2)*

7 Adapt building codes to improve indoor comfort (related to health) focusing on passive techniques (Gething, 2010) and especially on shading of the building, which reduces the impact of solar radiation in summer; trees and plants to shade walls and windows in summer and other shading devices for windows; highly insulative building materials; bright colors on all surfaces; orientation and window size; and ventilation (Heat-waves: risks and responses, WHO, 2005)

8 Design building foundations for the life time of a building (e.g. changing rainfall patterns may increase shrinkage of clay soils, slopes and retaining structures may become less stable) to resist changing wind patterns (Gething, 2010) *(cf. measure 8)*

9 Extent building gutters, downpipes and drainage (building rain water drainage) to deal with projected increase in extreme rainfall in building codes (Gething, 2010)

C. Capacity building

10 Facilitate transnational meetings between politicians and technical experts related to construction authorities in cities and towns to benefit from each other's knowledge,

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[111] http://books.google.de/books?hl=de&lr=&id=QXo68w7QLaYC&oi=fnd&pg=PP1&dq=ADAPTING+BUILDINGS+AND+CITIES+FOR+CLIMATE+CHANGE&ots=xtO5d6K8uO&sig=3CvDuKiEmZDIXFU8VkjCiKILdzo#v=onepage&q&f=false.

[112] http://www.griffith.edu.au/__data/assets/pdf_file/0004/275107/urp-rp32-matthews-2011.pdf.

[113] http://www.euro.who.int/__data/assets/pdf_file/0008/96965/E82629.pdf.

experiences and good practice in designing urban areas for future climate and adapting buildings – e.g. via Eurocities

D. Communication/Awareness raising

11 Gather evidence to inform upcoming building regulations through compiling case studies with the aim to raise awareness in the building industry of the need for adaptation (e.g. Design for Future Climate: Adapting Buildings[114], Gething, 2010)

E. Guidelines

12 Develop general guidance similar to the UK guidance - Design for Future Climate: Adapting Buildings[115]

13 Develop check lists for vulnerability assessments supporting the City Authorities related to building regulations

14 Publish guidelines in order for building developers to take climate change into account in connection with construction and operation

F. EU financing scheme

15 Integrate funding provisions to EU funding schemes which support specific adaptation measures mentioned under A to E

16 Explore tax support mechanism: provide tax reductions for certain measures could trigger their uptake by the private sector

3. Exploration of adaptation options for the EU level

Under the current policy framework related to buildings (including pole related constructions) impacts of climate change remain predominantly within Member States, mostly at the regional and municipal (city) responsibility. The White Paper on Adaptation (COM 2009) only identifies urban areas as one of the most vulnerable regions in Europe. It does not define the role of the European Commission with regard to urban areas though.

Thus, we have explored possibilities for adjustments of existing policies for mainstreaming adaptation (cf. A). The suggestions take up the adaptation measures presented under section 3 in terms of options for corresponding policy actions (References are given in brackets to most suggestions).

A. Suggestions for adjustments in existing policies

- **Communication "The Strategy on the Urban Environment" (COM (2005) 718 final)**

[114] http://www.innovateuk.org/_assets/pdf/other-publications/tsb-climatechangereport-0510_final1.pdf.

[115] http://www.innovateuk.org/_assets/pdf/other-publications/tsb-climatechangereport-0510_final1.pdf.

p8: Urban areas have an important role to play in both adapting to climate change and mitigating greenhouse gas emissions. Urban areas are vulnerable to the consequences of climate change such as flooding, heat waves, more frequent and severe water shortages. Integrated urban management plans should incorporate measures to limit environmental risk to enable urban areas to deal better with such changes.

Suggestion: Reference to integrated urban management plans: incorporate adaptation options into integrated urban management plans, especially design, building types and water storage to ensure that climate change impacts are addressed European wide in the construction or renewal of buildings in cities and towns. *(addresses measures 1, 2, 3, 4, 6, 7, 8, 9, 11, 12, 13 and 14)*

- **Communication "Cohesion policy and cities: the urban contribution to growth and jobs in the regions" (COM (2006) 385 final)**

Related to the previous point Making our cities attractive and sustainable:

p27: LIFE funds and the urban environment - The programme supports pilot projects in cities that develop new technologies, policy approaches, methods and instruments for urban environmental management, in line with the Thematic Strategy on the urban environment. For example, in 2005 LIFE supported Elefsina 2020, a project to regenerate this environmentally degraded port and city in Greece. LIFE+ has a total budget of €2 billion for the 2007-2013 period.

Cohesion policy funding for urban areas - Between 2007 and 2013, around €30 billion will be spent on urban projects within region policy programmes. In addition to the policy's financing for infrastructure and people-based actions, the European Territorial Cooperation objective (formerly "INTERREG") can be used by cities to develop joint cross-border or transnational projects.

The Commission also provides special support for cities to work together through the URBACT programme, which is a European exchange and learning programme promoting sustainable urban development. In the current programming period URBACT offered financial support to 289 cities participating in 44 different projects. The programme enables cities to jointly develop solutions to major urban challenges, reaffirming the key role they play in facing increasingly complex societal changes.

Suggestion: Concrete formulation of adaptation needs of buildings into the future cohesion policy, which will be stronger focusing on the urban dimension. The proposer of a building plan or developments needs to verify that the project is climate proof in order to receive support by the Cohesion Fund (COM 2006). This can be conducted e.g. by a brief climate assessment as a part of the building approval. *(addresses measure 15)*

- **EU Energy performance of Buildings Directive (2010/31/EU)**
  p9 (Art 8.1): technical building systems: adjustment and improvement of technical building systems like heating-, hot water-, air-conditioning- and cooling systems or as combination of such systems

p9 (Art 9.1): development of national plans for increasing the number of nearly zero-energy buildings

Suggestion: Concrete formulation of adaptation needs of buildings into the Energy performance of buildings Directive, which will be an important factor to adapt successfully and create synergies between adaptation and mitigation efforts. Methodologies and guidelines for climate proofing buildings could be incorporated into the national plans for increasing the number of nearly zero-energy buildings. A preliminary climate proof check needs to be performed, in order to get an approval of a building project. *(addresses measures 1, 2, 3, 4, 6, 7, 8, 9)*

- **COMMISSION RECOMMENDATION (2003): on the implementation and use of Eurocodes for construction works and structural construction products, C(2003) 4639), (2003/887/EC)**

Suggestion: Concrete formulation of integration of adaptation into Eurocodes for buildings. The building foundations need to be designed for the lifetime of a building, taking into account temperature increase, changed precipitation patterns and strong winds and storms. Additional green roofs have to be considered as a future standard for flat roofs. *(addresses measures 2, 6, 7, 8, 12)*

Communication infrastructure (incl. energy supply)

1. Impact Table:

The impact table provides a summary on future climatic pressures which may affect the communication infrastructure like data networks, telephone systems, cable TV, educational systems, information systems, Wi-Fi, the Internet, the mobile phone, satellite communication, the I-Pod, flat screen television, wireless devices, Skype, Face Book, Twitter, virtual communities, laptops (incl. energy supply) negatively.

Table 3-9: Impact table communication infrastructure

Type	Climatic pressures	Risk	Time frame of expected impact	Area mainly affected
Communication infrastructure (incl. energy supply)	Temperature increase and heat waves ----------------- Extreme rainfall ----------------- Storms ----------------- Groundwater level ----------------- Ice, snow cover	Interruptions, damages, increase of maintenance cost	No information	European wide

2. Exploration of possible adaptation measures

For the compilation of possible adaptation measures a comprehensive literature review was carried out (cf. reference list). The information was gathered from work performed on Climate Resilient Infrastructure: Preparing for a Changing Climate including adaptation options (e.g. Defra 2011)[116]. The literature on adaptation for communication infrastructure (incl. energy supply) is very rare. Thus, based on expert judgment we present a range of possible adaptation measures addressing those climatic pressures and risks identified for the communication infrastructure (incl. energy supply) (cf. 1). The measures are grouped using categories based on the Impact Assessment accompanying the White Paper on Adaptation (COM 2009).

A. Technical measures

1 Upgrade communication infrastructure and use new products (moisture and heat resistant material, wind strength, backup options) to better meet the requirements and make the networks more robust in case of future climatic changes like temperature increase and heat waves, extreme rainfall/high intensity rainfall, storms, groundwater level increase, ice and snow cover(Telecom Group New Zealand[117]) *(cf. measure 3)*

2 Foresee backup options to secure electricity supply (Telecom Group New Zealand):

- Two backup generators per exchange,
- Batteries in exchanges/mobile sites,
- Mobile generators for mobile sites. *(cf. measure 3)*

B. Regulation and standards

3 Ensure infrastructure is resilient to potential increases in extreme weather events such as storms, floods and heat waves as well as extreme cold weather via integrating climate change effects into Eurocodes. These contain inter alia resistance against more severe storms (higher wind speeds need more stable and flexible constructions), higher temperatures and more extreme rainfall (heat and moisture resistant materials) which needs to be seen in relation to the energy sector that is the basis for all these Information and Communication Technology (ICT) services. *(cf. measures 1 and 2)*

4 Ensure that an asset is located, designed, built and operated with the current and future climate in mind, via a climate proof check, before permitting the infrastructure. Build in flexibility so infrastructure assets can be modified in the future without incurring excessive cost. (DEFRA 2011)

5 Ensure that maintenance regimes incorporate resilience to the impacts of climate change over an asset's lifetime (DEFRA 2011)

C. Capacity building

[116] http://www.defra.gov.uk/publications/files/climate-resilient-infrastructure-full.pdf.

[117] http://www.telecom.co.nz/content/0,8748,203940-203113,00.html.

6 Ensure that infrastructure organisations and professionals have the right skills and capacity to implement adaptation measures. During the education phase of employees, possible climate pressures need to be taught as a mandatory part of the education program.

D. Communication/Awareness raising

7 Ensure investment decisions take account of changing patterns of consumer demand as a result of climate change, especially insuring 24/7 operation of internet, telecommunication, etc..

8 Develop response and recovery strategies for possible future extreme weather events with other infrastructure providers. This includes review of the facility location, engagement in the review of design standards and constantly improve work practices (Telecom Group New Zealand)

E. Guidelines

9 Guidance that account for climate change impacts on utility rehabilitation, repair, or replacement decisions as well as on new materials that can better withstand temperature fluctuations and drier or wetter conditions (Climate Change Clearinghouse, Water Research Foundation[118])

10 Guidance on decentralized systems that give the ability to single out and manage individual zones of distribution during extreme events-related emergencies as a way of managing climate change impacts (Climate Change Clearinghouse, Water Research Foundation)

F. EU financing scheme

11 Integrate funding provisions to EU funding schemes (Structural Funds, Cohesion policy and European Territorial Cooperation), to develop new technologies to aid climate resilience, e.g. providing networks of sensors and other data points to provide information in relation to weather events, which support specific adaptation options mentioned under A to E for urban areas

12 Explore tax support mechanisms. Providing tax reductions for certain measures could trigger their uptake by the private sector (e.g. telecommunication companies, energy suppliers, internet companies, infrastructure provider, owner and maintenance)

13 Improve access to finance. In particular, partnerships between local authorities, funders, service providers and SMEs facilitate the bringing together of financial and non-financial instruments, to meet local needs. Packages may consist of grants; micro credit schemes; guarantee funds for sharing high risks; mezzanine funds, advice and training.

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118 http://www.theclimatechangeclearinghouse.org/ResearchByTheFoundation/InfrastructureAndClimateChange/default.aspx.

Cities can be important initiators in this field in coordination with regional and national financial initiatives (COM (2006), 385 final)

3. Exploration of adaptation options for the EU level

Under the current policy framework related to communication infrastructure (incl. energy supply) impacts of climate change remain predominantly within Member States, mostly at the regional and municipal (city) responsibility. The White Paper on Adaptation (COM 2009) only identifies urban areas as one of the most vulnerable regions in Europe. It does not define the role of the European Commission with regard to urban areas though.

Thus, we have explored possibilities for adjustments of existing policies for mainstreaming adaptation (cf. A). The suggestions take up the adaptation measures presented under section 2 in terms of options for corresponding policy actions (according references are given in brackets to most suggestions).

A. Suggestions for adjustments in existing policies

- **Common regulatory framework for electronic communications networks and services (2009/140/EC)[119]**

  No direct reference

Suggestion: Concrete formulation of integration of adaptation into Energy supply for communication infrastructure. This means to integrate backup options to secure electricity supply (e.g. decentralized), the usage of adequate materials, which are heat and moisture resistant. *(addresses measures 1, 2 and 13)*

- **COMMISSION RECOMMENDATION (2003): on the implementation and use of Eurocodes for construction works and structural construction products, C(2003) 4639), (2003/887/EC)**

Suggestion: Concrete formulation of integration of adaptation into Eurocodes for communication infrastructure. This means the usage of adequate materials, which are heat and moisture resistant. For example a must have of a backup option for electricity supply *(addresses measures 1, 2, 3, 4, 5 and 13)*

- **Communication "Cohesion policy and cities: the urban contribution to growth and jobs in the regions" (COM (2006) 385 final)**

Related to the previous point Making our cities attractive and sustainable:

p27: LIFE funds and the urban environment - The programme supports pilot projects in cities that develop new technologies, policy approaches, methods and instruments for urban environmental management, in line with the Thematic Strategy on the urban environment. For example, in 2005 LIFE supported Elefsina 2020, a project to regenerate this environmentally degraded port and city in Greece. LIFE+ has a total budget of €2 billion for the 2007-2013 period.

[119] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:337:0037:0069:EN:PDF.

Cohesion policy funding for urban areas - Between 2007 and 2013, around €30 billion will be spent on urban projects within region policy programmes. In addition to the policy's financing for infrastructure and people-based actions, the European Territorial Cooperation objective (formerly "INTERREG") can be used by cities to develop joint cross-border or transnational projects.

The Commission also provides special support for cities to work together through the URBACT programme, which is a European exchange and learning programme promoting sustainable urban development. In the current programming period URBACT offered financial support to 289 cities participating in 44 different projects. The programme enables cities to jointly develop solutions to major urban challenges, reaffirming the key role they play in facing increasingly complex societal changes.

Suggestion: Concrete formulation of adaptation needs of communication infrastructure into the future cohesion policy, which will be stronger focusing on the urban dimension. A check to climate proofing communication infrastructure shall be fulfilled before permitting the infrastructure. Additional renewals of communication infrastructures need to pass the climate proof check. This check shall be a prerequisite to receive funds of the Cohesion Fund (COM 2006). *(addresses measures 11 and 12)*

- **Communication "The Strategy on the Urban Environment" (COM (2005) 718 final)**

p8: Urban areas have an important role to play in both adapting to climate change and mitigating greenhouse gas emissions. Urban areas are vulnerable to the consequences of climate change such as flooding, heat waves, more frequent and severe water shortages. Integrated urban management plans should incorporate measures to limit environmental risk to enable urban areas to deal better with such changes.

Suggestion: Reference to integrated urban management plans: incorporate adaptation measures of communication infrastructure into the integrated urban management plans to ensure that climate change impacts are addressed European wide in cities and towns. *(addresses measures 3, 4, 6, 9 and 13)*

Human health and air quality

1. Impact Table:

Table 3-10: Impact table human health and air quality

The impact table provides a summary on future climatic pressures which may affect the human health and air quality negatively.

Type	Climatic pressures	Risk	Time frame of expected impact	Area mainly affected
Human health and air quality	Temperature increase, heat stress and heat island effect	Higher mortality - related deaths, especially elderly, infants, woman in the last trimester of pregnancy and people	Medium negative to extreme negative	2025: Southern, Eastern EU 2080: Northern EU, Southern, Eastern, Central

		with low income Impacts on health (vector born diseases) Worsening of air quality		EU
	------------- Water scarcity and drought	---------------------------- Waterborne diseases (decrease of water quality) Lack of water in quantity and quality, water supply, urban waste water treatment and water efficiency	---------------------- Medium negative to high negative	--------------- 2025: Southern, Eastern EU 2080: Northern EU, Southern, Eastern, Central EU

2. Exploration of possible adaptation measures

For the compilation of possible adaptation measures a comprehensive literature review was carried out (cf. reference list). The information was gathered from work done on Human Health and Air Quality including adaptation options (e.g. EuroHEAT[120], cCASHh Project[121], Aphekom project[122]) and from relevant research projects and policies focusing on adaptation related to human health and air quality. The literature on adaptation regarding human health and air quality includes a variety of options, while some act on a very generic level (e.g. inform the citizens about longer duration periods of flowering and pollen seasons for some grasses and weeds, strengthening the health system preparedness and response, changing infrastructure to reduce the extent of an urban heat island effect). Thus, based on expert judgment we present a range of possible adaptation measures addressing those climatic pressures and risks identified for human health and air quality (cf. 1) with a particular focus on urban areas. The measures are grouped using categories based on the Impact Assessment accompanying the White Paper on Adaptation (COM 2009).

A. Technical measures

1 Strengthen and implement early warning systems like Heat Health Warning System (HHWS) (e.g. HHWS[123] of EuroHEAT) to address heat waves and hot temperature events with the aim to reduce mortality (cCASHh Project) *(cf. measure 6)*

2 Spray roads and pavements with water for cooling purposes

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[120] http://www.euroheat-project.org/dwd/.

[121] http://ec.europa.eu/research/environment/pdf/env_health_projects/climate_change/cl-ccashh.pdf.

[122] http://www.aphekom.org/web/aphekom.org/home.

[123] http://euroheat-project.org/dwd/hhws.php.

3 Distribute free drinking water

4 Allow additional breaks for workers on open air

5 Provide alternative water supply options, e.g. desalination, wastewater re-use, ground-water recharge, and rainwater harvesting to cope with water shortages

B. Regulation and standards

6 Mandatory implementation of Heat Health Warning System and joint guidance to the general public via e.g. recommendations for public health response to heat-waves[124] and improved linkages between the weather services, the health authorities and other relevant authorities and media. *(cf. measure 1)*

C. Capacity building

7 Improve health information and knowledge for the development of environmental health information systems addressing e.g. urban air pollution (EU Health Programme) and reaction during heat-waves (e.g. Heat-waves: risks and responses, WHO, 2005[125])

8 Partnership work with local authorities to identify and focus on vulnerable urban areas and populations – for example, certain urban areas may be affected more by high temperatures (heatwave plan for England 2010[126])

D. Communication/Awareness raising

9 Monitoring and awareness raising/information of vector- and rodent-borne diseases, especially its diagnosis and treatment, vaccination, vector control, reservoir host control, information, health education and disease surveillance (cCASHh Project)

10 Prepare the population for earlier onset and possibly longer duration of flowering and pollen seasons for some grasses and weeds via media. Monitor and communicate the spread of particular plant species to new climatically suitable areas (cCASHh Project)

11 Foster modified mobility patterns in urban areas. Especially the reduction of PM (particulate matter) and partly noise (more activities during night times) is necessary, which is increasingly harming human health especially in combination with heat-waves (Aphekom Project)

E. Guidelines

[124] http://www.euro.who.int/__data/assets/pdf_file/0004/112882/E91347_Annex_heatwaves_info.pdf.

[125] http://www.euro.who.int/__data/assets/pdf_file/0008/96965/E82629.pdf.

[126] http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_116029.pdf.

12 Guidelines for appropriate responses to heat events (cCASHh Project) like keeping your home cool (increase external shading, electric fan, mobile evaporation coolers), keep out of the heat, keep your body cool and hydrated (Recommendations for public health response to heat-waves)

F. EU financing scheme

13 Strengthen effective surveillance and prevention programmes (e.g. the EU Health Programme[127])

14 Integrate funding provisions to EU funding schemes (Cohesion policy and EU Health Program), which support specific adaptation options mentioned under A to E for urban areas, including the integration of insurances that can provide a contribution to e.g. minimize economic losses of heat waves

15 Explore tax support mechanisms. Providing tax reductions for certain measures (e.g. tree planting) could trigger their uptake by the private sector (e.g. hospitals, health services, elderly care, old people's homes, land owners)

3. Exploration of adaptation options for the EU level

Under the current policy framework related to human health and air quality impacts of climate change remain predominantly within Member States, mostly at the regional and municipal (city) responsibility. The White Paper on Adaptation (COM 2009) only identifies urban areas as one of the most vulnerable regions in Europe and refers to health[128]. It does not define the role of the European Commission with regard to urban areas though.

Thus, we have explored possibilities for adjustments of existing policies for mainstreaming adaptation (cf. A). The suggestions take up the adaptation measures presented under section 2 in terms of options for corresponding policy actions (according references are given in brackets to most suggestions).

A. Suggestions for adjustments in existing policies

- **EU Floods Directive**

p1 (§4): Directive, does not take into account the future changes in the risk of flooding as a result of climate change

p2 (§14): The elements of flood risk management plans should be periodically reviewed and if necessary updated, taking into account the likely impacts of climate change on the occurrence of floods

p7 (Chapter VIII, Art. 14, §4): The likely impact of climate change on the occurrence of floods shall be taken into account in the reviews of the preliminary flood risk assessment (starting in Dec. 2018) as well as in the review of the flood risk management plan(s)

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[127] http://ec.europa.eu/eahc/.

[128] SEC(2009) 416 - http://ec.europa.eu/health/ph_threats/climate/docs/com_2009-147_en.pdf.

Suggestion: Reference to risk of flooding: could additionally request to address short and long-lasting health effects (e.g. infectious disease outbreaks) related to climate change into the review of flood risk management plans *(addresses measure 9)*

- **White paper (2007): Together for Health: A Strategic Approach for the EU 2008 – 2013 (COM (2007) 630 final)**

p9: Health aspects on adaptation to climate change

p3: Climate change is causing new communicable disease patterns. It is a core part of the Community's role in health to coordinate and respond rapidly to health threats globally and to enhance the EC's and third countries' capacities to do so.

p8: Action is also needed on emerging health threats such as those linked to climate change, to address its potential impact on public health and healthcare systems.

Suggestion: Reference to health aspects and threats: programs like the EU Health Programme and funded projects shall support efforts to adapt the public health sector as well as health care system to possible climate change impacts. Additionally, the private sector (e.g. private hospitals, private ambulances and health insurances) needs to share the knowledge and contribute to protects urban inhabitants *(addresses measures 3, 6, 7, 8, 9, 10, 11 and 15)*

- **Communication "The Strategy on the Urban Environment" (COM (2005) 718 final)**

p8: Urban areas have an important role to play in both adapting to climate change and mitigating greenhouse gas emissions. Urban areas are vulnerable to the consequences of climate change such as flooding, heat waves, more frequent and severe water shortages. Integrated urban management plans should incorporate measures to limit environmental risk to enable urban areas to deal better with such changes.

p9: Sustainable urban transport plans will help reduce air pollution and noise, and encourage cycling and walking, improving health and reducing obesity. Sustainable construction methods will help promote comfort, safety, accessibility and reduce health impacts from indoor and outdoor air pollution, notably particulate matter from heating systems.

Existing Air Quality legislation requires plans to be established when limit values are or might be exceeded. Those situations are experienced in many cities, particularly for particulate matter (PM10) pollution mainly emitted by road traffic and combustion plants.

Suggestion: Reference to sustainable urban transport plans: incorporate adaptation measures into these plans and reducing traffic exposure for urban populations.

Reference to air quality: air quality plan and short term action plan need to be continuously revised, especially in urban areas where exposure levels can induce harmful effects on human health, based on the additional impacts of a changing climate *(addresses measures 7, 11, 13 and 14)*

- **Communication "Cohesion policy and cities: the urban contribution to growth and jobs in the regions" (COM (2006) 385 final)**

Related to the previous point Making our cities attractive and sustainable:

p27: LIFE funds and the urban environment - The programme supports pilot projects in cities that develop new technologies, policy approaches, methods and instruments for urban environmental management, in line with the Thematic Strategy on the urban environment. For example, in 2005 LIFE supported Elefsina 2020, a project to regenerate this environmentally degraded port and city in Greece. LIFE+ has a total budget of €2 billion for the 2007-2013 period.

Cohesion policy funding for urban areas - Between 2007 and 2013, around €30 billion will be spent on urban projects within region policy programmes. In addition to the policy's financing for infrastructure and people-based actions, the European Territorial Cooperation objective (formerly "INTERREG") can be used by cities to develop joint cross-border or transnational projects.

The Commission also provides special support for cities to work together through the URBACT programme, which is a European exchange and learning programme promoting sustainable urban development. In the current programming period URBACT offered financial support to 289 cities participating in 44 different projects. The programme enables cities to jointly develop solutions to major urban challenges, reaffirming the key role they play in facing increasingly complex societal changes.

Suggestion: Concrete formulation of adaptation needs into the future cohesion policy, which will be stronger focusing on the urban dimension. The Cohesion fund shall offer financial support for the implementation of Heat Health Warning System or health information systems. *(addresses measures 1, 6, 7, 9, 14 and 15)*

In case further policy initiatives are taken on the below mentioned Green Paper, the following suggestion can be given:

- **Green paper – Towards a new culture for urban mobility (SEC (2007 1209) and Communication "Action plan on urban mobility" (SEC (2009 1211/1212)**

p8: environmental conditions are still not satisfactory: local authorities are facing serious problems to meet the requirements on air quality, such as the limits of particulates and nitrogen oxides in ambient air. These have a negative impact on public health.

p15: Health care for the elderly can become more difficult to organise if the transport solutions are not right (on top of "social isolation"). Customised solutions could serve better suburban areas, such as transport on demand or transport services that interlink the usually radial and city-centre oriented connections.

Suggestion: Reference to urban mobility: programs and projects shall include elements of adapting the current and future transport modes to a changing climate and promote an integral approach linking energy and climate change with transport, recent project outcomes of the Aphekom project state urban population is very vulnerable due to polluted air, especially in relation to heat-waves *(addresses measure 11)*

[*Comment: Suggestions only relevant if a White Paper is foreseen*]

Urban transport

1. Impact Table:

Table 3-11: Impact table urban transport

The impact table provides a summary on future climatic pressures which may affect urban transport negatively.

Type	Climatic pressures	Risk	Time frame of expected impact	Area mainly affected
Urban Transport (road infrastructure, bike lanes, walkways, rail infrastructure, waterways, public and private transport)	Temperature increase and heat waves	Increase of the heat island effect (e.g. melting asphalt, increased asphalt rutting due to material constraints, thermal expansion on bridge expansion joints and paved surfaces, and damage to bridge structure material)	Medium negative to extreme negative	2025: Southern, Eastern EU 2080: Northern, Southern, Eastern, Central EU
	Heavy precipitation events (extreme flash floods)	Damage to infrastructure due to flooding, property at risk due to location, heavy water run-off	Medium negative (2025;2080) to high negative (2080)	2025: Southern, Western 2080: Eastern, Southern, Northern, Western, Central
	Sea level rise and storm surage flooding	Risk of inundation of road infrastructure and flooding of underground tunnels, degradation of the road surface and base layers from salt penetration	Medium negative to extreme negative	2025: Southern, Western, Northern EU 2080: Southern, Western, Northern EU
	Extreme storms, strong winds	Damages, increase of maintenance cost	Small to medium impacts	European wide

2. Exploration of possible adaptation measures

For the compilation of possible adaptation measures a comprehensive literature review was carried out (cf. reference list). The information was gathered from work done on Urban Transport including adaptation options (e.g. GRaBS project[129]) and from relevant research projects and policies focusing on adaptation related to urban transport. The literature on adaptation regarding urban transport includes a variety of options, while some act on a very generic level related to road infrastructure (e.g. asphalt roadway composed of light-colored aggregate; porous asphalt), related to urban street design (e.g. green infrastructure network for walking and cycling) and public transport (e.g. controlled air-cooling systems, better windows, white roofs, insulated roofs and side panels, controlled heating systems). Thus, based on expert judgment we present a range of possible adaptation measures addressing those climatic pressures and risks identified for urban transport (cf. 1). The measures are grouped using categories based on the Impact Assessment accompanying the White Paper on Adaptation (COM 2009).

A. Technical measures

1. Compose asphalt roadway of light-colored aggregate and/or binder producing high solar reflectance index (SRI) values in order to reduce the heat it generates (grabs project) and plant roadside vegetation to decrease the exposure of roads to heat *(cf. measure 10)*
2. Use porous asphalt, which is standard asphalt concrete mixed without fine particles and with low binder content to leave space for water to drain through to an open-graded stone bed to reduce run-off into the sewer system and the likelihood of puddles or slick or icy surface conditions (*GRaBS* project) *(cf. measure 10)*
3. Link road infrastructure with other transportation modes and add alternative paths (parallel structures) to enhance resilience (Taylor 2011) and link to the green infrastructure network, which is a set of connected green spaces (*GRaBS* project[130])
4. Install air conditioning and cooling systems through retrofitting in urban tramways and metros (sustainable cooling schemes for the London underground and railway network [131]) and reduce the temperatures of buses (e.g. controlled air-cooling systems, better windows, white roofs, insulated roofs and side panels, controlled heating systems)
5. Intensify maintenance of relevant waterways and assess the likeliness of constraints on urban waterway usage and plan for alternatives

B. Regulation and standards

6. Explore more resilient design standards (Eurocodes), urban drainage and materials for infrastructure construction; may be needed to withstand higher temperatures and expected increase in rainfall intensity *(cf. measures 1 and 2)*

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[129] http://www.grabs-eu.org/downloads/PGS_Transport%20FINAL.pdf.

[130] http://www.grabs-eu.org/membersArea/files/Database_Final_no_hyperlinks.pdf.

[131] http://www.cibse.org/pdfs/Cooling.pdf.

7 Minimise the need for road infrastructure through compact urban planning and provide sufficient redundancy to allow for alternative ways of passage, when obstruction occurs

8 Develop joint adaptation action plans in vulnerable urban areas (risk mapping) with clearly assigned responsibilities for all participating parties (*GRaBS project)*

C. Capacity building

9 Inform that transport planning and operations need to take current and future climatic changes into account. This means that new tools, such as regional climate scenarios, vulnerability and risk assessments need to be integrated

D. Communication/Awareness raising

10 Develop recommendations to urban transport, which provides scope for a rational use of private cars (Europe at a crossroads – The need for sustainable transport)

E. Guidelines

11 Develop Practitioners' guides for climate proofing for transport planning

F. EU financing scheme

12 Integrate funding provisions to EU funding schemes (Cohesion policy and co-funded infrastructures in urban areas), which support specific adaptation options mentioned under A to E for urban transport

13 Explore tax support mechanisms. Providing tax reductions for certain measures (e.g. air conditioning and cooling systems in urban tramways and metros) could trigger their uptake by the private sector

3. Exploration of adaptation options for the EU level

Under the current policy framework related to urban transport impacts of climate change remain predominantly within Member States, mostly at the regional and municipal (city) responsibility. The White Paper on Adaptation (COM 2009) only identifies urban areas as one of the most vulnerable regions in Europe and refers to transport, but not specifically to urban transport. It does not define the role of the European Commission with regard to urban areas though.

Thus, we have explored possibilities for adjustments of existing policies for mainstreaming adaptation (cf. A). The suggestions take up the adaptation measures presented under section 2 in terms of options for corresponding policy actions (according references are given in brackets to most suggestions).

A. Suggestions for adjustments in existing policies

- **Communication "The Strategy on the Urban Environment" (COM (2005) 718 final)**

p8: Urban areas have an important role to play in both adapting to climate change and mitigating greenhouse gas emissions. Urban areas are vulnerable to the consequences of *climate change such as flooding, heat waves, more frequent and severe water shortages. Integrated urban management plans should incorporate measures to limit environmental risk to enable urban areas to deal better with such changes.*

p9: Sustainable urban transport plans will help reduce air pollution and noise, and encourage cycling and walking, improving health and reducing obesity. Sustainable construction methods will help promote comfort, safety, accessibility and reduce health impacts from indoor and outdoor air pollution, notably particulate matter from heating systems.

Existing Air Quality legislation requires plans to be established when limit values are or might be exceeded. Those situations are experienced in many cities, particularly for particulate matter (PM10) pollution mainly emitted by road traffic and combustion plants.

Suggestion: Reference to sustainable urban transport plans: incorporate adaptation measures into these plans and reduce traffic exposure for urban populations.

Reference to integrated urban management plans: incorporate adaptation measures into the integrated urban management plans to ensure that climate change impacts are addressed European wide in cities and towns. *(addresses measures 3, 9, 10, 11 and 12)*

- **Communication "Cohesion policy and cities: the urban contribution to growth and jobs in the regions" (COM (2006) 385 final)**

Related to the previous point Making our cities attractive and sustainable:

p27: LIFE funds and the urban environment - The programme supports pilot projects in cities that develop new technologies, policy approaches, methods and instruments for urban environmental management, in line with the Thematic Strategy on the urban environment. For example, in 2005 LIFE supported Elefsina 2020, a project to regenerate this environmentally degraded port and city in Greece. LIFE+ has a total budget of €2 billion for the 2007-2013 period.

Cohesion policy funding for urban areas - Between 2007 and 2013, around €30 billion will be spent on urban projects within region policy programmes. In addition to the policy's financing for infrastructure and people-based actions, the European Territorial Cooperation objective (formerly "INTERREG") can be used by cities to develop joint cross-border or transnational projects.

The Commission also provides special support for cities to work together through the URBACT programme, which is a European exchange and learning programme promoting sustainable urban development. In the current programming period URBACT offered financial support to 289 cities participating in 44 different projects. The programme enables cities to jointly develop solutions to major urban challenges, reaffirming the key role they play in facing increasingly complex societal changes.

Suggestion: Concrete formulation of adaptation needs into the future cohesion policy, which will be stronger focusing on the urban dimension. The Cohesion fund shall offer financial support for adapting the urban transport systems to climate change impacts. *(addresses measures 1, 2, 3)*

In case further policy initiatives are taken on the below mentioned Green Paper, the following suggestion can be given:

- **Green paper – Towards a new culture for urban mobility (SEC (2007 1209) and Communication "Action plan on urban mobility" (SEC (2009 1211/1212)**

p8: environmental conditions are still not satisfactory: local authorities are facing serious problems to meet the requirements on air quality, such as the limits of particulates and nitrogen oxides in ambient air. These have a negative impact on public health.

p15: Health care for the elderly can become more difficult to organise if the transport solutions are not right (on top of "social isolation"). Customised solutions could serve better suburban areas, such as transport on demand or transport services that interlink the usually radial and city-centre oriented connections.

Suggestion: Reference to urban mobility: programs and projects shall include elements of adapting the current and future transport modes to a changing climate and promote an integral approach linking energy and climate change with transport *(addresses measures 3, 6, 7, 8, 9, 10, 11 and 12)*

[*Comment: Suggestions only relevant if a White Paper is foreseen*]

3.4 Agriculture - Rural Development Programs and adaptation

Please note: This paper is prepared based on the current programming period as the text for the next period are not ready yet. If these become available, more concrete actions can be proposed.

Climatic changes will have complex effects on the bio-physical processes that underpin agricultural systems, with both negative and positive consequences in different EU regions. Rising atmospheric CO_2 concentration, higher temperatures, changes in annual and seasonal precipitation patterns and in the frequency of extreme events will affect the volume, quality and stability of food production and the natural environment in which agriculture takes place. Climatic variations will have consequences for the availability of water resources, pests and diseases and soils, leading to significant changes in the conditions for agriculture and livestock production[132].

Projected climatic developments may affect the achievement of CAP objectives of ensuring availability of sufficient food at reasonable and stable prices, contributing to the viability of farming and rural areas, and promoting environmentally-friendly farming practices. The future Rural Development programs could play an important role to prepare and to transform the agricultural sector towards these adaptation needs.

The following sections analyse the current EU legal framework on Rural Development and outline the changes needed in order to streamline adaptation efforts into this policy area more concretely.

3.4.1 Next Rural Development Programmes

The Commission Communication on the CAP towards 2020 outlines three potential axes around which support measures might be structured:

- the competitiveness of agriculture: by promoting innovation and restructuring and by enabling the farm sector to become more resource efficient;
- the sustainable management of natural resources, by taking care of the environment and agriculture's resilience to climate change and the countryside, and maintaining the production capacity of the land;
- the balanced territorial development of rural areas throughout the EU by empowering people in local areas, building capacity and improving local conditions and links between rural and urban areas.

Adaptation to climate change could be added as a specific issue for the next programming period as part of the Axis “competitiveness of agriculture” or Axis “the sustainable management of natural resources”.

3.4.2 Community strategic guidelines

Within the framework of the objectives established in Rural Development Regulation EC No. 1698/2005, the strategic guidelines set out below identify priorities for the Community in accordance with Article 9 thereof. The guidelines aim at the integration of major policy priorities as spelt out in the conclusions of the Lisbon and Göteborg European Councils. For each set of priorities, illustrative key actions are presented. On the basis of these strategic guidelines, each Member State has prepared its national strategy plan as the reference framework for the preparation of Rural Development Programmes.

It is assumed that the next RD period will follow a similar approach, which would allow to clearly address adaptation and to present illustrative key actions such as support for technological improvements or payments for green infrastructure.

3.4.3 National strategy plans – the basis for national/region programmes

Under Article 11 RDR Member States have to develop national strategic plans which (beside others) shall ensure that Community aid for rural development is consistent with the Community strategic guidelines and that Community, national and regional priorities all coordinate.

If such an approach will also be applied in the next programming period the national plans should be linked to the national/regional adaptation strategies (if available or made mandatory). In particular, national/regional adaptation strategies could take up measures funded under the RD to trigger mainstreaming adaptation and ensure consistency with national plans for the agricultural sector. If no such national/region adaptation strategies exist, MS should be directed to take climate change adaptation into account in the context of developing national strategy plans for the agricultural sector.

3.4.4 The SWOT assessment as an entry point

Currently when developing the RDP each MS has to prepare an assessment of Strengths, Weaknesses, Opportunities and Threats (SWOT) on various aspects to be addressed in the RD (Art 16 RDR). The issue of adaptation to climate change is currently not required mandatory to be considered in the SWOT assessment (CC mitigation is more often addressed in combination with air pollution)[133]. Examples of such an adaptation assessment have been found in FI, DE-NRW and RO. It has to be acknowledged, that several RDP are referring to increased flooding in relation to climate change and the need that the agricultural sector needs to adapt to such a situation

Box 1: Example of an assessment of adaptation needs in relation to Climate change under the SWOT assessment

Impacts of the climate change on agriculture (FI)

The climate change is expected to change agricultural activity. Rising temperatures and increased precipitation may change the nutrient economy and structure of the soil. As the temperature and humidity increase, the decomposition of organic matter speeds up. The risk of erosion and of the release and leaching of nutrients increases. A shorter period of frost in the ground may increase the compaction of the clay soil which is particularly common in southern Finland, and hinder cultivation. Global warming may increase the drought and heat stress of plants during the growing period and the overwintering of plants in southern Finland may be reduced, as the snow cover becomes thinner.

Pest insects benefit from a warmer climate and a longer growing period. The risk of plant disease epidemics particularly various fungi and moulds, as well as potato blight, may increase. Also the number of weeds may rise. The boundary of the area suitable for crop farming may move towards the north. The quality of cereal grassland and root plant crops may drop because of precipitation in the harvest time, resulting in the ear sprouting and lodging of crops. Stagnant water in arable land may bring problems in threshing. Horticulture is expected to significantly benefit from the climate change.

The pasture season may become longer. This would improve animal welfare, if outdoor grazing were increased, but increased grazing might increase the loading of watercourses. The risk of animal diseases might rise.

Climate change is estimated to have an impact on biodiversity, as well. Global warming will mostly affect species that are able to migrate quickly. In Finland, changes have already been detected in areas of distribution e.g. for many butterfly species. Areas of distribution for many species that have until now been found in southern Finland are expanding towards the north and north-east. If the temperature continues to rise strongly enough, some species in northern Finland will inevitably decline as suitable habitats are reduced, and some species are in danger of disappearing altogether. Northern ecosystems are less varied in their biodiversity and species than many southern areas. They are less adaptable and simpler in their structure and diversity, with a smaller buffering capacity than southern ecosystems and

[133] Based on a rough screening of the RD programmes of AT, SE, PO, EE, FI, SE, PT, DE (partly), UK-SCT, RO.

their variety of species. The harsh climate also affects their adaptability, making them vulnerable to irregular variations in natural phenomena and to changes in species. The ability of ecosystems and species to adapt to climate change can be promoted, for example, by maintaining and restoring original diverse habitats.

It is necessary to support the adoption of new technologies and cultivation methods and the diversification of agriculture. To control the agricultural load to watercourses in changing circumstances, water protection methods should be assessed in terms of increased nutrient leaching and measures should be taken to prevent pests and plant diseases. The maintenance of the general growing condition of arable land is particularly important as the climate changes. The negative impacts of the climate change on the soil can be reduced by developing cultivation methods; for example, the leaching of nutrients from the soil can be prevented by the cultivation of perennial plants, the plant cover of arable land in winter and catch plants, and riparian zones. Soil structure can be improved by ploughing straw in the soil, by reducing tilling and by direct sowing.

Assuming that such a SWOT assessment will also be required under the next programming period the efforts taken by MS for developing the issue of CC adaption in the national strategy plans should be taken further. MS should be required to carry out a "simplified" vulnerability assessment that highlights areas or agricultural subsectors where most action is needed. Such a "simplified" vulnerability assessment could at least contain information on potential impacts and the related costs, current adaptation efforts and potential costs for adaptation ahead. The results should (as for other issues) feed into the design of the detailed measures.

3.4.5 Adaptation measures that could be included under the current RD period

The Commission Working Document "Adapting to climate change: the challenge for European agriculture and rural areas"[134] outlines the following adaptation measures on the farm level:

1. Adjusting the timing of farm operations, such as planting or sowing dates and treatments;
2. Technical solutions, such as protecting orchards from frost damage or improving ventilation and cooling systems in animal shelters;
3. Choosing crops and varieties better adapted to the expected length of the growing season and water availability, and more resistant to new conditions of temperature and humidity;
4. Adapting crops with the help of existing genetic diversity and new possibilities offered by biotechnology;
5. Improving the effectiveness of pest and disease control through for instance better monitoring, diversified crop rotations, or integrated pest management methods;

[134] See http://ec.europa.eu/agriculture/climate_change/workdoc2009_en.pdf.

6. Using water more efficiently by reducing water losses, improving irrigation practices, and recycling or storing water;
7. Improving soil management by increasing water retention to conserve soil moisture, and landscape management, such as maintaining landscape features providing shelter to livestock;
8. Introducing more heat-tolerant livestock breeds and adapting diet patterns of animals under heat stress conditions.
9. Building adaptive capacity by awareness raising and provision of salient information and advice on farm management,

The current CAP has already included some of these measures (Measures number 2, 6, 7, 9). Nevertheless the current RD measures allows including a much wider set of measures that facilitate adaptation to climate change. Some of these measures are already applied in some MS, but could clearly expanded (see table 12 below).

The design of measures will need to consider possible interactions between adaptation and mitigation operations and ensure that trade-offs and synergies (which will be regionally specific) are considered.

Table 3-12: RD Measures and the current use of adaptation measures

RD-CODE	RD-MEASURE	Measure that could be included [135]	Current use of adaptation measures[136]	
	Rural Development Axis I		Number MS	Measures
111	Vocational training and information actions (Art. 21)	- Training and use of farm advisory services in relation to climate change	All	- training and dissemination support to the agriculture and forestry sector in relation to water management, biodiversity and adaptation to climate change (19)
114	Use of advisory services (Art. 24)	- Training and use of farm advisory services in relation to climate change	7 countries	- - provide advisory services to farmers and foresters in order to enhance agricultural sustainability (2) - provision of advisory services to increase awareness about the implementation of agri-environmental measures (1) - advisory services for sustainable woodlands (1)
115	Setting up management, relief and advisory services (Art. 25)	- supports farmers in making environmental changes	3 countries	- investments in agricultural buildings for the construction of supporting structures for perennial crops (1) - supports farmers in making environmental changes (1)
121	Modernisation of agricultural holdings (Art. 26)	- Preventive mechanisms against adverse effects of climate-related extreme events (e.g. setting up	All but Portugal	- water saving technologies (e.g. efficient irrigation systems) (11)

[135] Please note that the list of possible adaptation measures will be updated in the next version of the document.

[136] A screening exercise has been undertaken at Member State level to identify how the issue of climate change is being tackled in the RDPs. See http://enrd.ec.europa.eu/rural-development-policy/climate-change-country-profiles/en/climate-change-country-profiles_home.cfm

		of hail nets) - Water saving technologies (e.g. efficient irrigation systems) - Water storage (including water overflow areas) - Water saving production techniques (e.g. adapted cropping patterns, irrigation practices) - Installations for waste water treatment on farms and in processing and marketing - Investments for on-farm diversification and diversification into non agricultural activities - Adaptation of agricultural infrastructures such as buildings (e.g. ventilation systems in livestock buildings) - Installations and equipment for manure management and treatment of manure waste		- installations for waste water treatment on farms and in processing and marketing (6) - water storage (including water overflow areas) (5) - water saving production techniques (e.g. adapted cropping patterns, irrigation practices) (6) - adaptation of agricultural infrastructures such as buildings (e.g. ventilation systems in livestock buildings) (8) - preventive mechanisms against adverse effects of climate-related extreme events (e.g. setting up of hail nets) (5) - manure storage and treatment (2) - promoting the establishment of young farmers and make farms profitable and modern (1) - rehabilitation of natural features (1) -- improvement of energy efficiency (1) - improve animal rearing conditions (1) - animal welfare (1) - infrastructure for bee-keeping and honey production (1) - support for energy crops, RE (1) - investment support related to dairy production (1)
123	Adding value to agricultural and forestry products (Article 20(b)(iii) and Article 28)	- Diversification of productions - Water saving technologies (e.g. efficient irrigation systems)	5 countries	- installations for waste water treatment on farms and in processing and marketing (2)

		- Water storage (including water overflow areas) - Water saving production techniques (e.g. adapted cropping patterns, irrigation practices) - Installations for waste water treatment on farms and in processing and marketing		- water saving technologies (e.g. efficient irrigation systems) (1) - water saving production techniques (e.g. adapted cropping patterns, irrigation practices) (1) - improving the dairy sector (1) - improvement of cattle rearing conditions and welfare (1)
124	Cooperation for development of new products-processes-technologies (Article 20(b)(iv) and Article 29)	- Development of new technologies, products and processes that support adaptation objectives	2 countries	- cooperation for development of new products, processes and technologies in the agriculture and food sector and in the forestry sector (2)
125	Infrastructure related to the development and adaptation of agriculture and forestry (Art. 30)	- Land improvement - Energy supply - Water saving technologies (e.g. efficient irrigation systems) - Water storage (including water overflow areas) - Water saving production techniques (e.g. adapted cropping patterns, irrigation practices) - Installations for waste water treatment on farms and in processing and marketing	15 countries	- water saving technologies (e.g. efficient irrigation systems) (12) - water storage (including water overflow areas) (9) - construction, reconstruction and upgrading of drainage infrastructures (6) - installations for waste water treatment on farms and in processing and marketing (4) - water saving production techniques (e.g. adapted cropping patterns, irrigation practices) (2) - infrastructure works on the irrigation network (1) - construction and modernisation of water inflow and outflow facilities (1) - improved protection against floods (1) - additional support for procuring water retention equipment; counter-

				acting soil dehydration, and; the "re-naturalisation" of peats and water courses development of irrigated land (1) - sustainability of public irrigated plots (1) - modernisation of traditional collective irrigated plots (1) - development and beneficiation of collective irrigated plots systems (1)
126	Natural disaster & prevention actions (Art. 20 b ((vi))	- Flood prevention and management measures (e.g. projects related to coastal and interior flood protection, introduction of flood-tolerant crops for watershed management) - Restoration of perennial crops damaged by weather extreme events - Restoration of agricultural land and soil quality after storm or flooding	4 countries	- investment regarding the reestablishment/restoration of fixed capital, including on-farm plantations, greenhouses and infrastructures (3) - restoration of agricultural land and soil quality after storm or flooding (1) - re-establishment or restoration of dykes (1)
	Rural Development Axis II			
211 212	Natural handicap payments in mountain areas and payments in other areas with handicaps (Art. 37)	- Support for areas with natural handicaps in mountain areas and other areas	3 countries	- support for areas with natural handicaps in mountain areas and other areas (2) - support of management in mountain areas and areas with natural handicaps (3) - meet cross compliance standards (1)
213	NATURA 2000 payments and payments linked to the WFD (Art. 38)	- Sustainable use of agricultural land including the exclusion of fertiliser use	3 countries	- supporting agricultural producers, disadvantaged as a result of the implementation of EU directives on the protection of birds, flora and fauna, so they can continue with sustainable land practices (1)

			- provide payments to overcome problems of Natura 2000 requirements linked to prohibited use of fertilisers and pesticides, as well as seeking to improve water quality and biodiversity (1)
214	Agri-environmental payments (Art. 39)	- Water saving technologies (e.g. efficient irrigation systems) - Water storage (including water overflow areas) - Water saving production techniques (e.g. adapted cropping patterns, irrigation practices) - Installations for waste water treatment on farms and in processing and marketing - Soil management practices, tillage methods, diversified crop rotations and patterns, catch crops - Planting of hedgerows; reintroducing/maintaining terraces - Organic farming - Integrated pest management - Conservation of genetic resources - Conversion of arable lands to permanent pastures - Permanent grassland with low inputs - Improved manure management - Support for the management of wetlands - Ditch management - Management of field corners - Wild bird seed mixture - 12m buffer strips for water courses on cultivated land - 4m buffer strips on intensive grassland -- Stonewall protection and maintenance	- preservation of habitats and biodiversity (16) - conservation of genetic resources (12) - integrated pest management (11) - restoration/management/protection of wetlands (9) - organic farming (6) - planting of hedgerows; reintroducing/maintaining terraces (4) - management of natural grasslands (e.g. late mowing and extensive grazing) (4) - water saving techniques (3) - soil management practices, tillage methods, diversified crop rotations, catch crops (3) - improvement of animal rearing conditions (2) - establishment of riparian margins (2) - extensification of livestock and pastures (2) - water storage (2) - establishment of semi-natural water bodies (1) - planting of trees to protect crops from wind (1)

		- Earth bank management - Earth bank restoration -		- conversion of arable land into a variety of grasslands (1) - provision of alternative water sources for bovines aim to promote water quality (1) - support for providing a healthy forage area for bees (1) - provide rules governing water management in relation to drainage, digging, quality and creating dams etc. (1)
215	Animal welfare payments (Article 36(a)(v) and Article 40)	- Improvement of animal rearing conditions adapted to climate change	1 country	- decreasing stocking density and providing outdoor access where possible (1) - improving housing and feeding conditions for cows (1) - preventing diseases and parasite infections (1) - applying better hygiene and feeding standards (1) - promoting high quality production (1)
216	Non-productive investments (Art. 41)	- Soil management practices, tillage methods, diversified crop rotations and patterns, catch crops - Planting of hedgerows; reintroducing/maintaining terraces - Conversion of arable lands to permanent pastures - Restoration of dykes - Establishment of wetlands	7 countries	- establishment of wetlands (2) - wetland restoration (2) - restoration of dykes (1) - periodical flooding of farmland (1) - specific nature conservation projects - restoration of natural hydrological conditions e.g. wet meadows (1) - restoration of hedgerows and terraces that have been destroyed/damaged by forest fires or

				floods (1) - fencing on grasslands (1) - providing instruments made from natural materials for the protection of birds (1) - establishing winter refuges for insects (1) - construction of preventive dry walls (1) - investments that tackle water conservation, droughts and dehydrated soils including in nature reserves and designated areas (1) - conversion of agricultural land into swamps (1) - establishment of sediment ponds (1) - controlled drainage (1) - boundary features (1) - tree planting (1) - land use change (1)
221	First afforestation of agricultural land (Art. 43)	- Afforestation	3 countries	- establishment of forests and their maintenance (1) - investments for forest infrastructure to reduce soil erosion, establish reservoirs, drain harmful waters and construct exploration roads (1)
222	First establishment of agroforestry systems on agricultural land (Art. 44)	- Establishment of agro-forestry systems	2 countries	- establishment of agro-forestry systems in agricultural land and corresponding infrastructures (1)
223	First afforestation of non-agricultural land (Art. 45)	- Afforestation	2 countries	- establishment of forests and their maintenance (2) - improve the water balance in the

				supported afforested and neighbouring areas (1)
224	Natura 2000 payments (Art. 46)		1 country	- support will be granted to overcome the disadvantages associated with the Natura 2000 directive namely the prohibition of tree felling, using fertilisers and intervening in the forest coppice (1)
225	Forest-environment payments (Art. 47)	- Conversion to more resistant forest stand type	4 countries	- supports actions for protection against adverse weather conditions such as frost and strong winds (1) - conserve/reconstitute habitats (1) - preserve biodiversity and rare or threatened animal/plant species (1) - conversion to more resistant forest stand types (1)
226	Restoring forestry potential and introducing prevention actions (Art. 48)	- Prevention actions against forest fires and climate-related natural disasters	10 countries	- introduction of forest fire prevention/fight measures (construction of roads, fire breaks, water points…) (9) - restoration of forestry potential in the areas affected by fire and/or natural disasters (5) - fighting erosion and desertification from natural catastrophes such as forest fires and floods (4) - diversification of vegetation structure by transforming coniferous plantations into broadleaved or mixed stands (1) - preventive flood control operations (1) - elimination of damage caused by flooding to small watercourses and in

				their catchments basins, on forest roads and associated facilities (1) - stabilisation of ravines on land designed for forest functions (1)
227	Non-productive investments (Art. 49)	- creation and recovery of open spaces in forests (clearings) - elimination of undesirable or intrusive plant species - investments for providing information on the use of forests and other non-productive investments - Conversion to more resistant forest stand type	6 countries	- hydro-forest restoration (2) - (introduction e.g. drought tolerant species or broadleaves under coniferous stand, improving forest edges to create better microclimate and biodiversity etc…) - creation and recovery of open spaces in forests (clearings), elimination of undesirable or intrusive plant species (1) - investments for providing information on the use of forests (1) - restoration of green cover and activities of re-plantation (1) - construction of structures like ditches, fences, bays, etc (1) - restoration of forest lanes (1)
	Rural Development Axis III			
311	Diversification (Article 52(a)(i) and Article 53)	- Investments for on-farm diversification and diversification into non agricultural activities		
312	Business creation and development (Article 52(a)(ii) and Article 54)			
313	Tourism activities (Article 52(a)(iii) and Article 55)	- Investments for on-farm diversification and diversification into non agricultural activities		
321	Basic services (Article 52(b)(i) and Article 56)	- Construction/reconstruction/ rehabilitation of the water supply system and related facilities	2 countries	- construction/reconstruction/rehabilitation of the water supply system and related facilities (1)

				- basic water management infrastructure development including water network distribution and sewerage systems and waste water treatment plants (1)
322	Village renewal and development (Article 52(b)(ii))			
323	Conservation and upgrading of the rural heritage (Art. 57)	- development of management plans for Natura 2000 sites and other places of a high nature value - environmental awareness actions - restoring and upgrading cultural heritage		
331	Training and information (Article 52(c) and Article 58)			
341	Skills acquisition and animation (Art. 59)	Training of staff involved in the preparation and implementation of a local development strategy (that could include adaptation actions)		

4 Costing of future key measures

4.1 Energy

4.1.1 Introduction, key impacts and key adaptation options

This paper addresses the question of adaptation costs for the European electricity sector, facing the threats and opportunities of climate change. It pursues the aim of defining the costs for adaptation in the energy sector by transferring regional, national and local case study results to the European level.

The main impacts in the European energy sector are the following:

- Cooling water constraints for thermal power generation (especially during heat waves)
- Decreased transmission capacity due to higher temperatures and heat waves
- Damage to offshore or coastal production facilities due to sea level rise and storm surges
- Damage to transmission and distribution lines due to storm events, flooding
- Unpredictable hydropower potential
- Affected yield in renewable energy sector (hydropower in Southern Europe, possibly biofuels due to vector diseases and forest fires)
- Melting permafrost affecting energy production and distribution in cold climates
- Damages and output constraints in wind energy due to storms and increased average wind speed

In order to reduce these negative climate impacts, the energy sector has to adapt to new climatic conditions. This report investigates and quantifies the costs of this adaptation in Europe. It analyses in depth only some key options identified by chapter 3 which are named in Table 4.1:

Table 4-1: Proposed adaptation options by chapter 3 and respective chapters and notes regarding the cost analysis

Adaptation measure proposed by Chapter 3	Cost estimate in this report	Notes
Demand side: Set standards for energy efficiency of air conditioning devices	Chapter 4.1.5	Due to data availability, only industrial ventilator devices could be analysed.
Supply side: Adjustment of thermal power plants to dealing with water shortages; alternative cooling cycles and technologies	Chapter 4.1.4	
Supply side: Protection measures for thermal power plants (in particular nuclear) against coastal storm surges and flooding	Chapter 4.1.4.4 for extreme weather warning systems and chapter 4.5 for vulnerability of coastal nuclear plants	Costs of protection measures against coastal storm surges could not be assessed due to data availability.
Transmission and distribution: Investment and additional maintenance costs due to storm exposure, higher vegetation and additional cooling demand	Chapter 4.1.3	With differentiation between distribution and transmission networks.

4.1.2 Literature Review

In chapter 4 a more comprehensive literature review on the adaptation costs has been performed. The objective was to identify studies which may give valuable input for a European cost estimate, to define cost drivers and cost structures, and to get an overview of possible adaptation measures. The findings of the review are summarized in the Excel file accompanying this document, named “Adaptation Costs Energy Literature Review”.

In the review, 35 studies have been analyzed. 11 studies are covering only the demand side of energy market, hence the autonomous adaptation of altered energy consumption. These studies are shaded grey in the spreadsheet. Of the remaining 24 studies, 12 do not indicate costs in a quantitative manner. However, they could be used to identify cost drivers and possible adaptation measures.

Regarding main cost drivers, the intensity of climate change is obviously an important parameter. More interesting is the finding that additional maintenance costs for overhead lines in forest areas are higher than in the fields or road sites. Also cooling degree days were seen as important for the costs of network adaptation. Hence, these cost drivers were included in the cost transfer exercise. Closeness to coasts was not mentioned in the bottom-up studies as an adaptation cost driver for networks, although it is an important factor for damage costs in the sector. By that link closeness to coasts also influences adaptation costs, but the effect is hard to assess quantitatively. The present study concentrates on cost drivers that directly affect adaptation costs.

4.1.3 Adaptation costs in the electricity infrastructure

4.1.3.1 Definition of concrete measures and costs to be transferred

The development of the European energy networks is one of the main objectives of EU structural and cohesion funds. Within these networks, at least in Europe electricity grids play the major role. Oil and gas pipelines are also endangered by climate change and also have to be adapted to new climatic conditions; however the bulk of adaptation investment in European energy networks is expected to occur for enhancing the electricity network (ENA 2009). This is also one reason why research has focused on these networks and the data availability is much better.

Adaptation of electricity networks includes strengthening of pylons and lines, the relocation of lines, more frequent and intense maintenance, laying underground cables, and to some extent also building new lines in order to meet additional demand for cooling purpose[137] (e.g. ENA 2009, Martikainen et al. 2007, Swedish Government 2007, National Grids 2010). However, in the available literature, there are mainly cost indications for additional maintenance costs, investment costs for securing networks against storms and additional investment costs for new lines due to additional demand. Lying underground cables and cable coating are often named as adaptation measures, but costs are very uncertain as the actual amount of expected adaptation is hard to foresee. It is widely agreed that these technical adaptation measures are mainly possible for lower voltage, local networks.

To date, additional investments in power networks due to new cooling demand is only mentioned in quantitative manner for Australia. There this kind of adaptation makes more than half of total adaptation costs. Though, conclusions for adaptation in Europe are not directly possible. The European Network of Transmission System Operators for Electricity (ENTSO-E) does not mention this aspect in its 10 Year Network Development Plan (ENTSO-E 2010b). It may be expected that in Europe this effect is heavily overlaid with additional network capacity demand due to renewable energy increase and the resulting connection line needs in the European grid. Moreover, currently only Greece, Italy, Cyprus and Malta have their electricity demand peak in summer. All other countries would be able to meet the additional cooling demand (partly) by their existing capacities, hence additional grid capacity needs are reduced or non-existent. Due to the expectedly low relevance for Europe and the insufficient data situation (e.g. there is no regional or national study on grid capacity needs by additional cooling demand) we ignore this aspect of adaptation and focus on strengthening networks from adverse direct climate effects.

The data is relatively more reliable for additional maintenance costs due to higher vegetation growth (clearing and trimming of trees close to the overhead lines) and investments for strengthening pylons and lines against storm damage.

Thus, the costs that will be estimated for the European Union are

[137] In Europe the latter effect is probably heavily overlaid by additional network capacity demand due to renewable energy increase and the resulting connection line needs in the grid. However, one can also justify new lines by adaptation because redundancy in the power transmission system decreases the risk of a weather-induced outage. How much redundancy is needed to adapt to the expected climate change in Europe has never been quantified in the literature, thus we limit our analysis to new power lines due to cooling demand.

- annual investment costs for securing local distribution networks and national transmission networks from storm damage,
- additional annual maintenance costs of existing transmission and distribution networks due to higher vegetation, and
- annual investment costs for additional networks (transmission and distribution) due to cooling demand.

The data basis is very limited for most of these costs. Often, the estimate relies on actually just one source and is transferred to another context (see chapter 4.1.3.2). However, we consider this exercise as the first attempt to derive adaptation costs in the European electricity network from bottom up. As literature on this topic grows, more reliable estimates will become possible in the coming years.

In the results section costs for adapting local distribution grids and national transmission grids are differentiated. In the sense of cost definitions in the Inception report, these costs are direct costs. They accrue mainly to the network operator, and can generally be passed-through to the client (see section 4.0).

4.1.3.2 Cost transfer

The cost transfer exercise is made transparent in the Excel file "Adaptation Cost Energy Infrastructure.xls" accompanying this paper. In the central sheet, named "Cost estimates NUTS2 regions", the estimated adaptation costs in terms of maintenance and investment costs are indicated for 270 NUTS2-level regions and three member countries[138] and for the total EU except for Malta. For Malta, no consistent grid length data was available, so it was left out of the analysis. The actual analysis was done in this sheet, hence mainly on NUTS2-level. The results, however, are summarized on country-level in the sheet "Summary on country-level". Similarly, also in this report only results on country-level are presented, although they stem from a more disaggregated analysis. The detailed procedure will be presented in the following.

Extraction of relevant estimates from literature review

The first step of the cost transfer is the elicitation of relevant, quantitative, and transferable adaptation cost information in all the analyzed studies. This is done in the sheet "Cost information". Some of the cost information refers to one-off investments, and some to annual expenditure. If possible, they are transferred to €/yr/km in this step. It became clear that different sources give a very high range of different estimates of maintenance and investment costs.

The European studies mainly cover Northern countries. The Finnish study indicates maintenance costs for distribution networks. The authors differentiate two climate change scenarios ("smallest change prediction" and "biggest change prediction") but provide identical maintenance costs for each scenario. They also differentiate by four Finnish regions but again derive identical costs of climate change adaptation. However, the Finnish study gives a flavor of how a forest surrounding influences additional maintenance costs (Cost information

[138] For Bulgaria, Romania and Cyprus NUTS2-level data was not available in the Eurostat sources.

No. 10 and 12). In Australia, additional maintenance costs in the distribution networks are of the same order of magnitude (No. 24). The Swedish publication studies transmission networks and provides a rough range of additional maintenance costs in Sweden (No. 16). The lower limit of this range is confirmed by another rough guess referring to the Finish network (No. 26) and the information from Australia (No. 25). We used the lower and upper limit of Cost information No. 16 for two temperature change scenarios under consideration, namely A1FI and B1. The underlying assumption is that the uncertainty of the Swedish estimates originated, inter alia from climate change uncertainty. Unfortunately the authors state neither the underlying climate scenarios nor the sources of the uncertainty range.

Regarding investment costs for securing networks from storm damage, the estimates rely on cost information derived from the French transmission network (Cost information No. 27) and the Swedish distribution network (No. 15). Both sources indicate costs of securing networks from additional storm damage without referring to a certain climate scenario or expected storm intensities. The order of magnitude of both cost information is comparable, with higher costs per km for the French transmission network than for the Swedish distribution network. The Swedish study is the only publication that gives a cost estimate for moving overhead lines to underground. This information has been used for the estimation of investment costs for securing local networks from wind felling. We highlight that this information could not be sufficiently verified with other sources.[139] By the same time it is crucial for total adaptation costs, as these investment costs make a large part of total costs.

For a note on the dependency of adaptation costs on climate scenarios, see “Important assumptions resulting from the methodology and data availability”.

Investments in securing networks from storm damage

Transmission networks

The basis of these cost estimates are the following data:

- $L_{Tcountry}$: Length of transmission lines in country *i* in km (Source: ENTSO-E 2010a).
- a_i : Total area of region *i* in km².
- $a_{country}$: Total area of country *i* in km²
- L_{Ti} : Length of transmission lines in region *i* in km. It was estimated by the formula $L_{Ti} = L_{Tcountry} * a_i / a_{country}$. This assumes that the transmission network is equally distributed over the total area of each country.
- SI_i : Change in storm intensity in region *i* by 2080, mean of three storm scenarios basing on SRES scenario A1B (Source: Rademaekers et al. 2011). This value is not available for each country, but for four large regions in Europe.

[139] There is more information available for costs of underground cables per km, but it is not known how much of the European networks will be laid underground. The Swedish study estimates costs for securing all “endangered” parts of the total network.

- CI_{27}: Cost information No. 27 (Source: RTE 2010). Costs for securing one km of transmission line from storm damage in France.

For each EU member state *i* the costs of strengthening transmission networks from storm damage is calculated by the formula:

$$C_{TISi} = L_{Ti} * SI_i / SI_{France} * (CI_{27(\max)} + CI_{27(\min)}) / 2$$

Distribution networks

Data of distribution network length is not available for all EU member states. We gathered distribution network data of ten countries (Austria, Finland, France, UK, Greece, Italy, Luxemburg, The Netherlands, Slovenia, and Sweden). Basing on these available data, we derived an approximate ratio of overhead distribution network over total transmission network length of 15. Although a usage of national distribution grid data for these ten countries would be possible, we prefer a Europe-wide parameter as too many countries provide no national data on their distribution network. Using national data for some countries and a derived network length for others would infer the consistency within the dataset.

The relevant parameters for estimating costs for securing distribution networks from storm damage are the following (additional to parameters already mentioned before):

- R : Ratio of overhead distribution network length over transmission network length (may be defined in excel sheet, available data suggest a value of around 10)
- $L_{Dcountry}$: Length of distribution lines in country *i* in km. It is derived by the formula $L_{Dcountry} = L_{Tcountry} * R$
- a_{RSi} : Residential and Service area in region *i*
- $a_{RScountry}$: Residential and Service area in country *i*
- L_{Di} : Length of distribution lines in region *i* in km. It is derived by the formula $L_{Di} = L_{Dcountry} * a_{RSi} / a_{RScountry}$. This implies that the distribution network is spread over the regions of a country according to the spread of residential and service areas.
- $l_{DFFinland}$: Ratio of distribution lines going through forests in Finland (=0.5) (Source Kirkinen et al. 2005)
- f_i : Ratio of total area covered by forests in region *i* (Source Eurostat)
- l_{DFi} : Ratio of distribution lines going through forests in region *i* (derived by $f_i * l_{DFFinland} / f_{Finland}$)[140]

[140] The correction factor is determined by available data from Finland (Kirkinen et al. 2005, p. 22). There the information is given that 50 % of power lines are within forests. Combining this information with the Finnish forest ratio yields the correction factor which is then used for all the other countries. For Sweden, this procedure

- CI_{15}: Cost information No. 15 (Source Swedish Government 2007). Costs for securing endangered Swedish local grids from wind-felling.

For each region *i* the costs of strengthening distribution networks from storm damage is then calculated by the formula:

$$C_{DISi} = L_{Di} * l_{DFi} * SI_i / SI_{Sweden} * (CI_{15(\max)} + CI_{15(\min)}) / 2$$

Additional maintenance

Additional maintenance costs for electricity networks arise if higher vegetation and higher storm intensities pose a higher risk to power lines, as trees may fall on the lines. These costs are considerably lower than new investment costs, but may be substantial in total.

Transmission networks

In addition to already mentioned parameters, the following data are relevant for transferring cost estimates:

- T_{Si}: Annual mean temperature change in country *i* 2080s compared to 1961/1990 in the SRES scenario *S* (Source: Tyndall Centre for Climate Change Research). The two scenarios under consideration are the IPCC scenario A1FI and B1. Raw data are available for four climate models (CGCM2, CSIRO mk 2, DOE PCM, HadCM3). We have used the mean of these four climate model outcomes.

- CI_{16}: Cost information No. 16 (Source Swedish Government 2007). Rough guess of additional maintenance costs for the transmission network. The order of magnitude is confirmed by other sources (Cost information No. 26 for Finland and No. 25 for Australia).

The additional maintenance costs in region *i* for the transmission networks are derived by the formula:

$$C_{TMi} = L_{Ti} * T_{Si} / T_{SSweden} * (CI_{16(\max)} + CI_{16(\min)}) / 2$$

Distribution networks

For additional maintenance costs for distribution networks Martikainen et al. 2007 indicates differentiated costs per km in forests and in other landscape types. We also make use of this differentiation and estimate maintenance costs in forests and outside forests separately:

Maintenance costs in forests

The only additional parameter needed for this cost transfer is

- CI_{10}: Cost information No. 10 (Source: Martikainen et al. 2007). Additional annual maintenance costs in forests in Finland.

The additional maintenance costs in region *i* for the distribution networks in forests are derived by the formula:

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yields a value of around 0.5, which is in line with available literature. Information for other countries for testing this approach would be desirable, but were not available.

$$C_{DFMi} = L_{Di} * l_{DFi} * T_{Si} / T_{SFinland} * CI_{10}$$

Maintenance costs in other landscape types

The only additional parameter needed for this cost transfer is

- CI_{12}: Cost information No. 12 (Source: Martikainen et al. 2007). Additional annual maintenance costs outside forests in Finland.

The additional maintenance costs in region *i* for the distribution networks outside forests are derived by the formula:

$$C_{DNFMi} = L_{Di} * (1 - l_{DFi}) * T_{Si} / T_{SFinland} * CI_{12}$$

Important assumptions resulting from the methodology and data availability

For calculating the additional maintenance and investment costs in each member state, different assumptions and limitations had to be made:

- Apart from effects by altered storm intensity, temperature change, forest density and cooling demand, the adaptation costs per km circuit length and per year are equal throughout Europe.

- As no data about the length of local distribution networks was available on the European level, the analysis has to rely on assumptions regarding the length of local networks. This assumption is based upon data from five countries (Finland, France, Sweden, The Netherlands, and Italy).

- The actual adaptation costs obviously depend on the magnitude of climate change. For example, different climate scenarios such as the IPCC SRES scenarios would imply different adaptation costs. However, this important relation could not be illustrated in this report, due to a too scarce literature base. E.g., the costs for securing transmission lines from storm damage rely on one single cost estimate for the French network (CI_{27}). This source does not indicate a climate scenario or any assumption about climatic developments it is based upon. Hence, the derived adaptation costs for Europe could also not be connected to a specific climate scenario (in other words, a sensitivity analysis is not possible). This obvious weakness of the analysis is caused by literature scarcity and could be improved in coming years as the literature body (in particular regional and national case studies) on these issues is growing.

- Grid data are only available on member state level, not on a regional level. Regional grid data have been estimated by the use of area data and land use data.

- In average, different kinds of power lines (in terms of voltage capacity) have the same vulnerabilities and adaptation costs. There is only a difference between transmission and distribution networks.

- The length of underground cables in the transmission grid is assumed to be zero.

4.1.3.3 Results: Costs of adapting electricity grids in the EU

In the following the results of the adaptation cost transfer exercise are presented. They are also visible, for each member state and for the total EU26 (without Malta) in the accompanying Excel file (sheet "cost estimates").

The total costs for adapting the electricity transmission network to the effects of climate change comprise investments costs for securing networks from storm damage, additional maintenance costs, and additional investment costs due to higher cooling energy demand. Except for the latter, they can be differentiated between transmission and distribution grids. Inter alia, they depend on the assumption regarding new investment share (see section 4.1.3.4). Table 4.2 gives an overview of the cost transfer results for different assumptions.

Table 4-2: Results of the cost transfer exercise on EU level

Adaptation costs for electricity grids in Europe (million € p.a.)	Scenario A1FI	Scenario B1
Investment costs for securing networks from storm damage (transmission)	190.3	
Investment costs for securing networks from storm damage (distribution)	368.8	
Additional maintenance costs (transmission)	32.4	15.7
Additional maintenance costs (distribution)	62.6	61.8
Total costs without new network investments (transmission)	222.7	206.0
Total costs without new network investments (distribution)	431.4	430.6
Total costs for adaptation of infrastructure (investment and maintenance)	654.1	636.6

Table 4.3 shows the shares of some EU member states (the ten states with the largest transmission network), according to the A1FI scenario.

Table 4-3: Shares of EU member states (10 states with the largest electricity network) of EU-wide adaptation costs for energy infrastructure (in %). Underlying scenario: A1FI.

Country	Transmission circuit length (in km)	Share of total EU costs
France	47,820	12.6
Germany	35,761	13.2
Spain	35,068	11.9
Italy	22,044	7.2
Greece	16,168	5.7
Sweden	15,340	8.3
Finland	14,339	8.1
Poland	13,307	5.1
UK	12,034	2.1
Romania	8,991	3.0
Rest	61,017	22.9
Total EU26	281,889	100.0

The cost estimates presented in 4.3 may be considered as unexpectedly low, particularly compared to top-down studies for adaptation of the European energy infrastructure. Table 4.4 gives an overview about some recent top-down studies which publish findings on adaptation costs in the European energy sector.

Table 4-4: Overview of top-down studies on adaptation costs in the energy sector in Europe and their results.

Study	Regional coverage	Notes	Estimated annual adaptation costs
Bosello et al. 2009	„Western Europe“	Integrated assessment model AD-WITCH – adaptation costs in terms of additional cooling expenditure minus reduced heating expenditure	-8.8 billion USD (i.e. positive net effect)
ADAM 2009 (Jochem and Schade 2009)	EU27 plus Norway and Switzerland	Energy demand changes	-6.9 to -27.6 billion € (i.e. positive net effect)
		Additional cooling investments	4.3 to 8.4 billion €
		Additional cooling technique investments for thermal power generation	1 billion € in 2050
World Bank 2009	Eastern Europe and FSU	Only adaptation of power and wire infrastructure, using rough cost estimates – for the total World Bank Region including former Soviet Union. Only minor areas of the region are part of the EU.	600 million USD in prices of 2005 by 2050
Rademaekers et al. 2011	EU27	Stakeholder interviews, asking for expected damage per impact category (including adaptation costs and residual damages)	4.4 billion € in 2080

However, a comparison of the bottom-up-based estimates in **Fehler! Verweisquelle konnte nicht gefunden werden.** is not directly possible, since the regional coverage and the assumed adaptation measures differ starkly. E.g., the top-down studies often focus on changes in the expenditures for energy consumption, whereas our cost transfer exercise bases on adaptation costs for transmission and distribution. Only the studies World Bank 2009 and Rademaekers et al. 2011 analyze adaptation of electricity grids. The comparison with World Bank 2009 is hampered by the different region under investigation. In Rademaekers et al. 2011, adaptation costs and damage costs cannot be distinguished from each other (personal communication with authors). The cost estimates in **Fehler! Verweisquelle konnte nicht gefunden werden.** do not include any residual impacts, like failure costs, compensations, repair costs and reconstructions after damages. This definitely hampers a meaningful comparison with the Rademaekers et al study.

The difference in cost definitions may explain part of the huge difference that arises between the estimates. However, the cost transfer results are still unexpectedly low and the difference cannot be explained by differences in assumptions and design of the studies alone. A possible conclusion is that existing bottom-up case studies underestimate (or top-down studies overestimate) adaptation costs. Another possibility is that the transfer of bottom-up estimates as such is not reliable. We want to highlight that our cost transfer exercise is based on a very limited range of sources, due to a lack of data and literature on the topic of adaptation costs for electricity grids. However, to our knowledge, this report is the first attempt of systematically combining various bottom-up studies to yield a purely bottom-up-based cost estimate for adaptation in Europe. The methodology of the cost transfer can definitely gain from better data availability and a denser literature base, referring to many different contexts. At least the latter can be expected for the near future.

4.1.3.4 Cost sharing

After the insight into adaptation costs it is of interest which economic actor has to bear these costs. The measures that have been analyzed in the preceding chapters are clearly measures that have to be initiated and pursued by the network operators. These companies, however, do not act in an unregulated, free market. Thus, the cost sharing depends also on the regulation of the power transmission and distribution sector.

This business has always been regulated in some way due to network externalities. In the EU member states, the regulation itself is currently characterized by two slightly different strategies. In both alternatives the network is operated by a transmission system operator (TSO), which is separated from the generating companies (legally, by management or by ownership). Either the TSOs are private companies, regulated by a governmental authority (e.g. the Federal Network Agency in Germany), which sets price ceilings or return-on-investment ceilings. Moreover, TSOs are legally committed to secure an enduring energy supply. In the other alternative TSOs are publicly owned companies, as it is the case in most EU member states. In both cases TSOs should charge prices that ensure a cost-effective operation of the network, without any cross-subsidies. That means if budgetary costs rise due to adaptation of energy networks by state-owned TSOs, these costs should be reflected by higher transmission fees ultimately charged from the consumer. So finally, from an economic point of view the end consumers will be affected and not the public purse, regardless of the ownership structure of the TSO.

For other adaptation measures mentioned in the literature review (e.g. smart grids, risk assessment studies, flood protection), adaptation costs are more likely to accrue partly to the governments. This fiscal engagement is rationalized e.g. by public good properties of flood protection and of basic research. The estimation of these costs borne by the public actors, however, goes beyond the scope of this report.

4.1.4 Adaptation costs in the thermal power generation

4.1.4.1 Definition of concrete measures and costs to be analysed

For adaptation costs within power generation, there is less literature available. Currently the findings are mostly quite rough top-down estimates which are not a good input for a cost transfer of bottom-up results (e.g. ADAM 2009, Förster and Lilliestam 2009). There is no bottom-up study known to the authors which determines the concrete amount of adaptation in terms of investment and maintenance costs for a certain country or region. Hence, a comprehensive cost transfer exercise as in section 4.1.3.2 for electricity infrastructure was not feasible. But, in order to provide some plausible magnitude of expected adaptation costs, we refer to available cost information of industrial producers of cooling techniques and early warning systems for floods and make an attempt to scale up these unit costs according to the power generation structure and vulnerability patterns in Europe. This procedure could be applied for the following adaptation costs:

- Additional costs for cooling of nuclear, coal-fired and gas-fired power plants, by employing more advanced techniques than once-through cooling (by far the alternative with the highest water needs). These advanced techniques may be cooling towers (a form of recirculation cooling) hybrid or dry cooling.

- Investment and maintenance costs of early warning systems for floods.

4.1.4.2 Investment costs of alternative cooling systems

All data and calculations presented in this section are available in the accompanying Excel file “Adaptation Costs Energy Cooling.xlsx”. Parameters may also be changed in this file in order to conduct sensitivity analyses.

Vulnerability and adaptation of thermal power generation in Europe

The first step of a cost analysis in the topic of thermal power generation is the collection of data concerning the vulnerability of thermal power generation. The Excel file which accompanies this section contains data from different sources about electricity generation (Eurostat, World Nuclear Association, ENTSO-E, own calculations) and changes of relevant climate parameters per country (from the ESPON project). The aim is to yield a plausible magnitude of additional (or alternative) cooling capacities which may be installed due to climate change. In section 4.1.6, these estimations will be combined with available cost information from section 4.1.5 in order to derive adaptation costs per country in section 4.1.4.3.

The data show that in the EU27 more than 55 % of total power generation is produced by conventional (i.e. non-nuclear) thermal power. In 2007, a total of 1867 GWh was generated by coal, oil, gas, and other thermal power plants. The total number of thermal power plants in Europe amounts to approximately 4900, with an average capacity of 87 MW. It is assumed that these production units need sufficient cooling, either by wet cooling systems, hybrid or dry cooling systems.

The present shares of different cooling systems stem from 2005 data for coal-fired and nuclear power plants in the US, expert estimations and the database “Global Energy Observatory”. For oil-fired plants, sufficient cooling system data were not available. For nuclear power plants, cooling tower and dual systems can be regarded as a form of adaptation to limited cooling water availability. In the case of dual systems the traditional water cooling is supplemented by cooling tower systems which can also work under higher ambient temperatures. In the US, currently a share of 42% of all nuclear power units (reactors) uses one of these systems. In the EU, only 24 of 142 Nuclear power units are not equipped with a cooling tower and are not located at the sea (own research). NPPs which are located at the sea presumably do not need additional cooling techniques, as the cooling water from the sea is expected to be sufficient also under climate change conditions (Lenz, personal communication). Additional detailed information about current shares of cooling technologies is given in the Excel file (sheet “Cost information”), as they vary considerably within Europe.

Unit costs of alternative cooling systems

As for many cost data, it is difficult to obtain reliable and generalizable cost information for cooling systems which also work under higher ambient temperatures.

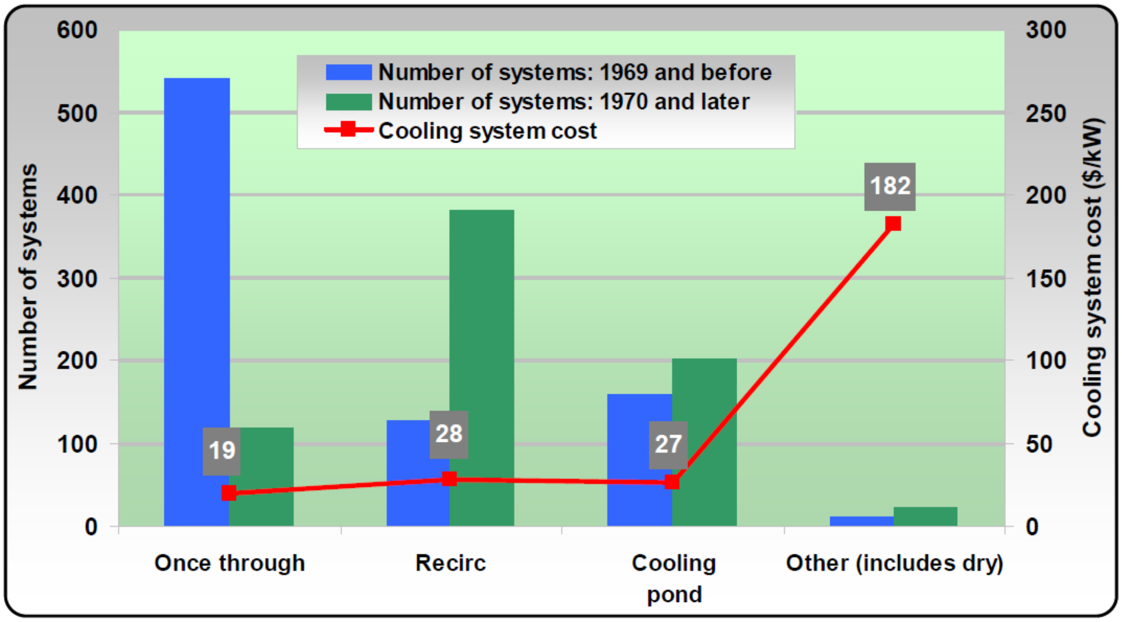
In general terms, the costs of alternative cooling systems can be divided into three main categories: First, the capital costs of the technical equipment, second the annual operation and maintenance costs, and third the so-called energy penalty, i.e. recurring costs of cooler system-induced efficiency losses in energy generation (Micheletti and Burns 2002). This source unfortunately does not indicate concrete costs.

Förster and Lilliestam (2009) mention that cooling towers are widely accepted as an alternative cooling system to an once-through cooling for nuclear plants. Regarding the costs, they state that using existing cooling towers implies efficiency losses which are lower than the losses from the alternative – a decline of production. According to the authors, the concrete costs of retrofitting plants by cooling towers are difficult to estimate and plant-specific analyses are needed.

This is also the main message of experts which were contacted to get verifiable cost estimates for Europe. None of the contacted stakeholders (in total six large companies and two apex associations) was able or willing to indicate average or illustrative cost estimations in quantified manner. Mostly they stated that the costs depend on the specific site, ground, water availability and costs, water and air regulations, distances between the single components of the system, size of the plant, type of plant, bargaining power of the respective companies, climate etc. Indicating averages or even broad ranges of unit costs would simply be “unsound”, according to one expert. He stated that each number which is cited in the literature and in discussions can be correct – regardless which number it is (Lenz). Another expert indicated an order of main cooling techniques, from the most costly to the one with the lowest costs: dry cooling by air condensers– groundwater pumping – wet cooling tower – cooling pond – river or sea once-through cooling. The cost factor between the lowest and highest cost alternative is around 20, according to this expert (Merkel, personal communication).

Nevertheless, for the US average estimates in monetary terms exist. A frequently cited source is a study of the US Department of Energy (DoE and NETL 2009). Here the reported cooling system costs of thermal power plants from the US are summarized in one single graph. The data suggest that recirculation cooling systems (of which cooling towers are a form) are around 40% costlier than once-through cooling systems, and dry coolers are by far the most expensive technique (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). The database for dry cooling however is very small so that the indicated costs are subject to a high degree of uncertainty. Moreover, it is unclear whether the numbers contain capital, maintenance or both kinds of costs.

Figure 4-1: Average total cost and number of cooling systems by type.



Source: DoE and NETL, 2009.

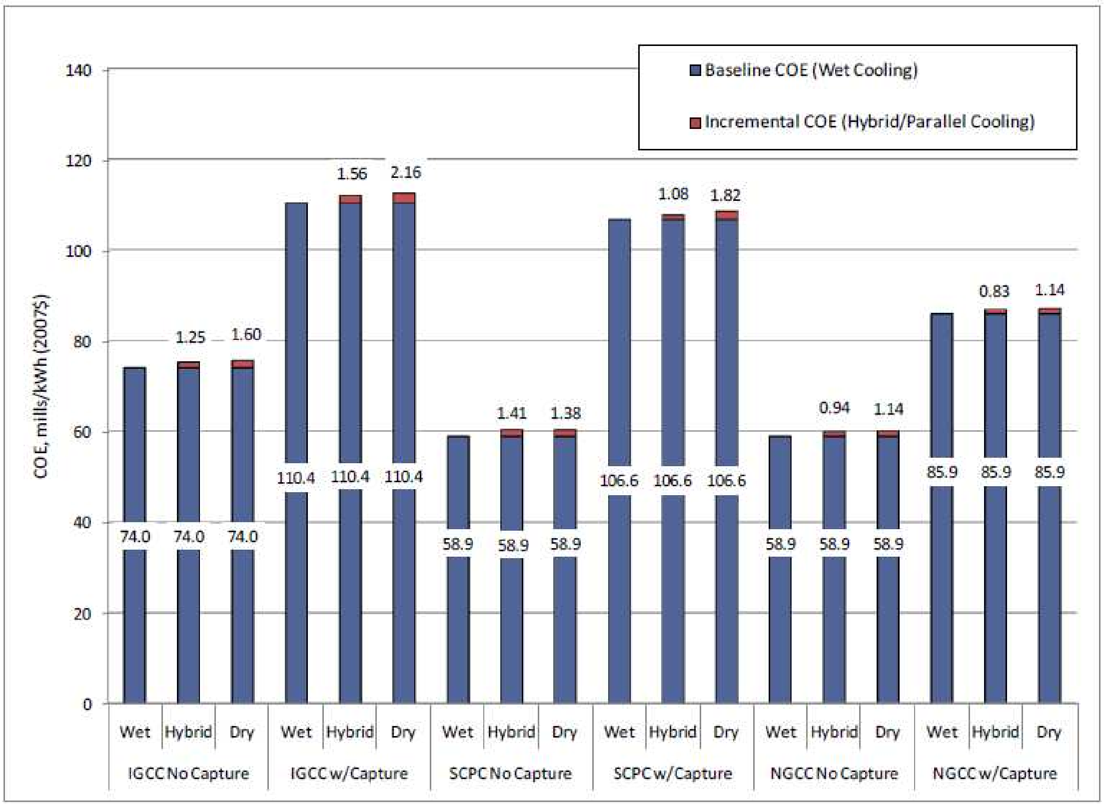
Complementary to the numbers of DoE and NETL (2009) we use several plant-specific cost studies in order to obtain unit costs of recirculation cooling systems. These sources are by definition highly context-specific, which may hamper a useful transfer to other power plants. At most, they may be understood as an empirical kind of cross-check of the numbers of DoE and NETL (2009). One of these studies is Tetra Tech (2002), which focuses on a nuclear power plant with two reactor units in California. Here the costs of a recirculation system with a cooling tower are estimated. They are in the same magnitude as suggested by the data of DoE and NETL (2009) (annual costs of 31 $ per installed kW, see sheet "Cost information" in the accompanying Excel file). Transferred to €, the costs are almost exactly the same due to exchange rate fluctuations (22 € per installed kW in both sources). However, as one source does not indicate whether the costs are annual or one-time costs and the other source is highly dependent on case-specific conditions in terms of costs for lying idle, we could not use these unit costs for the cost estimation.

However, Tetra Tech (2002) is a part of a broader study (Tetra Tech 2008), which examines costs of cooling towers for all Californian coastal power plants. To our knowledge, this is the most comprehensive and detailed cost study focusing on recirculation cooling. Two nuclear plants and 16 plants fired by natural gas are examined. This study indicates fuel-dependent average costs for enhancing the existing once-through cooling systems by recirculation systems with cooling towers in terms of $/MWh generated. These unit costs are the basis for the cost estimation of water cooling towers for thermal power plants in section 0. Unfortunately no feasible data for coal-fired plants were available, so we assumed the same value as for gas-fired plants.

There is another recent study of EPRI (2011), which estimates US-wide costs for retrofitting all once-through cooled thermal power plants by cooling towers. These costs, when transferred to unit costs per installed MW, are considerably lower than the unit costs suggested by Tetra Tech (2008) – they amount to roughly the half. As in this analysis the higher end of possible adaptation costs should be illustrated, we restrict the cost estimation to values of Tetra Tech (2008).

As for dry cooling techniques, we prefer the estimates of NETL (2010) instead of recurring to the small database of DoE and NETL (2009). Here the concept of "Costs of electricity" is used which includes capital, maintenance and operational and other costs in one single cost number per generated kWh. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows a comparison of costs of electricity for different plant types with and without carbon capture and storage technology. In terms of costs per installed kW, these estimated are around 50% of the costs presented **Fehler! Verweisquelle konnte nicht gefunden werden.**. For the estimation of dry cooling costs in the EU, we mainly recur to these costs as they seem to be the best grounded and most comprehensive data source available today.

Figure 4-2: Costs of electricity for wet, hybrid and dry cooling systems, in tenths of $-cents per kWh (mills/kWh)[141].



Source: NETL 2010.

Another study for performance and costs of alternative cooling systems is Zhai and Rubin (2010). The authors use a technical and economic model in order to quantify plant-level costs of wet recirculation cooling tower systems and dry air condenser cooling systems for a coal-fired plant. The sensitivity analyses are particularly interesting. Whereas ambient air temperatures do have an effect on the cooling costs in the case of dry coolers, this

141 Meaning of abbreviations: IGCC Integrated Gasification Combined Cycle; SCPC Supercritical Pulverized Coal; NGCC Natural Gas Combined Cycle.

parameter is of minor relevance for the costs of wet cooling tower systems. For both systems, the net plant efficiency is a key variable for the costs of the cooling system. With regard to cooling costs, the model outcomes of Zhai and Rubin (2010) are around three times higher than the data from NETL (2010).

In the case of geothermal generation, there exists a case study for a small specific power plant in Nevada, US (capacity of 1 MW, Kutscher Costenaro, 2002). Due to the low relevance of geothermal power production in the EU and questionable transferability to Europe, we did not use their results in the cost analysis.

Methodology of estimating cooling costs in Europe

Costs of additional wet cooling towers instead of once-through cooling

Nuclear power plants

For the estimation of the annual costs for additional water cooling towers for NPPs, the following data and parameters are of interest:

NO_i Number of inland nuclear power plants without cooling tower in country i

nc_1 Share of inland NPPs which needs to be equipped with a cooling tower in the country with the most severe climatic change

CC_i Index of climatic change in country i, derived from the change of annual number of summer days and the change of mean precipitation in summer months[142]

CC_j Index of climatic change in the country with the most severe climatic change, derived from the change of annual number of summer days and the change of mean precipitation in summer months

In the first step, the number of NPPs which are in need of a cooling tower and so far are not adequately equipped is estimated per country. The formula behind the values is the following:

$$NC_i = NO_i * (CC_i / CC_j) * nc_1$$

This implies that the country with the most severe climatic change (in terms of summer days increase and precipitation decline) needs to equip all (if $nc_1 = 1$) inland NPPs with a cooling tower which do not have one so far. All other countries need to adapt their NPP fleet proportionally to their change in climatic conditions. If a country takes the minimum value of both climate parameters, it implicitly means that this country does not adapt at all. Indeed this is the case for Finland.

The second step implements the unit costs of a water cooling tower. In the literature they are given in the format $ per installed kW, so the following data and parameters are of relevance for estimating the costs, additionally to the ones already described:

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[142] The climate change index is constructed in the accompanying Excel file in the sheet “Countries CC”. It uses country-wise climate projections of annual number of summer days and change of mean precipitation in the months June, July and August. The projections base upon the climate model CLM and the SRES scenario A1B and refer to changes between the periods 2071/2100 and 1961/1990. The authors suggest to use a weight of 0.8 for precipitation change and 0.2 for change of summer days.

K_{cN} Annual costs of a cooling tower in a nuclear power plant in € per generated MWh

P_{Ni} Total generation of the nuclear power plant fleet in country i in TWh

N_i Number of nuclear power units (reactors) in country i

p_{Ni} Average generation of a typical NPP in country i in TWh, derived by P_{Ni} / N_i

With these parameters, the additional annual costs of cooling towers for nuclear power plants in country i are roughly estimated by the formula:

$$AC_{Ni} = NC_i * p_{Ni} * K_{cN} * 10^6$$

Obviously, this calculation is highly dependent on the calibration of parameter values. In particular, the key parameters K_{cN} and nc_1 are difficult to validate empirically or theoretically. For the results presented in section 4.1.4.3, the following parameter values have been used. They have been selected according to various literature sources, but some of them are still very uncertain. Unfortunately, also the contacted experts were not able or willing to give an informed guess of these parameters.

Table 4-5: Values of parameters for the calculation of additional cooling costs for nuclear power plants.

Parameter	Value	Notes
nc_1	1	In the country most affected, all inland NPPs need to be equipped with cooling towers. Assumption by authors.
K_{cN}	8 €/MWh	According to Tetra Tech (2008).

Fossil thermal power plants

For non-nuclear thermal power plants, the procedure of estimating cooling tower costs is very similar to nuclear power plants. New sources of uncertainty, however, are the current stock of cooling techniques and the expected share of generation equipped with recirculation systems (in most cases cooling towers) after climate change. As for unit costs of a cooling tower system, we refer to data of Tetra Tech (2008) for gas-fired plants, due to data scarcity.

Regarding the current stock of cooling towers, we have to rely on the database "Global Energy Observatory[143] (GEO - many EU countries are missing) and on few experts' estimates. The details can be assessed in the Excel file (sheet "GEO database – Fossil"), but for many countries no database or expert estimate was available, and here we assume a current share of thermal capacity which is equipped by recirculation cooling systems. Instead of cooling by a recirculation cooling system, fossil power plants may also be cooled by sea water. Here sufficient water is always available and adaptation in form of additional cooling techniques is not necessary, according to all interviewed experts. Hence, the current share of power generation from power plants located at the sea-side is also relevant for the following

[143] http://globalenergyobservatory.org/list.php?db=PowerPlants&type=Coal#, http://globalenergyobservatory.org/list.php?db=PowerPlants&type=Gas, and http://globalenergyobservatory.org/list.php?db=PowerPlants&type=Oil. Accessed on 30.08.2011.

calculations. This data was summarized from the GEO database, experts statements and own assumptions – with this priority.

The same holds for the "target" share for the most affected country, in terms of the climate change indicator CC_i. Here we also had to assume a share of capacity equipped with recirculation by best guess. Thus, the following parameters and data are relevant:

K_{cF} Annual costs of a cooling tower in a fossil power plant in € per generated MWh

rs_i Share of fossil generation located at the sea-side in country i. Data by GEO database. For countries without database information, we assumed the parameter rs .

rc_i Share of fossil generation currently equipped by recirculation cooling techniques in country i. Data by GEO database or expert estimates. For countries without database or expert information, we assumed the parameter rc .

rc_1 Share of inland fossil generation equipped by recirculation cooling techniques in the most affected country after adaptation ("target share")

P_{Fi} Total generation of the fossil power plant fleet in country i in TWh

The additional cooling costs for fossil power plants in country i, in terms of additional annual investment and maintenance costs for recirculation cooling systems, are then roughly estimated by the formula

$AC_{Fi} = (rc_1 * CC_i / CC_j - rc_i - rs_i) * P_{Fi} * K_{cF} * 10^6$ if $rc_1 * (CC_i / CC_j) - rc_i - rs_i > 0$

$AC_{Fi} = 0$ otherwise

For the estimation in section 4.1.6, the following parameter values have been chosen (Table 4.6):

Table 4-6: Values of parameters for the calculation of additional cooling costs for fossil power plants.

Parameter	Value	Notes
rc_1	1	In the country most affected, all inland fossil power plants need to be equipped with recirculation systems. Assumption by authors.
rc	0.4	Europe-wide share of fossil generation currently equipped with recirculation cooling. Assumption by authors. For some countries database or expert information is available and will be used in the calculation.
rs	0.3	Share of fossil generation located at the sea for countries without database information.
K_{cF}	6 €/MWh	According to Tetra Tech (2008)

Costs of additional dry cooling systems for gas-fired power plants

In the sector of fossil power plants, we found sufficiently reliable cost estimates for dry cooling systems for coal- and gas-fired plants (see section 4.1.4.6). In the following, we present the methodology for estimating EU27-wide costs for gas-fired plants. For coal-fired plants the procedure would in theory be possible in the same manner, but experts concordantly suggested that the technology is not economically feasible in Europe, even under climate change conditions, although recently this sector is growing in some hot countries outside Europe. The costs and losses in efficiency are just too high.

Moreover, the calculation is very much similar to the procedure in section 0. The costs of dry cooling have to be interpreted as costs on top of the costs for recirculation cooling, as the source defines wet cooling as the base line.

The following data and parameters will be used:

G_i Generation of gas-fired power plants in country i, in Twh

gd_{i0} Share of gas-fired generation in country i already equipped with a dry cooling system today. This value is assumed according to rough experts' information.

gd_1 Share of coal-fired generation which needs to be equipped with a dry cooling system in the country with the most severe climatic change ("target" share of dry cooled gas generation)

CC_i Index of climatic change in country i, identical to the parameter in section 0

CC_j Index of climatic change in the country with the most severe climatic change

K_{gdi} Costs of a dry cooling system for a gas-fired plant in € per generated electricity, €/MWh

Hence, the adaptation costs in country i in terms of dry-cooling costs for gas-fired power plants are roughly derived by the formula:

$$AC_{gdi} = G_i * ((CC_i / CC_j) * gd_1 - gd_{i0}) * K_{gdi} * 10^6 \qquad \text{if } (CC_i / CC_j) * gd_1 > gd_{i0}$$

$$AC_{gdi} = 0 \qquad \text{otherwise.}$$

For the calculation, the following parameter values have been chosen:

Table 4-7: Values of parameters for the calculation of dry cooling costs for coal- and gas-fired power plants.

Parameter	Value	Notes
gd_{i0}	IT 0.75 ES 0.2 GR, IE, UK 0.1 FR 0.02 Rest 0.1	Mentioned countries: Expert guess Rest: Assumption by authors
gd_1	0.3	Assumption by authors
K_{gdi}	0.86 €/MWh	According to NETL (2010)

4.1.4.3 Results: Costs of alternative cooling in Europe

For the nuclear power plants in Europe, additional installation of water cooling towers may become necessary due to water scarcity and higher water temperatures. For this adaptation option, the methodology described in section 4.1.3.3 yields the following costs:

Table 4-8: Cost estimates for cooling of nuclear power plants in Europe.

Country	Costs in million € p.a.
France	303.3
Spain	110.2
Hungary	58.7
Bulgaria	58.6
Romania	30.8
Total EU27	561.6

For fossil power plants, the according figures are shown in 4.9:

Table 4-9: Cost estimates for recirculation cooling in fossil power plants in Europe.

Country	Costs in million € p.a.
Italy	24.2
Portugal	14.0
Hungary	10.7
Slovenia	3.5
Slovakia	0.8
Luxembourg	0.5
Total EU27	53.6

Finally, **Fehler! Verweisquelle konnte nicht gefunden werden.** presents the estimated costs of dry cooling adaptations for gas-fired plants:

Table 4-10: Cost estimates for additional dry cooling systems in gas-fired power plants in Europe.

Country	Costs in million € p.a.
Germany	8.8
France	3.4
Hungary	1.9
Romania	1.6
Portugal	1.5
Other EU27 countries	4.9
Total EU27	22.1

The total adaptation costs for cooling of thermal power plants amount to, as shown in 4.11:

Table 4-11: Cost estimates for additional cooling of thermal power plants in Europe.

Country	Costs in million € p.a.	% of total EU27 costs
France	306.7	48.1
Spain	110.2	17.3
Hungary	71.3	11.2
Bulgaria	58.9	9.2
Romania	32.4	5.1
Other EU27 countries	57.8	9.0
Total EU27	637.3	100.0

The results presented in **Fehler! Verweisquelle konnte nicht gefunden werden.** to **Fehler! Verweisquelle konnte nicht gefunden werden.** are heavily dominated by costs for retrofitting nuclear power plants by recirculation cooling (cooling towers). This is driven by the fact that – compared to fossil production – a relatively high number of nuclear power units need to be equipped by cooling towers, according to our assumptions. For fossil generation, the available data suggest that in many countries great parts of the power plant fleet are already well equipped with cooling towers or are located at the sea, which means that additional cooling systems may not be necessary.

The cost estimates of this report are considerably lower than the top-down estimate of ADAM (2009) (p. 207). Here the authors assume additional annual investments costs of 1 billion € by 2050. These costs include, other than ours, also investments in new capacities due to efficiency losses and additional cooling demand. Thus our bottom-up approach is not contradicting these existing estimates. Other adaptation cost estimates for thermal power generation in Europe are not known to the authors.

4.1.4.4 Costs of early warning systems for floods

Procedure of cost estimation

The concept of early warning system in connection with climate change adaptation is relatively well established in the literature about health impacts of climate change. There are economic studies about early warning systems for urban heat waves (their costs and benefits), stating that most of these systems are definitely worth their costs (e.g. Ebi et al. 2004). For early warning systems for river floods, fewer studies exist and to our knowledge no economic study about their costs has been released yet. In this section, we will use existing cost information from a German study and apply these cost estimates for a large European power plant (like a nuclear power plant) located at a riverside. Multiplying this case-study-based value by the number of endangered power plants which are willing to adopt this system would yield the costs of river flood warning systems for the European power industry. Unfortunately the literature does not allow for meaningful conclusions how many of the European power plants are vulnerable to climate-induced flood risk and are expected to imply early warning systems. Moreover the estimations on plant-level are so uncertain that a transfer to a higher levels (national or European) would not yield reliable results due to too much uncertainty in the calculations. Hence this analysis has to remain on the plant-level.

The SAFE warning system for extreme weather events

The SAFE-system is a "sensor-actor-based early warning system" for extreme weather events developed for the case of the municipality of Mering (13.000 citizens) in Bavaria, Germany (Meissen and Auge, 2007). It contains complex sensor technology to measure relevant data for the forecasts, an extensive software system to communicate and diffuse the information and a forecast module predicting the drain effect of floods in tributary streams on a municipality's sewer system. The estimated costs of the system's components for a community are shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

Table 4-12: Costs of the SAFE-system

I. One-time costs	Worst case	Best case	Unit
I.a acquisition of sensors	1.500 €	500 €	one sensor
I.b installation of sensors	100 €	150 €	one sensor
I.c software development	300.000 €	100.000 €	for less than 250.000 stakeholders
I.d installation of the software	10.000 €	5.000 €	
I.e modeling of sewer system and water supply system	24.000 €	8.000 €	one sewer system for 10.000 residents
II. Annual operation costs			
II.a servicing and exchange of the sensors	50 €	10 €	one sensor
II.b communication of the sensors	200 €	120 €	one sensor
II.c rental and servicing of the hardware	15.000 €	5.000 €	
II.d servicing of the software	50.000 €	30.000 €	
II.e supply of meteorological/hydrological data	depends on stakeholders		
II.f communication between stakeholders	1,20 €	0,60 €	one stakeholder

To calculate the total costs for one user unit (e.g. one municipality) Meissen and Auge use multipliers for the components' costs. If you install the system in for example 20 municipalities the software costs are multiplied by 0.05 since it can be used collectively. For the municipality Mering they calculate annual costs of 16,990 € assuming 20 sensors, 600 stakeholders (= participating households) and that the system will be realized in 20 other municipalities.

Results: Application of SAFE to a power plant

Now we apply the system's costs to an early warning system for a power plant. As far as the sensors (costs: I.a, I.b, II.a, II.b) are concerned the costs are expected to be the same because a large industrial complex may need as many sensors as a small municipality of 13.000 citizens.

To transfer the costs for the modeling of sewer system and water supply system (I.e) is rather difficult because it depends on the site-specific canal structure, which is hard to generalize. On the one hand a fossil power plant does not need a decentralized sewer and water supply system with wide spatial coverage; on the other hand it is always next to a river and needs a well-functioning cooling water system. Due to missing specific information, we assume the same costs as for the modeling of a canal system in a small municipality.

Regarding the software costs we expect them to be lower. The SAFE software has a very complex design, which enables the different types of users (households, companies etc.) to create an account adjusted to their distinguished needs. The information of the numerous accounts then needs to be evaluated and distributed. Different means of communication (e.g. a special system for TV-transmissions) are involved. Further there is a device for building automation (e.g. windows close automatically in case of a storm). All these devices are probably too expensive for the needs of an industrial complex since it has reduced coverage and complexity compared to a municipality. So we assume 50% of the costs for software development and servicing of the software (I.c, II.d). For the installation of the software and the servicing of the hardware (I.d, II.c) we assume the same costs.

Since we calculate the costs for one power station only, the multiplier will be 1 in most cases. The number of sensors to be installed was already mentioned to be the same as for a small municipality, namely 20. For the communication costs we need the number of stakeholder, i.e. parties who are informed by the warning system. The big nuclear power plant Isar in Germany employs 700 workers per one of the two blocks. Assuming that maybe half of them are working at once, we assume 700 to be the multiplier for the whole plant. Since the communication inside a power plant is less complex than inside a municipality, we assume its costs (II.f) to be 50%.

Based on these assumptions we calculate total one-time costs of between 76,000 € and 216,000 € and total annual operating costs of 22,810 € and 45,420 € for an early warning system for extreme weather dangers of a power plant. If the economic lifetime of the investments is assumed to be 5 years (as in Meissen and Auge, 2007), the total annual costs may be between 38,010 € and 88,620 €. An overview is given in Table 4.13.

Table 4-13: Costs for an early warning system for extreme weather dangers for a power plant

I. One-time costs	Worst case	Best case	Multiplier
I.a acquisition of sensors	1,500 €	500 €	20
I.b installation of sensors	100 €	150 €	20
I.c software development	150,000 €	50,000 €	1
I.d installation of the software	10,000 €	5,000 €	1
I.e modeling of sewer system and water supply system	24,000 €	8,000 €	1
Total one-time costs	216,000 €	76,000 €	
Annual investment costs for an economic lifetime of 5 years	43,200 €	15,200 €	
II. Annual operating costs			
II.a servicing and exchange of the sensors	50 €	10 €	20
II.b communication of the sensors	200 €	120 €	20
II.c rental and servicing of the hardware	15,000 €	5,000 €	1
II.d servicing of the software	25,000 €	15,000 €	1
II.e supply of meteorological/hydrological data	depends on stakeholders		?
II.f communication between stakeholders	0.60 €	0.30 €	700
Total annual operating costs	45,420 €	22,810 €	
Total annual operating and investment costs	88,620 €	38,010 €	

This calculation can only be a first rough indication for the actual costs of an early-warning system for a power plant. As an example, here we do not consider costs for the supply of meteorological and hydrological data. If the power generation company does not own these data before, they may be bought and shared by several power plants, resulting in a rather low incremental cost increase. Similarly, the software development and servicing may also be cheaper than indicated in Table 4.13, if several power plants cooperate in this aspect. Hence, the costs indicated here can be understood as the upper bound of early warning system costs to a single power plant.

4.1.4.5 Cost sharing

Both adaptation measures in the domain of thermal power generation –cooling systems and local early warning systems for floods – are predominantly private goods which should be purchased and maintained by power generation companies. In the case of location-specific early warning systems it may happen that there are social benefits, e.g. by the inclusion of dwelling zones or neighbouring industry complexes in the observed area. In this report however, we ignored this possibility of external effects and assumed a system which works exclusively for one industry complex.

The adaptation in thermal power generation seeks to maintain the security of energy supply also under extreme environmental conditions, such as floods and enduring heat waves and drought periods. The benefits of security of supply accrue to the final energy consumers, and so do the costs (at least in an economic framework). Expectedly, power generation companies will try to compensate their expenses for adaptation with higher energy retail prices reflecting the additional production costs. So ultimately, the costs of adaptation in the thermal power generation should be borne by electricity consumers.

As in the case of electricity network, also in the power generation there is a significant level of government intervention. The logic for cost sharing is however also the same as for interventions in networks. Power generation companies may be state-owned but ultimately they need to work at least in a cost-covering manner. At least in the run, additional production costs have to be borne by the consumer, independently on the ownership structure of the power company. An exemption is the case that a government decides for stricter price regulation in the energy sector. This may happen if free prices would increase so starkly that parts of the population cannot afford their basic energy needs ("energy poverty"). In this case subsidies may be a solution, resulting in a cost sharing between general tax payers and electricity consumers.

4.1.4.6 Excursion: Exposure of nuclear power plants to sea level rise

For estimating adaptation costs for thermal power generation, it is also of interest whether there is a need for action due to low-lying thermal power plants located close to a coast. One may think of a starkly rising sea level and a costly protection or relocation of power plants. In the following we will give a deeper insight into the exposure of nuclear power plants to a rising sea level, as an example for thermal power plants which may need cooling water from the sea. It is expected that the exposure of nuclear power plants is a good indicator for other thermal power plants as well. At the same time, the number of nuclear plants is more limited and data are more easily available.

Table 4.14 gives an overview about the location and exposure of European nuclear power plants. The approach is rather simple, but nevertheless allows a first judgment whether adaptation with regard to sea level rise should be investigated in more depth or not. The third column indicated the number of nuclear power plants (NPPs) per country close to a coastline. One NPP is defined as one nuclear reactor, thus several NPPs may be located at the same site. This definition allows a more detailed analysis of exposure as a high number of exposed reactors also calls for higher adaptation efforts. The potentially exposed locations are then investigated with regard to their altitude, as a rough indication of exposure to possible storm surges. For sake of data constraints, this analysis ignores existing protection structures, such as dikes, which is an explanation for the high exposure values in low-lying areas. The analysis shows that one third of European offshore NPPs are exposed to a storm surge of more than 2 meters, if no protection is taken into account. For these sites specific adaptation cost studies are suggested. It can be expected that in most of these cases an advanced flood protection by heightened and strengthened constructions is more cost-efficient than a (quite costly) relocation of power plants. Besides, NPPs located at the sea usually have a very good thermal efficiency, due to available cooling water. According to World Nuclear Association, a NPP would lose 0.9% of its output if it was sited at a river instead of at the sea, resulting in a production unit cost increase of 3% (World Nuclear Association 2011). How high the total adaptation costs will be has to be explored by site-specific case-studies.

Table 4-14: Exposure of European nuclear power plants to sea level rise, as of August 2011.

			Without protection inundated by a storm surge of more than…		
Country	No. of NPPs	Offshore NPPs	9 m	5 m	2 m
Belgium	7	4	4	4	0
Bulgaria	2	0	0	0	0
Czech Republic	6	0	0	0	0
Germany	17	4	4	3	3
Spain	8	2	0	0	0
Finland	4	4	0	0	0
France	58	18	14	10	10
United Kingdom	18	18	10	9	9
Hungary	4	0	0	0	0
Netherlands	1	1	1	1	1
Romania	2	0	0	0	0
Sweden	10	10	7	4	0
Slovenia	1	0	0	0	0
Slovakia	4	0	0	0	0
Other EU27 countries	0	0	0	0	0
Total	142	59	40	31	23

Sources: World Nuclear Association 2011 (http://www.world-nuclear.org/info/reactors.html), own research with the use of google maps and flood map (http://flood.firetree.net).

4.1.5 Adaptation costs for electricity demand

4.1.5.1 Definition of concrete measures and costs to be analysed

Adaptation in the domain of energy consumption is already quite well covered in the literature. The literature review in chapter 4.1.2 enlists 11 studies which analyze the expected changes in energy demand from industrial and private consumers, partly with economic impacts. In this domain of the literature more peer-reviewed papers exist which also shows broader existing knowledge than in the other domains. However, the direct consequences of climate change in energy consumption have only limited implications for key EU policies. We will therefore not contribute a further estimate of energy consumption changed by climate change, but rather focus on the EU policy of energy efficiency regulation in private households. Thus we will focus on the adaptation measure “Set standards for energy efficiency of air conditioning devices”.

Costs of energy efficiency standards may arise in different forms and for different actors. Low-efficiency (and low-cost) products will be banned from the markets, which will raise the average price of devices on the then-regulated market. In the short run, the demand for cooling devices will decrease due to the higher prices. In the total economy, welfare is lower than in the free market situation. This welfare loss is the result of changes in consumer and producer surpluses. Whereas the consumer surplus unambiguously decreases, the producer surplus depends on the net of loss due to lower demand and possible gains due to higher purchase prices. Gains due to higher purchase prices however only occur if producers are able to raise the prices more than their production costs rise. As a result, energy standards imply total welfare losses in the short run (possible positive side effects and benefits in terms of climate change mitigation are not accounted for).

In the longer run, the expected increase in demand may shift this picture to a more optimistic one. Higher autonomous demand for cooling devices (due to climate change, overall economic development or any other reason) could lead to higher market prices and a higher market volume compared to the short run situation with regulation. Compared to a free market however, energy standards will always imply market distortions with welfare losses if other effects like benefits of lower GHG emissions are ignored.

A comprehensive quantitative modeling of these market processes in beyond the scope of this report. But it is possible to provide a plausible estimate of the magnitude of the price change induced by energy standards for ventilator devices. Reliable data for air conditioning devices was not available, so we recur to comparable devices which may also be regulated in the same manner like air conditioning devices. These price increases are the direct costs of an EU regulation for the consumers. If the total life cycle of the devices is considered, consumers may be better off due to energy savings during the lifetime – although this aspect is also disputed in the literature (Meyers et al. 2003, Parry et al. 2010, Sutherland 2003). These possible benefits of regulation are not considered in this report.

4.1.5.2 Additional investment costs for high efficiency ventilation

In order to estimate the magnitude of additional investments in the sector of cooling devices, the projected demand for appliances is relevant. Table 4-15 shows the estimated number of products in use in Europe for non-residential building ventilation in 2005 and 2025 according to Radgen et al. 2008. The authors used available Eurostat data from 1995 to 2005 on production, imports and exports to calculate the number of products entering the market in one year. Missing data was estimated. With the obtained data of products entering the market per year from 1995 to 2005 past and future growth rates in four different scenarios were estimated. The four scenarios are logarithmic growth, linear growth, both based on a regression regarding apparent consumption from 1995 to 2005 and two constant geometrical growth rates of 2% and 10%. For the calculation an average product lifetime of 15 years was taken into account. Hence, the table shows a minimum and a maximum value for each category. The methodology does not allow taking climate change deliberately into account, but the different growth rates may also be interpreted as outcomes of different climate scenarios.

Table 4-15: Estimated Number of Products in use in 2005 and 2025. Source: Radgen et al. 2008.

Product Category	Direction of flow	Type	Number of products in use for non-residential building ventilation	
			2005	2025
1	Axial	<= 300 Pa (static pressure)	6,1 – 7,3 Mio.	14,0 – 40,4 Mio.
2	Axial	> 300 Pa (static	16,8 – 20,2 Mio.	38,8 – 112,3 Mio.

		pressure)		
3	Centrifugal	forward curved blades (with casing)	9,2 – 10,3 Mio.	16,8 – 61,4 Mio.
4	Centrifugal	backward curved blades (no casing)	2,8 – 3,2 Mio.	5,2 – 19,0 Mio.
5	Centrifugal	backward curved blades (with scroll housing)	3,2 – 3,5 Mio.	5,8 – 21,2 Mio.
6	Other	Box fans	20,6 – 23,0 Mio.	29,8 – 86,3 Mio.
7	Other	Roof fans	36,2 – 40,4 Mio.	52,5 – 151,7 Mio.
8	Other	Cross-flow fans	2,4 – 2,7 Mio.	3,6 – 10,3 Mio.

Even if there is a wide range between the estimated numbers for 2025 it seems to be clear that the number of products in use will be nearly doubled or more until 2025. This growth can be found in each category, so the demand for every product will increase significantly.

These unit numbers are the basis for estimating additional costs due to higher energy standards. They need to be coupled with unit prices. Table 4.16 shows the prices of the products of each category. The prices vary heavily, especially because the products are available with different levels of power. The table shows the minimum and maximum of both price and power for each product, roughly estimated by reading the graphs of Radgen et al. 2008.

Table 4-16: Prices of products of each category, varying with power. Source: Radgen et al. 2008. Primary source: Manufacturers' price lists

Product Categor y	Direction of flow	Type	Price	Power
1	Axial	<= 300 Pa (static pressure)	400€ - 1650€	0.2kW - 2.5kW
2	Axial	> 300 Pa (static pressure)	1200€ - 2900€	1kW - 9kW
3	Centrifugal	forward curved blades (with casing)	700€ - 2700€	0.5kW - 16kW
4	Centrifugal	backward curved blades (no casing)	550€ - 3100€	0.1kW - 15 kW
5	Centrifugal	backward curved blades (with scroll housing)	700€ - 23.000€	>0kW - 140 kW
6	Other	Box fans	450€ - 2400€	0.2kW - 4kW
7	Other	Roof fans	500€ - 3800€	0.05kW - 3kW
8	Other	Cross-flow fans	not available	

As these prices are expected to decrease in the future (as they have done in the past), we assume an overall price fall of 2 to 5 % per year by 2025 in order to avoid an overestimation of future costs due to energy standards. We furthermore assume an average lifetime of appliances of 15 to 20 years, according to values given by Radgen et al. 2008.

In the next step we combine these data with results from the literature about an average incremental price increase caused by higher energy standards. Radgen et al. 2008, by recurring on Garcia et al. 2007, mention a rule of thumb saying that reaching a higher efficiency standard for the energy efficiency of motors cause an average price increase of 25

%. Other sources assume incremental costs of ca. 0.20 € per annual kwH saved (Mahlia et al. 2004 for Malaysia), which results in a relative incremental price mark-up of around 10%.[144] Nadel 2002 states after a review of several ex-ante price estimates that mostly price changes are overestimated. Applying a range of 5 to 25 % incremental price increase to the number of units and unit prices projected by Radgen et al. 2008 yields a broad range of possible annual costs for the consumers of 100 million € to 41.8 billion € in 2025. These numbers should not be interpreted alone, but rather be compared to possible benefits to the consumers by energy savings – which is however beyond the scope of chapter 4.

It has to be noted that these values only refer to ventilation systems used in non-residential buildings, such as factories, supermarkets, etc. They are, however a clear hint that cost effects from imposing energy standards may reach magnitudes which are significant to the economy. Therefor a comprehensive ex-ante analysis of costs and benefits of energy regulations is crucial to avoid unnecessarily expensive regulation of autonomous adaptation.

4.1.5.3 Cost sharing

For the measure of imposing stricter energy standards for cooling and ventilation appliances, the costs will be borne by private actors, namely producers and consumers of the regulated products. Whether producers or consumers will pay more of the costs depends on the specific market structures. In a seller's market producers are able to factor the higher production costs into the product prices. The costs have to be borne entirely by consumers, either by paying more or by abstaining from the use of desired products. If prices are more sticky (as in a buyer's market) producers will also have to bear costs of regulation, either by lower margins or by withdrawing from the market due to high production costs. Which kind of market will exist for ventilation and cooling devices in the future is not possible to predict in the scope of this project. Anecdotic evidence is ambiguous. One the one hand prices are rather decreasing due to more competition from Far East (sign of a buyer's market, Radgen et al. 2008), on the other hand demand is rising due to climate change, implying a tendency for seller's market and therefor rising prices.

4.1.6 Summary of cost estimates

This section summarizes in one table (4.17) the key findings of this report – estimated adaptation costs in the energy sector for key adaptation measures. The figures have been estimated by transferring results of bottom-up studies to the European level using numerous case studies, expert information and databases. The results are subject to various assumptions and constraints described before in the respective chapters.

[144] For the calculation, data of Mahlia et al. 2004 and other internet sources have been used: Incremental cost of regulation: 0.512 RM$ per kWh saved per year; reduction of energy consumption by regulation 213 kwH per year; approximate price of a refrigerator-freezer in Malaysia 1500 RM$.

Table 4-17: Summary of cost estimates

<table>
<tr><th>Adaptation option</th><th colspan="4">Total costs</th></tr>
<tr><td rowspan="2">Adaptation of electricity grids in EU26 (without Malta) (in million € p.a.)</td><td colspan="4">654.1 (A1FI)</td></tr>
<tr><td colspan="4">636.6 (B1)</td></tr>
<tr><td>Additional cooling of thermal power plants in EU 27 (in million € p.a.)</td><td colspan="4">637.3</td></tr>
<tr><td rowspan="3">Early warning system for extreme weather events for one power plant</td><td colspan="2">Annual investment costs</td><td colspan="2">Annual operating costs</td></tr>
<tr><td>Worst case</td><td>Best case</td><td>Worst case</td><td>Best case</td></tr>
<tr><td>43,200 €</td><td>15,200 €</td><td>45,420 €</td><td>22,810 €</td></tr>
<tr><td>High efficiency ventilation in 2025 (in € p.a.)</td><td colspan="4">100 million to 41.8 billion</td></tr>
</table>

4.2 Transport and Infrastructure:

4.2.1 Introduction and key impacts

Climate change associated with extreme weather events like storm, flooding, heat waves, and precipitation with increased intensity will require adaptation of transportation infrastructure and transport systems. This paper is an approach to define costs of adaptation for the European transport sector. Within the transport sector four modes rail, roads, aviation and shipping can be differentiated.

The main impacts in the European transport sector especially caused by higher temperatures or extreme events like precipitation, floods, storms are the following:

- Track buckling due to higher temperatures
- Damage to roads and infrastructure of rail due to higher temperatures or floods
- Damage to road materials due to stronger precipitation
- Embankment instability due to moisture fluctuation

The key adaptation measures responding to these main climate change threats can be summarized:

- Develop and implement early warning systems to predict extreme events
- Modify surface materials for roads and runways
- Retrofitting infrastructure of rail and roads

This report investigates and quantifies the costs of this adaptation in Europe. It analyses in depth only some key options identified by chapter 3 which are named in Table 4.18:

Table 4-18: Proposed adaptation options by chapter 3 and respective chapters and notes regarding the cost analysis

Adaptation measure proposed by Chapter 3	Cost estimate in this report	Notes
Rail: • Strengthened earthwork to reduce embankment instability due to moisture fluctuation caused by wetter winters and drier		No cost estimates due to data availability.
Rail: • Use materials for new or upgrades of rail infrastructure which better cope with summer heat to prevent track buckling • Higher standards of rail used to prevent track buckling in increased temperatures.	Chapter 4.2.4	Costs for the use of new materials could not be assessed due to data availability. Cost estimates for speed restrictions to prevent track buckling at hot days are presented in Chapter 4.2.4.1
Rail: • Modify standards for air conditioning systems in trains and for signals to be better adopted to higher temperature	Discussion in Chapter 4.2.4.3	No cost estimates due to data availability.
Roads: • Install early warning systems in case of extreme events (e.g. floods, storms)	Chapter 4.2.8	
Roads: • Identify and implement cost-effective means of retrofitting existing infrastructure (e.g. roads, tunnels, bridges) and equipment (in particular buses and coaches) to more extreme climatic conditions (e.g. technical flood protections) • Modify standards for road materials (e.g. pavement, embankments) to be able to cope with higher temperature and extreme	See Chapter 4.2.5.1 for retrofitting the streets with heat resistant pavement and Chapter 4.2.5.2 for the adaption of drainage systems of roads.	

precipitation events		
Aviation: • Modify surface materials of runways to be able to cope with higher temperature and extreme precipitation events	Chapter 4.2.6.1	
Aviation: • Upgrade drainage system to better cope with intensive precipitation events and storm water runoffs	Chapter 4.2.6.2	
Shipping: • Improve or develop monitoring system, e.g. for river depth information or sea level rise	Chapter 4.2.7	

4.2.2 Literature Review

An extensive literature review on specific adaptation measures in the transport sector has been performed to get input for cost estimations for Europe. The results are accessible in the Excel file “Adaptation Costs Transport Literature Review.xlsx”. Criteria of studies for entering the review include: Taking account of climate change impacts, proposing adaptation options to cope with these impacts and giving some information about the costs of adaptation. The findings are summarized in the Excel file accompanying this document. The literature on concrete adaptation measures and their costs is scarce. This is in line with a questionnaire among experts by the Chameleon Research Group which revealed that adaptation is discussed in the transport sector but planned or even implemented adaptation measures are only seldom at this stage (Stecker et al., 2011).

Four studies deal with adaptation in general and consider also measures in the transport system. Another six studies address climate change impact within the transport sector.

13 studies were identified for the *rail transport* including studies which are not solely dealing with rail but with adaptation measures in the transport system in general or adaptation as a general issue. Research has been mainly conducted in Great Britain by different authors but primarily published by the Railway Safety and Standards Board (RSSB) in Great Britain. The cost estimations are limited to delay minute costs, only one study containing estimates about maintenance and surveillance. The majority of the reviewed studies does not include cost estimates but concentrate on the impact of climate change on the rail system and the adaptation measures. We found only three peer-reviewed papers.

Influencing factors of *road* conditions are higher temperature and stronger or longer precipitation. In this report we concentrate on impact due to higher temperatures on road infrastructure. Studies about costs for different asphalt types that can withstand higher temperatures were found for the United States and Canada. To the best of our knowledge there are no cost estimates on more heat resistant asphalt for Europe, which might be reasoned by the several types of asphalt and the volatile prices for binder material. There is one study on Germany's motorways on future costs for more heat resistant asphalt. Seven studies focus on the transport mode roads including two studies about bridges.

The literature on *aviation* and *shipping* concerning adaptation costs is scarce. One case study was found on the pavement used in seven European countries at airfields. For shipping two German studies about shipping were found. Nevertheless, aviation and shipping are included in most of the literature on transport infrastructure or also on adaptation in general.

4.2.3 Definition of concrete measures and costs

Adaptation measures in the transport sector depend on the mode of transport. Therefore the threats, adaptation measures and costs will be presented in the four subareas:

- Rail
- Road
- Aviation
- Shipping

The general situation of these subareas will be explained in the different subsection of the report. We will concentrate on adaptation costs for the most relevant measures. An excursion at the end of the paper will discuss costs of early warning systems concerning floods of maritime waterways. Such warning systems are overarching systems because roads, railways, and shipping, but also urban areas, power stations and farming can be affected by flood. Hence, such adaptation measures cannot be related to one single sector. Furthermore we will concentrate on adaptation of infrastructure instead of management of operations. The development of technical solutions seems to be the most important adaptation measure because of the long lifetime of transport infrastructure. Major transport infrastructure has an expected lifetime between 50 and 100 years (Horrock et al., 2010; HM Government, 2011), depending on the resilience to climate conditions. According to literature on the transport sector and experts' information, adaptation to changed climate conditions can be pursued in the course of usual renewal cycles, which would be done anyhow. Therefore additional costs solely attributable to adaptation measures are difficult to verify.

4.2.4 Rail

The main threats of climate change to the rail system are higher temperatures and extreme weather events like floods or storms (see e.g. RSSB, 2010 or Chapman et al., 2008). The effects of these events are increased risk of track buckling, instability of embankments or damage to bridges (HM Government, 2011; Chapman et al., 2008).

All calculations and data of this subchapter are available in the accompanying Excel file "Adaptation Costs Transport Rail.xlsx".

4.2.4.1 Retrofitting existing infrastructure concerning increased temperatures on tracks

Definition of concrete measures and costs for tracks

The necessity for adaptation within the rail transport system depends on the age of infrastructure, the track bed condition, material of the tracks and vulnerability (Dobney, 2010). Detailed data about these factors are not available for the European countries.

Track Buckling

The most severe impact of higher temperatures on the railway system is track buckling (HM Government, 2011).[145] Track buckling is the lateral misalignment or even derailment of continuous welded rail (CWR) (Volpe, 2003). A narrower definition is used by Kish et al. (2003) which describes track buckling as a "suddenly occurring large deflection type instability phenomenon." The major factors influencing track buckling are the rail neutral temperature or stress free temperature (SFT), the track bed and air temperature (see e.g. Volpe, 2003; Kish et al., 2003). Vulnerability and risk analysis on track buckling would have to include these main components, which are mostly unknown or differ regionally (Dobney, 2010). The rail stress free temperature "is the temperature where no thermal forces are acting upon the rail and is the temperature at which railtracks are laid" (Chapman et al., 2008). It depends on local weather conditions like wind or direct sunlight (cf. Dobney, 2010). Predictions for the likelihood of buckling are rare and their results are predominantly general assessments but do not provide specific data (e.g. Eddowes et al., 2003). Due to a lack of detailed data we concentrate on change in average mean number of summer days provided by ESPON[146], the SFT, the critical rail temperature (CRT) and the passenger km as vulnerability criteria.

Possible adaptation measures against track buckling are the usage of more heat resistant materials, the change of SFT standards and speed restrictions (cf. Eddowes et al., 2003; Tröltzsch, 2011).

The usage of more heat resistant material

According to an expert from a steel producer for railways, the lifetime of railways is about 35 years on average. The material itself is heat resistant and high temperatures will not harm it. The current technology can be used under extreme conditions (e.g. in deserts as well as in regions with very cold winter). Therefore the steel of rails is resistant to higher temperatures, but problems can occur under extreme conditions when rails are welded.

Adaptation of stress free temperature (SFT)

A questionnaire by Ryan and Hunt (2005) among network operators (Irish Rail, Dutch Railways, Deutsche Bahn AG, USDoT) reveals the different SFT in these countries (see corresponding Excel file) ranging from 25-27℃. Acc ording to the homepage of the Department of Climate Change and Energy Efficiency of the Australian Government, the

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[145] Also other studies focus on track buckling like Dobney, 2010 or RSSB Phase 1 report on Tomorrow's railway and climate change adaptation (2010).

[146] Summer days are days with a maximum temperature over 25℃; days with maximum temperature over 30℃ are called hot days (PIK, http://www.pik-potsdam.de/services/infothek/climate-weather-potsdam/climate-diagrams/air-temperature-maximum/index_html?set_language=de, access 12.08.2011).

stress free temperature is 75% of the expected maximum temperature of the region.[147] In Ryan and Hunt (2005) the operators state that a differentiation between high speed and other tracks are made. Furthermore only in the US the tracks are stressed two times a year for winter and summer. Stressing is a technique to avert track problems like fracturing or buckling at the temperature extremes. Thereby, stress can be induced by removing a piece of rail is removed. Within the European countries summer and winter stressing are the same.

The stress free temperature is not constant (explained as rolling out effect by Ryan and Hunt (2005) and according to Chapman et al., 2008 a loss up to 3℃ in the first year is possible. Therefore re-stressing might be necessary to prevent track buckling (Ryan and Hunt, 2005).

Nevertheless, according to Ryan and Hunt (2005) an increase of stress free temperature above 27℃ can lead to an increased risk of rail br eaks. Therefore the adaptation by an increase of stress free temperature is limited to 27℃ and additionally to weather constraints in winter. During cold weather periods tension cracks can occur, if track conditions do not fit the climate situation.

Regarding the actual adjustment of SFT to higher ambient average temperatures, the available data do not allow a Europe-wide adaptation cost estimation.

Speed Restrictions

The limits of adaptation to more heat resistant tracks and higher stress free temperature leads to speed restrictions as one main adaptation measure for higher temperatures especially when it comes to heat waves.[148] Speed restriction can be seen as one part of the management of the track buckling risk as adaptation measure (RSSB, 2010) to aim at a minimal buckling probability (Kish et al., 2003) and to minimize the forces applied to the tracks by the train (Volpe, 2003). As mentioned above, the possible rail buckling depends on the track conditions, track loads and the speed of trains. We concentrate on speed restriction due to data constraints.[149] The costs of speed restrictions are calculated in delay minutes costs (see e.g. Dobney, 2010). Delay minutes referring to passengers and the monetary value of a minute lost are called delay minute costs (Burr, 2008). The delay minute costs for the European countries with a different number of projected summer days and different passenger volume is calculated for additional adaptation costs to prevent track buckling at higher temperatures.

Transfer of cost estimates for additional maintenance

Estimates on delay minutes and their costs are rare and the literature we refer to deals with Great Britain's rail network. The heat wave in Great Britain in 2003 caused a lot more of delay minutes than in other years. In literature the delay minutes of 2003 are compared to 2004 to figure out the heat related delay minutes (Enei et al., 2011 or Hunt et al., 2006). The difference (135,000 delay minutes) is the basis for calculating additional delay minutes per summer day and passenger kilometer. Dobney et al., (2010) estimate that the costs during

[147] http://wiki.climatechangeadaptation.org.au/tiki-index.php?page=Track+buckling, access 24.08.2011.

[148] Speed limits will also be implemented for other weather related causes for safety reasons (see e.g. Eddowes, 2003; Chapman, 2008).

[149] Also Dobney (2010) notices that that "The costs involved in mitigating and maintaining the network against temperature-related delays were not available."

the heat wave in 2003 will become an average summer in 2050s with a high emissions scenario and in 2080s for low emissions scenario respectively.

To provide an overview on the likelihood of track buckling and the need for speed restrictions, the critical rail temperature is compared to the rail temperature which is related to the mean maximal temperature in summer (June-July-August) within a period of 15 years (1995-2008). Because the temperatures may vary in the different European countries, this analysis is done for each country separately. The following steps to identify the threshold temperatures of potential track buckling were taken:

The maximal air temperatures were taken from the ESPON database. This air temperature was converted into rail temperature according to two commonly used approaches: $T_{rail} = 1.5 * T_{air}$ as well as $T_{rail} = 17 + T_{air}$ (see eg. Chapman et al., 2008).

The critical rail temperature (CRT) is the temperature at which track buckling is possible. It is calculated for good and worse track standard to represent best and worst cases by the two corresponding formulas taken from Hunt et al. (2006) and Chapman et al. (2008): for good track conditions $CRT_i = SFT + 32°C$ and for bad track conditions $CRT_i = SFT + 10°C$

The stress free temperature (SFT) for different countries was taken from Dobney (2010) who refers to Ryan and Hunt (2005) and Hunt (1994).[150] For countries with unknown SFT a SFT of 26℃ was assumed. The results show (see correspo nding excel file "Adaptation Costs Transport Rail.xlsx") that in the best case scenario no track buckling is to expect for all countries, whereas in the worst case all countries may have track buckling (both independent of air to rail temperature conversion). These results are very limited because only two extremes are shown. The real track condition is not known and they can differ within a country. Furthermore another factor influencing the track buckling is the microclimate of different regions. Therefore severe problems may also occur with lower temperatures as Dobney (2010) states that in some regions incidents can happen already at temperatures above 20℃. Moreover during the heat wave in Great Britain in 2003 the likely range of rail temperature was 50-60℃ (Chapman et al., 2008). Com paring this to the calculated rail temperatures, almost all countries reach the 50℃ o r are even higher. Taking this into account, track buckling may occur much earlier than the simplified calculations of critical rail temperatures can predict. This is also true vice versa because even with high temperatures and worse track conditions track buckling does not necessarily occur. But as track buckling cause severe damage and threat to life, speed restrictions are initiated as adaptation measure to high temperatures even if the real magnitude of the problem is uncertain.

For calculating purposes, the change of annual mean number of summer days (ESPON database) were taken into account and weighted by the passenger kilometer (Eurostat). The estimates refer to three different average delay minute costs by Enei et al. (2011), Burr (2008) and Eddowes et al. (2003). Enei et al. (2011) provide delay minute costs of £16.70, which was calculated by the total costs for additional delay minutes during the heat wave in Great Britain in 2003 related to the delay minutes in August 2003. Eddows et al. (2003) assume costs of £50 as a national average. The average delay minute costs provided by Burr (2008) are based on a survey among passengers about their willingness to pay to

[150] The original source Hunt (1994) is not available.

reduce their journey time. All the average delay minute costs are not specifically related to hot weather delays but are average costs mostly independent of the cause of delay.

In detail the basis of these cost estimates are the following data:

- SD_i: Change in annual mean number of summer days in summer in country *i* in number of days (1961 to 2100 (Source: ESPON)

- PKM_i^{day}: Passenger kilometer in country *i* in average passenger km per day (Source: Eurostat)

    - Calculated on the basis of Eurostat data by the formula:

    $$PKM_i^{day} = PKM_i^{year}/365$$

- DM_{pkm}^{day}: Additional delay minutes per summer day and passenger km (Source: own calculation based on different sources)

  Calculations are based on delay minutes during the heat wave in Great Britain in 2003 by the formula: $DM_{pkm}^{day} = \frac{(DM^{2003\,Aug} - DM^{2004\,Aug})}{16} / PKM_{UK}^{day\,2003}$

    - Additional delay minutes in 2003 related to hot weather: delay minutes 2003 during heat wave minus delay minutes in 2004 for same time: $DM^{add} = DM^{2003\,Aug} - DM^{2004\,Aug} = 165{,}000 - 30{,}000 = 135{,}000$ (Enei et al., 2003)

    - Summer days during heat wave in August 2003: 16 days as assumption by the authors based on maximal number of summer days of four weather station within the four regions of Great Britain (North, South, Middle, West) in August 2003.[151]

    - Passenger kilometers for the year 2003 were not available. Therefore the passenger kilometers of 2004 were used and calculated through passenger kilometers per day.

- c_{DM}^{Enei}: Average cost of delay minute in EUR (Source Enei et al., 2011) transferred from £ to Euro: $c_{DM}^{Enei} = 24.14\ EUR$ (average exchange rate in 2003, for more details see excel file)

[151] The weather stations were chosen according to Dobney (2010) except for the North region, where the example of Dobney (2010) was not provided and a different was chosen. From graphs provided by weather online UK the days over 25℃ were counted as summer days.

- $c_{DM}^{Eddowes}$: Average cost of delay minute in EUR (Source Eddowes et al., 2003) transferred from £ to Euro: $c_{DM}^{Eddowes} = 72.28\ EUR$ (average exchange rate in 2003, for more details see excel file)

- c_{DM}^{Burr}: Average cost of delay minute in EUR (Source Burr, 2008) transferred from £ to Euro: $c_{DM}^{Burr} = 107.39\ EUR$ (average exchange rate in 2007, for more details see excel file)

- C_i^{DM}: Total future delay minute costs for country *i in EUR*

For each EU member state *i* the total possible delay minute costs for the different average delay minute costs are calculated by the following formulas:

Average delay minute costs of 24.14 EUR:

$$C_i^{DM} = SD_i * PKM_i^{day} * c_{DM}^{Enei} * DM_{pkm}^{day}$$

Average delay minute costs of 72.28 EUR:

$$C_i^{DM} = SD_i * PKM_i^{day} * c_{DM}^{Eddowes} * DM_{pkm}^{day}$$

Average delay minute costs of 107.39 EUR:

$$C_i^{DM} = SD_i * PKM_i^{day} * c_{DM}^{Burr} * DM_{pkm}^{day}$$

i.e, for country i : the average cost of delay minutes (C_i^{DM}) is equal to the change in the number of summer days (SD_i) times the average passenger km per day (PKM_i^{day}) multiplied by the average cost of delay minutes (c_{DM}^{x}) times the additional delay minutes per summer day and passenger km (DM_{pkm}^{day}).

Table 4-19: Parameter values chosen for the estimation

Parameter	Description of parameter	Assumed value (can easily be changed in the Excel file)	Notes
c_{DM}^{Enei}	Average cost of delay minute in EUR	24.14	Source Enei et al. (2011) transferred from £ to Euro: $c_{DM}^{Enei} = 24.14\ EUR$
$c_{DM}^{Eddowes}$	Average cost of delay minute in EUR	72.28	Source Eddowes et al. (2003) transferred from £ to Euro: $c_{DM}^{Eddowes} = 72.28\ EUR$
c_{DM}^{Burr}	Average cost of delay minute in EUR	107.39	Source Burr (2008) transferred from £ to Euro: $c_{DM}^{Burr} = 107.39\ EUR$
DM_{pkm}^{day}	Additional delay minutes per summer day and pkm	7.08398E-05	Own calculations based on different sources and assumption by the authors (details please see above)

Important assumptions resulting from the methodology and data availability

The calculations of additional cost for delay minutes should just give a first insight and they are very rough, primarily due to the assumptions and limitations that had to be made. Furthermore due to data constraints, no prediction can be made about specific possibilities of track buckling or if in the future decisions on speed restrictions and to what extend speed limits will have to be taken. The limitations and assumptions in detail are the following:

- No differentiation if delay minutes occur due to track buckling or speed limits.
- Track length in km was not explicitly used because the passenger kilometers already include this data.
- The different possible speeds on specific tracks were not included.
- Delay minutes in Great Britain during the heat wave 2003 were used as a basis for further calculations. According to Enei et al. (2003) the delay minutes related to the heat wave in August 2003 were 135,000 (calculated from total delay minutes of 165,000 minus delay minutes during same time in 2004 of 30,000). This means important parameters in the calculation rely on one single event and source.
- Track buckling events in Great Britain during the heat wave in August 2003 were used for further calculation. 16 days as assumption by the authors based on maximal number of summer days of four weather station within the four regions of Great Britain (North, South, Middle, West) in August 2003.
- The passenger kilometers of Great Britain in 2003 were not available. Therefore the passenger kilometers of Great Britain in 2004 were used and calculated into passenger kilometers per day.
- The additional delay minutes per summer day and passenger km were calculated by dividing the additional delay minutes in Great Britain during August 2003 by 16 days divided by passenger kilometers per day.
- The change of summer days per country from 1961 to 2100 was taken from ESPON. This implies uncertainty regarding the regional pattern of climate change (as national values were used) and the actual magnitude of climate change.

- Cost for delay minutes were derived from three different sources to show the different ranges: Enei (2011) with £16.70. Eddowes (2003) with £50 and Hunt (2005) with £73.47. All the average delay minute costs are not specifically related to hot weather delays but are average costs mostly independent of the cause of delay.
- Differentiations on embankment conditions were only taken into account as best and worst case scenarios to provide roughly limited assessments about the occurrence of track buckling.
- Mean maximal summer temperature during June-July-August from ESPON was the only source for calculating the rail temperature for comparison with the critical rail temperature.
- Transfer of air temperature into rail temperature is provided for two different equations, used in literature: Trail=3/2 Tair and Trail= Tair +17. Other non-linear connections were not included.
- The Stress free temperature of different countries were used as published in Dobney (2010, citing Ryan and Hunt, 2005 and Hunt, 1994). Were no data on Stress free temperature was available 26℃ was assumed.

Results: Costs of adapting of tracks to higher temperatures in the EU

Table 4.20 below shows the delay minute costs independent of whether the track buckling really occurs or speed restrictions are implemented to prevent track buckling. As the SFT cannot be increased to more than 27℃ without disadvantages for winter temperatures, the costs for delay minutes give an insight to adaptation to high temperatures. The actual vulnerability and the costs for adaptation depend not only on the SFT and the air temperature, but on other factors like speed of trains, embankment conditions or the age of tracks. The results give a rough insight into the topic of additional delay minute costs, if the number of summer days increase in the future.

Table 4-20: Results of additional delay minute costs in EUR for different average delay minute costs assumptions

Country	Average Cost of Delay Minute 24.14 EUR (Enei et al., 2011)	Average Cost of Delay Minute 72.28 EUR (Eddowes, 2003)	Average Cost of Delay Minute 107.39 EUR (Burr, 2008)
AT	1,041,031 €	3,116,859 €	4,630,545 €
BE	1,586,911 €	4,751,230 €	7,058,640 €
BG	314,076 €	940,348 €	1,397,022 €
CY	0 €	0 €	0 €
CZ	865,172 €	2,590,336 €	3,848,319 €
DE	11,530,633 €	34,522,855 €	51,288,694 €
DK	268,972 €	805,307 €	1,196,400 €
EE	3,743 €	11,206 €	16,648 €
ES	4,759,717 €	14,250,650 €	21,171,402 €
FI	11,825 €	35,404 €	52,598 €
FR	17,975,192 €	53,817,944 €	79,954,339 €
GR	304,897 €	912,865 €	1,356,192 €
HU	1,294,302 €	3,875,155 €	5,757,103 €
IE	67,839 €	203,111 €	301,751 €
IT	8,212,691 €	24,588,898 €	36,530,364 €
LT	9,553 €	28,602 €	42,493 €
LU	58,526 €	175,229 €	260,327 €
LV	19,112 €	57,221 €	85,010 €
MT	0 €	0 €	0 €
NL	1,848,474 €	5,534,353 €	8,222,081 €
PL	1,816,916 €	5,439,870 €	8,081,714 €
PT	907,826 €	2,718,041 €	4,038,043 €
RO	887,565 €	2,657,380 €	3,947,922 €
SE	104,910 €	314,101 €	466,643 €
SI	139,575 €	417,890 €	620,836 €
SK	343,960 €	1,029,820 €	1,529,947 €
UK	4,239,444 €	12,692,947 €	18,857,208 €
EU 27	58,612,862 €	175,487,622 €	260,712,241 €

Delay costs for Malta and Cyprus are equal to zero because there are no operating railway lines anymore.

Cost sharing

At first the delay minute costs apply to private persons. There are legal regulations how passengers can recover financial compensation for delays depending on type of train (speed trains or regional trains).[152] Hence, the costs of delays due to high temperatures may be borne by passengers and network operators partly.

4.2.4.2 Retrofitting existing infrastructure on Railway Bridges

Climate threats to which bridges are vulnerable are storm surge, prolonged rainfall, flood, change in wind direction and scour patterns (Royal Academy of Engineering (2011). In 2009, severe flooding in England resulted in a number of road bridges collapsing. Hence, to adapt to climate change bridges have to be built higher in order to accommodate larger tidal ranges and foundations have to be reinforced to cope with increased river flow speeds (HM Government 2011).In the framework of the project “Sustainable Bridges” within the Sixth Framework Programme of the European Commission (see report Bell, 2004), a survey was conducted among railway owners in Europe about the infrastructure of railway bridges in Europa. The railway owners were asked to report the number, structure and age of existing bridges in order to identify their need for rehabilitation and strengthening. Of the bridges reported in the survey were nearly 23% concrete constructions, 21% metallic, 41% arches and 14% had steel/concrete composite or encased beams construction. The data of the survey contained data about 500.000 concrete bridges, 47,000 metallic bridges, 90,000 arch bridges, and 30,000 composite or encased beam bridges. 35% of the bridges are older than 100 years, 31% are between 50 and 100 years old, 22% are between 20 and 50 years old and nearly 11% are younger than 20 years. According to the report, the demand on rehabilitation and renewal of aged bridges has increased in the recent years due to higher demand on freight and passenger transportation. This will lead to necessary renewal in the next years. The deterioration of individual bridges depends inter alia on material degradation, initial use of poor materials and flaws in design. Therefore, there is no information about the number of bridges which has to be replaced in the next decades in Europe.

If bridges need to be replaced anyway, the additional adaption costs will be close to zero (Dore and Burton 2001). The costs for retrofitting railway bridges to climate change depend on the individual characteristics of each bridge as the geographical location and materials used. Because information about the number of necessary replacements and details about existing bridges is not available on European level, cost calculations were not possible given the data available to the authors.

4.2.4.3 Retrofitting existing infrastructure concerning increased temperatures on Air Conditioning

In summer 2010 and 2011 with outside temperatures about 38 degrees Celsius, the air conditioning systems in several German high speed ICE trains experienced problems or broke down completely. The reason for this was and is the insufficient adaptation of these systems to high temperatures. The current air conditioning systems operate only appropriately at temperatures of maxima between 32 and 35 degrees[153]. Some of the older

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[152] As example see regulation for Deutsche Bahn transport: http://www.bahn.de/p/view/service/fahrgastrechte/nationale_regelungen.shtml, access 25.08.2011.

[153] Information from press articles. See for instance http://www.sueddeutsche.de/politik/deutsche-bahn-ice-und-die-hitze-bei-grad-streikt-die-klimaanlage-1.975380 (released 7/15/2010 by süddeutsche.de) or http://www.spiegel.de/international/germany/0,1518,707938,00.html (released 7/22/2011 by spiegelonline.de).

air conditioning systems will even fail given much lower temperatures. According to the Transport Minister Peter Ramsauer, this adaptation deficit can be attributed to costs cuts in order to prepare the Deutsche Bahn AG for a planned initial public offering in 2008 which were too deeply. Due to these savings the maintenance of the technical equipment was neglected which still leads to technical problems of air conditioning systems. This raises the question whether politics should set higher standards for air conditioning in trains in order to guarantee the physical safety of the passengers even under extreme weather conditions. According to the CEO of the state-owned German rail company Rüdiger Grube the company will assure that air-conditioning systems could cope with up to 45 degrees Celsius in the future. According to a railway expert[154] of the Südwestrundfunk (SWR), a German public broadcasting service, retrofitting of the 3300 railway carriages with air conditioning will cost 5 million Euro. Unfortunately, the German railway operator Deutsche Bahn does not provide official data about retrofitting requirements.

The situation in Germany is very special and cannot be transferred to other European countries due to heterogeneity of the European rolling stock.

Eurostat provides the number of trainsets differentiated by speed and the number of railway trailers and coaches in Europe , but does not distinguish between railway carriages for high-speed trains and for regional trains and does not provide further details about age or air conditioning of carriages.

4.2.5 Road

Climate change can cause higher temperatures as well as precipitation with increased intensity (e.g. HM Government, 2011; Stecker et al., 2011). In the next section the retrofitting of roads to higher temperatures is explained and the costs for this adaptation measure are estimated. The second section in this chapter concentrates on drainage systems for roads. In reality the adaptation measures might be done simultaneously and therefore costs may differ. All data and calculations of this subchapter can be found in the accompanying Excel file “Adaptation Costs Transport Road.xlsx”.

4.2.5.1 Retrofitting existing infrastructure concerning increased temperature

Definition of concrete measures and costs for roads

The impact of temperature increase on roads is the potential increase of rut occurrence (Peterson et al., 2008). Other severe consequences are not to be expected. Roads consist of different layers: a surface course, a binder course and a base course, sub-base and subgrade. For renewal and possible adaptation to climate change only the surface course and in some cases the binder course have to be exchanged, unlike to concrete asphalt, which has to be completely exchanged for renewal. The single layers have a different durability: surface course 15 years, a binder course 20 years and a base course 30 years.

The use of more heat resistant asphalt would be a solution for climate change induced impact of higher temperatures. Asphalt consists of 95% aggregates (crushed rock, sand, gravels or slags) and 5% bitumen as binder material. The allowed mixtures and their use are

[154] The interview with the expert can be downloaded under http://www.swr.de/swr1/bw/tipps/automobil/-/id=446370/did=8148780/pv=mplayer/vv=popup/nid=446370/1roa0n0/index.html.

restricted by the EU standard EN 13108, which is transferred into national norms (e.g. for Germany DIN EN 13108).

Whereas the different types of aggregates are not temperature sensitive, bitumen is a viscous-elastic material which is highly sensitive to temperature. According to two experts[155] bitumen resistant to higher temperatures could be used from the technological point of view. The price effects for such material usage are assessed to be low.[156] However the actual usage of such temperature robust bitumen is limited. If the temperatures increase in both summer and winter and consequently the temperature amplitude over the year remains unchanged, heat resistant bitumen could be used. But if climate change leads to an increase of the amplitude between summer maximum and winter minimum temperatures, the use of heat resistant bitumen would be no suitable solution (see also runways, where the same problem might occur) but highly sophisticated binder material would be necessary.

Transfer of cost estimates for additional maintenance

The price for bitumen is necessary to derive cost estimates for more heat resistant asphalt. According to three experts, the prices for asphalt are strongly determined by the bitumen price, which is highly volatile. Bitumen used to be a by-product of the oil refinery process, but meanwhile the technology progressed and bitumen is no by-product anymore. Therefore the bitumen price is connected to the crude oil prices and is expected to increase in the future.[157]

According to three experts average unit prices for conventional asphalt or high temperature resistant asphalt or highly sophisticated asphalt are not available.[158] The asphalt price depends on several variables like thickness, subgrade, type of asphalt (EN 13108-1 to EN 13108-7), weather conditions, weight on the road and type of road (high speed, low speed, stop and go). Therefore no price per km road could have been applied.

Hence the cost estimates are based on the assumptions of the report by Ecologic Institute on cost estimates for Germany (see Tröltzsch et al., 2011). They refer to costs for one km motorway renewal of 1.75 million Euros in the canton Zurich. For the renewal prices on state, provincial and communal roads we base on data provided by the Regierungsrat Canton Zurich (2006) with 72,000 Swiss Franc/km for state and communal roads and 417,000 Swiss Franc/km for national roads. As the differentiation of road type in Switzerland is not the same as in provided in the data by Eurostat, we use the average of both prices for roads other than motorways transferred into Euros.

Furthermore we use the value of 5-15% additional costs for better asphalt, stated by an expert interviewed by Ecologic Institute (Tröltzsch et al., 2011). The renewal cycles were differentiated between motorways with 10 years cycle and other roads of 15 years cycle. After retrofitting the roads with better asphalt it is possible that the renewal cycle will extend, but this would depend also on other factors, e.g. volume of traffic, specific type of asphalt, type of street. The length of roads by type is data provided by Eurostat.

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[155] According to two experts of European Asphalt Pavement Association (EAPA) and Deutscher Asphalt Verband (DAV).

[156] Information via telephone form the Bundesanstalt für Straßenwesen (BASt).

[157] Information via telephone from the Bundesanstalt für Straßenwesen (BASt).

[158] Information via telephone from BAST, EAPA, DAV.

In detail the basis of these cost estimates are the following data:

- L_{Ri}: Length of road in country *i* in km (Source: Eurostat)
    - L_{Ri}^{M}: Length of motorways in country *i* in km
    - L_{Ri}^{SR}: Length of state roads in country *i* in km
    - L_{Ri}^{PR}: Length of provincial roads in country *i* in km
    - L_{Ri}^{CR}: Length of communal roads in country *i* in km
- R: Renewal cycle (Source: Expert judgment)
    - R^{M}: Renewal cycle for motorways (10 years according to Tröltzsch et al., 2011)
    - R^{SPCR}: Renewal cycle for state roads, provincial roads and communal roads.

      According to EAPA[159] and DAV[160] expert between 15 and 20 years.

      Conservative assumption of 15 years cycle
- $c_{motorways}$: Costs for standard surface asphalt for motorways in million EUR per km (Source: Tröltzsch et al., 2011 referring to renewal cost in canton Zurich) with 1.75 million EUR/km
- $c_{otherroads}$: Costs for standard surface asphalt for state, provincial and communal roads in million EUR per km (Source: Regierungsrat Canton Zurich, 2006) with 0.16 million EUR/km
- $c_{motorways}^{min}$: Costs for better surface asphalt for motorways in million per km (Source: Tröltzsch et al., 2011 referring to expert judgment of additional cost of 5-15%), as minimum 5% is used and calculated by $c_{motorways}$*1.05 = 1.8375
- $c_{motorways}^{max}$: Costs for better surface asphalt for motorways in million per km (Source: Tröltzsch et al., 2011 referring to expert judgment of additional cost of 5-15%), as maximum 15% is used and calculated by $c_{motorways}$*1.15 = 2.0125

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[159] EAPA: European Asphalt Pavement Association (http://www.eapa.org/index.php).

[160] DAV: Deutscher Asphalt Verband (http://www.asphalt.de/site/startseite/).

- $c_{otherroads}^{min}$: Costs for better surface asphalt for state, provincial and communal roads in million per km (Source: Regierungsrat Canton Zurich, 2006; Tröltzsch et al., 2011 referring to expert judgment of additional cost of 5-15%), as minimum 5% is used and calculated by $c_{otherroads}$*1.05 = 0.168

- $c_{otherroads}^{max}$: Costs for better surface asphalt for or state, provincial and communal roads in million per km (Source: Regierungsrat Canton Zurich, 2006; Tröltzsch et al., 2011 referring to expert judgment of additional cost of 5-15%), as maximum 15% is used and calculated by $c_{otherroads}$*1.15 = 0.184

- C_{Rsi}: total costs for standard asphalt per year in country *i*

- C_{Rbi}^{min}: total minimum costs for better surface asphalt per year in country *i*

- C_{Rbi}^{max}: total maximum costs for better surface asphalt per year in country *i*

- C_{Add}^{min}: total minimal additional costs per year in country *i*

- C_{Add}^{max}: total maximal additional costs per year in country *i*

For each EU member state *i* the total minimum and maximum costs for better surface asphalt are calculated by the two formulas:

Minimum total costs per year:

$$C_{Rbi}^{min} = L_{Ri}^{M} / R^{M} * c_{motorways}^{min} + (L_{Ri}^{SR} + L_{Ri}^{PR} + L_{Ri}^{CR}) / R^{SPCR} * c_{otherroads}^{min}$$

Maximum total costs per year:

$$C_{Rbi}^{max} = L_{Ri}^{M} / R^{M} * c_{motorways}^{max} + (L_{Ri}^{SR} + L_{Ri}^{PR} + L_{Ri}^{CR}) / R^{SPCR} * c_{otherroads}^{max}$$

The minimum and maximum additional costs for each EU member state *i* are calculated by the two formulas:

Minimum additional costs per year:

$$C_{Add}^{min} = C_{Rbi}^{min} - C_{Rsi}$$

Maximum additional costs per year:

$$C_{Add}^{max} = C_{Rbi}^{max} - C_{Rsi}$$

Table 4-21: Parameter values chosen for the estimation

Parameter	Description of parameter	Assumed value (can easily be changed in the Excel file)	Notes
$c_i^{motorways}$	Costs for renewal motorways with standards asphalt in million EUR/km	1.75	Based on Tröltzsch et al., 2011 referring to costs for canton Zurich
$c_i^{other\ roads}$	Costs for renewal state, provincial and communal with standards asphalt in million EUR/km	0.16	Based on Regierungsrat Canton Zurich, 2006
R^M	Renewal cycle motorways	10	Based on Tröltzsch et al., 2011
R^{SPCR}	Renewal cycle state roads	15	Assumption by authors based on expert information of 15-20 years renewal cycle
R^{SPCR}	Renewal cycle provincial roads	15	
R^{SPCR}	Renewal cycle communal roads	15	
$c_{motorways}^{min}$	% minimal cost for better asphalt for motorways	5%	Based on Tröltzsch et al., 2011 referring to expert information
$c_{motorways}^{max}$	% maximal costs for better asphalt for motorways	15%	Based on Tröltzsch et al., 2011 referring expert information
$c_{other\ roads}^{min}$	% minimal cost for better asphalt for state, provincial and communal roads	5%	Based on Tröltzsch et al., 2011 referring to expert information
$c_{other\ roads}^{max}$	% maximal costs for better asphalt for state, provincial and communal	15%	Based on Tröltzsch et al., 2011 referring expert information

Important assumptions resulting from the methodology and data availability

For calculation of the additional renewal costs of roads in each member state, the following assumptions and limitations had to be made:

- There is no data for renewal of roads available. Therefore assumptions on renewal costs per km for standard asphalt on motorways for the canton Zurich (referring to Tröltzsch et al., 2011) were used for motorways. For state, provincial and communal roads data by the Regierungsrat Canton Zurich (2006) was used. The mean of costs for other roads than motorways at the Canton Zurich is transferred into EUR 0.16. Hence the costs are identical throughout Europe but differentiated by type of road.

- Additional costs were calculated by a 5-15% cost increase for better asphalt referring to expert information in Tröltzsch et al. (2011).

- No differentiation between several types of asphalt is made, due to lack of information where which type is used.

- The speed limits and frequency of traffic on different road types were not included.

- The temperature increase is not included because for vulnerability assessment the specific asphalt type and thickness would be necessary. Furthermore, according to expert information, a temperature increase of 1-2℃ would not have significant impact on roads.

- The renewal cycle is based on experts' judgment. It is assumed that motorways are renewed every 10 years and other streets every 15 years.

- In case there was no data on road length for 2009 available the latest data was used.

- When there was no data on road length available, their length is assumed to be zero.

Results: Costs of adapting roads to higher temperatures in the EU

Table 4.22 below shows the costs for standard asphalt in the second column, total costs for better asphalt in the middle for minimal and maximal cost assumptions and on the right side the referring additional costs for better asphalt. The costs are reported in million € per year, although in reality the (investment) costs do not occur yearly.

Table 4-22: Results of additional costs for better surface asphalt per year for European countries in million EUR

Country	Total costs for standard asphalt	Total costs for better asphalt		Additional costs for better asphalt	
		min	max	min	max
AT	1,414	1,485	1,626	71	212
BE	1,931	2,028	2,221	97	290
BG	595	625	684	30	89
CY	174	183	200	9	26
CZ	1,513	1,589	1,740	76	227
DE	8,036	8,438	9,241	402	1,205
DK	1,071	1,125	1,232	54	161
EE	606	636	697	30	91
ES	3,982	4,181	4,579	199	597
FI	1,261	1,325	1,451	63	189
FR	12,940	13,587	14,881	647	1,941
GR	147	154	169	7	22
HU	3,126	3,282	3,595	156	469
IE	1,140	1,197	1,311	57	171
IT	3,747	3,935	4,310	187	562
LT	918	964	1,056	46	138
LU	81	85	93	4	12
LV	634	666	729	32	95
MT	22	23	26	1	3
NL	1,822	1,914	2,096	91	273
PL	4,246	4,458	4,883	212	637
PT	1,149	1,206	1,321	57	172
RO	928	974	1,067	46	139
SE	1,812	1,903	2,084	91	272
SI	538	565	619	27	81
SK	532	559	612	27	80
UK	5,084	5,339	5,847	254	763
EU 27	59,451	62,424	68,369	2,973	8,918

Cost sharing

The road structure in length per country is based on Eurostat data, which contains only public roads. Therefore the estimated costs will arise for the public budget. The national governmental levels will be affected differently, depending on the responsibility (central vs. federal state) for types of roads. If there is a private ownership of roads, the costs have to be borne by the private owner. Furthermore some European countries (like Austria) levy a toll for their motorways. This toll could be used to maintain the roads and therefore also for adapting the roads to higher temperatures in the future. The expenditures are then carried privately by the users of the motorways, at least part of them.

4.2.5.2 Retrofitting existing infrastructure concerning increased precipitation

Definition of concrete measures and costs for roads

Beside of adaptation to higher temperatures, roads are also affected by an increase of rain (Stecker et al., 2011). The capacity increase of roads' drainage systems is the most appropriate adaptation measurement to precipitation increase. According to an expert of a major drainage system supplier, the drainage system for communal roads is designed in a way that two incidents a year are permitted. For motorways extreme events within a period of five years is consulted.

Transfer of cost estimates for additional maintenance

The cost estimations for roads are based on the cost estimations for runways (see 4.2.6.2). There was no literature found on the additional costs for adaptation of drainage system on roads. Therefore we refer to expert information on airport and road drainage system. The experts gave as average costs for a drainage system of a Ukrainian airport[161] and German roads and airports.[162] The Ukrainian basic price for current drainage capacity is 120 Euro per m for a runway width of 48 m. We assume that the price of drainage system does not proportionally depend on the width of runway or road. Therefore we took the price of drainage at a Ukrainian airport also as basic for roads.

This price was transferred to current prices for drainage system of each European country basing on the mean annual wet day frequency 1961-1990 (Tyndall, CY 1.1) in days for each country. The adaptation costs were calculated for three possible capacity increases of drainage system, namely 100%, 50% and 20%. The cost increase for the different capacities is transferred from the Ukraine cost increase for a 100% change in capacity according to an expert from the major supplier MEA. The total costs were calculated with the countries' additional costs and their total length of roads (data from Eurostat).

In detail the basis of these cost estimates consists of the following data:

- L_i: Total length of motorways with a share of 50% and all communal roads in country *i* in km (Source: Eurostat)
- WD_i: mean wet day frequency in 1961-1990 for country *i* in days (Source: Tyndall, TYN CY 1.1)
- $WD_{Ukraine}$: mean wet day frequency in 1961-1990 for the Ukraine in days (Source: Tyndall, TYN CY1.1): $WD_{Ukraine} = 141.7\ days$

[161] Information by Carsten Schreyer, MEA Water Management GmbH, Aichach-Ecknach, Germany via telephone.

[162] Information by Michael Sieber, ACO.

- c_{DU}: Costs for drainage system at current capacity constraints in the Ukraine in EUR/m (Source: MEA expert information): $c_{DU} = 120\,EUR/m$

- c_{Di}: Costs for drainage system at current capacity constraints in country *i* in EUR/m. Calculated by the formula: $c_{Di} = \frac{WD_i}{WD_{Ukraine}} * c_{DU}$

- c_{Di}^{100}: Costs for drainage system with 100% capacity increase in country *i* in EUR/m. Calculated by the formula: $c_{Di}^{100} = c_{Di} * 1.40$

- c_{Di}^{50}: Costs for drainage system with 50% capacity increase in country *i* in EUR/m. Calculated by the formula: $c_{Di}^{50} = c_{Di} * 1.20$

- c_{Di}^{20}: Costs for drainage system with 20% capacity increase in country *i* in EUR/m. Calculated by the formula: $c_{Di}^{20} = c_{Di} * 1.08$

- C_{Di}^{100}: Total costs for capacity increase of 100% in country *i in EUR. Calculated by the formula:* $C_{Di}^{100} = c_{Di}^{100} * L_i$

- C_{Di}^{50}: Total costs for capacity increase of 50% in country *i in EUR. Calculated by the formula:* $C_{Di}^{50} = c_{Di}^{50} * L_i$

- C_{Di}^{20}: Total costs for capacity increase of 20% in country *i in EUR. Calculated by the formula:* $C_{Di}^{20} = c_{Di}^{20} * L_i$

Table 4-23: Parameter values chosen for the estimation

Parameter	Description of parameter	Assumed value (can easily be changed in the Excel file)	Notes
L_i	Length of roads, counting only the half of motorways to be equipped with a drainage system and other roads will be completely equipped	50% (motorways) 100% (other roads)	Assumption by authors based on expert information
c_{UC}	Costs for drainage system at current capacity constraints in the Ukraine in EUR/m	120	Based on information by MEA expert
$WD_{Ukraine}$	Mean wet day frequency in 1961-1990 for the Ukraine in days	141.7	Based on data from Tyndall TYN CY 1.1
IC^{100}	100% increase of capacity of drainage system	100%	Assumption by authors to portray different future need of capacity adaptation
IC^{50}	50% increase of capacity of drainage system	50%	
IC^{20}	20% increase of capacity of drainage system	20%	
AC^{100}	% of cost increase of current cost for drainage system for a 100% increase of drainage capacity	40%	Based on information by MEA expert, who stated a cost increase of 30-50% for an increase of capacity of 100%. Using the mean of the 30-50% range.
AC^{50}	% of cost increase of current cost for drainage system for a 50% increase of drainage capacity	20%	Assumption by authors based on information of cost increases for a 100% capacity increase. Calculated as proportion (50*40/100 = 20%)
AC^{20}	% of cost increase of current cost for drainage system for a 20% increase of drainage capacity	8%	Assumption by authors based on information of cost increases for a 100% capacity increase. Calculated as proportion (20*40/100 = 8%)

Important assumptions resulting from the methodology and data availability

- The estimations are based on information about drainage systems for airports.
- The basis is the costs for a Ukrainian drainage system with costs of 120 EUR per meter for its current capacity.
- Differentiation between motorways and other roads were made. For motorways a share of 50% with drainage system was assumed, whereas other roads are completely equipped with drainage systems.
- The width of roads was not taken into account. It was assumed that the width will not affect the price of drainage system proportionally. So that it does not matter whether the drainage system is built for a width of 48 m (Ukraine) or a narrower street.

- As current capacity of the drainage systems, the mean wet day frequency for the years 1961-1990 (Tyndall) was used for the European countries.
- The Ukrainian mean wet day frequency of 141.7 days was used to calculate the current costs of drainage system for other European countries depending on their specific mean wet day frequency.
- The costs for current capacity in European countries were inferred by the basic price of the Ukraine drainage system by applying the mean wet day frequency.
- The additional costs for an increased capacity were based on information of Ukraine. The MEA expert assumed a 30 to 50% cost increase for a capacity change of 100%. We used the mean of cost increase, namely 40% (48 EUR/m for the Ukraine). The cost increase for the 50% and 20% capacity change were proportionally calculated. Which leads to 20% (24 EUR/m for Ukraine) cost increase for a capacity change of 50% and 8% (9.6 EUR/m for Ukraine) cost increase for a capacity change of 20%.

Results: Costs of adapting roads to increase in precipitation in the EU

Tabel 4.24 below shows the results of additional costs in EUR for different increase of capacity of the existing drainage system. The investments in drainage system are long-term issues. The implementation of a drainage system with specific increased capacity should take the future need for precipitation capacities into account.

Table 4-24: Results of estimations for additional costs of drainage system adapting more wet days in Europe in thousand EUR

Country	total additional costs in EUR depending on % increase of drainage capacity for each country		
	100% increase of capacity	50% increase of capacity	20% increase of capacity
AT	6,237	3,118	1,247
BE	10,388	5,194	2,078
BG	1,612	806	322
CY	301	151	60
CZ	7,386	3,693	1,477
DE	33,561	16,780	6,712
DK	4,812	2,406	962
EE	3,376	1,688	675
ES	6,867	3,434	1,373
FI	7,149	3,574	1,430
FR	57,947	28,974	11,589
GR	290	145	58
HU	13,144	6,572	2,629
IE	7,272	3,636	1,454
IT	10,383	5,191	2,077
LT	5,017	2,508	1,003
LU	353	176	71
LV	3,668	1,834	734
MT	40	20	8
NL	8,551	4,275	1,710
PL	22,116	11,058	4,423
PT	3,390	1,695	678
RO	3,810	1,905	762
SE	8,574	4,287	1,715
SI	2,053	1,026	411
SK	2,460	1,230	492
UK	29,314	14,657	5,863
EU 27	243,223	121,612	48,645

Cost sharing

Like for the renewal of roads surface the length per country is based on Eurostat data and these values were used to calculate the costs for drainage systems. This database contains only public roads. Therefore the estimated costs will arise for the public budget. The national governmental levels will be affected differently, depending on the responsibility (central vs. federal state) for specific types of roads.

Road Bridges

The impact of climate change on road bridges are mainly threats due to floods causing e.g. scour (Dore and Burton, 2001). Effects caused by higher temperature on the surface of the bridges are covered by the estimations of road renewal. Effects of temperature changes to the bridge itself depend on the type of bridge and the location. According to Dore and Burton most Canadian bridges will withstand a temperature increase of 5℃. This seems to be also valid for Europe, as the clime in Canada is more extreme than in Europe.

There is one report about the infrastructure of road bridges in Germany by the Federal Ministry of Transport, Building and Urban Development (BMVBS, 2006). According to it the total area of bridges on German state roads is 27.27 million m². The bridges are differentiated into four types by their method of building: concrete, metal, arch and steel. In Germany the age of bridges varies between 30-50 years (BMVBS, 2006). This will lead to necessary renewal in the next years (BMVBS, 2006).

Another study by Dore and Burton (2001) refers to adaptation cost for Canada. They claim that 75% of the Canadian bridges require replacement anyway and therefore the adaptation costs will be close to zero. Applying this to Germany, the costs for adaptation will also be low. Bridges are designed with a timeframe up to 100 years (Peterson et al., 2008), which means that the standards are already high when they are built. The costs for bridges provided by Dore and Burton (2001) are:

- Average bridge for all weather road in Ontario will cost between 65,000-150,000 Canadian Dollar per bridge (this corresponds approximately to 46,880-108,185 Euro with an average exchange rate of 2001)
- Average replacement cost for a coast bridge is 600,000 Canadian Dollar

This data give a first insight into possible costs for bridges, but not if additional costs caused by climate change will arise. Moreover data for bridges are only provided for rail bridges by Eurostat. Furthermore the geographic location of the bridge would have to be taken into account to decide if it is affected by floods or not. Unfortunately, the available data does not allow the estimation of adaptation costs concerning road bridges.

4.2.6 Aviation

Like roads the adaptation measures for runways concern the effects of higher temperatures as well as more frequent rain events (Stecker et al., 2011). For airport facilities there are high standards due to security reasons. For example the asphalt used for runways is highly sophisticated (see e.g. Peterson et al., 2008; EAPA, 2003 airfield uses of asphalt). The already high standards and the adjustments to future transport conditions like larger planes or a higher frequency of air traffic leads to the conclusion that high additional costs induced by climate change adaptation measures are not expected.

4.2.6.1 Retrofitting existing infrastructure of airports concerning increased temperature

Definition of concrete measures and costs for airports

A temperature increase may cause rut occurrence at airports like on roads (National Research Council, 2008). At airports not only the road infrastructure but also parking spaces, taxi ranks and especially runways will be affected. The possible adaptation measures and the limits are the same as for roads concerning increased temperature. The renewal of the surface course by a more temperature robust asphalt is only a proper solution if temperatures increase in summer as well as in winter time. Nevertheless, due to lack of other data for highly sophisticated asphalt and its costs, we refer to the data used for roads.

Transfer of cost estimates for additional maintenance

We transfer the cost estimates and the assumptions made for road renewal to runways. The renewal of parking spaces, taxi ranks or other infrastructure of airports are not taken into account, due to lack of data about their extension. The cost estimates are again based on the assumptions of the report by Ecologic Institute that stated costs of 1.75 million € per km renewal of motorways and 5-15% additional costs for better asphalt (for a detailed explanation see section 0). As for roads, also for runways a general statement about which asphalt type is used cannot be made (see case study by EAPA, 2003). Different asphalt types and mixtures are possible. The usage strongly depends on the volume of traffic (see EAPA, 2003). Therefore the costs for motorways' pavement are applied to runways to portray the traffic volume and the higher standards. As these costs per km refer to motorways we transferred the costs to runways by including the width of a runway. We assume that a motorway has a width of approximately 10 m (3.75 meter per line) and transfer it to runways by linking the length published at the World Factbook (CIA, 2011) to the width according to the Aerodome reference code (ICAO, 1999, p. 17).

In detail the basis of these cost estimates are the following data:

- A_{Ri}: Area of runways in country *i* in km² (Sources: World Factbook and ICAO)

  Calculated by the formula: $A_{Ri} = \sum_{j=1}^{n} L_j * W_j /1{,}000{,}000$

  - L_j: Length of runway *j* in m (Source World Factbook)

    Calculated by the mean values of lengths for four categories (3047 m, 2742.5 m, 1980.5 m, 1218.5 m)

  - W_j: Width of runway *j* in m (Source ICAO)

    Calculated by the mean values of width for four categories (20.5 m, 26.5 m, 37.5 m, 52.5 m)

  - N: Number of Runways within one country *i*

- R: Renewal cycle

  - R^5: Renewal cycle of 5 years

  - R^{10}: Renewal cycle of 10 years

- c_{RSi}: Costs for standard surface asphalt in million EUR per km²

  (Source: Tröltzsch et al., 2011 referring to renewal cost in canton Zurich for motorways)

Calculated by the formula: $c_{Ri} = \frac{1.75}{10} * 1000 = 175\ million\ Euro\ per\ km^2$

- c_{Rbi}^{min}: Costs for better surface asphalt in million per km (Source: Tröltzsch et al., 2011 referring to expert judgment of additional cost of 5-15%), as minimum 5% is used and calculated by c_{RSi}*1.05 = 183.75

- c_{Rbi}^{max}: Costs for better surface asphalt in million per km (Source: Tröltzsch et al., 2011 referring to expert judgment of additional cost of 5-15%), as maximum 15% is used and calculated by c_{RSi}*1.15 = 201.25

- C_{Rsi}: total costs for standard asphalt per year in country *i*

- C_{Rbi}^{min}: total minimum costs for better surface asphalt per year in country *i*

- C_{Rbi}^{max}: total maximum costs for better surface asphalt per year in country *i*

- C_{Add}^{min}: total minimal additional costs per year in country *i*

- C_{Add}^{max}: total maximal additional costs per year in country *i*

For each EU member state *i* the total minimum and maximum costs for better surface asphalt are calculated by the two formulas:

Minimum total costs per year:

$$C_{Rbi}^{min} = A_{Ri} * \ c_{Rbi}^{min}/R$$

Maximum total costs per year:

$$C_{Rbi}^{max} = A_{Ri} * * \ c_{Rbi}^{max}/R$$

The minimum and maximum additional costs for each EU member state *i* are calculated by the two formulas:

Minimum additional costs per year:

$$C_{Add}^{min} = C_{Rbi}^{min} - C_{Rsi}$$

Maximum additional costs per year:

$$C_{Add}^{max} = C_{Rbi}^{max} - C_{Rsi}$$

Table 4-25: Parameter values chosen for the estimation

Parameter	Description of parameter	Assumed value (can easily be changed in the Excel file)	Notes
c_{Rsi}	Costs for standard surface asphalt in million EUR/ km²	175	Based on assumptions for pavement cost for motorways according to Tröltzsch et al., 2011 referring to costs for canton Zurich. Authors' transfer costs per km into costs per km² by assuming a road width with 10 m and then calculating the costs for km².
R^5	Renewal cycle of 5 years	5	Authors assumption with more frequent renewal than motorways
R^{S10}	Renewal cycle of 10 years	10	Authors assumption based on renewal cycle of motorways
c_{Rbi}^{min}	% minimal cost for better asphalt	5%	Based on pavements for roads from Tröltzsch et al., 2011 referring to expert information
c_{Rbi}^{max}	% maximal costs for better asphalt	15%	Based on pavements for roads from Tröltzsch et al., 2011 referring to expert information

Important assumptions resulting from the methodology and data availability

The calculation for runway renewal is based on the assumptions for road renewal (see section 4.2.4.1), but additional assumptions and limitations had to be made:

- There is no data for renewal of runways available. Therefore assumptions on renewal costs per km for standard asphalt on motorways for the canton Zurich (referring to Tröltzsch et al., 2011) were used. Hence the costs are identical throughout Europe.
- Additional costs were calculated by a 5-15% cost increase for better asphalt referring to expert information in Tröltzsch et al. (2011).
- The frequency of arrivals and departures is not included.
- Like for roads the temperature increase is not included because the specific asphalt type and thickness would be necessary for vulnerability assessment. Furthermore, according to expert information, the temperature increase of 1-2℃ would not have significant impact on roads and this would also count for runways.
- The10-years renewal cycle is based on Kahrl and Roland-Holst (2008 referring to National Research Council). Additionally calculations for a 5 year cycle are provided in the corresponding excel file.

- Only cost estimations for the renewal of runways were made. Calculations for parking space, taxi ranks or other paved infrastructure of airports is not taken into account, due to lack of data.

- For the length of runways the mean length per category were taken because detailed lengths of airfields per airport are not available.

- The width of runways is based on the categories of ICAO. The mean values for each category corresponding to the length were used.

Results: Costs of adapting runways to higher temperatures in the EU

Below the estimates for annual costs with a ten year cycle of renewal is provided (see Table 4.26). The costs are reported in million Euros per year, although in reality the costs are not yearly. The costs for standard asphalt are on the left side and the additional costs for better asphalt are shown for the minimal and maximal cost increase in the very right column. As mentioned in the preface of this chapter the figures should be treated with care, because the adjustment of runways to future traffic volume may outrange adaptation costs so that the impact of climate change on runways is marginal compared to impacts of expected traffic volume.

Table 4-26: Results of additional costs for better surface asphalt per year for European runways in million EUR with a 10-year cycle

Country	Total costs for standard asphalt	Total costs for better asphalt		Additional costs for better asphalt	
		min	max	min	max
AT	29	30	33	1	4
BE	49	52	57	2	7
BG	133	140	153	7	20
CY	24	25	27	1	4
CZ	63	66	73	3	9
DE	414	435	476	21	62
DK	42	44	48	2	6
EE	28	30	33	1	4
ES	149	157	172	7	22
FI	118	124	136	6	18
FR	397	417	457	20	60
GR	108	114	124	5	16
HU	38	40	44	2	6
IE	20	21	23	1	3
IT	166	174	191	8	25
LT	33	35	38	2	5
LU	3	3	3	0	0
LV	26	27	30	1	4
MT	3	3	3	0	0
NL	38	40	44	2	6
PL	167	175	192	8	25
PT	63	66	73	3	9
RO	57	60	66	3	9
SE	219	229	251	11	33
SI	10	11	12	1	2
SK	24	25	28	1	4
UK	431	453	496	22	65
EU 27	2,855	2,998	3,283	143	428

Cost sharing

The cost sharing depends on the ownership structure of airports. At some airports public owners are involved. One example is the Frankfurt Airport, which is operated by Fraport AG and the federal state Hesse holds shares.[163] Nevertheless, the operator can charge the end users and therefore can pass through some amount of the costs to consumers.

4.2.6.2 Retrofitting existing infrastructure of airports' drainage system to increase of wet days

Definition of concrete measures and costs for airports

Beside of adaptation to higher temperatures airports are affected by increase of rain (Stecker et al., 2011). The measure taken against more humid weather conditions in the future is the increase in drainage capacity at airports and mainly for runways (National Research Council, 2008; ICAO, Environment Report, 2010; Saarelainen, 2006). Nowadays for adapting drainage systems at airports the half-year incident is decisive.

Transfer of cost estimates for an increase of drainage capacity at runways

The cost estimation is limited to runways, other airport infrastructure where drainage systems are also used are not included due to data constraints. To the best of our knowledge costs for drainage system at airports and especially for runways in whole Europe are not provided. We refer to expert information on a drainage system of a Ukrainian airport.[164] The Ukraine basic price for current drainage capacity is 120 Euro per m for a runway width of 48 m. This price was transferred to current prices for drainage system of each European country basing on the mean annual wet day frequency 1961-1990 (Tyndall, CY 1.1) in days for each country. The adaptation costs were calculated for three possible capacity increases of drainage system, namely 100%, 50% and 20%. The cost increase for the different capacities is inferred from the Ukraine cost increase for a 100% change in capacity according to an expert from MEA, a major supplier of drainage systems. The total costs were calculated with the countries' additional costs and their length of runways (data from CIA World Factbook 2011). The mean average width of the European runways is at about 45 m, which is not considerably different to the based 48 m. Furthermore the width will not proportionally affect the price of a drainage system. Therefore the width of runways was not taken into account.

In detail the basis of these cost estimates are the following data:

- L_i: Length of runway in country *i* in m (Source: World Factbook)
    - Using the mean values of lengths for four categories (3047 m, 2742.5 m, 1980.5 m, 1218.5 m): L_j
    - N: Number of Runways within one country *i*
    - Calculated by the formula: $L_i = \sum_{i=1}^{n} L_j * N$

[163] For more details see: http://www.fraport.de/content/fraport-ag/de/investor_relations/die_fraport-aktie/basisdaten_aktionaersstruktur.html.

[164] Information by Carsten Schreyer, MEA Water Management GmbH, Aichach-Ecknach, Germany via telephone.

- WD_i: mean wet day frequency in 1961-1990 for country *i* in days (Source: Tyndall, TYN CY1.1)

- $WD_{Ukraine}$: mean wet day frequency in 1961-1990 for the Ukraine in days (Source: Tyndall, TYN CY1.1): $WD_{Ukraine} - 141.7\ days$

- c_{DU}: Costs for drainage system at current capacity constraints in the Ukraine in EUR/m (Source: MEA expert information): $c_{DU} = 120\ EUR/m$

- c_{Di}: Costs for drainage system at current capacity constraints in country *i* in EUR/m. Calculated by the formula: $c_{Di} = \frac{WD_i}{WD_{Urkaine}} * c_{DU}$

- c_{Di}^{100}: Costs for drainage system with 100% capacity increase in country *i* in EUR/m. Calculated by the formula: $c_{Di}^{100} = c_{Di} * 1.40$

- c_{Di}^{50}: Costs for drainage system with 50% capacity increase in country *i* in EUR/m. Calculated by the formula: $c_{Di}^{50} - c_{Di} * 1.20$

- c_{Di}^{20}: Costs for drainage system with 20% capacity increase in country *i* in EUR/m. Calculated by the formula: $c_{Di}^{20} = c_{Di} * 1.08$

- C_{Di}^{100}: Total costs for capacity increase of 100% in country *i in EUR. Calculated by the formula:* $C_{Di}^{100} = c_{Di}^{100} * L_i$

- C_{Di}^{50}: Total costs for capacity increase of 50% in country *i in EUR. Calculated by the formula:* $C_{Di}^{50} = c_{Di}^{50} * L_i$

- C_{Di}^{20}: Total costs for capacity increase of 20% in country *i in EUR. Calculated by the formula:* $C_{Di}^{20} = c_{Di}^{20} * L_i$

Table 4-27: Parameter values chosen for the estimation

Parameter	Description of parameter	Assumed value (can easily be changed in the Excel file)	Notes
c_{DU}	Costs for drainage system at current capacity constraints in the Ukraine in EUR/m	120	Based on information by MEA expert
$WD_{Ukraine}$	Mean wet day frequency in 1961-1990 for the Ukraine in days	141.7	Based on data from Tyndall TYN CY 1.1
IC^{100}	100% increase of capacity of drainage system	100%	Assumption by authors to portray different future need of capacity adaptation
IC^{50}	50% increase of capacity of drainage system	50%	
IC^{20}	20% increase of capacity of drainage system	20%	
AC^{100}	% of cost increase of current cost for drainage system for a 100% increase of drainage capacity	40%	Based on information by MEA expert, who stated a cost increase of 30-50% for an increase of capacity of 100%. Using the mean of the 30-50% range.
AC^{50}	% of cost increase of current cost for drainage system for a 50% increase of drainage capacity	20%	Assumption by authors based on information of cost increases for a 100% capacity increase. Calculated as proportion (50*40/100 = 20%)
AC^{20}	% of cost increase of current cost for drainage system for a 20% increase of drainage capacity	8%	Assumption by authors based on information of cost increases for a 100% capacity increase. Calculated as proportion (20*40/100 = 8%)

Important assumptions resulting from the methodology and data availability

- We only estimate costs for increased capacity of drainage system of runways. Other infrastructure like parking space or taxi ranks is not taken into consideration due to lack of data.
- The length of runways is based on the data provided by the CIA World Factbook. The mean length of runways per category was taken because detailed lengths of airfields per airport are not available.
- The width of runways was assumed to be the same for each runway. Because the mean average width of European runways is about 45 m and the calculations are based on a price for drainage system for a runway with 48 m width. Furthermore the costs will not proportionally depend on the width of runway.
- The basic for costs of a drainage system are the costs for a Ukrainian drainage system with costs of 120 EUR per meter for its current capacity.
- As current capacity of the drainage systems, the mean wet day frequency for the years 1961-1990 (Tyndall) was used for the European countries.

- The Ukraine mean wet day frequency of 141.7 days was used to apply the current costs of drainage system for other European countries depending on their specific mean wet day frequency.
- The costs for current capacity in European countries were inferred by the basic price of the Ukraine drainage system by applying the mean wet day frequency.
- For the increase of capacity three scenarios were derived: 100%, 50% and 20% increase of drainage system's capacity.
- The additional costs for an increased capacity were based on information of the Ukraine. The MEA expert assumed a 30 to 50% cost increase for a capacity change of 100%. We used the mean of cost increase, namely 40% (48 EUR/m for the Ukraine).
- The cost increase for the 50% and 20% capacity change were proportionally calculated. Which leads to 20% (24 EUR/m for Ukraine) cost increase for a capacity change of 50% and 8% (9.6 EUR/m for Ukraine) cost increase for a capacity change of 20%.

Results: Costs of adapting runways to increase in precipitation in the EU

The estimations (Table 4.28) show that additional costs for adaptation measures depend on the aimed increase of capacity. The decision whether a drainage system with high capacity or low capacity should be implemented will depend on future rainfall forecasts. Furthermore it should be taken into account that investments in drainage infrastructure have a long-term horizon, which may lead to decisions for higher capacities. The estimates do not include the adaptation of pipes and filter systems, which would also be necessary with more precipitation, according to an expert from the drainage system supplier ACO.

Table 4-28: Results of estimations for additional costs of drainage system at runways adapting more wet days in Europe in thousand EUR

Country	Total additional costs in T EUR depending on % increase of drainage capacity for each country		
	100% increase of capacity	**50% increase of capacity**	**20% increase of capacity**
AT	2,134	1,067	427
BE	3,806	1,903	761
BG	5,557	2,778	1,111
CY	656	328	131
CZ	4,220	2,110	844
DE	30,816	15,408	6,163
DK	2,931	1,466	586
EE	1,937	968	387
ES	7,376	3,688	1,475
FI	9,390	4,695	1,878
FR	26,792	13,396	5,358
GR	3,881	1,940	776
HU	2,131	1,065	426
IE	1,833	916	367
IT	8,125	4,062	1,625
LT	2,471	1,236	494
LU	206	103	41
LV	1,928	964	386
MT	59	30	12
NL	2,869	1,434	574
PL	10,670	5,335	2,134
PT	3,245	1,622	649
RO	2,894	1,447	579
SE	15,527	7,764	3,105
SI	651	325	130
SK	1,683	841	337
UK	35,804	17,902	7,161
EU 27	181,591	90,796	36,318

Cost sharing

Like for runways also the cost sharing for drainage systems at airports depends on the ownership structure of the specific airport. Charging the end users would lead to payment by private persons at least for a part of the costs.

4.2.7 Shipping

Shipping on inland waterways is vulnerable to low water level and to flooding which both might occur more frequently if summer precipitation decreases and the intensity of precipitation increases. Adaptation to the effects of changes in rainfall may involve the improvement of the collection of hydrological data and existing early warning systems. Monitoring and data management enables inland navigation authorities to decide about navigation restrictions and closures and to improve the management of locks, sluices an weirs.

4.2.7.1 Retrofitting existing infrastructure of shipping concerning extreme events

Definition of concrete measures and costs for early warning systems

In the following section we will present cost estimates for the installation of additional hydrological stations in Europe. Even though most of the European countries already have a very sophisticated early warning und data collection system for inland waterways, there are still deficits. The increased risk of flooding and low water due to climate change will require the installation and maintenance of additional stations to guarantee a sufficient standard of monitoring.

Transfer of cost estimates for the installation of additional hydrological stations

In detail the basis of these cost estimates are the following data:

- N_{Si}: the number of stations in country *i* (Source: personal communication with the German Federal Institute of Hydrology (BFG))
- L_{Wi}: the length of waterways in country *i* (Sources: CIA World Factbook 2011)
- N_{Skmi}: number of stations per km of waterway in country *i,* calculated by the formula: $N_{Skmi} = N_{Si}/L_{Wi}$
- T: threshold for the required minimum number of stations per km. The threshold is set to $T = 0.015$ by the authors. This threshold is roughly related to the European average numbers of stations per km of waterway.
- D: cost for device for each new station installed (Source: personal communication with the Swiss Federal Office for the Environment (FOEN) transferred to Euro: $D = 27{,}000\ EUR$
- CC^{min}: minimum construction costs for one station (Source: FOEN) transferred to Euro: $CC^{min} = 18{,}000\ EUR$
- CC^{max}: maximum construction costs for one station (Source: FOEN) transferred to Euro: $CC^{max} = 73{,}000\ EUR$

- MC: maintenance costs for one station per year (Source: FOEN) transferred to Euro: $MC = 9{,}000\ EUR$

- M_{Si}: the number of missing stations in country *i*, calculated by the formula:

  - $M_{Si} = 0$ if $N_{kmSi} \geq T$. If the existing number of station per waterway km exceeds or equals the threshold, the number of missing stations is set to zero.

  - $M_{Si} = (T - N_{Skmi}) * L_{Wi}$ if $N_{kmSi} < T$. If the existing number of station is too low compared to the threshold, the number of missing stations is equal to the difference multiplied by the length of the waterways in country *i* in km.

- OTC_i: one-time costs for the installation of missing stations in country *i*

- AC_i: additional annual maintenance costs as consequence of the installation of missing stations for country *i*

The one-time costs for the installation of missing stations and the additional annual maintenance costs for each EU member state *i* are calculated by the following two formulas:

One-time costs:

$$OTC_i = M_{Si} * (\mathrm{D} + (CC^{min} + CC^{max})/2)$$

i.e. the one-times costs are defined as the number of missing stations multiplied by device and average construction costs associated with the construction of a new station. Thereby $(CC^{min} + CC^{max})/2$ are the average construction costs according on the information given by FOEN.

Annual costs:

$$AC_i = M_{Si} * MC$$

i.e. the annual costs are defined as the number of missing stations multiplied by the annual maintenance cost for a new station.

Table 4-29: Parameter values chosen for the estimation

Parameter	Description of parameter	Assumed value (can easily be changed in the Excel file)	Notes
T	Threshold for the minimum number of stations per km of waterway	0.015	Set by the authors according to the European average
D	Cost for device	27,000 EUR	FOEN
CC^{min}	Minimum construction costs for one station	18,000 EUR	FOEN
CC^{max}	Maximum construction costs for one station	73,000 EUR	FOEN
MC	Maintenance costs for one station per year	9,000 EUR	FOEN

Important assumptions resulting from the methodology and data availability

The threshold for the required minimum number of stations per km had to be set by the authors because values for the "optimal" number of station per km of waterway were not found in the literature. We chose $T = 0.015$ because this choice is consistent with the order of magnitude of the European average numbers of stations per km which is 0.019. In this sense, the number of missing stations reflects how countries are behind the status quo. Hence, costs for installation and maintenance of additional stations can be interpreted as costs associated with current adaption deficits.

Results: Costs of additional early warning systems in the EU

Below the estimates for the number of missing stations and the costs for installation and maintenance of these missing stations are provided differentiated by EU-member states (see Table 4.30).

Table 4-30: Results of additional costs for the installation of missing stations in the EU

Country	Number of missing stations	One-Time Costs	Annual Costs
AT	0	0 €	0 €
BE	27.6	2,004,262.50 €	248,805,00 €
BG	0	0 €	0 €
CY	0	0 €	0 €
CZ	0	0 €	0 €
DE	10.0	725,362.50 €	90,045.00 €
DK	0	0 €	0 €
EE	1.0	74,312,50 €	9,225.00 €
ES	0	0 €	0 €
FI	82.6	5,990,675.00 €	743,670.00 €
FR	72.5	5,257,337.50 €	652,635.00 €
GR	0	0 €	0 €
HU	5.3	386,425.00 €	47.970,00 €
IE	0	0 €	0 €
IT	24.0	1,740,000.00 €	216,000.00 €
LT	0	0 €	0 €
LU	0	0 €	0 €
LV	0	0 €	0 €
MT	0	0 €	0 €
NL	83.2	6,032,725.00 €	748,890.00 €
PL	9.0	649,237.50 €	80,595.00 €
PT	0	0 €	0 €
RO	7.0	504,962.50 €	62.685.00 €
SE	0	0 €	0 €
SI	0	0 €	0 €
SK	0	0 €	0 €
UK	0	0 €	0 €
EU 27	322.3	23,365,300.00 €	2,900,520.00 €

We also estimated the costs for some Non-EU countries for which the required data were available. As Table 4.31 shows, in order to fit the existing situation to the European average, additional stations are necessary in the Ukraine, Croatia, Russia, Belarus, and Moldova.

Table 4-31: Results of additional costs for the installation of missing stations for Non-EU states

Country	Number of stations	Waterways in km	Number of missing stations
Norway	52	1,577	0
Switzerland	25	1,299	0
Ukraine	24	2,185	8.8
Serbia	9	587	0
Croatia	2	785	9.8
Turkey	28	1,200	0
Russia	378	102,000	1152.0
Belarus	5	2,500	32.5
Moldova	2	558	6.4
Albania	9	41	0
Syria	4	900	0

4.2.8 Excursion: Cost estimates for the installation of additional hydrological stations concerning flood damages of all sectors

Flood warning system basing on data from hydrological stations described in the previews section is not only useful for shipping. Because roads, railways, and shipping, but also urban areas, power stations and farming can be affected by riverine flooding, the existence and improvement of sophisticated early warning systems can also be interpreted as an adaptation measure for other sectors. In the following we will present cost estimates for new stations in relation to estimated macroeconomic flood damages. We present two different scenarios: a control scenario based on the hydrological model representing the situation of today and a model under the A2 climate change scenario. In detail the basis of these cost estimates are the following data:

- FD_i^c: expected macroeconomic flood damage under the control scenario in country *i* in € (Source: Feyen et al. 2009)
- FD_i^{A2}: expected macroeconomic flood damage under the A2 scenario in country *i* in € (Source: Feyen et al. 2009)
- St_i^x: number of stations per million € damage under scenario x (x=c,A2) in country *i*, calculated by the formula: $St_i^x = N_{Si}/(\frac{FD_i^x}{1{,}000{,}000})$
- TD: threshold for the required minimum number of stations per million € damage. The threshold is set to $T = 0.15$ by the authors. This threshold is roughly related to the European average numbers of stations per million € damage.
- M_{si}^x: the number of missing stations under scenario x in country *i*, calculated by the formula:

- $M_{si}^{x} = 0$ if $St_i^x \geq T$.
- $M_{si}^{x} = (TD - St_i^x) * \frac{FD_i^x}{1{,}000{,}000}$ if $St_i^x < T$, i.e. the number of missing stations is equal to the difference between the threshold (measured in stations per million € flood damage) and the number of existing stations (measured in stations per million € damage) multiplied by the expected flood damage (in million €).

- OTC_i^x: one-time costs for the installation of missing stations under scenario x in country *i*
- AC_i^x: additional annual maintenance costs after the installation of missing stations under scenario x for country *i*

The one-time cost for the installation of missing stations and the additional annual maintenance costs for each EU member state *i* are calculated analogue to section 0:

One-time costs:

$$OTC_i^x = M_{si}^x * (D + (CC^{min} + CC^{max})/2)$$

Annual costs:

$$AC_i^x = M_{si}^x * MC$$

Table 4-32: Parameter values chosen for the estimation

Parameter	Description of parameter	Assumed value (can easily be changed in the Excel file)	Notes
TD	Threshold for the minimum number of stations per per million € flood damage	0.15	Set by the authors according to the European average
D	Cost for device	27,000 EUR	FOEN
CC^{min}	Minimum construction costs for one station	18,000 EUR	FOEN
CC^{max}	Maximum construction costs for one station	73,000 EUR	FOEN
MC	Maintenance costs for one station per year	9,000 EUR	FOEN

The threshold for the required minimum number of stations per million € of flood is set to $T = 0.15$ because this choice is consistent with the order of magnitude of the European average numbers of stations per million € damage which is 0.13. In this sense, we compare the existing situation in a country, here the number of stations in relation to estimated overall flood damage, with the status quo given by the European average.

The results for the two scenarios are given in the following tables. Table 4.33**Fehler! Verweisquelle konnte nicht gefunden werden.** shows the result for the control scenario.

Note that the number of missing stations varies from the number estimated in the previous section because we now consider the number of stations per million € flood damage and not per km of waterways anymore.

Table 4-33: Results of the control scenario

Country	Number of missing stations	One-Time Costs	Annual Costs
AT	17	1,232,500 €	153,000 €
BE	21	1,522,500 €	189,000 €
BG	0	0 €	0 €
CY	0	0 €	0 €
CZ	27	1,921,250 €	238,500 €
DE	0	0 €	0 €
DK	0	0 €	0 €
EE	0	0 €	0 €
ES	5	362,500 €	45,000 €
FI	10	725,000 €	90,000 €
FR	95	6,887,500 €	855,000 €
GR	0	0 €	0 €
HU	34	2,428,750 €	301,500 €
IE	0	0 €	0 €
IT	122	8,808,750 €	1,093,500 €
LT	0	0 €	0 €
LU	0	0 €	0 €
LV	0	0 €	0 €
MT	0	0 €	0 €
NL	44	3,190,000 €	396,000 €
PL	14	978,750 €	121,500 €
PT	0	0 €	0 €
RO	14	1,015,000 €	126,000 €
SE	0	0 €	0 €
SI	0	0 €	0 €
SK	0	0 €	0 €
UK	0	0 €	0 €
EU 27	401	29,072,500 €	3,609,000 €

The following Table shows the result for the A2 scenario.

Table 4-34: Results of the A2 scenario

Country	Number of missing stations	One-Time Costs	Annual Costs
AT	18	1.326.096 €	164.619 €
BE	33	2.413.586 €	299.618 €
BG	20	1.416.719 €	175.869 €
CY			
CZ	25	1.832.619 €	227.498 €
DE	0	0 €	0 €
DK	15	1.068.581 €	132.651 €
EE	23	1.691.530 €	209.983 €
ES	1	81.306 €	10.093 €
FI	0	0 €	0 €
FR	0	0 €	0 €
GR	25	1.805.754 €	224.163 €
HU	20	1.435.492 €	178.199 €
IE	0	0 €	0 €
IT	30	2.147.408 €	266.575 €
LT	22	1.620.325 €	201.144 €
LU	30	2.150.234 €	266.926 €
LV	27	1.932.734 €	239.926 €
MT			
NL	29	2.131.615 €	264.614 €
PL	0	0 €	0 €
PT	12	897.251 €	111.383 €
RO	16	1.162.761 €	144.343 €
SE	0	0 €	0 €
SI	20	1.429.628 €	177.471 €
SK	13	950.227 €	117.959 €
UK	0	0 €	0 €
EU 27	**379**	**27.493.862,44 €**	**3.413.031,20 €**

4.2.9 Summary of cost estimates

Table 4.35 below provides the cost estimates for the transport sector summarized for Europe. The specific adaptation measures corresponding to the chapters above are explained in the left column. The assumptions and limitations made in the different cost estimates and explained above in the specific sections hold also for these summarized

European cost estimates. For the detailed constraints on particular adaptation measures please see the corresponding chapters above.

Table 4-35: Summary of cost estimates for the European transport infrastructure

Adaptation Option	Total Costs (if not indicated differently, in million € p.a.)		
Adapting tracks to higher temperatures in the EU	Average Cost of Delay Minute 24.14 € (Enei et al., 2011)	Average Cost of Delay Minute 72.28 € (Eddowes, 2003)	Average Cost of Delay Minute 107.39 € (Burr, 2008)
	58.6	175.5	260.7
Adapting roads to higher temperatures in the EU	Min	Max	
	2,973	8,918	
Adapting roads to increase in precipitation in the EU	100% increase of drainage capacity	50% increase of drainage capacity	20% increase of drainage capacity
	139.6	69.8	27.9
Better surface asphalt for European runways	Min	Max	
	142.8	428.2	
Retrofitting existing infrastructure of airports' drainage system to increase of wet days	100% increase of drainage capacity	50% increase of drainage capacity	20% increase of drainage capacity
	181.6	90.8	36.3
Installation of additional hydrological stations	One-time	Annual	
	20.9	2.6	
Installation of additional hydrological stations concerning flood damages of all sectors	Control Scenario		
	One-time	Annual	
	25.5	3.2	
	A2 Scenario		
	One-time	Annual	
	27.5	3.4	

4.3 Urban areas:

4.3.1 Introduction, key impacts and key adaptation options

In this paper, key adaptation options in response to climate impacts in the urban areas in the EU are analysed with regard to their costs. We thereby employ a bottom-up-approach, based upon several case studies and combining their results with available Europe-wide data sets. This first section gives a brief overview about the key findings of Chapter 3 which are of high relevance for this report; chapter 4.1.2 presents the literature sources which have been used for the cost estimates; the remaining chapters present the methodology and results of the cost analyses of two adaptation options, namely for green spaces and green roofs.

Climate impacts and possible adaptation measures in European urban areas have been analysed in depth within chapter 3. Here we shortly summarise the most significant risks due to climate change:

- On the built environment: Temperature increase and heat waves; floods from rivers, heavy rain and the sea.
- In the domain of buildings (including pole-related constructions): decrease of comfort due to heat, flood damages.
- On the communication infrastructure: Interruptions, damages, increase of maintenance cost.
- On human health and air quality: Higher mortality and morbidity due to heat-related and vector-borne diseases.
- On urban transport: Damage to infrastructure and higher maintenance costs due to increasing temperatures and flooding.

In chapter 3, key adaptation measures for further investigation with regard to their costs and general economic impacts have been identified. In consideration of the fact that many of the abovementioned impacts result from or are related to the urban heat island effect, the proposed options aim to reduce the temperature increase in inner cities by technical measures. The adaptation options analysed in this report are

- Green spaces, e.g. parks, urban forests and other vegetated areas in the city areal; and
- Green roofs, i.e. roof tops covered with some sort of vegetation on private and public buildings in the city.

Besides reducing effects on the inner-urban temperature, green spaces and green roofs also have an effect on the urban drainage system, as significant amounts of run-off water can be stored, resulting in a lower stress on technical water drainage systems in times of extremely high precipitation. Hence, green spaces and green roofs work by the same physical mechanisms: The albedo of urban surfaces is increased by lighter colour; higher vegetation (trees) produces shadowed spaces; the function of water storage may relieve the technical waste water infrastructure; stored water cools the environment by the physics of evaporation. In addition, green spaces may also be helpful for establishing or maintaining effective cool air lanes which enable a sufficient air exchange of inner cities and their cooler environment.

4.3.2 Literature Review

In chapter 4, a more comprehensive literature review on the adaptation costs for key sectors has been performed. The objective was to identify studies which may give valuable input for Europe-wide cost estimates and to define cost drivers and cost structures. The findings of the review for urban adaptation to climate change are summarized in the Excel file accompanying this document, named “Adaptation Costs Urban Literature Review”.

In the review, all identified studies about urban adaptation are enlisted which contain some concrete information about the costs of adaptation. In total, 20 studies were reviewed. We did not restrict the review to the two key measures in order to get a more comprehensive picture, but effectively most (10 of 20) of the available studies are concerned with costs of green (or eco-) roofs. Among the analysed publications, only 4 are peer-reviewed, most of them covering the topic of eco-roofs. This shows that the current research in the domain of urban adaptation costs is clearly better established for green roofs than for any other measure. The review also reveals that the topic of costs in urban adaptation seems to be a relatively new field – there is no study older than 2004, and around half of the studies is dated in 2010 and 2011 (also some yet unpublished).

Regarding the methodologies of studied documents, the highly place-specific character of urban adaptation becomes apparent. Only one source uses a macro-economic model which is also relatively crude. The other cost estimates are based upon concrete case studies or indicate rough costs retrieved from the literature.

4.3.3 Costs for green spaces

4.3.3.1 Definition of concrete measures and costs to be analysed

For a meaningful cost analysis, the general adaptation option of “green spaces” needs some concretization. In the following, we will refer to green spaces as water surfaces (sometimes called “blue areas”) and vegetated areas within cities (natural and artificial). However, some vegetated surfaces do not count as green space – the most relevant exemptions being agricultural areas, private gardens in residential areas, and green roofs. Due to data availability, we furthermore limit ourselves to the analysis of new creation of green space, ignoring maintenance and operation costs.

The approach to estimate the costs of creation of new green space is based upon the logic of opportunity costs. In the next section, we will estimate the overall economic profit which is foregone because an additional green space was created. This does not include the actual costs of building a green space or maintaining it. However, the costs for installation and maintenance are expected to be significantly lower than the total economic profit given up for the green space. In the sense of cost definition in the Inception report, the costs estimated in this section are indirect costs.

Moreover, we assume that the creation of green spaces is undertaken on the desk, namely by changes in the land-use plan for currently undeveloped areas, instead of real physical changes on the real estate, e.g. by abridgements of existing buildings. For example, a green space can be created by shifting an unbuilt real estate from the intended use for economic activity to the use as green area. This averts the use as economic area but does not result in forced abridgements. We expect that the creation of green areas will work exactly in this way instead of reassigning areas with existing buildings as green areas. The latter would imply unforeseeable liability consequences for the urban planner. However, a reassignment may also be possible if the respective area is owned by the public planner and a reassignment is not prohibitively costly, e.g. at the time when an existing building need to be deconstructed anyway. The only identified case study of a change in a land-use plan (Ecologic Institute, 2011) presents a case in Stuttgart, Germany. After originally designated as space for a large hospital, an area of 6 ha has been reassigned as green area before the construction works for the hospital had begun. This change was motivated by considerations of urban climate and fresh air supply and effectively prevented possible economic activity on the respective area.

Hence, the costs we will estimate on a European level in the next section are opportunity costs of changes in the land-use plan. These changes are in favour of green spaces and (partly) at the cost of economically used area. The foregone overall economic profits of the lost economic area are the costs of the land-use plan change.

4.3.3.2 Cost estimation

Data source

The cost estimation is made transparent in the Excel file “Adaptation Cost Urban.xls” accompanying this paper. In the central sheet, named “Estimations”, the estimated adaptation costs in terms of foregone economic production are indicated for large cities of the EU27. We consider these cities as a good representation of urban centres in the EU27. The data source is the Urban Audit database of Eurostat covering 323 cities, with data from the survey waves of 2007-2010, 2003-2006, and 1999-2002. For each variable, the most recent of the available values has been used. Unfortunately, this database is in some variables very incomplete, and partly these missing data hamper reliable cost estimations. These constraints are further described in section 0. The detailed procedure and relevant data and parameters are described in the following:

4.3.3.3 Procedure of estimation

In a first step, relevant data are extracted from the Urban Audit database. These data include:

P_i Total population living in the city i

P_{55i} Total population aged over 55 years in city i

L_i Total area of city i in km^2

L_{bluei} Blue area of city i in km^2

L_{greeni} Green area of city i in km^2 (without private gardens, green roofs and agricultural area)

$L_{€i}$ Area used for economic activity (industry, commerce, services) in city i in km^2

T_i Current average temperature of the hottest month in city i in ℃

R_i Current average annual precipitation in city i in l/m^2

O_i Current days per year with more than 120 microgram/m^3 O_3 pollution in city i

y_i GDP per capita in the NUTS 3 region of city i, in (€) purchase power parities

Then, in order to identify the cities which are in need of additional green areas due to their current climate, a vulnerability indicator is calculated. Here the following parameters are needed and can be defined freely in the accompanying Excel sheet:

V_i Vulnerability indicator for city i, combined from ozone, elderly population share, average summer temperature and average annual precipitation

v_O Weight of ozone pollution for vulnerability indicator

v_{55} Weight of elderly population share for vulnerability indicator

v_T Weight of summer temperature for vulnerability indicator

v_R Weight of annual precipitation for vulnerability indicator

The indicator is calculated by the formula

$$V_i = (v_O * (O_i - \min O)/(\max O - \min O) + v_{55} * (P_{55i} - \min P_{55})/(\max P_{55} - \min P_{55})$$
$$+ v_T * (T_i - \min T)/(\max T - \min T) + v_R * (R_i - \min R)/(\max R - \min R))/\sum v$$

This ensures a value of V_i between 0 and 1, with higher values for typically ozone-polluted, warm, wet cities and cities with a relatively elderly population. If all input categories are weighted equally, the most extreme cities are Bologna in Italy (with the highest vulnerability) and Suwalki in Poland (with the lowest vulnerability).

In the next step the vulnerability indicator V_i is used to determine a need for additional green and blue area in the cities. Thereby, we simplify the calculation by assuming that all cities which are above a certain threshold vulnerability need to cover a certain share of their area with green or blue surfaces. In order to estimate the additional needed green area, the following parameters are of relevance:

g_i Share of current green and blue areas with regard to total area in city i, in the following called “share of green space”.

$\underline{g}$ “Target” share of green space

$\underline{V}$ Threshold vulnerability indicator. For all cities above this threshold, it is assumed that they need the target share of green space $\underline{g}$.

In the following, the economically used area is estimated, which will be lost due to the expansion of green space. The economic area in the data set is defined by the area used for industrial purpose, commerce and service. We assume that one km^2 of newly created green space implies losses for all other areas, proportionally to their current shares of the total area. That is, if in a city currently one fifth of the total area is economic area, one km^2 of new green space implies a loss of 0.2 km^2 of economic area. We furthermore assume that parts of this gross lost area is re-established somewhere else in the city, and the net loss of economically used area is smaller than the initial loss. This is in contradiction to the case study of Ecologic Institut 2011, where no compensation was possible in this specific case.

The share of lost area which cannot be compensated within the cities can be defined freely in the Excel sheet. Hence, the following additional variables are needed:

n Share of lost economic area which cannot be compensated within the cities

N_i Net loss of economic area in city i in km^2

Then, the net loss of economic area can be estimated by the formula

$N_i = 0$ if $V_i < \underline{V}$ or $g_i > \underline{g}$

$N_i = (\underline{g} - g_i) * L_i * L_{€i} / L_i * n$ otherwise

Note: The formula can by simplified by cancelling L_i, but then it is less accessible to the reader. In the presented form, the first product represents the needed green space in km^2 and the remaining factors the share of this area which affects economic area.

As the final step, the overall economic losses in terms of GDP losses are estimated using the lost economic area. Here we have to assume that the gross value added within the city equals the gross value added of the NUTS 3 region where the city is located, and that the GDP is only produced on the economic area of a city. These are quite strong assumptions, but for a first rough estimate, given the available data and uncertainties we consider them as necessary and justifiable. No further parameters or data are necessary for this last step in estimation. The annual loss of GDP, induced by the creation of new green spaces in city i, in € (PPP) (AC_i) is estimated by the formula:

$$AC_i = N_i * y_i * P_i / L_{€i}$$

Constraints

The procedure and the underlying data imply a number of limitations and constraints which have to be kept in mind when interpreting the results:

- Due to data availability we only can perform an analysis based upon current climate parameters. This means the estimation is actually not an adaptation cost analysis, but the analysis of adaptation needs to current climate – in the literature often referred to as "adaptation deficit" (Parry et al. 2009). For a forecast-orientated cost analysis, one would need to include climate projections for the cities and economic projections of their GDP developments. This would inevitably imply a severe loss of data accuracy and inter-city differentiation – which is one of the greatest strengths of the current approach.

- The modelling of adaptation in the presented approach is relatively crude. We found, however, no better approach in the literature which could be implemented with the available data. This is a consequence of the very scarce literature base for quantitative adaptation modelling in urban areas.

- We see a risk of underestimating the economic costs of green spaces, especially if much green space is to be created in inner city centres. Here the GDP per km2 of economic area is expected to be higher than the average value for the whole city. At the same time however, it is much more difficult to change land-use plans for inner city centres, such that the creation of new green spaces may be less intensive here.

- The chosen approach can only estimate indirect costs of new green spaces. Direct costs which accrue to the creation and maintenance of green areas are not included. We expect, however, that the indirect costs occurring to the total urban economy are higher than the direct costs which accrue only to the public planner.

- As in every analysis with surveyed data, the data quality might be a problem. In particular, we see a risk of incoherent data in the domain of area data. First of all, many cities do not provide complete data (see next point). Moreover, the reported figures, when combined with GDP, yield a wide range of GDP per economic area (from 99.5 million € per km^2 in Suwalki, Poland to 7208.4 million € per km^2 in Brussels, Belgium). Some extreme outliers with very small reported economic areas and high GDP-values per km^2 (mainly in Greece) have been excluded from the raw data. This raises suspicion about the validity of some of the other reported data, too. We see, however, not the possibility how to overcome this problem in a better way than just to exclude obviously wrong data.

- Missing data have already been mentioned before. The data set used in this analysis in relative comprehensive and comprises a lot of variables. The variables are however more or less complete regarding the reporting cities. Whereas GDP per capita and population-related variables have a quite good coverage, area-related data are much more fragmentary. At the same time they are indispensible for our analysis. This is why our approach, though feasible for all cities, yields results for only 111 of the total of 323 cities. In terms of city area covered by the results, we miss a share of 68% and in terms of GDP we miss 58% due to data availability. Table 4.36 classifies the countries according to their level of completeness of data, in order to get an impression of which data are missing.

Table 4-36: Overview of missing data per country

Cities that provide sufficient data	All cities	Part of the cities	No city
Countries	Belgium Germany Latvia	Estonia Finland France Greece Lithuania Malta The Netherlands Poland Portugal Slovakia Sweden United Kingdom	Austria Bulgaria Cyprus Czech Republic Denmark Hungary Ireland Italy Luxembourg Romania Slovenia Spain

Table 4.37 shows that many hotspots of climate change in Southern Europe are not covered by the available data of Eurostat. This is an indicator of considerably higher

adaptation costs than the costs that can be estimated by the used data set. This caveat has to be kept in mind when interpreting the results in section 4.3.3.4.[165]

- Finally, we want to remind that – even if the data were complete – the data set only covers 323 large cities. Although we see this sample as a very good representation of the European urban centres, there are smaller cities which may also engage in adaptation to climate change by the creation of green space. Here to total costs however are expected to be lower, due to less area affected and in most cases lower GDP per km^2 values. In addition, smaller cities are generally less vulnerable to urban heat island effects and often have already relatively high shares of green areas.

4.3.3.4 Results

In the following the results of the adaptation cost estimation are presented. They are also visible, for each city and for the total EU27, in the accompanying Excel file ("Adaptation Costs Urban.xls", sheet "Estimations"). The costs crucially depend on the magnitude of some parameters described in section 4.3.3.3. Table 4.37 lists the parameter values which are proposed and on which the results presented thereafter are based upon.

Table 4-37: Parameter values chosen for the estimation

Parameter	Description of parameter	Assumed value (can easily be changed in the Excel file)	Notes
v_O	Weight of Ozone pollution for vulnerability indicator	0.3	Assumption by authors
v_{55}	Weight of elderly population for vulnerability indicator	0.2	
v_T	Weight of summer temperature for vulnerability indicator	0.4	
v_R	Weight of annual precipitation for vulnerability indicator	0.1	
$\underline{g}$	"Target" share of green space	0.2	Assumption by authors, based upon current shares in the cities (EU-wide average: 0.31)
$\underline{V}$	Threshold vulnerability indicator.	0.33	Assumption by authors
n	Share of lost economic area which cannot be compensated within the cities	0.2	Assumption by authors

These parameter values yield economic costs of the creation of green space of the magnitude of 2.6 billion € GDP (PPP) per year. In this case, most of adaptation costs arise in Athens and in Belgian cities, since here the current shares of green and blue areas are relatively low. Because this value covers only some of the surveyed cities, one can expect

[165] We also tried to include rents and purchase prices for flats and houses in the analysis, but this proofed unreliable due to too much missing data.

considerably higher costs for the total EU27, of more than 5 billion € GDP loss per year if the abovementioned parameters hold.

4.3.3.5 Cost sharing

Regarding the issue of cost sharing, the nature of the estimated costs becomes important. We did not estimate the direct adaptation costs which arise by installation and maintenance of green spaces, but the loss of economic activity and thereby losses if GDP in the cities. These (indirect) costs accrue to the total economy, including private firms, households and the public actor. If an intended economic area is not realized, first the affected firms (those who intended to use the area) have to bear opportunity costs by losing their expected profits. This has also consequences for other firms (as business partners), private households (as employees) and the public purse (due to not realized tax revenue). The specific shares of these parties on the costs however, cannot be indicated ex-ante and in this very general analysis. They depend on the cost structure of the affected industries, their labour intensity, and their effective tax rate. These parameters are not only very industry-specific, but vary also considerably between the EU member states. Hence, in this general analysis it can only be stated that each economic agent (firms, households and government) are affected more or less negatively by the costs of green spaces, but the actual shares depend on site- and project-specific conditions.

4.3.4 Costs for green roofs

4.3.4.1 Definition of concrete measures and costs to be analysed

The direct costs (and benefits) of green roofs are relatively well researched. Around one half of the studied literature in section 4.1.2 focuses on costs and benefits of green roofs. Though, some of the literature results may be skewed into a certain direction, since many research reports stem from green roofs associations which are certainly not totally independent in their judgment. There are, however also some peer-reviewed scientific papers focussing on green roof costs. The most important cost information extracted from the literature is presented in section 4.1.2.

The costs estimated in the next section refer to incremental costs of green roofs in comparison to an average conventional roof. One-time installation costs and annual maintenance costs are considered and differentiated from each other. With regard to initial installation costs, one has to bear in mind that most experts state that green roofs have a lifetime which is longer than for conventional roofs, up to 40 years instead of 20 years for a conventional roof. This, however, does not affect the initial costs which will be estimated in the next section.

4.3.4.2 Cost estimation

Unit cost estimated extracted from the literature

The green-roof-related literature discusses a broad range of possible cost estimates for one m^2 of vegetated roof. As mostly, also in the case of green roofs the actual costs depend on a variety of factors. Most important is the type of green roof, meaning whether it is an extensive or intensive type. Intensive green roofs are roof gardens, accessible green roofs or other roofs with a lot of plant diversity and density. The typical green roof for private house-owners though is the extensive green roof top. Here a relatively simple technology is employed which is cheap in installation and maintenance. In most cases the plant diversity is limited, the vegetation has small heights and is easy to plant and maintain. The presented cost estimates refer to extensive green roofs. Other cost drivers, such as total roof area, height of the building, type of roof are important in the specific cases but cannot be generalised meaningfully. Hence we present ranges of cost estimates from the literature.

Table 4.38 gives an overview about available cost studies for extensive green roofs. The indicated costs refer to incremental costs in relation to a conventional roof top.

Table 4-38: Cost studies for extensive green roofs. The indicated costs refer to incremental costs in relation to a conventional roof top

Study	Installation costs		Annual maintenance costs		Studied market
	as in source	(€/m^2)	as in source	(€/m^2)	
Mann 2005	5 - 14 €/m^2	5 - 14	0.30 €/m^2	0.30	German market
Getter an Rowe 2006	twice as much as for conventional		n.a.		US-market
Acks 2006	1 - 25 $/sf	8.57 - 214.44	-0.04 - 1.15 $/sf	-0.34 - 9.86	US-market
Clark et al. 2007	129,000 $ for 2,000 m^2	47.13	n.a.		US-market
Carter and Keeler 2007	75.04 $/m^2	54.83	0	0	US-market
City of Portland 2008	5.75 $/sft	42.29	0.025 $/sft	0.18	US-market

The results of the literature review exhibits the broad range of cost estimates, which partly is reasoned by the different market environment of Germany and the US. Some authors from the US, after presenting their cost estimates, mention that economies of scale would lead to considerably lower unit costs, and explicitly refer to the example of Germany where prices are much lower and the market thicker.

For the estimation of EU-wide costs for green roofs, we can assume a quite large market and therefore have chosen a value lower than the US unit prices, but slightly higher than the range indicated by Mann (2005) (20 €/m^2). The unit prices used in the EU-wide cost estimate can be changed in the Excel sheet “Adaptation Cost Urban.xls”.

Procedure of estimation

The procedure of estimating Europe-wide costs for the installation and maintenance of green roofs is relatively straight forward. We use the same data set and modelling of adaptation behaviour as in section 4.3.3.3, such that a city implements green roofs if its vulnerability indicator reaches a certain threshold. We use the same vulnerability indicator as the driving forces for the need of green roofs are basically the same as for green space – namely urban micro climate and water storage capacities.

A new aspect for the analysis of green roofs is the analysis of the urban surface structure, also called fabric of the urban environment (Akbari et al. 2003a). This is necessary to get an impression of which area in European cities can be covered by green roof technology at the given unit costs. There are some scientific results available concerning the structure of the urban surface for US cities, but much less for European cities. Table 4.39 summarizes the available data.

Table 4-39: Study results for shares of roof areas (in % of total city area)

Study	Studies City	Share of roof area (% of total area)	Notes
Gray and Finster 1999	Chicago	27	
Akbari and Rose 2001a	Salt Lake City	22	
Akbari and Rose 2001b	Chicago	25	
Akbari et al. 2003a	Houston	21	
Akbari et al. 2003b	Sacramento	20	
Banting et al. 2005	Toronto	21	feasible for green roofs: 7.9% of total area = 37% of roof area
Holzmüller 2009	Düsseldorf	11.5	built area is assumed to be roof area
City of Seattle 2010	Seattle	14.4	

The results of the urban fabric analyses summarised in Table 4.39 are quite consistent for US cities, but the only European city providing data (Düsseldorf) is a striking outlier, compared to the US cities. There are case studies for other European cities, such as Birmingham, but they only cover a part of the inner city and cannot be used for a city-wide analysis. Thus the discrepancy between European and US data cannot be easily resolved by more data from Europe.

In order to reduce the dependency on data from the US, we additionally use information about roof areas from Germany, collected in the context of estimating the potential for photovoltaic energy generation on roofs. Personal communication with engineers working in this field yielded an estimate of 30-50 m^2 roof area per inhabitant in German cities and urban areas. This value varies and is most probably out of the given range for urban centres outside Germany, such as very densely populated cities in Greece or France. That is why we adjusted the roof area per inhabitant according to population density, with higher roof area values for less densely populated cities. This estimation technique (in the excel file marked by the sign “pop”) yields systematically lower roof areas than the approach based upon roof area shares on total area. In the estimation, both approaches are used at the same time by calculating a combined roof area. Weights for both approaches can be defined freely. We think that a combination of population- and area-based roof area estimation should yield realistic results, although they are by nature very rough.

Hence, in a first step the total green roof potential for each city of the data set has been estimated. The following parameters are used:

r Share of total city area covered by roofs, Europe-wide

R Roof area per inhabitant in typical German urban areas, in m^2

w_{area} Weight for the area-based approach for estimating the roof area per city

w_{pop} Weight for the population-based approach for estimating the roof area per city

p Share of roofs which are feasible for vegetation, Europe-wide[166]

L_i Total area of city i in km^2 as used in section 4.3.3.3

The total green roof potential in city i in km^2 is

$$G_{Poti} = (L_i * r * w_{area} + P_i * R / 10^6 / ((P_i / L_i) / (P_{Germany} / L_{Germany})) * w_{pop}) / (w_{area} + w_{pop}) * p$$

As in section 4.3.3.3, the potential for green roofs will only be used if the city proofs vulnerable to climate impacts, according to the vulnerability indicator V_i and the threshold indicator value $\underline{V}$. Then, it is assumed that a certain share of the full green roof potential in each city will be realised. The unit costs for installation and maintenance stem from the literature review in section 4.1.2 and 4.3.2. The following parameters will be used for the estimation of green roof costs:

h Share of green roof potential which will be vegetated if a city is vulnerable to climate change impacts. The current share is assumed to be zero, which is close to reality for most of the cities.

GC_{in} Once-off Installation costs of green roofs in € per m^2

GC_{ma} Annual maintenance costs of green roofs in € per m^2

The formulas for estimating the green roof costs in city i are

$GC_{ini} = GC_{mai} = 0$ if $V_i < \underline{V}$

$GC_{ini} = G_{Poti} * h * GC_{in} * 10^6$ otherwise

$GC_{mai} = G_{Poti} * h * GC_{ma} * 10^6$ otherwise

This approach obviously underlies a range of uncertainties and limitations. First, the modelling of adaptation behaviour is as crude as in section 4.3.3.3. This is in consequence of the very scarce literature base about quantitative adaptation modelling in the urban sector. Second, we generalise all cities in the database with regard to some key parameters, although their values are obviously different for the cities: Düsseldorf certainly has less roof area share than Athens, for example. In principle, the approach can incorporate for different parameter values of the cities, but as mostly the problem is the data availability or existence. As a first attempt of estimating EU-wide costs of green roofs however, the approach yields plausible results.

In the following section, we propose values for the parameters and estimate the costs for Europe.

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[166] Applying a specific share for each type of land use (residential vs. industrial for example) is in principle possible with the chosen approach, but in the end proofed disadvantageous because then too many cities provide insufficient data.

Results

For estimating the green roof costs, the following parameter values have been chosen:

Table 4-40: Parameter values chosen for the estimation

Parameter	Description of parameter	Assumed value (can easily be changed in the Excel file)	Notes
r	Share of total city area covered by roofs, Europe-wide	0.15	Assumption by authors, between value for Düsseldorf (0.11) and US-cities (around 0.2-0.25)
R	Roof area per inhabitant in typical German urban areas, in m^2	40	According to expert: 30-50 in urban centres, 80-100 in rural areas
w_{area}	Weight for the area-based approach for estimating the roof area per city	0.5	Assumption by authors. Higher values in tendency yield higher roof areas.
w_{pop}	Weight for the population-based approach for estimating the roof area per city	0.5	Assumption by authors. Higher values in tendency yield lower roof areas.
p	Share of roofs which are feasible for vegetation, Europe-wide	0.2	Assumption by authors, lower bound of two available literature sources (0.37 in Toronto; 0.2 for US cities according to Clark et al. 2007)
h	Share of green roof potential which will be vegetated if a city is vulnerable to climate change impacts	0.5	Assumption by authors, consistent with Clark et al. 2007
GC_{in}	Once-off Installation costs of green roofs in € per m^2	20	Based upon unit cost review in section 0, high uncertainty due to high ranges in the literature
GC_{ma}	Annual maintenance costs of green roofs in € per m^2	0.30	
$\underline{V}$	Threshold vulnerability indicator	as in section 4.3.3.4	Assumption by authors

These parameter values yield one-off investment costs for green roofs in the analysed European cities in the magnitude of 5.2 billion € and annual maintenance costs of 80 million €. In comparison to the results for green spaces, the underlying data base is much more complete, with 25% of city area with missing data, and the cities providing insufficient data are more spread in the total EU. By scaling up the results with this factor, the costs reach a magnitude of 7 billion € for installation and 100 million € p.a. for maintenance in all 323 cities.

4.3.4.3 Cost sharing

The costs that will occur due to new installation of green roofs mainly accrue to the owner of the buildings: private households and firms as well as public actors. Because of the slope of many private buildings the potential is expected to be higher for industry, commercial, service and public buildings such as supermarkets, town halls, parking garages, business buildings in the inner city centres. Here also the roof areas are larger, resulting in lower unit prices.

Great potential is also given in industrial areas with large factories and storage buildings. Hence, we expect the private firms to bear relatively more of the cost burden than private households, if the installation roughly follows the potential for green roofs.

Public costs may arise if the public planner decides to subsidise green roofs, as already established in one way or another in many cities. Subsidies may be in the form of reduced waste water fees (this is the common case), subsidised credit or even direct payments (as in Düsseldorf). The reason for these subsidies is public benefits of green roofs, which generally are not accounted for in the private calculation of the house-owner. These costs, however, should be compensated by savings of public expenditure e.g. for storm water management and health systems. Finally, if one of these schemes is introduced in a city, it causes administration costs for maintaining the green roof scheme. According to Acks (2006) these cost may range between 0.1% and 0.3% of total installation costs.

4.3.5 Summary of cost estimates

This section summarizes in one table (4.41 the key findings of this report – estimated adaptation costs in urban areas for key adaptation measures. The figures have been estimated by transferring results of bottom-up studies to the European level using numerous case studies, expert information and databases. The results are subject to various assumptions and constraints described before in the respective chapters.

Table 4-41: Summary of cost estimates

Adaptation option	Total costs in the EU27	
Green spaces	For all cities which provide sufficient data (111 of 323 cities)	Very rough estimation for all 323 cities in Urban Audit database
	2.6 billion € p.a.	more than 5 billion € p.a.
Green roofs	For all cities which provide sufficient data (240 of 323 cities)	Rough estimation for all 323 cities in Urban Audit database
	One-time investment: 5.2 billion € Maintenance: 80 million € p.a.	One-time investment: 7 billion € Maintenance: 100 million € p.a.

4.4 Agriculture:

4.4.1 Introduction, key impacts and key adaptation options

This report lays the focus on costs of key adaptation measures in the European agriculture sector. The approach is the same as for the other sectors, beginning with a comprehensive literature research on case studies indicating local or national adaptation costs, and a transfer of these cost estimates on the EU27 level. This section gives a brief overview about the key findings of chapter 3 regarding main impacts and adaptation options for the agriculture sector.

The most significant risks for agriculture in Europe due to climate change are (see also, chapter 3):

- Northward movement of suitable zones for crops with increasing crop productivity in Northern Europe, and declining productivity in Southern Europe;

- Increased pests and diseases, nutrient leaching, and reduced soil organic matter. Various insects, for example the European cornborer and the Mediterranean fruit fly, are expected to show a considerable northward expansion with rising temperatures;
- Crop productivity is expected to decrease where seasonal precipitation decreases significantly such as in the Mediterranean and South Eastern Europe;
- Extreme weather events can severely disrupt crop production and lead to a greater yield variability;
- Heat stress has several negative effects on animal husbandry, including reduced reproduction and milk production in dairy cows, and reduced fertility in pigs.

In chapter 3, key adaptation measures for coping with these risks have been selected for further investigation with regard to their costs:

- Irrigation
- Cooling of stables / animal husbandry
- Farm advice / capacity building

These measures will be analysed in the chapters after the literature review, i.e. chapters 4.4.3, 4.4.4 and 4.4.5.

4.4.2 Literature Review

In order to identify case studies which might provide helpful insights into adaptation costs in the agriculture sector, a comprehensive literature review has been performed within chapter 3. The respective overview of findings is provided in the accompanying Excel file named “Adaptation Costs Agriculture Literature Review.xlsx”. All references are also given in the references list of this section.

Criteria for entering the literature review were: Studies raise the topic of climate change in the context of agriculture and they give some information about climate adaptation costs. In total, 28 documents have been reviewed, of which five are published in peer-reviewed journals. In general, it should be noted that there is obviously much more literature available on impacts, adaptation options and even adaptation benefits in the domain of climate change and agriculture. The topic of this report, however, is costing of adaptation measures and thus only those studies have been analysed which give some information in this matter. Even if the analysis is restricted to these studies, the share of studies which give concrete cost estimates is still rather low. Only 15 of 28 analysed adaptation studies indicate costs for any measures in monetary terms – the others give rough statements about the cost order of different measures, state that costs are difficult to assess, mention that estimates are rare or recommend research on adaptation costs. Unlike the other sectors, in the agriculture sector we also included some top-down studies in the literature review in order to broaden the literature base with concrete cost estimates. These sources of course could not be used for estimating or transferring costs of single measures. In total, 10 of 28 analysed studies can be classified as top-down studies which give general information on adaptation costs incurring to the whole sector.

4.4.3 Irrigation

4.4.3.1 Definition of concrete measures and costs to be analysed

A possible measure to be analysed could be the enhancement of existing irrigation infrastructure in the EU27, resulting in an increase of irrigation efficiency. Irrigation efficiency is defined as the ratio of water stored in the crop root zone over the amount of irrigation water applied. The average value of irrigation efficiency for developed countries is around 0.5 (Fischer et al. 2007). However, for measures increasing this efficiency no single cost estimate was found in the literature. Instead, few cost estimates are available for total on-farm expenditures for crop irrigation. Hence, due to data availability, we focus the following analysis on the overall costs of irrigation due to climate change in the EU27.

The costs of irrigation include expenditure for purchase and installation of the infrastructure, recurring maintenance and repair costs, recurring operating costs (most important are energy and fuel costs), and costs for water consumption. The latter are generally not considered in available case studies because in most cases (at least in the US, where all available cost studies for irrigation stem from) water for agricultural purposes is not purchased but freely allocated by the authorities. According to one source (Gollehon and Quinby 2006), the total annual costs per irrigated ha could rise by 45% if the water has to be purchased from "off-farm sources". The relative magnitude of the different annual cost components, according to US cost studies, is very roughly the following: 50% capital costs for infrastructure, 40% fuel and energy costs for operation, 10% repair, maintenance and labour costs (Hogan et al. 2006; Gollehon and Quinby 2006; Tyson and Curtis 2008).

For a more detailed cost analysis than this, it would be crucial to examine how the additional irrigation requirement due to climate change will materialize in Europe – whether more land will have to be irrigated or whether previously irrigated land will require more m^3 per ha. The unit costs per m^3 are expected to differ considerably as in the latter case less expensive capital investments have to be met.

4.4.3.2 Cost estimation

The cost estimation is made transparent in the Excel file "Adaptation Cost Agriculture.xlsx" accompanying this paper.

Data sources

In order to estimate the costs for climate-induced additional irrigation in the EU27, the following data are needed:

- Irrigation requirement in m^3 per country (base case)
- Change of required irrigation in m^3 per country
- Irrigation costs per m^3
- For illustrative purpose, the irrigated agricultural land area in ha is also indicated per country.

In order to access these data, the following data sources have been used:

For the irrigation water requirement, there are three principal sources. Firstly Eurostat provides data on “Use of water from self supply by agriculture for irrigation purposes”. Unfortunately many countries do not provide data here. Second, FAO provides a comprehensive database named “FAO aquastat”, with data on agricultural water withdrawal for all EU27 countries. Since these values are not comparable with actual irrigation requirements, they have been scaled down to actual irrigation water use by the efficiency factor (0.5 according to Fischer et al. 2007). Still, the values are very much higher than the figures provided by Eurostat. Thirdly and finally, there is the JRC-publication of Wriedt et al. 2008 modelling the country-specific irrigation requirements for all EU27 countries. This source indicates the actual water demand in 2000, which is again very much higher than the recent Eurostat values. How we dealt with this contradicting information about base-case water requirement is explained in section 4.4.3.1.

Regarding the change of required irrigation in m^3 per country, the same phenomenon of contradicting sources can be reported – but not as heavily as in the case of irrigation water requirements. Two peer-reviewed articles were identified which indicate regional (West- and Eastern European) changes of irrigation requirement due to climate change. (Döll 2002 and Fischer et al. 2007). Both articles base on two climate change scenarios, which are different from each other and are not easily comparable to standard SRES scenarios. Consequently, for each region four different values were found in the literature. Apart from one scenario, they do not vary as much as base-case irrigation requirements. Since both articles use base-case irrigation requirements which are again different from each other and different from the ones we use, we transferred the changes reported in absolute terms to relative changes.

The unit costs of irrigation in € / annual m^3 are derived from one single source (Fischer et al. 2007). This article proofed to be highly valuable in our analysis. There are a number of other studies focussing on irrigation unit costs as well (see sheet “Cost information” in the accompanying Excel file), but as we intend to combine m^3 values with unit prices we have to refer to costs per irrigation water amount. Other studies indicate costs per irrigated area. The authors of Fischer et al. 2007, however, also indicate unit costs per ha which are broadly in the range of other sources, which makes us confident that the per m^3 cost information of Fischer et al. 2007 is not out of any possible range.

The land area currently irrigated is given in the Excel sheet for illustrative purpose. Here the same data sources were available as for current irrigation water requirement, with some countries missing in the FAO database. For irrigated land area, the data are much more comparable than for water requirement, with very similar (but not identical) data of FAO and Eurostat. Wriedt et al. 2008 report higher data for some countries and lower data for others.

Procedure of estimation

The first step of the cost estimation includes the consolidation of different data on current irrigation water requirements. The following data and parameters have been used:

$IR_{today,i}^{Wriedt}$	Irrigation water requirement without climate change in country i according to Wriedt et al. 2008, in million m^3
$IR_{today,i}^{Eurostat}$	Irrigation water requirement without climate change in country i according to Eurostat, in million m^3
$IR_{today,i}^{FAO}$	Irrigation agricultural water withdrawal without climate change in country i according to FAO aquastat database, in million m^3

w^{Wriedt} Weight of the source Wriedt et al. 2008 for calculating the current irrigation water requirements used for cost estimation

$w^{Eurostat}$ Weight of the source Eurostat for calculating the current irrigation water requirements used for cost estimation

w^{FAO} Weight of the source FAO for calculating the current irrigation water requirements used for cost estimation

IE Current average irrigation efficiency in Europe, as ratio of irrigation water requirement over agricultural water withdrawal

The current irrigation water requirement in country i in million m3 is then estimated by the formula:

$$IR_{today,i} = (IR_{today,i}^{Wriedt} * w^{Wriedt} + IR_{today,i}^{Eurostat} * w^{Eurostat} + IE * IR_{today,i}^{FAO} * w^{FAO}) / (w^{Wriedt} + w^{Eurostat} + w^{FAO})$$

Note: For countries without data from Eurostat, the formula is reduced by eliminating the Eurostat-related variables.

The next step is the country-wise estimation of change in irrigation requirement, in million m^3. No country-specific projections are available; hence we refer to region-specific estimates for Western- and Eastern Europe. The following parameters are used:

$a_{1,j}$ Change of irrigation water requirement due to climate change, as reported in Fischer et al. 2007, for region j, for climate change scenario “Hadley”, in %

$a_{2,j}$ Change of irrigation water requirement due to climate change, as reported in Fischer et al. 2007, for region j, for climate change scenario “CSIRO”, in %

$a_{3,j}$ Change of irrigation water requirement due to climate change, as reported in Döll 2002, for region j, for climate change scenario “ECHAM4”, in %

$a_{4,j}$ Change of irrigation water requirement due to climate change, as reported in Döll 2002, for region j, for climate change scenario “HadCM3”, in %

w_{a1} Weight of $a_{1,j}$ for calculating the consolidated change of irrigation requirement

w_{a2} Weight of $a_{2,j}$ for calculating the consolidated change of irrigation requirement

w_{a3} Weight of $a_{3,j}$ for calculating the consolidated change of irrigation requirement

w_{a4} Weight of $a_{4,j}$ for calculating the consolidated change of irrigation requirement

The country-specific change of irrigation water requirement in million m^3 per year is then roughly estimated by the formula:

$$\Delta IR_i = IR_{today,i} * (a_{1,j} * w_{a1} + a_{2,j} * w_{a2} + a_{3,j} * w_{a3} + a_{4,j} * w_{a4}) / (w_{a1} + w_{a2} + w_{a3} + w_{a4}) / 100$$

The last step incorporates the unit costs of one additional m^3 of irrigation water requirement:

C_{IR} Costs of additional irrigation water requirement, in € per year and per 1000 m^3, including capital costs, maintenance and repair costs, energy and labour costs, but not water withdrawal costs.

The additional costs per country due to higher irrigation requirements due to climate change, in € per year are roughly estimated by the formula:

$$AC_{IRi} = \Delta IR_i * C_{IR} * 1000$$

Constraints

The procedure and the underlying data imply a number of limitations and constraints which have to be kept in mind when interpreting the results:

- The three used data sources on actual irrigation water requirement (base case) are providing differing data, partly in different orders of magnitudes. This could not be explained by slightly differing definitions of measured units. We cannot judge the reliability of the different data sources, thus we give the possibility to weight the different sources as desired. However, relying only on Eurostat data is not possible as many countries are missing here. The fact that top-down studies (Döll 2002 and Fischer at al. 2007) also use differing data which are themselves not compatible to any of our sources does not increase our trust in these data.

- The estimations rely on one single unit cost information (Cost information no. 2 in the Excel sheet “Cost information”). This value stems from the US. For Europe, no general, country- or region-specific information was available. A recent article (Moriondo et al. 2010) analyses in depth the benefits of irrigation and spends one sentence on its cost, saying that costs are difficult to quantify. Also Olesen et al. 2011 name irrigation as a key adaptation option and suggest general adaptation cost as a future research topic.

4.4.3.3 Results

In the following the results of the adaptation cost estimation are presented, as calculated in the accompanying Excel file “Adaptation Costs Agriculture” in the sheet “Main sheet”. The costs depend on the magnitude of some parameters described in section 4.3.2.2. Table 4.42 lists the parameter values which are proposed and on which the results presented thereafter are based upon.

Table 4-42: Cost estimates for additional irrigation water requirement by 2030, in million € p.a.

Parameter	Description of parameter	Assumed value (can easily be changed in the Excel file)	Notes
w^{Wriedt}	Weight of the source Wriedt et al. 2008 for the current irrigation water requirement	0.2	Assumption by authors
$w^{Eurostat}$	Weight of the source Eurostat for the current irrigation water requirement, applicable if data are available	0.5	
w^{FAO}	Weight of the source FAO for the current irrigation water requirement	0.3	
IE	Irrigation efficiency	0.5	Assumption by authors, based upon Fischer et al. 2007
w_{a1} to w_{a4}	Weights of four climate scenarios from two sources	0.25 each	Assumption by authors
C_{IR}	Costs of additional irrigation water requirement, in € per year and per 1000 m^3	42	Based upon Fischer et al. 2007

These parameter values yield the following cost estimates, presented in Table 4.43.

Table 4-43: Cost estimates for additional irrigation water requirement by 2030, in million € p.a.

Country	For illustration: Irrigated area in ha	Additional irrigation costs in million € p.a.	Percentage of total EU27
Italy	2,666,210	114.9	34.8
Spain	3,266,330	95.5	28.9
Greece	1,279,520	46.3	14.0
France	1,511,730	28.6	8.6
Portugal	421,520	21.7	6.6
Other countries	1,436,169	23.7	7.2
Total EU27	10,581,479	330.8	100.0

The regional pattern of the estimated adaptation costs reproduces the situation in Europe regarding irrigation demand. More than 90 % of the costs of this adaptation option occur in countries bordering the Mediterranean Sea.

We will now compare the magnitude of our estimation with available top-down studies: Top-down studies indicating agriculture-related adaptation costs for Europe are Bosello et al. 2009, UNFCCC 2007 (basing on McCarl 2007) and Parry et al. 2009. World Bank (2010) also indicates adaptation costs in the agriculture sector for Eastern Europe, but there the approach and all calculations base exclusively upon the aspect of malnourishment of children. Therefore their estimates seem to be inappropriate to compare with estimates for the EU. The comparison with the other top-down studies is presented in Table 4.44. Although the comparison is not always straight forward, it appears that our bottom-up-based estimates are not in the same order of magnitude as the few existing top-down studies – but much lower. An interesting point is also that all feasible top-down estimates rely on one single paper, which itself relies on very rough, arbitrary assumptions (according to Parry et al. 2009).

Table 4-44: Comparison of our results with available top-down studies for agriculture adaptation costs in Europe

Top-down study	Adaptation cost estimate for agriculture in Europe	Notes
UNFCCC 2007 and McCarl 2007	2.3 to 2.7 billion $ in 2030 in high income countries for capital formation in agriculture	No European estimate available. Estimate is based upon very rough assumptions of the climate change mark-up of existing investment flows. As irrigation infrastructure is expected to be the most important capital formation in the analysed sectors, the costs seem to be quite higher than our estimates.
Parry et al. 2009	Cost estimate of UNFCCC 2007 is a reasonable first approximation, but probably too low.	Review focuses on the global perspective – no Europe-specific comments are made.
Bosello et al. 2009	7.8 billion $ in Western Europe and 12.3 billion $ in Eastern Europe and FSU in the 2060s.	Irrigation in a scenario of 2x current CO_2 levels and +2.5℃. Costs base upon cost estimates for water supply in UNFCCC 2007. Comparison is difficult due to different time frames and regions, but the order of magnitude suggests that our cost estimates are much lower.

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4.4.3.4 Cost sharing

In an economic framework, the costs estimated in this section are clearly private costs occurring to the agricultural producers. If, however, irrigation systems are subsidised, this may change and public costs may arise. Then the cost sharing depends on the concrete arrangement of subsidy schemes and in which way member states apply Art 9 of the Water Framework Directive[167]. Another caveat refers to water costs. These are generally not included in irrigation cost estimates, as water from on-farm water sources (such as groundwater) is assumed to cause no expenses to the farmer (water as “free-access public good”, Latinopoulos and Sartzetakis 2011). But water use causes costs – in form of external costs to other water users, eventually to next generations or to the environment. Therefore a

[167] Article 9.1 of the Directive reads that Member States shall ensure by 2010 an adequate contribution of the different water uses, disaggregated into at least industry, households and agriculture, to the recovery of the costs of water services, based on the economic analysis conducted according to Annex III and taking account of the polluter pays principle. Member States may in so doing have regard to the social, environmental and economic effects of the recovery as well as the geographic and climatic conditions of the region or regions affected. In other words the main costs of irrigation should be beard by the farmers but Member States may subsidise under certain conditions.

comprehensive cost sharing analysis would have to incorporate sustainability criteria of water usage patterns.

The direct costs, however, are clearly on-farm costs that occur to agricultural producers. Whether and to what extent these costs may be passed through to the consumers depends very much on the world markets of agricultural products. Since European producers are by tendency less harmed by climate change and therefore irrigation costs, one may expect that world prices increase due to climate change more than production costs in Europe (Anderson and Valenzuela 2011; Calzadilla et al. 2010). This would generally give the opportunity to European farmers to pass through additional irrigation costs.

4.4.4 Cooling of stables

Cost estimates for the cooling of stables are very difficult to obtain. The intended bottom-up approach of transferring unit costs to national and European values could not be applied for this measure due to missing information from the literature. There are few sources in the literature review in chapter 4.1.2 which raise the topic of animal husbandry but none of them contains any concrete information about cooling costs. Due to very different technical requirements and building conditions, costs for residential or office building cooling are not comparable or transferable to cooling of stables, either. Therefore we had no possibility to estimate the costs of this adaptation option. We also found no other study (top-down or bottom-up) on this aspect which indicates any cost estimation.

4.4.5 Farm advice

4.4.5.1 Definition of concrete measures and costs to be analysed

In the framework of the 2003 CAP reform, the cross compliance regime was introduced linking the respect of existing directives and regulations in the field of environment, public, animal and plant health, and animal welfare (Statutory Management Requirements - SMR) and the obligation to maintain land in good agricultural and environmental condition (GAEC) to EU direct payments. Farmers have to comply with these so called cross compliance standards in order to receive full EU support.

In this context, Chapter 3, articles 12-13 of the Regulation (EC) No 73/2009 requires all EU Member States to operate[168] a Farm Advice Service (FAS) to support farmers in understanding cross compliance rules and help them meet standards. Furthermore, Member States may determine, in accordance with objective criteria, the priority categories of farms that have access to the FAS. At a minimum, the FAS must advise farmers about compliance with SMRs and GAEC; participation in FAS in voluntary. To support the use of advisory services and the setting up of new advisory services, Council Regulation 74/2009 on support for rural development by the European Agricultural Fund for Rural Development for period 2007-2013 offers a few different financing instruments. Article 21 “Vocational Training”, article 24 “Use of advisory services” and article 25 “Setting up of management, relief and advisory services” are the three main articles used to fund advisory services under the rural

[168] Member States were required to set up a FAS by 1 January 2007 at the latest (Council Regulation No 1782/2003).

development programmes. Using rural development money to fund farm advisory services requires that the services include advice on at least SMR, GAEC and occupational safety standards.

However in the context of this study two scenarios are assumed:

a. In the next financial perspective the participation in FAS will become mandatory as it is seen as an essential measure to improve the overall environmental performance of farms. This will mean that all farmers receiving direct payments will have to absolve a mandatory FAS focusing on adaptation to climate change issues

b. The current system of voluntary advisory schemes remains and there are additional one to one and group advices due to climate change issues.

4.4.5.2 Cost estimation

The cost estimation and all underlying data are made transparent in the Excel file "Adaptation Cost Agriculture.xlsx" accompanying this paper.

Data sources

Although literature about farm advisory service of the EU is available, its costs are mostly only covered marginally or without providing sufficient details. One source which gives a deeper insight into costs is ADE 2009b, where country-specific unit costs for one-to-one farm advice are provided. These unit costs are needed for estimating the costs of additional voluntary one-to-one advices. The costs vary a lot, from around 400 € per one-to-one service to around 2000 € per service. The broad variation stems from different factors:

- Overall purpose and content of the advice provided: In some member states the farm advice is rather well oriented at the needs and requirements of the farmers and is only delivered "on demand" for the topics the farmer is interested in. Other member states pursue another approach with broader advice covering many topics which the farmer might not be aware of before.

- Manner in which the advice is delivered: According to ADE (2009b), farm advice can look very differently between the countries. The range goes from the simple ticking of a checklist up to multi-phase, several-day long farm-specific advice.

- Prevailing market unit costs in member state: Hourly costs of experts and facilities vary between the countries.

Unit costs per beneficiary for small group-advice are provided in AEA (2010), but only for the case of the UK. There a cost range of 37 to 350 € per beneficiary is indicated. In our analysis of voluntary advice service (scenario b) we use the mean value of these two extremes for all countries. In the case of compulsory advice (scenario a) we use a value close to the lower range since it may be assumed that compulsory events are more standardized and less costly.

The question how voluntary farm advice is currently used is tackled in ADE (2009a). The authors state that information about the number of beneficiaries is "extremely difficult to gather". Reliable and comparable figures are only available for 17 countries (one-to-one) and 10 countries (small group advice). We estimated the rough number of current farm advice beneficiaries by using the share of participating farms on the total farm number in those countries covered by the data. We assumed a hypothetical number of beneficiaries in 2008 even for those countries which did not have the service implemented by 2008 since we assume that in the coming years the service will be implemented in each member states. We will use these hypothetical values for estimating additional voluntary farm advice units which are needed due to climate change impacts (scenario b). In the case of compulsory advice services (scenario a) we assumed that every farm has to be present at one advice unit once in two years.

By combining the numbers and unit costs of voluntary advice services we can yield a rough estimate of current total costs of all events in this scheme. The resulting value (ca. 355 million € p.a.) is in the order of magnitude of twice the annual EU budget allocations for this kind of farm advisory service (ca. 162 million €). Indeed, the share of total costs funded by the EU is around 50%, according to personal communication. This makes us confident that our estimations of unit costs and current number of voluntary advisory services are realistic.

Procedure of the estimation

Scenario a: Compulsory farm advice for all farms receiving direct payments

For the estimation of costs of mandatory farm advice services for all farms under the direct payment scheme, the following data and parameters are needed:

FD_i	Number of farms in country i receiving direct payments by the CAP in 2007, provided by ADE 2009a. For Greece, Italy and Sweden the data in ADE 2009a were missing or higher than total farm number. For missing data the EU-wide average share of farms has been applied to estimate the number of receiving farms. If the number was too high, it was assumed that all farms receive direct payments.
c	Number of compulsory advice services per year and per farm, i.e. $c = 0.5$ if each farm has to participate once in two years.
NCG_i	Number of compulsory group advice services in country i, estimated by the formula $NCG_i = FD_i * c$
C_{CG}	Unit cost of compulsory group advice service in € per beneficiary

With these variables, the costs of new mandatory farm advice services under scenario a in country i in € p.a. are estimated by the formula:

$$AC_{a,i} = NCG_i * C_{CG}$$

Scenario b: Additional voluntary farm advice

The first step of the calculation of additional costs for farm advisory services is the estimation of the current numbers and unit costs of voluntary farm advice services. Obviously the unit costs differ between one-to-one farm advice and small group advice. Hence, the following data and parameters are of interest:

$NVO_{today,i}$	Number of current voluntary one-to-one farm advice services in country i, provided by ADE 2009a
$NVG_{today,i}$	Number of current voluntary group advice services in country i, provided by ADE 2009a

For those countries which are not covered by ADE 2009a, we estimate the number of current voluntary farm advice services by using the mean share of total farms which participate in the respective programs in the countries covered by the data. That is, the share of farms participating in voluntary one-to-one services equals roughly 2%, whereas the share for group advice is around 2.7%. Applying these shares on the countries without own data yields our EU-wide estimate of the current number of farm advice services.

In the second step additional service units due to climate change impacts are estimated. Here the following data and parameters are used:

$NVO_{CC,i}$	Number of additional voluntary one-to-one farm advice services in country i, due to climate change
$NVG_{CC,i}$	Number of additional voluntary group advice services in country i, due to climate change
YL_i	Agricultural yield loss in country i in %, according to Ciscar et al. 2010
$GVA_{Agr,i}$	Share of agriculture sector in gross value added of country i, according to Eurostat
w_{YL}	Weight of YL_i for the vulnerability indicator V_i
w_{GVA}	Weight of $GVA_{Agr,i}$ for the vulnerability indicator V_i
V_i	Indicator of the vulnerability of country i regarding climate change impacts in the agriculture sector, derived by the formula $V_i = ((YL_i - \min YL_i)/(\max YL_i - \min YL_i) * w_{YL} + (GVA_{Agr,i} - \min GVA_{Agr,i})/(\max GVA_{Agr,i} - \min GVA_{Agr,i}) * w_{GVA})/(w_{YL} + w_{GVA})$
s	Increase in % of farm advice units due to climate change in the country most affected by climate change

With these variables, the numbers of additional farm advice services in each category are estimated. The procedure implies that in the country the number of advice services increases by s %. In all other countries the relative increase is lower, linearly to their respective vulnerability.

$$NVO_{CC,i} = V_i / \max V_i * s / 100 * NVO_{today,i}$$

$$NVG_{CC,i} = V_i / \max V_i * s / 100 * NVG_{today,i}$$

The final step incorporates the unit costs of farm advisory services. Following parameters are needed:

$C_{VO,i}$	Unit cost of voluntary one-to-one advice service in € per beneficiary, according to ADE 2009b. For countries without data in ADE 2009b, an average value has been assumed.

C_{VG} Unit cost of voluntary group advice service in € per beneficiary, according to one source focussing on the UK (AEA 2010)

Then, the additional costs in the farm advisory service under scenario b in € p.a. in country i are roughly estimated by the formula:

$$AC_{b,i} = NVO_{CC,i} * C_{VO,i} + NVG_{CC,i} * C_{VG}$$

Constraints

- Unit costs of one-to-one farm advice service rely partly on information for specific regions, not the total country. For many countries, no unit costs were available and the EU-wide average was used.
- Unit costs for one-to-one and group advice are based upon few sources. Group advice costs are taken from the UK context.
- The current number of beneficiaries is difficult to assess. Only some countries provide data. The rest had to be estimated by using the EU-wide share of participating farmers out of the total number of farmers.
- There is no literature available with indications of additional costs or number of farm advice units. This is a crucial parameter which had to be estimated solely by the authors.
- The modelling of adaptation behaviour is quite crude, due to a scarce data and literature availability. It is assumed that the country most affected by climate change increases its advice amount by a certain amount, and in all other countries the increase is lower, linearly to their vulnerability.

4.4.5.3 Results

For yielding concrete adaptation costs for the measure of increasing farm advisory service, some parameter values have to be assumed. Table 4.45 lists the relevant parameters and their values used for the estimation. It becomes apparent that the analysis is highly dependent on our own assumptions, whereas we particularly want to shed light on the crucial parameter s . The overall results change proportionally with this parameter, which has never been estimated in the literature. The assumed value can clearly only be a first rough guess.

Table 4-45: Parameter values chosen for the estimation

Parameter	Description of parameter	Assumed value (can easily be changed in the Excel file)	Notes
c	Number of compulsory advice services per year and per farm	0.5	Assumption by authors
w_{YL}	Weight of agricultural yield losses for the vulnerability indicator	0.6	Assumption by authors
w_{GVA}	Weight of agricultural gross value added share for the vulnerability indicator	0.4	
s	Increase in % of farm advice units due to climate change in the country most affected by climate change	20	Assumption by authors
C_{CG}	Unit cost of compulsory group advice service in € per beneficiary	50	Assumption by authors, according to AEA 2010

Applying these parameter values to the data presented before yields the following cost estimations for additional farm advisory service due to climate change, per country (Table 4.46 for scenario a and Table 4.47 for scenario b). The distribution of EU-wide costs over the member states is triggered by the number of farms, their use of direct payments and voluntary advisory services and their vulnerability to climate change. There is no study known to the authors which yields similarly defined cost estimates, therefore a comparison with top-down studies is not possible.

Table 4-46: Cost estimates for additional farm advisory service according to scenario a (compulsory farm advice for each farm under the direct payment scheme), in million € p.a.

Country	For illustration: Total number of farms receiving direct payments	Additional voluntary farm advisory costs, in million € p.a.	Percentage of total EU27
Romania	1,248,000	14.5	27.2
Poland	1,452,620	9.3	17.6
Italy	968,417	9.1	17.1
Spain	899,940	4.1	7.7
Greece	860,150	3.9	7.4
Other countries	2,470,950	12.2	22.9
Total EU27	7,900,077	53.1	100.0

Table 4-47: Cost estimates for additional farm advisory service according to scenario b (additional voluntary farm advice), in million € p.a.

Country	For illustration: Total number of farms receiving direct payments	Additional voluntary farm advisory costs, in million € p.a.	Percentage of total EU27
Romania	1,248,000	14.5	27.2
Poland	1,452,620	9.3	17.6
Italy	968,417	9.1	17.1
Spain	899,940	4.1	7.7
Greece	860,150	3.9	7.4
Other countries	2,470,950	12.2	22.9
Total EU27	7,900,077	53.1	100.0

4.4.5.4 Cost sharing

As set out in Berglund and Dworak (2010), the current situation of FAS varies among the Member states. The costs that a farmer has to cover vary significantly among the MS. Currently the costs for mandatory FAS are shared between the European Commission, MS and farmers or farmers organisations. It is assumed that such a diverse and MS approach will remain as the issue of cost sharing clearly falls with the subsidiarity principle. For voluntary FAS there is a 50 : 50 share between the European Commission and the Member states, which is expected to remain under the next financial perspective.

4.4.6 Summary of cost estimates

This section summarizes in one table (Table 4.48) the key findings of this report – estimated costs for key adaptation measures in the agriculture sector. The figures have been estimated by transferring results of bottom-up studies to the European level using numerous case studies, and databases. The results are subject to various assumptions and constraints described before in the respective chapters.

Table 4-48 Summary of cost estimates

Adaptation option	Total costs in the EU27 (million € p.a.)	
Additional irrigation	330.8	
Additional farm advisory service	Scenario a: Additional voluntary farm advice 53.1	Scenario b: Compulsory farm advice for all farms under the direct payment scheme 197.5

5 Assessment of economic, social and environmental impacts of key measures

5.1 Energy

5.1.1 'Climate Proofing' measures for the Energy Sector – Adaptation of the European electricity infrastructure

Europe's electricity grid will be affected by climate change in various ways. Direct impacts on the electricity grid include the following:

- Storms can lead to the collapse of transmission towers and poles of overhead power lines;
- Ice coating can damage power cables;
- Faster plant growth increases the need for maintenance of power lines (cutting back undergrowth);
- Droughts can affect underground cables because of dilatation and underground soil movement.

Further, indirect effects arise through climate-induced changes in power generation and power consumption, which in turn affect the electricity grid: These effects occur both on the supply side and on the demand side:

- Power generation from thermal power plants (coal, gas, nuclear) depends on cooling water, often taken from rivers. In heat periods, river water can become too warm to allow for effective cooling;
- Hydropower generation depends on precipitation patterns. Shortages may occur especially in summer months, if a larger share of precipitation comes in the form of rain rather than snow.
- Power generation from wind obviously depends on the availability of wind. Whereas a storm may initially increase power production, windmills are shut down during heavy storms for security reasons.
- On the demand side, changes in temperature will affect the demand for electricity. The need for cooling drives up electricity demand during heat periods, whereas demand for heating will be lower during winter (in those parts of Europe where electricity is used for heating in a significant way).

The above changes in electricity demand and supply pose new challenges for the spatial and temporal coordination of electricity generation and consumption, which need to be reflected in the layout of the grid.

5.1.2 Basic information

The economic value of a stable and reliable electricity supply is undisputed, and is illustrated by the huge economic cost of power shortages: virtually all economic processes stop immediately if power fails, leading to huge production losses. Only few critical processes (e.g. in the health sector) incur the cost of maintaining back-up power generation capacities.

Power supply belongs to the category of “critical infrastructure”: The modern economy is as reliant on power supply as it depends on information and communication services.

The adaptation of power distribution networks enhances their resilience against climate change. This includes a more robust physical infrastructure (transmission towers, power lines etc.), design to withstand more extreme climate impacts like heavy storms and higher temperature amplitudes. It can also include the option of having underground lines instead of overhead lines, so that power lines are less exposed to climate impacts. At a more general level, it includes the option of more finely meshed transmission and distribution networks, with some buffer capacities and redundancy to accommodate unforeseen outages.

The EU has some role in this process, owed to its role in coordinating (and partly funding) the integration of European energy markets and the interconnection of electricity grids across Europe (Trans-European Networks, TEN-E). The EU promotes the expansion and the interconnection of European electricity grids, both to integrate a growing share of renewable electricity from a variety of sources into the grid, and also to enhance the integration of electricity markets across Europe, and ultimately to develop an EU-wide smart grid for electricity.

The Commission Communication "Energy infrastructure priorities for 2020 and beyond - A Blueprint for an integrated European energy network" was adopted in November 2010. The communication focuses on the integration of the existing national and regional electricity networks across Europe and defines EU priority corridors for the transport of electricity, gas and oil. Adaptation to climate change, however, does not feature in the Communication.

5.1.3 Effectiveness of adaptation

Relevance:

The measure can be considered as a need-to-have adaptation option, because the energy transmission and distribution networks are part of the critical infrastructure, i.e. the infrastructure backbone that is essential for the functioning of society and economy. A failure or disruption of the electricity grid has severely and immediate impacts on the public life and all economic activities. The associated costs are very high (van Ierland 2007; UBA 2011). De Groot (2006) describes the economic loss because of a power cut with up to 30 € per non-delivered KwH, if the power cut lasts eight hours or more (De Groot 2006).

The damage to electricity networks through storms, ice, floods, etc. can be reduced by designing the infrastructure for more extreme weather events. In addition, a tighter-knit grid with higher redundancy would provide for a higher resilience in case individual lines or part of the grid should fail. While it may not be possible to avoid the impacts of weather extremes altogether, a grid structure with higher redundancy means that impacts will occur only locally, i.e. the effects of power outages will mostly be limited to local effects, while avoiding regional knock-on effects.

Spatial distribution of effects:

The adaptation measure has an impact on different spatial levels: to have the desired effect, the measure will need to be implemented throughout the EU, but especially in locations prone to damage from storms and other extreme weather events. The benefits in terms of avoided power outages will be felt at the local to regional level (van Ierland 2007).

Urgency:

The urgency of the adaptation measure is high. This is due to the long lifetime of the electricity transmission and distribution infrastructure (50-100 years), and due to the fact that a substantial overhaul and expansion of Europe's electricity grids is imminent. In order to incorporate and transmit the growing share of renewable electricity, substantial investments into the grid will be made in the coming years, which will determine the structure and layout of the electricity grid for coming decades. Climate-proofing of the electricity networks can only be achieved in a cost-effective way if it is integrated into this overhaul and expansion; a retrofitting of existing infrastructure would be significantly more expensive. This applies in particular to any measures that change the structure of a grid towards meshed web with a higher degree of built-in redundancy (Vattenfall Europe AG 2005; Rademaekers et al 2011).

Interactions between adaptation measures:

The adaptation of the electricity distribution network may lead to conflicts with biodiversity protection and the extension of protected areas, especially where it involves the establishment of new corridors for transmission lines. Building and retrofitting of power lines (both overhead and underground) marks a considerable intervention into the ecosystems through which power lines run. This applies especially during the construction phase, to a lesser degree during the operation, as the corridors of transmission lines need to be kept free of vegetation. Overhead lines tend to be less intrusive during construction, whereas underground lines are less problematic during their operation.

Flexibility:

As such, upgrading the physical infrastructure of the electricity networks to cope with more extreme weather events does not produce positive side-effects for objectives other than climate change adaptation. But, given that the transformation of the European energy system towards low-carbon power generation and an integrated EU-wide energy market necessitates a substantial overhaul of the electricity grid anyway, climate-proofing of the electricity networks blends in with the already-planned investments. Against this background, and provided that the climate-proofing can indeed be integrated with the ongoing overhaul, the adaptation of electricity networks to climate change can be seen as a no-regret measure (van Ierland 2007; UBA 2011; European Commission 2010).

Also, the adaptation measure is effective under different climate scenarios. If climate change impacts turn out to be lower than anticipated, so would the effects of the adaptation measure. However, the risk of misinvestments or "misadaptation" appears limited, also in view of the cost relations and the general uncertainty about the Europe's future energy supply and the according infrastructure needs.

5.1.4 Efficiency/ costs and benefits

5.1.4.1 Electricity infrastructure

Costs of energy infrastructure

The cost calculation can be found in chapter 4.1.3.

Distribution of costs, windfall profits

In principle, the operators of electricity networks can recover their investment and maintenance costs from the power consumers: transmission charges are included as part of the electricity bill, although the level of these charges may be regulated. Where governments pay financial support for adapting electricity networks to deal with climate change impacts, there is at least a risk of generating windfall profits for the network operators. In the past, after damages through weather extremes, the network operators in Western Europe already invested in the improvement of their networks. Some "autonomous adaptation" can therefore already be observed. At the same time, to achieve a more fundamental transformation of the grid (towards a meshed network), either dedicated public support or strict regulation would seem necessary (Rademaekers et al 2011).

Benefit for energy infrastructure

Definition

The adaptation measure "Adaptation of the electricity grid" consists of several components: a higher frequency of maintenance work (to respond to extreme weather events and faster plant growth); use of stronger, more robust overhead lines and pylons (to limit the impacts of extreme weather events) investment into new power lines to realise a tighter-meshed grid and provide for redundancy, and expanding the use of underground cables, especially in areas exposed to extreme weather. All these measures help to create a more resilient electricity grid, lowering the risk of large power outages. These power cuts are mostly caused by extreme weather events, such as thunder-, ice- or hailstorms. The calculation of benefits of the discussed adaptation measures is therefore based on avoided power outages due to storm events.

A literature research on the effects of past storm events, affected people and resulting damage costs revealed that the benefits of adapting electricity networks to the impacts of climate change are mostly captured as anecdotal evidence. The main benefit is the avoided cost of climate-induced power outages. For example:

- In the winter of 2005, snow and ice covering overhead lines in Northwest Germany lead to a disruption in power supply of several days. The power outage affected 250.000 people and resulted in an economic loss of 50 to 100 million € (IHK Nord Westfalen 2006), i.e. 200 to 400 Euro per person affected.
- Likewise, due to severe storms in January 1999 3.5 million customers in France were left without power supply, at a costs of €1.1 billion (Rademaekers et al 2011), i.e. some 300 Euro per person affected.
- A winter storm in January 2009 caused a power outage in South West France where 1.7 million people were affected. The information to costs varies between € 350 million and up to € 1.4 bn, i.e. some 200 – 820 Euro per person affected (Guy Carpenter & Company Ltd 2009).
- On 27 October 2002 a storm event led to a supply disruption in England & Wales. Circa 2 million people were cut from electricity supply, some for almost ten days. The costs were calculated with more than € 45 million (£ 30 million) (Watkiss et al 2006).
- Because of a fallen tree in Switzerland on the 28 of September 2003, 20 million people in Italy were left without electricity supply. The northern regions were back at the grid within three hours. For the other regions the outage lasted maximum 24 hours. The outage is discussed as the worst power cut in Europe. (Kundur 2004, Andersson 2003)
- In North America, in August 2003 the US and Canadian East Coast was without electricity supply due to a storm event. Some 50 million people were without

electricity, and 61.8 GW was not delivered. The damage is estimated between € 6.8 and 10.3 billion (Frontier Economics 2008).

Unfortunately, the available anecdotal evidence only quantifies the cost of power cuts as such. It does not indicate how much of this cost could have been avoided through adaptation measures, nor does it specify how much (if any) of the observed damage could be considered as a climate-change impact. The damage cost estimates can, however, serve as illustrations of the cost of inaction.

Calculation

The calculation of benefits is based on following parameters:

- B_i: Benefit of adaptation measures to strengthen power lines against storm events per different country *i* (transmission and distribution lines)
- SI_i: Change in storm intensity in country *i* by 2080, mean of three storm scenarios basing on SRES scenario A1B (Source: Rademaekers et al. 2011). This value is not available for each country, but for four large regions in Europe.
- I : Increase of damage costs through a higher intensity of storm events (in 2080). The indicator for higher costs through a change in storm intensity is taken from Watkiss et al (2006). This source projects 60 % higher costs from a storm event in GB in 2080.
- C_{POi}: Costs of a power outage per country *i* (reasoned by storm)
- CR_x: Cost reduction on how much of this cost could have been avoided through adaptation measures. Evidence for this indication is very weak. RTE (2010) mentions that the construction of meshed power grid caused to a 50 % reduction of damage for two comparable storm events in France. So three different scenarios (*x*) are used (40%, 50% and 75%).
- SF_y: Frequency of storm events in 2080. Watkiss et al (2006) discusses a frequency of extreme storm events which lead to extended power cuts on a 5-year, 7.5-year and 10-year basis. To analyse different scenarios, a 5, 7.5 and 10-yearly basis was assumed (*y*).

$$B_i = C_{POi} * \left(I \ / SI_{GB} * SI_i\right) * SF_y * CR_x$$

For the benefit estimation, no distinction was made between transmission and distribution networks, because large extreme weather events affect both transmission and distribution lines, and since reliable data on the differential impacts to the two types of networks was not available. Since only a minor part of the power lines in the EU-27 are underground cables, and since these are generally less exposed to climate change impacts, adaptation to underground cables was not considered further.

Overhead lines in forests are especially vulnerable to damage from fallen trees, a common cause of power outages and a reason for the relatively high benefit of maintenance work to clear trees and undergrowth. At the same time, lines on open fields are more vulnerable to wind damage than lines in forest, since the wood offers some protection from wind.

Martikainen et al 2007, therefore argue that overhead lines should be relocated into forested areas.

It has proven particularly difficult to arrive at reliable estimates of which part of the damage costs could be avoided through the adaptation measures discussed here. Only one source (RTE 2010) quantified the adaptation effect, arguing that the construction of meshed power grid halved the damage for two comparable storm events in France. Because of this thin evidence base, three different scenarios are used – assuming that the adaptation measures can reduce the damage cost by 40%, 50% or 75%.

Watkiss et al (2006) discuss the higher frequency of extreme storm events, increasing the risk of extended power cuts on a 5-year, 7.5-year and 10-year basis. The further calculations are based on their assumptions for the frequency of extreme storms. This includes the possibility that storms may occur at a lower frequency, but with higher intensity.

The change in storm intensity in 2080 was taken from Rademaekers et al. (2011). The calculation is based on SRES scenarios. The estimation is made for four large regions in Europe which will experience different impacts of climate change.

The costs of power outages (C_{POi}) are calculated on the basis of the "Value of lost load" (a similar concept to the interrupted energy assessment rate (IEAR), or the value of service or unserved service).

The Value of Lost Load (VOLL) is defined as the value an average consumer puts on an unsupplied MWh of energy (Tol 2007). The Value of lost load can be differentiated according to the activities affected by the power cut, the availability of advance warning, the time of year and duration of the interruption. In the literature, different estimates of VOLLs can be found. Essentially, there are three ways to estimate the VOLL - preferences revealed in market behavior, stated preferences via survey of costumers, and estimation of the production function, which relates electricity consumption to output.

Some examples can be found in the following table, documenting the considerable variation between the different estimates, with VOLL figures ranging from 1.50 to almost 70 Euro/kWh.

Table 5-1: Literature review: Value of lost load (in €/kWh) (Extract)

Literature	Sector	Value of lost load (VOLL) (€/kWh)	Time/Region/Other remarks
Martikainen et al 2007	Agriculture	9.38	Finland
Egenhofer et al 2004	Household	1.8 – 3.8	3.8 for one hour outage; 1.8 for an outage of longer than 24 hours
Kariuki/Allan 1996	Household	4.6	UK
Watkiss et al 2006	Household	1.49-2.97	2.97 for first day; 1.49 for other days, UK, Original: £1-£2
Bay Area Economic Forum 2001	Household	3.23- 4.46	Original: $2.87-$3.97
Martikainen et al 2007	Household	4.29	Finland
Nooij/Bijvoet/Koopmans 2003	Household	6	Netherlands
Lo Schiavo 2005	Household	10.8	Italy
Carlsson 2004	Household	2.36-6.64	Sweden

Tol 2007	Household	8.0	Ireland
Martikainen et al 2007	Industry	24.5	Finland
Nooij/Bijvoet/Koopmans 2003	Industry	16.4	Netherlands
Bliem 2007	Industry	13.2	Austria
Tol 2007	Industry	68.0	Ireland
Baarsma 2005	Industry (SME)	31.0	Netherlands
Bay Area Economic Forum 2001	Commercial+ industrial consumer	42.71-65.18	Original: $38-$58, USA
Bay Area Economic Forum 2001	Commercial+ industrial consumer	12.36-21.35	Original: $11-$19, USA
Martikainen et al 2007	Public	15.1	Finland
Martikainen et al 2007	Service	29.9	Finland

For the further analysis, a minimum, average and maximum value for different customer groups were defined on the basis of the different literature estimates, see Table 5.2.

Table 5-2: Value of lost load (VOLL) (Maximum, Average, Minimum)

Households	**VOLL (in €/kWh)**
min	1,8
max	10,8
average	3,96
Industry	
min	12,36
max	68
average	27,96
Agriculture	
	9,38
Public/Service	
min	15,1
max	29,9
average	22,5

For households and industry, the minimum and maximum values reported in the literature were used as lower-bound and upper-bound estimates; the average value is simply the arithmetic mean of all values of the mentioned sources. Values for agriculture, public sector and services are only reported in Martikainen et al (2007). For agriculture, this value was used in the subsequent assessment. For the public sector and services, the available statistical data on energy consumption reported the combined electricity use of the public sector and services, so the lower VOLL for public (15.1 €/kWh) was used as lower-bound estimate for the combined electricity consumption, and the higher VOLL for services (29.9 €/kWh) as the upper bound, with the average in between these two values (22.5 €/kWh). The lower-bound estimate will be more accurate, the higher the share of the public sector in the combined electricity consumption, and vice versa for the services.

- C_{POi} : Costs of a power outage per country *i* (reasoned by storm)

- $VOLL_{sector}$: Value of lost load for *sectors* household, industry, agriculture, public/service

- UE_{ie} : Part of undelivered electricity consumption for country *i and scenario e (min, average, max)*

- ES_{sector} : Share of national electricity consumption for sectors household, industry, agriculture, public/service

$$C_{POi} = (VOLL_{household} * UE_{ie} * ES_{householdi}) + (VOLL_{industry} * UE_{ie} * ES_{industryi}) +$$
$$(VOLL_{agriculture} * UE_{ie} * ES_{agriculturei}) + (VOLL_{public/service} * UE_{ie} * ES_{public/servicei})$$

The undelivered electricity consumption is estimated on the basis of two past events: the 2002 power outage in England and Wales and the blackout in Italy in 2003, see Table 5.3:

Table 5-3: Storm events: cases

Time	27 October 2002	28 September 2003
Region	England & Wales	Italy
Affected persons	2.000.000	20.000.000
Undelivered electricity (estimate)	20 GWh	60 GWh

The blackout in Italy lasted for three hours in the North of the country, all parts of Italy were back on the grid in less than one day (Kundur 2004, Andersson 2003). The total power loss was estimated at 180 GWh (Ciauşiu & Eremia 2008), which seems to be a rather high estimate, given the relatively short duration of the blackout. Therefore, in the case study an amount of 60 GWh power loss is used. At any rate, the outage in Italy is seen as the biggest power outage in Europe so far.

The 2002 power cut in England and Wales lasted for no more than 18 hours for the majority of consumers, but some consumers were without electricity almost ten days (Watkiss et al 2006).

Based on these examples, the further calculation is based on a conservative value of a 10 hour power cut, equal to 20 GWh of undelivered electricity (if based on the England & Wales example) and 60 GWh for the case in Italy. A third, average scenario assumes 40 GWh of undelivered electricity. To estimate the undelivered electricity for every EU country, the undelivered electricity for the three cases were expressed as a proportion of the total annual electricity use in Italy and the United Kingdom, respectively. These ratios were then combined with the yearly total electricity consumption of every EU country.

$$UE_{\min i} = E_i * (20GWh / E_{GB+NI})$$

$$UE_{averagei} = E_i * \lfloor 40GWh / 0{,}5 * (E_{GB+NI} + E_{Italy}) \rfloor$$

$$UE_{\max i} = E_i * (60GWh / E_{Italy})$$

- $UE_{\min/average/\max i}$: UE_{ie}: Part of undelivered electricity consumption for country *i and scenario (min, average, max)*

- E_i: Total Electricity consumption per year for country *i*

- $E_{GB+NI/Italy}$: Total Electricity consumption per year for *Great Britain+North Ireland or Italy*

Important Assumptions

To estimate the benefits of adaptation against storm events, different assumptions had to be made:

- The expected impact of climate change obviously has a high effect on the expected benefit of the adaptation measures. Unfortunately, the data basis on the expected impacts of climate change on the electricity grid is still rather thin. Assumptions on the future intensity of storm events were based on Rademaeker (2010). There, the EU was divided into four country groups, with assumed increases of storm intensity ranging from 23.6 to 35.6 % for each country group. To link the impact of climate change on the grid with the resulting higher damage cost due to power outages, an estimate from the UK was used. Watkiss et al. (2006) estimated that the damage costs will be 60 % higher in 2080. This figure is then combined with the projected increase in storm intensity for the four country groups. It should be noted that the estimate is therefore strongly determined by the UK estimate; if more and better data becomes available, it would be advisable to rerun the calculation using a range of estimates.

- The cost per undelivered kWh due to storm-induces power outages is based on two historic events that occured in Italy and Great Britain, and which serve as lower-bound and upper-bound estimate. The percentage of kWh lost through these events was applied to other countries as a ratio of their total power consumption.

- Regarding the frequency of extreme storm events, Watkiss et al (2006) report the increase risk of 5-year, 10-year and 20-year storm events. This data was used for the further calculation, with 10-year basis as current status.

- The values of the value of lost load serve as minimum, average and maximum value. They were used as one EU-wide indicator, because national value were available only for some of the countries. Furthermore, the public sector and services were combined since the data on electricity consumption that was used for this analysis was only available as an aggregate of the two sectors. A minor percentage of electricity consumption was not accounted for in the calculation. This percentage differs for each country, with a maximum of 5.9 % for Austria. This electricity is used mainly by the transport sector. No concrete value of lost load was available for this percentage of electricity consumption. (Tol 2007).

- The data basis for actual effectiveness of adaptation measures – i.e. which proportion of the expected damage cost could actually be avoided by the discussed adaptation measures – is, again, very thin. RTE (2010) estimate that damage costs could be reduced by 50% through the construction of tighter-meshed, more resilient power grids. Acknowledging the limitations of using only one estimate, three values of 40%, 50% and 75% damage cost reduction were assumed as lower-bound, best-guess and upper-bound estimate of the effectiveness. Again, if more and more accurate data is available, it would improve the robustness of this estimate and reduce the associated uncertainty.

Results

The results of the benefit estimation for adapting the electricity grid in the EU-27 are shown in this chapter. The estimation deals with the following adaptation measures: securing networks from storm damage (by strengthening pylons and overhead power lines), additional maintenance especially in forests and building up additional transmission capacity in order to develop a tighter-meshed, more resilient grid.

The benefits were calculated on the basis of expected power outages caused by storms, assuming that the mentioned adaptation measures could avoid at least part of the damage:

Table 5-4: Benefits of adaptation options based on different scenarios

Different scenarios	Reduction of damage through adaptation options	Frequency of large storm events (in years)	Undelivered GWh per event (in GWh)	Benefits of the adaptation options to energy infrastructure (in million €/a)
Minimum scenario	40%	10	6	130
Average scenario	50%	7,5	13	874
Maximum scenario	75%	5	20	6,496

The best-guess estimate of the annual benefits at EU level is € 870 million per year. This ranges from a lower-bound estimate of € 130 million up to an upper-bound estimate of € 6,500 million per year.

Table 5-5: Overview: Benefits of adaptation options – Energy infrastructure (10 EU countries with highest benefits)

Country	Total Electricity Consumption (mean value 2004-2009) (GWh/a)	Minimum scenario (in million €)	Average scenarios (in million €)	Average scenario (% of total EU)	Maximum scenario (in million €)
Germany	519,156	28.69	197.51	22.6%	1.503.05
Italy	302,307	15.74	108.00	12.4%	817.19
France	425,465	14.21	93.98	10.7%	682.79
Spain	252,615	12.84	85.70	9.8%	629.70
UK	339,961	11.45	76.17	8.7%	558.32
Poland	111,005	6.49	42.86	4.9%	309.04
Sweden	129,162	6.00	41.83	4.8%	323.38
Finland	82,664	4.15	29.61	3.4%	233.67
Netherlands	106,127	4.16	27.08	3.1%	194.50

Austria	58,763	3.05	21.42	2.4%	166.52
EU Total	**2,792,767**	**129.15**	**874.30**	**100.0%**	**6,496.71**

The above Table 5.5 shows the results for the ten countries with the highest expected benefits, i.e. the countries with the highest absolute power consumption, but also those most vulnerable to climate change impacts. Germany is tops the range, due to its high total electricity consumption and a high share of electricity consumption in the industry sector (44%).

The relatively high figure for smaller economies like Finland or Austria can be explained with their relatively high share of electricity used in the industry sector (53% and 45%, respectively, for Finland and Austria), which has the highest damage cost of lost load.

Table 5-6: Values of lost load in Industry Sector

Country	Mean Total Electricity Consumption (2004-2009) (GWh/a)	Share Electricity Consumption Industry (Average 2004-2009)	Value of lost load of average undelivered GWh in industry sector (in €)	% value loss in industry sector of total value loss (average case)
Romania	39,832	57.4%	1,920.9	79.8%
Finland	82,664	53.0%	3,238.2	72.8%
Italy	302,307	46.6%	10,603.5	65.3%
Austria	58,763	44.6%	2,201.2	68.3%
Germany	519,156	44.2%	19,267.5	64.9%
Sweden	129,162	43.8%	4,177.2	66.4%
Spain	252,615	39.6%	7,524.8	58.4%
Poland	111,005	38.5%	3,591.8	55.8%
Netherlands	106,127	38.5%	2,277.3	56.0%
United Kingdom	339,961	32.8%	6,205.2	54.1%
France	425,465	31.3%	7,412.3	52.4%
Cyprus	4,275	13.5%	43.6	24.3%
EU Total	**2,792,767**	**39.7%**	**81,833.0**	**60.8%**

In the Table 5.6 the data of the ten countries with highest benefit can be found, as well as Romania and Cyprus as the countries with highest and lowest share of electricity consumption in industry sector.

The lower-bound estimate of € 130 million can be seen as a conservative estimate. For example, the value of lost load for households in the minimum estimated was set at 1.80 €/kWh, which a rather low figure. Also, the frequency of storm events in this scenario is similar to what is already observed today. The best-guess scenario therefore seems as a more realistic approximation, but the actual benefit will of course depend strongly on how climate change impacts actually unfold.

The benefits are estimated for the major economic sectors, based on their relative share of electricity use. In most countries, industry accounts for the largest share. For the EU-27, it represents almost 40 % of the power consumption, followed by households (29 %) and the combined consumption of the public sector and services (26 %), with the remainder in agriculture and some unaccounted-for electricity use. But on a country basis, the division of electricity consumption may differ. In France, Denmark or Hungary for instance, the electricity consumption of households exceeds that of industry. The relatively highest share of consumption by the public sector and services can be observed in Greece, Latvia, Lithuania and Cyprus. These different shares in sectors have consequences for the benefits for the sectors. The following table shows the benefits split by different sectors for the ten countries with highest total benefit. For the EU 26 (without Malta) industry shows the highest share, followed by public and service, households and agriculture.

Table 5-7: Benefits of adaptation options – splitted by different sectors (in mio. €)

Country	Industry (in mio. €)		Households (in mio. €)		Agriculture (in mio. €)		Public/Service (in mio. €)	
	min	max	min	max	min	max	min	max
Germany	32.19	560.04	2.87	54.45	0.90	2.84	21.43	134.19
Italy	17.71	308.21	1.24	23.51	0.53	1.66	12.01	75.21
Spain	12.57	218.72	1.24	23.49	0.55	1.73	11.32	70.91
France	12.38	215.45	2.06	39.10	0.24	0.76	13.74	86.07
United Kingdom	10.37	180.36	1.66	31.58	0.28	0.90	10.59	66.31
Sweden	6.98	121.42	0.73	13.93	0.16	0.50	4.13	25.84
Austria	3.68	63.98	0.34	6.44	0.09	0.28	2.01	12.56
Poland	6.00	104.40	0.54	10.23	0.16	0.52	6.29	39.37
Finland	5.41	94.12	0.38	7.21	0.08	0.26	2.43	15.24
Netherlands	3.80	66.19	0.33	6.25	0.46	1.47	3.73	23.34
EU 26 (without Malta)	**133.49**	**2,309.56**	**13.79**	**260.93**	**4.49**	**14.13**	**106.52**	**663.73**

Comparison of benefits and costs

The report includes several adaptation measures to enhance the energy infrastructure in the EU and make it more resilient to climate change impacts. This study estimates the costs of adapting the existing energy infrastructure (see chapter 4.1.3) at some € 500 to 650 million per year. These calculation results are rather low estimates when compared to existing top-down-studies. The reasons are shortly described in chapter 4.1.3.3.

The benefits are estimated at € 130 million to € 6,500 million per year, with a best-guess estimate of € 870 million per year. While both the cost and benefit estimates are fraught with uncertainties, it seems more likely that the benefits exceed the costs than that the opposite is true.

5.1.4.2 Electricity Demand

Costs for electricity demand

See chapter 4.1.5.

Benefit of electricity demand

It is expected that, particularly in Southern Europe, climate change will lead to a higher electricity demand due to the need for cooling. Some of this additional demand can potentially be limited through the use of high-efficiency ventilation. Several research projects, such as Euroheatcool, have investigated the options to increase the efficiency of cooling systems or to promote district cooling systems.

To ensure comparison with the cost data from chapter 4.1.5 and to allow the estimation of a benefit-cost ratio, the calculation is based on data by Radgen et al (2008) on ventilation systems of non-residential buildings. In this study, the authors modeled the expected number of non-residential building ventilation units that will be in use in 2025 (see following table). Radgen et al (2008) estimated these numbers for eight different product groups, including components of different air conditioning systems. Furthermore, the report contains the regular average electricity consumption for these eight product groups. Acknowledging the different building types and uses in which these units are applied, Radgen et al applied a different time profile to the use of the product groups, see Table 5.8.

Table 5-8: Electricity consumption of ventilation products 2025 (Source: Radgen et al 2008)

Product Category	Number of products in use for non-residential building ventilation	Electricity use (kWh)	On-time (h/year)	Electricity consumption for all products in use min (Gwh/year)	Electricity consumption for all products in use max (Gwh/year)
	2025	2005	2005	2025	2025
1	14,0 – 40,4 mio.	0,80	2000	22,400	64,640
2	38,8 – 112,3 mio.	1,32	2000	102,432	296,472
3	16,8 – 61,4 mio.	0,44	3000	22,176	81,048
4	5,2 – 19,0 mio.	3,76	3000	58,656	214,320
5	5,8 – 21,2 mio.	3,82	3000	66,468	242,952
6	29,8 – 86,3 mio.	0,37	1715	18,910	54,762
7	52,5 – 151,7 mio.	1,20	2520	158,760	458,741
8	3,6 – 10,3 mio.	0,42	1865	2,820	8,067.99
Total				452,622	1,421,002

There is little data on the potential for increasing the efficiency of ventilation units. For instance, Adnot et al (2003) report that high efficiency units could achieve an use of electricity of 20 to 50 % below that of average products. Because of the lack of reliable and more recent data, the benefits were estimated using minimum, average and maximum values, with a minimum case of 20 % higher efficiency of products in 2025, average 35 % and maximum 50 % lower electricity use.

If these three figures are combined with current electricity prices for the EU-27, the savings can be estimated as follows. The electricity prices for the EU-27 were taken from Eurostat, using the average of 2009 and 2010 (9,37 ct/kWh). The saved costs through more efficient ventilation units would then vary between € 8.5 bn and € 66.6 bn.

Table 5-9: Saved costs through more efficient ventilation (Source: Radgen et al 2008)

	Electricity Consumption for all products in use (Twh/a)	Reduction in electricity use through higher efficiency (TWh/a)	Lower Costs for electricity for consumer, (bn €/a)
Minimum case (lowest number of new ventilation in 2025, 20% higher efficiency)	452.6	90.5	8.5
Average case (average number new ventilation, 35% higher efficiency)	936.8	328	30.8
Maximum case (highest number of new ventilation in 2025, 50% higher efficiency)	1,421	710	66.6

To break this information down to country-level, more information on the size of buildings was needed. Adnot et al (2003) publish projections on the building floor area which will require cooling by 2020 for each EU-15 country. These projections were then extended to 2025, applying the same rate of increase that was also observed between 2015 and 2020. No comparable data could be found for the rest of the EU, so that the country level estimation is limited to the EU-15.

To derive the number of ventilation units installed in the EU15 and in the rest of the EU, the surface area of buildings in the service sector was used as a proxy. This approach was also employed by Euroheat & Power (2006) in the project Euroheatcool, with the result that almost 87 % of the areas in the service sector are in the EU15, and 13% in the other EU-countries.

Table 5-10: Lower electricity consumption divided by country (EU-15 only) in 2025

Country	Area conditioned in each country (in million m2) (non-residential buildings) (2025)	Efficiency 20% higher (lower electricity use in TWh/year) (2025)	Efficiency 35% higher (lower electricity use in TWh/year) (2025)	Efficiency 50% higher (lower electricity use in TWh/year) (2025)
AT	34.9	1.0	3.5	7.6
BE	56.6	1.6	5.7	12.3
DE	437.9	12.1	43.9	95.1
DK	47.6	1.3	4.8	10.3
ES	362.5	10.0	36.3	78.7
FI	51.8	1.4	5.2	11.2
FR	534.5	14.8	53.6	116.0
GR	151.2	4.2	15.2	32.8
IR	21.4	0.6	2.1	4.6
IT	486.0	13.4	48.7	105.5
LU	2.3	0.1	0.2	0.5
NE	116.8	3.2	11.7	25.4
PT	89.6	2.5	9.0	19.4
SW	89.1	2.5	8.9	19.4
UK	354.3	9.8	35.5	76.9
EU 15 Total	**2,834.6**	**78.4**	**284.0**	**615.4**

The reduction of electricity use through higher efficiency is then split according to the available data on cooled area in non-residential buildings. It can be seen that France has the highest share of reduced electricity consumption, followed by Italy, Germany and Spain, reflecting both the absolute size of the built-up area, and the exposure to higher temperatures in these countries.

These estimates were combined with electricity prices in different EU15 countries. Data on electricity prices were taken from Eurostat, using a average of 2009 and 2010. For Austria, the latest information available was from 2008, for Italy from 2007.

Table 5-11: Lower amount of electricity costs for consumers through high efficient ventilation divided by countries (in 2025, EU-15 only)

Country	Electricity price (Average 2009-2010, partially 2007 or 2008) (in ct/kWh)	Lower amount of electricity costs for consumer (min) 2025 (million Euro)	Lower amount of electricity costs for consumer (average) 2025 (million Euro)	Lower amount of electricity costs for consumer (max) 2025 (million Euro)	% of total EU15
AT	8.97 (2008)	86.6	313.8	680.0	1,3%
BE	9.85	154.1	558.1	1,209.5	2,3%
DE	7.93	960.6	3,479.2	7,539.2	14,6%
DK	9.48	124.9	452.4	980.3	1,9%
ES	11.04	1,107.0	4,009.7	8,688.8	16,9%
FI	6.65	95.3	345.2	747.9	1,5%
FR	6.77	1,000.9	3,625.4	7,856.0	15,3%
GR	9.02	377.3	1,366.5	2,961.1	5,7%
IR	11.62	68.8	249.1	539.9	1,0%
IT	10.27 (2007)	1,380.8	5,001.5	10,837.9	21,0%
LU	10.26	6.6	24.0	52.1	0,1%
NE	8.97	289.8	1,049.5	2,274.2	4,4%
PT	9.08	224.8	814.3	1,764.5	3,4%
SW	7.31	180.3	653.0	1,414.9	2,7%
UK	10.12	991.9	3,592.7	7,785.1	15,1%
EU 15 Total	**8.37**	**6,563.0**	**23,771.6**	**51,511.4**	**100%**

For the EU-15, the increased efficiency results in annual savings of 6.5 to 51.5 billion Euros. Due to the higher electricity prices and the need for cooling, the highest reduction potential is observed in Italy, which alone represents 21% of the cost savings potential of the EU-15, followed by Spain (17%), France (15%), UK (15%) and Germany (15%). This means that the minimum (20% higher efficiency, small amount of new ventilation systems) and the maximum scenario (50% higher efficiency, high amount of new ventilation systems) differ by about one order of magnitude.

Comparison of benefits and costs

The costs of ventilation systems vary between 100 million and 41.8 billion Euros (estimated above). The benefit-cost-ratio is positive for the most scenarios. But if the costs tend to the higher value of 41.8 billion also a negative ratio is possible, also dependent on the actual impacts reasoned by climate change.

The benefit was estimated from 8.5 to 66.6 billion Euros for EU-27 (EU-15: 6.5 to 51.5 billion Euro). The estimation was based on the same number of new ventilation systems in 2025, so a comparison of the value is possible. However, these estimates depend on a number of assumptions: for instance, current electricity prices were used to estimate the benefits of electricity savings; at the same time, given the necessary investments in this sector, it is likely that electricity prices will increase at a quicker pace than the rate of inflation over the next years. Furthermore, the projected increase in efficiency is based on strong assumptions.

While it is possible to replace all alliances by 2025 (given their economic lifetime of 15 to 20 years) an efficiency increase of 50 % represents an ambitious target.

5.1.5 Side effects

5.1.5.1 Economic side effects

The current EU Communication on “Energy infrastructure priorities for 2020 and beyond” (2011) provides a view of how energy networks will need to evolve to meet future needs. It takes up the targets of the Europe 2020 Strategy and its flagship initiative “resource-efficient Europe”[169] and the Climate and Energy Package[170] including the target of a 20% share of renewable energy sources of the total EU energy consumption until 2020.

The Communication concludes that, by 2020, investments of about 200 billion Euro are needed for energy transmission and distribution infrastructure alone. Realizing all this needed investment would create an additional 775.000 jobs during the period 2011-2020 (European Commission 2010a). While it is evident that adaptation requirements should be integrated into these investments, in order to make energy infrastructure climate-proof and avoid costly retrofitting. However, it is not feasible, nor would it seem plausible, to tag any specific part of the overall investment activity and job creation as specifically adaptation-induced.

The development and construction of new, more robust pylons and overhead lines, but also the development of more resilient grid layouts can help to promote the diffusion of European technologies. The EU industry is a main producer of technologies for energy infrastructure (European Commission 2010a). Many countries outside the EU are also facing the challenge of installing electricity networks that are better-adapted to climate change and that meet the needs of changing generation patterns, which potentially increases the demand for European technologies and expertise in the world market. The investment need in this sector would have also a positive impact on small and medium enterprises (SMEs) in the fields of construction, mechanical engineering and business services (European Commission 2010b).

Negative impacts may occur during the construction of new lines and during their operation, affecting agriculture and forestry. Transmission lines can affect agricultural activities including irrigation, aerial spraying, wind breaks and future land development. The placement of pylons on agricultural land can create problems for turning field machinery, lead to the compaction of soils, damage drain tiles, obstruct moving irrigation systems and interfere with a future consolidation of farm fields (PSCW 2009, BDEW 2011, Vattenfall Europe 2005).

Forestry may be affected since tree growth is limited underneath power lines and in their vicinity. Where the use of land is limited, land owners will be compensated: for underground cables, this compensation is almost 100 % of the value of the land; for overhead lines, compensation ranges from 10 to 20 % of the land value (BDEW 2011. Vattenfall Europe 2005).

[169] Europe 2020 strategy - COM(2010) 2020.

[170] COM(2008)30.

While the empirical evidence is unclear, there is an ongoing discussion about the health impacts of the electro-magnetic fields of power lines, both for overhead and underground lines, manifested in many instances of public resistance to the construction of new lines. Where power lines are built close to residential areas, they may also impact the value of nearby houses. Overhead lines have affected the natural landscape, and may thereby diminish its recreation value. This negative effect on the landscape may also have impacts on touristic uses, and possibly affect revenues in this sector (Vattenfall Europe 2005). Such effects can be limited by constructing new energy infrastructure in the vicinity of existing infrastructure, such as motorways, canals or railway lines.

5.1.5.2 Environmental side effects

The construction of new lines or the relocation of lines can have impacts on natural resources. Both during the construction phase, but also during the operation (reduced plant coverage in the vicinity of the lines), power lines may affect local biodiversity (flora and fauna). For overhead lines, an area of 40 m^2 to 70 m^2 around the pylons will be affected through construction work and the base of the pylon. A pylon is necessary every 400 to 600 meters (Vattenfall Europe 2005). Overhead lines require a corridor of 60 to 100 m where no high trees can grow. The minimum clearance between the lines and trees has to be three meters (Schering 2009. Vattenfall Europe 2005. National Grid 2008). Another aspect is the danger of overhead lines for animals. While there is no conclusive evidence on these effects, occasional studies have linked the death of birds to overhead lines (NABU 2005. PSCW 2009. National Grid 2008). Other impacts include noise emissions from overhead lines (corona discharge), particularly in case of rain or damage to the lines (National Grid 2008, PSCW 2009).

For underground cables, a corridor of at least four metres width is required, with only low vegetation and without trees. Extensive excavation work and soil movement occurs during the construction of underground cables (Schering 2009, BDEW 2011). The excavation work is followed by long-term impacts on soil. Since underground cables produce heat, they may exacerbate droughts in drying out the soil, with adverse effects on the vegetation and agriculture (Gouda et al 1997, Vattenfall Europe 2005).

The degree of potential impact of new lines can be differenced by the ecological value or the uniqueness of the ecosystems along the proposed route. Different factors define the quality of the existing environment, next so species composition and abundance this also includes the presence of particular unique species, the degree of the already existing disturbance and the threat of future disturbance. The potential impacts on ecosystems are especially high where energy infrastructure crosses protected natural areas. On the positive side, through suitable design, transmission lines can also be used to provide habitat for certain endangered or threatened species. Examples are nesting platforms built on top of transmission pylons (PSCW 2009).

Options to limit or mitigate environmental impacts are to combine power lines with existing infrastructure corridors, such as railway lines, roads or gas pipelines (European Commission 2010b), as well as upgrading the capacity of existing lines by replacing or double-circuiting them. While this reduces the need for additional clearing is required, it also defeats the objective of building a more resilient, tightly meshed grid, but instead would result in a more concentrated grid layout (PSCW 2009).

Beyond the impacts on the local, natural environment, an obvious link exists with the EU climate policy agenda. The EU's climate and energy target include a substantial increase in the use of renewable energy (increasing to 20% of final energy demand by 2020). The EU's aspiration to reduce greenhouse gases even further by mid-century will ultimately require an emissions-free electricity sector. This has numerous implications on the future shape of the electricity grid – from the need to integrate large and growing amounts of electricity from decentralized generation all over Europe, to the need to transmit electricity over very long distances (e.g. from offshore wind farms to inland industrial centres, from solar power generation in Southern Europe and North Africa to consumers in central and Northern Europe, or by exploiting the storage capacity of Scandinavian hydropower plants).

5.1.5.3 Social side effects

Citizens in the vicinity of new infrastructure might be affected temporarily at the time of construction, or permanently through changes of the local environmental or visual impacts on the landscape. The visual impact of electricity lines on the landscape, and the uncertain health effects of electromagnetic fields, can be of great concern to the inhabitants of the region, and have sparked public resistance to new construction projects in numerous instances.

This indicates the need for a debate involving all stakeholders leading to an accepted solution. It should be provided transparency for all stakeholders involved and a high involvement and participation of the public in the decision-making process by ensuring open and transparent debates at local regional and national level to enhance public trust and acceptance of the installations. The selected route should seek to reduce the visual effect of the line in terms of the number of people affected and the degree to which they are affected. The visual effect is also affected by the nature and topography of the landscape where the line will be situated. It would typically to be sought to avoid crossing the highest contours. where pylons would generally be most prominent. Ideally an overhead line should be viewed against a background of existing landscape or other development (i.e. buildings) rather than against the sky. In some cases this acceptable solution will require higher costs, for example when alternate routes are chosen or underground cables are used in very sensitive parts of the route. Underground cables have in general a higher acceptance than overhead lines. (Comission of the European Communities 2003. European Commission 2010a. BDEW 2011. National Grid 2008)

The investment costs of companies for the construction of new lines, as well as the incremental costs for strengthening pylons and lines and for more maintenance due to faster growth of plants, will ultimately be recovered from power consumers through higher transmission charges. While these costs will add to the power bill of households and industrial power consumers, the incremental costs of climate-proofing the electricity infrastructure are arguably very small in comparison to the overall investment needed to make the European energy infrastructure fit to changing supply and demand patterns.

5.2 Transport

5.2.1 'Climate Proofing' measures for the Transport Sector – Adaptation of the Transport infrastructure

Climate change may affect transport infrastructure in different ways. Especially the following impacts can damage transport infrastructure or affect its functioning:

- River floods and storm surges can submerge and thereby damage railway tracks, roads or airport runways. Strong precipitation may also lead to aquaplaning on roads or runways.
- Increased temperatures, and particularly heat waves, are another climate change impact that can affect railways, roads and aviation through the buckling of rails or damage to the asphalt surface of roads and runways.
- Storms can affect the electricity supply, which is especially relevant for electrified railway lines.

The following assessment focuses on the impacts of increased temperature and stronger precipitation. The investigated adaptation options are: the use of more heat resistant asphalt to avoid damage to roads and runways, and limiting the effects of rail buckling by applying speed restrictions for trains. Regarding to increased frequency of extreme precipitation events, increasing the capacity of drainage systems for roads and runways will be studied.

These two adaptation measures both work by reducing the exposure to climate change impacts, and thereby reducing the damages through increased temperature and extreme precipitation to a tolerable level.

5.2.2 Basic information

The transport infrastructure is an essential basis for all economic activity, but ensuring mobility is also a central precondition for social wellbeing. The increasing economic integration across Europe and the high export dependency of EU economies adds to the vulnerability of industrial production to interruptions in transport chains, as does the increased reliance on just-in-time supply of production inputs and components.

In March 2011, the European Commission published the White Paper on transport infrastructure: “Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system” (COM(2011) 144 final). The objective is to establish an efficient trans-European transport network. An efficient EU-wide transportation infrastructure is essential for the economic development of EU. As regards climate change, the White Paper focuses on the reduction of greenhouse gas emissions, however adaptation to climate change is not named as a particular challenge. The activities foreseen under the White Paper are financed through several EU financial instruments, such as the TEN-T programme, the European Regional Development Fund and the Cohesion Fund (European Commission 2011).

5.2.3 Effectiveness of adaptation

Transport infrastructure forms part of the so-called “critical infrastructure” that is essentially for the functioning of economy and society, by ensuring a steady supply of goods and mobility of individuals. Given its public good characteristics, the state is usually involved in the provision and maintenance of transport infrastructure at least to some degree. Maintaining a functioning transport infrastructure is therefore of public interest.

The adaptation measures discussed here can help to avoid damages to the transport infrastructure. The extent of the avoided damage clearly depends on the underlying climate change projections, but the tendency towards higher average and maximum temperatures is common to all climate scenarios. The adaptation of roads and runways to increased precipitation can partly avoid damages, but only to a certain extent. The measures analysed here concentrate on flash floods and flooding events that would statistically be expected at a frequency of 5-20-years. However, major floods like 100-year events will inevitably lead to disruptions of road, rail and airports, and in many cases will exceed the adaptation capacity of transport infrastructures.

Given the public good character of transport infrastructure, and in view of the fact that most transport infrastructure is owned and/or maintained by the public sector, there is a low risk that financial support for adaptation would crowd out private investments into adaptation (autonomous adaptation) or result in windfall profits for the affected firms. If at all, windfall profits may occur for privately owned roads and railway lines. Here, the private owner is responsible for maintenance. The scope of the effect can vary between regional and international, depending on the significance of the affected infrastructure.

The urgency of measures will be discussed separately for measures targeted at increased temperature and precipitation. There are two components that determine the urgency of taking action: first, the urgency of the climate threat itself (how soon are the effects of climate change going to materialize), and second, the time lag between the implementation of a measure and observing its (full) effects.

- Higher temperature and heat waves are already problematic at present. Climate projections predict with high certainty a further gradual increase of temperatures in Europe, as well as an increasing frequency of heat waves during the next decades. The urgency of climate threat is therefore already high in the short to medium-term (Goodess et al. 2009).
- Scenarios for intensity and frequency of precipitation show a higher degree of uncertainty. Significant effects are expected from 2050 onwards; the urgency of climate impacts can therefore be stated with medium-to long-term (Goodess et al. 2009).
- The time-lag between implementation of the measure and effects is medium for increased temperature for road and aviation, and short for rail. For roads and runways, some technologies are already available, but others still in the R&D phase. If ready for use, the measure of heat resistant asphalt is effective immediately when applied. But especially for road networks, the required overhaul of road surfaces implies substantial and protracted investment activities. These should be included in the normal reinvestment cycle, which is typically between 10 and 20 years for roads. Speed restrictions and heat stressing as a measure to mitigate the impacts of rail buckling can be applied at short notice and is effective immediately when applied. For increased precipitation, the time-lag between implementation and effect is short to medium: Technologies are available and effects can be seen immediately. But also here, the renewal of all exposed road infrastructure takes time and should be integrated into the normal reinvestment cycles.

- The lifetime of the measure – the duration when the measure produces an adaptation effect - is by and large equal to the lifetime of the roads, i.e. the normal reinvestment cycle of 10 – 20 years. For improved heat-resistant asphalt, sources suggest a longer lifetime, but currently no clear evidence is available on this point (Beckedahl 2011).

The discussed measures are regret-measures, in the sense that they only show positive adaptation effects to the extent that climate change indeed materializes. Other than climate adaptation, the measures do not deliver additional benefits. The scenario-variability for increased temperature is relative low, since all climate projections show an increase in heat days. For increased precipitation the scenario results vary significantly, suggesting a high climate variability of the effects of the measure. For measures to adapt road and railway surfaces to higher temperature, the potential for adapting or reversing the measure is zero: once measures have been taken, it is essentially impossible to adapt them, or only at prohibitive cost.

5.2.4 Efficiency/ costs and benefits

5.2.4.1 Rail Transport – Retrofitting existing infrastructure concerning increased temperatures (Track buckling)

Costs of retrofitting rail transport infrastructure concerning increased temperatures

The cost calculation can be found in chapter 4.2.4.1.

Benefit for retrofitting rail transport infrastructure concerning increased temperatures

Definition

The adaptation measure “Adaptation of Rail infrastructure to higher temperatures” as defined in previous chapter on costs (chapter 4) includes the avoidance of track buckling through the use of heat resistant material, adaptation of stress free temperature and reduction of speed on days with high temperature. In the very warm summer of 2003, a high number of track buckling incidents were reported especially in UK. Buckled rails can potentially lead to derailment of trains (Ellis 2006, Dobney 2010, Eddowes et al 2003, Zarembski et al 2005).

In order to estimate the benefits of the adaptation of rail infrastructure caused by higher temperature, the avoided cost of derailments is used as a measure of the benefits. The cost of derailments include costs for repair and recovery of tracks and rolling stock, expenses for investigation and auditing, injuries to passengers or costs of the loss of freight (including contamination for spills of liquid freight), and loss of income or productivity when services are interrupted (Queensland Government 2003, US Federal Railroad Administration 2011).

In reality, these costs will not necessarily materialise, since rail companies will reduce the speed at hot summer days when the probability for track buckling is highest, in order to avoid derailments in the first place.

The frequency of track buckling and the associated risk of derailment depend on the conditions of the fundament: the worse track conditions are, the more likely buckles are to occur. There is no unified, EU-wide data on the current conditions of rail tracks across the EU countries, let alone projects on how this factor will evolve in coming decades. But for the discussion of the estimation results. this factor also has to be taken into account.

Calculation

The derailment costs are estimated based on the following equation:

- B_{SRi} : Benefits for speed restrictions on hot days to avoid track buckling per country *i*
- $C_{D\min/\max}$: Damage costs per derailment (min, max)
- TL_{2003UK} : Rail track length 2003 of UK
- TL_{2009i} : Rail track length 2009 per country *i*
- RB_{2003UK} : Number of rail buckles in hot summer 2003 in UK
- $RB_{AverageUK}$: Average number of rail buckles in UK
- SD_i : Change in annual mean number of summer days in summer in country *i* in number of days (1961-2100, Source: ESPON)

$$B_{SRi} = C_{D\min/\max} * SD_i * TL_{2009i} * \left(RB_{2003UK} - RB_{AverageUK}\right) / \left(SD_{UK} * TL_{2003UK}\right)$$

Empirical studies that have assessed the costs of derailments due to rail buckling are few and far between. In Australia in 2003, a train with 250 passengers derailed due to rail buckling. The investigation report assesses the costs for recovery of tracks and equipment, investigation/auditing and further costs at less than 70.000 Australian Dollar, or about € 40.000[i]. There were no serious injuries or even fatalities involved, which explains the relatively modest damage estimate. It is subsequently used as the lower-bound cost estimated for the cost of one train derailment. (Queensland Government 2003)

Further data on the costs of derailment due to rail buckling could be found in the USA. The database of the US Federal Railroad Administration, Office of Safety Analysis contains information on track damages and equipment damages due to derailment for the last years. For the estimation, the average costs per incident were calculated across all listed incidents from 2005 to 2010. The result is an average of circa € 250.000 damage costs per derailment incident. For the subsequent estimation, this number was used as the upper-bound value of the damage costs, which should not be taken to imply that the costs of individual incidents could not be higher than this value – which is clearly the case.

Table 5-12: Damage Costs through Derailment due to track buckling in USA (2005-2010)

Year	Average Equipment Damage in €	Average Track Damage in €	Average Total Damage in €	Number of Incidents	Average Damage costs per incident in €
2005	4,897,389	1,361,094	6,258,483	27	231,795.7
2006	7,758,594	2,456,666	10,215,260	55	185,732.0
2007	6,962,464	2,662,073	9,624,536	35	274,986.8
2008	1,054,373	917,740.3	1,972,113	15	131,474.2
2009	4,714,711	1,213,483	5,928,194	21	282,295.0
2010	9,705,670	3,325,211	13,030,880	37	352,186.0
Total (2005-2010)	35,093,201	11,936,267	47,029,467	190	247,523.5

(Source: Own calculations on basis of data from US Federal Rail Administration 2011)

In Europe, some research on rail buckling has been carried out in the UK, especially following the hot summer in 2003. During this summer, an unusually high number of buckles occurred in British railway lines. Hunt et al (2006) reviewed the number of incidents and showed that the number of buckles increased significantly: between 1991 and 1994, 32 track buckles had been reported on average; this rose slightly to 36 in the 1996 to 2002 period. In the two exceptionally warm years 1995 and 2003, the number of buckles increased significantly to 133 and 137, respectively. Also for the hot summer of 1976, a similar value (132) is reported. The difference of rail buckling incidents between average years and very hot summers (1976, 1995 and 2003) thus amounts to 100 incidents for the UK, about a four-fold increase.

In the literature, especially Hunt et al (2006), Dobney (2010) argue that the summer of 2003 has the characteristics of what would be seen as a normal summer at the end of 2100. Following this argument, the additional 100 buckles served as a reference for the anticipated impact of climate change on the UK rail network in 2100. This is obviously a strong assumption: it assumes a) that the length of the UK rail network would not change significantly in this century, and b) that the economic significance of rail transport is not going to change significantly over this period. While these are strong and also debatable assumptions, it was beyond the scope of this project to develop scenarios for the future evolution of transport over the very long-term, and neither was there a set of widely accepted standard scenarios that could have served as a reference.

Based on the UK data, the increased risk of rail buckling was estimated for all of the EU-27, based on a value per summer day per track km (in 2003). This value was then extrapolated, using the track length of the railway system in all EU countries based on Eurostat data, and using the change in mean annual summer days between 1961 and 2100 for the different EU countries based on ESPON, in line with the cost calculation in the previous chapter.

Assumptions

The calculation is based on different assumptions:

- Because of data constraints the calculation concentrates on costs for repair and recovery of tracks and train equipment. The Australian data also includes data on investigation and auditing. The data does not include the cost of injuries or fatalities, since no injuries or fatalities occurred in the incidents that served as a basis for the estimation. If injuries or fatalities had occurred, the damage cost would have been significantly higher (easily by an order of magnitude)
- Damage cost estimates are taken from Australia and USA, since European data was not available.
- There is no clear evidence to quantify the risk of rail buckles actually leading to derailments. The literature shows that most, but not all rail buckles cause derailments when trains pass without speed restriction. Since there was no solid evidence, it was assumed that all rail buckles in the UK 2003 led to derailments (Dobney 2010, Ellis 2006, Zarembski et al 2005, Eddowes et al 2003).
- Data on the number of rail buckles was only available for the UK. Whether buckling occurs will also dependent the general condition of the tracks and fundaments. These are different in the different EU countries, not least due to the age of the railway infrastructure. However, lacking a universal measure of the quality of the tracks and fundaments, it was not possible to include this aspect in the estimation. Using the UK

railway network as a reference, which is arguably not in the best condition, may lead to a slight overestimation of the actual damage costs.

Results

The following Table 5.13 shows the estimated avoided damage costs of derailments due to track buckling on summer days. These can be interpreted as the benefit of applying speed restrictions on hot days, assuming that speed limits are an effective way of avoiding derailments due to rail buckling.

Table 5-13: Estimated avoided damage costs of derailments due to track buckling on summer days.

Country	Benefits per year min (in Euro)	Benefits per year max (in Euro)	Benefits per EU country
Austria	2,072,949	12,427,752	2.3%
Belgium	1,698,335	10,181,869	1.9%
Bulgaria	1,866,717	11,191,352	2.1%
Cyprus	0	0	0.0%
Czech Republic	3,920,507	23,504,239	4.4%
Denmark	439,054	2,632,223	0.5%
Estonia	55,047	330,019	0.1%
Finland	55,293	331,494	0.1%
France	18,302,709	109,728,475	20.4%
Germany	16,433,771	98,523,810	18.3%
Greece	1,437,852	8,620,219	1.6%
Hungary	3,660,488	21,945,376	4.1%
Irland	233,147	1,397,769	0.3%
Italy	9,168,297	54,965,812	10.2%
Latvia	147,396	883,671	0.2%
Lithuania	223,845	1,341,999	0.2%
Luxembourg	341,272	2,045,996	0.4%
Malta	0	0	0.0%
Netherlands	1,028,832	6,168,059	1.1%
Poland	6,248,362	37,460,209	7.0%
Portugal	1,874,896	11,240,386	2.1%
Rumania	4,905,072	29,406,911	5.5%
Slovakia	1,685,400	10,104,319	1.9%
Slovenia	678,977	4,070,606	0.8%
Spain	8,968,837	53,770,010	10.0%
Sweden	315,510	1,891,549	0.4%
United Kingdom	3,875,762	23,235,988	4.3%
EU 27	**89,638,340**	**537,400,122**	100.0%

The estimation shows benefits between 89 and 537 million Euro per year. Since the estimated benefits are a function of the expected increase in heat days, and the length of the national railway network, this also shows in the national-level breakdown of the benefits. The largest shares are estimated for France with 20 % and Germany with 18 %. This is followed by the larger Southern European countries like Italy and Spain, due to their relatively high exposure. As mentioned, this estimate does not reflect the quality or the robustness of the rail infrastructure (rails and fundaments).

The benefits will accrue to railway companies in the first instance, since they would have to pay for the repair of equipment / rolling stock and tracks. Obviously, such benefits would also accrue to customers in the form of (marginally) lower ticket prices, provided that markets are competitive and costs, as well as cost savings, are passed on to consumers. Where railway companies and / or rail infrastructure are state-owned, some of the benefit would also accrue to the public budget and, ultimately, the taxpayer. But it would require some heroic assumptions to predict what the European rail transport market will look like in 2100. At any rate, this merely concerns the incidence of the costs and benefits, but not their level.

Comparison benefits and costs

The previous chapter on cost calculation shows the estimated costs for track buckling in the form of costs induced by speed restriction that could prevent derailments. The costs for speed restrictions due to track buckling are estimated to range from 59 million to 260 million Euro per year for EU-27 according to different values for delay minutes.

The benefits are estimated to fall within a range of 90 million to 537 million Euros per year. It is therefore likely, but not certain that the benefits of the measure would exceed the costs. If the costs are at the higher end of the projected range, but the benefits at the lower end, it is also possible that benefits may exceed the cost.

5.2.4.2 Road Transport – Retrofitting existing infrastructure concerning increased temperatures (heat resistant asphalt)

Costs of retrofitting road transport infrastructure concerning increased temperatures

The cost calculation can be found in chapter 4.2.5.1.

Benefit for retrofitting road transport infrastructure concerning increased temperatures

Definition

This adaptation measure involves the use of more heat-resistant asphalt to adapt road surfaces to withstand very high temperatures. According to projections of climate change, the number of days with high temperature will increase. For roads, this increases the risk of ruts and other types of damage and deformation of the road surface. Using different types of asphalt can increase the resistance of road surfaces under very hot conditions.

The benefit of this adaptation measure can be estimated through the avoided delays of road traffic, which would occur if roads have to be closed due to damage to the road surface. Such delays will not only inconvenience motorists, but may also delay or interrupt production processes, with associated costs to businesses.

Further benefits occur through avoided costs of road maintenance and the avoided wear and tear of cars, as well as avoided costs of injuries following road accidents. However, since no reliable data was available for any of these benefit categories, the following estimation focuses on the delay through road closure or speed restrictions.

Calculation

The estimation of avoided time loss is based on the calculation of Tröltzsch et al. (2011) which analyses the time loss through heat-induced ruts and road surface damage in Germany. Other than this source, no further literature on benefits of heat-resistant asphalt could be found.

Passenger traffic:

- B_{Pi}: Benefit of adaptation measure to avoid ruts through heat resistant asphalt for passenger traffic per different country *i*
  - B_{Pi}^{M} : Benefit of adaptation of motorways in country *i* in Euro per year
  - B_{Pi}^{SR} : Benefit of adaptation of state roads in country *i* in Euro per year
  - B_{Pi}^{PR} : Benefit of adaptation of provincial roads in country *i* in Euro per year
  - B_{Pi}^{CR} : Benefit of adaptation of communal roads in country *i* in Euro per year
- $VTTS_{worki}$: Value of travel time savings for passenger trips during work per different country *i* (Source: HEATCO)
- $VTTS_{non-worki}$: Value of travel time savings for passenger-non-work trips per different country *i* (min, max value used) (Source: HEATCO)
- P_{Ri} : Passenger km Road Transport per different country *i* (Source: Eurostat)
  - P_{Ri}^{M} : Passenger km traveled on motorways in country *i* (own assumption: 40% of total passenger km travelled in country *i*)
  - P_{Ri}^{ST} : Passenger km traveled on state roads in country *i* (own assumption: 30% of total passenger km travelled in country *i*)
  - P_{Ri}^{PR} : Passenger km traveled on provincial roads in country *i* (own assumption: 20% of total passenger km travelled in country *i*)
  - P_{Ri}^{CR} : Passenger km traveled on communal roads in country *i* (own assumption: 10% of total passenger km travelled in country *i*)
- L_{Ri}: Length of road in country *i* in km (Source: Eurostat)
  - L_{Ri}^{M}: Length of motorways in country *i* in km
  - L_{Ri}^{SR}: Length of state roads in country *i* in km
  - L_{Ri}^{PR}: Length of provincial roads in country *i* in km
  - L_{Ri}^{CR}: Length of communal roads in country *i* in km

- ST : Share of work and non-work time of traveled km (13.6 % work, 86.4% non-work, Source: German Federal Ministry of Transport, Building and Urban Development 2010)
- ND_i : Number of disruptions in country *i* (Source: Tröltzsch et al. 2011)
  - ND_i^M : Number of disruptions on motorways in country *i*
  - ND_i^{ST} : Number of disruptions on state roads in country *i*
  - ND_i^{PR} : Number of disruptions on provincial roads in country *i*
  - ND_i^{CR} : Number of disruptions on communal roads in country *i*
- DD : Duration of disruptions (one day per disruption; Source: Tröltzsch et al. 2011, own assumptions)
- DE : Duration of detour per road (Source: Tröltzsch et al. 2011, own assumptions)
  - DE^M :Duration of detour on motorways (30 minutes, Source: Tröltzsch et al. 2011)
  - DE^{ST} :Duration of detour on state roads (30 minutes, own assumption)
  - DE^{PR} :Duration of detour on provincial roads (15 minutes, own assumption)
  - DE^{CR} : Duration of detour on communal roads (15 minutes, own assumption)

Calculation for motorways:

$$B_{Pi}^M = \left(P_{Ri}^M / L_{Ri}^M * ND_i^M * DD * DE^M * ST_{work} * VTTS_{worki}\right) + \left(P_{Ri}^M / L_{Ri}^M * ND_i^M * DD * DE^M * ST_{non-work} * VTTS_{non-worki}\right)$$

Correspondingly:

Calculation for state roads:

$$B_{Pi}^{SR} = \left(P_{Ri}^{SR} / L_{Ri}^{SR} * ND_i^{SR} * DD * DE^{SR} * ST_{work} * VTTS_{worki}\right) + \left(P_{Ri}^{SR} / L_{Ri}^{SR} * ND_i^{SR} * DD * DE^{SR} * ST_{non-work} * VTTS_{non-worki}\right)$$

Calculation for provincial roads:

$$B_{Pi}^{PR} = \left(P_{Ri}^{PR} / L_{Ri}^{PR} * ND_i^{PR} * DD * DE^{PR} * ST_{work} * VTTS_{worki}\right) + \left(P_{Ri}^{PR} / L_{Ri}^{PR} * ND_i^{PR} * DD * DE^{PR} * ST_{non-work} * VTTS_{non-worki}\right)$$

Calculation for communal roads:

$$B_{Pi}^{CR} = \left(P_{Ri}^{CR} / L_{Ri}^{CR} * ND_i^{CR} * DD * DE^{CR} * ST_{work} * VTTS_{worki}\right) + \left(P_{Ri}^{CR} / L_{Ri}^{CR} * ND_i^{CR} * DD * DE^{CR} * ST_{non-work} * VTTS_{non-worki}\right)$$

Calculation of total benefit:

$$B_{Pi} = B_{Pi}^{M} + B_{Pi}^{SR} + B_{Pi}^{PR} + B_{Pi}^{CR}$$

Number of disruptions (ND_i) is estimated on the following basis:

- SD_i : Change in annual number of summer days (1961-2100) (Source: ESPON)
- F : Frequency of rut problems (every second summer day, Tröltzsch et al. 2011)
- RR : Ratio of rut problems per length of road (every 500 km, Tröltzsch et al. 2011)

For motorways:

$$ND_i^{M} = SD_i * F * L_{Ri}^{M} / RR$$

Correspondingly for other road types:

$$ND_i^{SR} = SD_i * F * L_{Ri}^{SR} / RR$$

$$ND_i^{PR} = SD_i * F * L_{Ri}^{PR} / RR$$

$$ND_i^{CR} = SD_i * F * L_{Ri}^{CR} / RR$$

The benefit of the adaptation measure was estimated per country, distinguishing between different types of roads: motorways, state roads, provincial roads, and communal roads. For these different roads the number of disruptions was calculated on the basis of assumptions from Tröltzsch et al. 2011. There, the authors assumed that on every second summer day with exceptionally hot temperatures, ruts and other road surface problems will occur one per 500 km road length. The expected change in the number of hot summer days for the different EU countries was taken from estimations of ESPON, with a time horizon until the year 2100.

For the estimation of damage costs, the expected number of disruptions per country and per road type were combined with the number of passengers per road km, and with the duration of disruptions and detours. The number of passengers per road km is simply the total passenger travel volume by road (measured in pkm) divided by the length of the road network in any country. The duration of a disruption is based on an assumption by Tröltzsch et al. 2011, which assumes a disruption to last of one day for motorways, assuming that the road surface damage will be fixed at least in a provisional way within one day. The same assumption was also applied for the other road types. Tröltzsch et al. 2011 define the duration of detours as 30 minutes for motorways. This assumption was also applied to state roads. For provincial and communal roads the detour duration was assumed with 15 minutes, reflecting the denser network of communal roads.

The Value of travel time savings (VTTS) are discussed and estimated extensively in the literature, and are routinely used to assess benefits of road construction projects. The HEATCO project estimated VTTS for all EU countries, either accounting for actual cost savings or by analysing willingness-to-pay.

The VTTS differs between passenger travel and freight transport. Passenger transport is further differentiated into work travel and non-work travel, with the latter including commuting, shopping and leisure. HEATCO (2006) estimates the VTTS for different non-work travels, like long-time and short time commuting, etc. For the different non-work VTTS values, lower-bound and upper-bound values are reported below.

The following table shows the five EU countries with lowest and highest VTTS.

Table 5-14: Value of travel time savings (VTTS) for ten EU countries (in €) (Source: HEATCO 2006)

Country	VTTS work (per passenger per hour) (in €)	VTTS non-work min, (per passenger per hour) (in €)	VTTS non-work max, (per passenger per hour) (in €)
Luxembourg	38,02	9,99	15,30
Denmark	31,54	7,11	10,88
Sweden	30,30	6,88	10,53
Ireland	29,87	7,04	10,77
United Kingdom	29,02	6,99	10,70
Poland	12,87	4,14	6,34
Estonia	12,82	4,18	6,40
Slovakia	12,36	3,86	5,91
Latvia	11,73	3,82	5,85
Lithuania	11,58	3,72	5,69

The German Federal Ministry of Transport, Building and Urban Development published data on the share of work and non-work travel with 13.6 % work-related business travel (for the year 2007). The remaining share relates to the above definition of non-work travel, like commuting, vacation, shopping (German Federal Ministry of Transport, Building and Urban Development 2010).

The EEA Transport and Environment Reporting Mechanism (TERM) reports the total passenger-kilometers travelled per country. For the length of different road types per country, Eurostat data was used. Unfortunately, the Eurostat data is not complete: Data on road length is not up-to-date for many countries, for some countries the most recent estimates date back to early 1990s. These data constraints may affect the accuracy of the following estimations.

Freight transport:

The calculation for freight transport is similar to passenger travel. The same assumptions are used for number of disruptions, the duration of disruptions and the time loss caused by the necessary detours.

The Value of travel time savings for freight transport is combined with the number of disruption and the estimated goods transported by road-km.

- B_{Pi}: Benefit of adaptation measure to avoid ruts through heat resistant asphalt for freight transport per different country *i*
    - o B_{Fi}^{M}: Benefit of adaptation of motorways in country *i* in Euro per year

- B_{Fi}^{SR} : Benefit of adaptation of state roads in country *i* in Euro per year
- B_{Fi}^{PR} : Benefit of adaptation of provincial roads in country *i* in Euro per year
- B_{Fi}^{CR} : Benefit of adaptation of communal roads in country *i* in Euro per year

- $VTTS_{freight}$: Value of travel time savings for freight transport per different country *i* (Source: HEATCO)
- FR_{Ri} : Freight per km per different country *i* (in tons) (Source: Eurostat)
  - FR_{Ri}^{M} : Freight per km motorway per different country *i* (in tons) (own assumption: 40% of total freight per km in country *i*)
  - FR_{Ri}^{SR} : Freight per km state road per different country *i* (in tons) (own assumption: 30% of total freight per km in country *i*)
  - FR_{Ri}^{PR} : Freight per km provincial road per different country *i* (in tons) (own assumption: 20% of total freight per km in country *i*)
  - FR_{Ri}^{CR} : Freight per km communal road per different country *i* (in tons) (own assumption: 10% of total freight per km in country *i*)
- L_{Ri}: Length of road in country *i* in km (Source: Eurostat)
  - L_{Ri}^{M}: Length of motorways in country *i* in km
  - L_{Ri}^{SR}: Length of state roads in country *i* in km
  - L_{Ri}^{PR}: Length of provincial roads in country *i* in km
  - L_{Ri}^{CR}: Length of communal roads in country *i* in km
- ND_i : Number of disruptions in country *i* (Source: Tröltzsch et al. 2011)
  - ND_i^{M} : Number of disruptions on motorways in country *i*
  - ND_i^{ST} : Number of disruptions on state roads in country *i*
  - ND_i^{PR} : Number of disruptions on provincial roads in country *i*
  - ND_i^{CR} : Number of disruptions on communal roads in country *i*
- DD : Duration of disruptions (one day per disruption; Source: Tröltzsch et al. 2011, own assumptions)

- DE : Duration of detour per road (Source: Tröltzsch et al. 2011, own assumptions)
  - DE^{M} : Duration of detour on motorways (30 minutes, Source: Tröltzsch et al. 2011)
  - DE^{ST} : Duration of detour on state roads (30 minutes, own assumption)
  - DE^{PR} : Duration of detour on provincial roads (15 minutes, own assumption)
  - DE^{CR} : Duration of detour on communal roads (15 minutes, own assumption)

Calculation for motorways:

$$B_{Fi}^{M} = FR_{Ri}^{M} / L_{Ri}^{M} * ND_{i}^{M} * DD * DE^{M} * VTTS_{freight}$$

$$B_{Fi}^{ST} = FR_{Ri}^{ST} / L_{Ri}^{ST} * ND_{i}^{ST} * DD * DE^{ST} * VTTS_{freight}$$

Correspondingly:

Calculation for state roads:

$$B_{Fi}^{SR} = FR_{Ri}^{SR} / L_{Ri}^{SR} * ND_{i}^{SR} * DD * DE^{SR} * VTTS_{freight}$$

Calculation for provincial roads:

$$B_{Fi}^{PR} = FR_{Ri}^{PR} / L_{Ri}^{PR} * ND_{i}^{PR} * DD * DE^{PR} * VTTS_{freight}$$

Calculation for communal roads:

$$B_{Fi}^{CR} = FR_{Ri}^{CR} / L_{Ri}^{CR} * ND_{i}^{CR} * DD * DE^{CR} * VTTS_{freight}$$

Calculation of total benefit:

$$B_{Fi} = B_{Fi}^{M} + B_{Fi}^{SR} + B_{Fi}^{PR} + B_{Fi}^{CR}$$

The estimation corresponds to the approach for passenger transport, obviously applying the Value of Travel Time Savings for freight are calculated on the basis on data from HEATCO (2006). The five highest and lowest amounts are shown in the following table:

Table 5-15: Value of travel time saving for freight transport (Source: HEATCO 2006)

Country	VTTS freight (Euro per tonne per hour)
Luxembourg	4,14
Denmark	3,63
Sweden	3,53
Ireland	3,48
United Kingdom	3,42
Poland	1,92
Estonia	1,90
Slovakia	1,86
Latvia	1,78
Lithuania	1,76

The Eurostat data on freight transport is more complete and more up-to-date than the passenger travel statistics. The estimation includes all EU countries except Malta. Still, the estimation also suffers from the outdated statistics on the length of road networks.

Results

Passenger travel:

Bearing in mind that data on the length of road networks is frequently out of date, the estimated results are as follows (see following Table 5.16).

Table 5-16: Total Benefit of heat resistant asphalt for passenger transport

Country	Min (in million Euro)	Max (in million Euro)
Austria	21.56	28.47
Belgium	46.96	61.86
Bulgaria	16.50	22.24
Cyprus	2.50	3.38
Czech Republic	17.94	24.44
Denmark	7.04	9.24
Estonia	0.24	0.33
Finland	0.44	0.58
France	453.35	616.74
Germany	310.62	410.57
Greece	35.26	47.50
Hungary	13.11	17.75
Ireland	5.74	7.57
Italy	398.31	541.72
Latvia	0.49	0.67
Lithuania	1.08	1.46
Luxembourg	4.43	5.90
Malta	0.28	0.37
Netherlands	41.90	55.13
Poland	39.84	54.06
Portugal	39.21	52.72
Romania	29.23	39.40
Slovakia	6.24	8.45
Slovenia	9.30	12.74
Spain	200.91	272.30
Sweden	2.48	3.26
United Kingdom	145.37	192.03
EU	1,850.35	2,490.88

From the analysed countries, Italy has the highest benefit, followed by Spain and the United Kingdom. Besides the length of the road network in these countries, this also reflects the increase in hotter summer in Southern Europe.

Table 5-17: Benefit of heat resistant asphalt for passenger transport divided for road types (motorways, state, provincial, communal roads)

Country	motorways min (in million Euro)	motorways max (in million Euro)	state roads min (in million Euro)	state roads max (in million Euro)	Provincial roads min (million Euro)	Provincial roads max (million Euro)	Communal roads min (million Euro)	Communal roads max (million Euro)
Austria	10.14	13.40	7.61	10.05	2.54	3.35	1.27	1.67
Belgium	22.10	29.11	16.58	21.83	5.53	7.28	2.76	3.64
Bulgaria	8.80	11.86	6.60	8.90	n.d.	n.d.	1.10	1.48
Cyprus	1.18	1.59	0.88	1.19	0.29	0.40	0.15	0.20
Czech Rep.	8.44	11.50	6.33	8.63	2.11	2.88	1.06	1.44
Denmark	3.31	4.35	2.49	3.26	0.83	1.09	0.41	0.54
Estonia	0.12	0.17	0.09	0.12	0.03	0.04	n.d.	n.d.
Finland	0.24	0.31	0.18	0.23	n.d.	n.d.	0.03	0.04
France	213.34	290.23	160.01	217.67	53.34	72.56	26.67	36.28
Germany	146.17	193.21	109.63	144.91	36.54	48.30	18.27	24.15
Greece	20.15	27.14	15.11	20.36	n.d.	n.d.	n.d.	n.d.
Hungary	6.17	8.35	4.63	6.27	1.54	2.09	0.77	1.04
Ireland	2.70	3.56	2.03	2.67	0.68	0.89	0.34	0.45
Italy	187.44	254.93	140.58	191.19	46.86	63.73	23.43	31.87
Latvia	0.24	0.33	0.18	0.25	0.06	0.08	n.d.	n.d.
Lithuania	n.d.	n.d.	0.72	0.98	0.24	0.33	0.12	0.16
Luxembourg	2.08	2.78	1.56	2.08	0.52	0.69	0.26	0.35
Malta	n.d.	n.d.	n.d.	n.d.	0.18	0.25	0.09	0.12
Netherlands	19.72	25.94	14.79	19.46	4.93	6.49	2.46	3.24
Poland	18.75	25.44	14.06	19.08	4.69	6.36	2.34	3.18
Portugal	18.45	24.81	13.84	18.61	4.61	6.20	2.31	3.10
Romania	13.75	18.54	10.31	13.91	3.44	4.64	1.72	2.32
Slovakia	2.94	3.97	2.20	2.98	0.73	0.99	0.37	0.50
Slovenia	4.96	6.79	3.72	5.10	n.d.	n.d.	0.62	0.85
Spain	94.55	128.14	70.91	96.11	23.64	32.04	11.82	16.02
Sweden	1.17	1.53	0.88	1.15	0.29	0.38	0.15	0.19
UK	68.41	90.37	51.31	67.77	17.10	22.59	8.55	11.30
EU	875.34	1,178.37	657.22	884.75	210.72	283.64	107.06	144.13

The comparison of different road types shows that the larger share of benefits is made by retrofitting motorways with heat resistant asphalt. This result reflects both the facts that passengers travel on motorways, and the longer duration of detour for motorways. In all countries, the motorway network represents only a small fraction of the overall length of road network, but accounts for a large share of the transport volume. By contrast, communal or provincial roads account for the majority of road-kilometers. However, due to their lower transport volumes, the adaptation of communal and provincial roads generates a smaller benefit than the retrofitting of motorways.

Freight Transport:

The results for freight transport are calculated for all EU countries (except Malta), with results reflecting the differences between the EU countries.

Table 5-18: Total Benefit of heat resistant asphalt for freight transport

Country	Goods transport by road (mio tonne km per year)	Total benefit for freight transport (in million Euro) (all road types)
Austria	28,659	2.60
Belgium	35,002	4.44
Bulgaria (EU average)	19,433	1.87
Cyprus	1,087	0.12
Czech Republic	51,832	3.55
Denmark	15,018	0.61
Estonia	5,614	0.04
Finland	29,532	0.07
France	182,193	30.49
Germany	313,104	36.90
Greece	28,585	2.74
Hungary	33,721	2.70
Ireland	10,939	0.38
Italy	175,775	24.61
Latvia	10,590	0.11
Lithuania	19,398	0.19
Luxembourg	8,694	1.52
Netherlands	68,242	6.61
Poland	210,846	10.08
Portugal	35,368	4.89
Romania (EU average)	25,889	2.85
Slovakia	27,575	1.94
Slovenia	15,931	1.58
Spain	210,068	32.52
Sweden	36,268	0.29
United Kingdom	139,536	9.53
EU	1,738,899	183.21

Based on the assumptions above the benefit of adaptation by applying heat resistant asphalt amounts to approximately 183 million Euro per year for freight transportation in EU 27 (except Malta). This only includes the value of time savings from avoided detours and delays, not the avoided cost for repair and maintenance, and neither the avoided cost of accidents.

The results show that Germany benefits most, almost one quarter of the total amount, followed by Spain and France. This reflects the extensive road networks and the high volume of transported goods in these countries. The expected benefit is comparatively low for some Central European countries, such as Poland or Bulgaria. One reason for this is the different structure of the transport network: for the estimation, it was assumed that a large share of transport takes place via motorways. In countries where only limited motorways exist, the transport volumes on national roads will be correspondingly higher. The estimation also reflects significant differences in the VTTS values, with a VTTS of 1.92 Euro per ton per hour in Poland, and almost double in Germany with 3.38 Euro per ton per hour:

Table 5-19: Benefit of heat resistant asphalt for freight transport divided for road types

Country	Motorways (in million Euro)	State roads (in million Euro)	Provincial roads (in million Euro)	Communal roads (in million Euro)
Austria	1.22	0.92	0.31	0.15
Belgium	2.09	1.57	0.52	0.26
Bulgaria	0.99	0.75	n.d.	0.12
Cyprus	0.06	0.04	0.01	0.01
Czech Republic	1.67	1.25	0.42	0.21
Denmark	0.29	0.22	0.07	0.04
Estonia	0.02	0.01	0.005	n.d.
Finland	0.04	0.03	n.d.	0.004
France	14.35	10.76	3.59	1.79
Germany	17.36	13.02	4.34	2.17
Greece	1.57	1.18	n.d.	n.d.
Hungary	1.27	0.95	0.32	0.16
Ireland	0.18	0.13	0.04	0.02
Italy	11.58	8.69	2.90	1.45
Latvia	0.06	0.04	0.01	n.d.
Lithuania	n.d.	0.12	0.04	0.02
Luxembourg	0.71	0.54	0.18	0.09
Netherlands	3.11	2.33	0.78	0.39
Poland	4.74	3.56	1.19	0.59
Portugal	2.30	1.72	0.57	0.29
Romania	1.34	1.01	0.34	0.17
Slovakia	0.91	0.68	0.23	0.11
Slovenia	0.84	0.63	n.d.	0.11
Spain	15.30	11.48	3.83	1.91
Sweden	0.14	0.10	0.03	0.02
United Kingdom	4.48	3.36	1.12	0.56
EU	86.63	65.10	20.84	10.64

As for passenger travel, improving the road surface of motorways has the highest benefits, as these carry a higher share of transported goods. The benefit for communal roads is significantly lower.

Passenger and Freight transport:

The results for both freight and passenger transport can be seen in the following table. Overall benefits range between 2 and 2.6 billion Euro for the EU-27, of which 90% are due to passenger transport. The notable difference between passenger transport and passenger transport is due to the underlying VTTS values: despite the move towards just-in-time production, the cost of delayed freight (per ton and hour of delay) is significantly less than the delay for individuals - be it work- or leisure-related travel.

Table 5-20: Total Benefit of heat resistant asphalt for freight transport and passenger transport

Country	Passenger travel min (in million Euro)	Passenger travel max (in million Euro)	Freight transport (in million Euro)
Austria	21.56	28.47	2.60
Belgium	46.96	61.86	4.44
Bulgaria	16.50	22.24	1.87
Cyprus	2.50	3.38	0.12
Czech Republic	17.94	24.44	3.55
Denmark	7.04	9.24	0.61
Estonia	0.24	0.33	0.04
Finland	0.44	0.58	0.07
France	453.35	616.74	30.49
Germany	310.62	410.57	36.90
Greece	35.26	47.50	2.74
Hungary	13.11	17.75	2.70
Ireland	5.74	7.57	0.38
Italy	398.31	541.72	24.61
Latvia	0.49	0.67	0.11
Lithuania	1.08	1.46	0.19
Luxembourg	4.43	5.90	1.52
Malta	0.28	0.37	n.a.
Netherlands	41.90	55.13	6.61
Poland	39.84	54.06	10.08
Portugal	39.21	52.72	4.89
Romania	29.23	39.40	2.85
Slovakia	6.24	8.45	1.94
Slovenia	9.30	12.74	1.58
Spain	200.91	272.30	32.52
Sweden	2.48	3.26	0.29
United Kingdom	145.37	192.03	9.53
EU	1,850.35	2,490.88	183.21

5.2.4.3 Comparison costs and benefits

As described in the previous chapter, the costs for better heat-resistant asphalt have been estimated between 2.9 and 8.9 bn Euro per year. The highest costs are assessed for Germany, France, United Kingdom and Poland.

The benefits are estimated between 1.8 and 2.5 bn Euro per year for passenger travel and approximately 183 million Euro per year for freight transport. In comparison to the benefits, this implies that, if the costs are at the lower end of the estimated range, benefits and costs would be almost equal. It is more likely though that the costs of the measure would exceed the estimated benefits. It has to be kept in mind that the estimated benefits only measure the benefits of avoided delays and detours in terms of saved travel time. Thus, they only represent a share of the overall benefits: for instance, the avoided costs of road accidents have not been counted, and neither have the avoided maintenance and repair costs for fixing heat-induced damages to the road surface.

5.2.4.4 Road Transport – Retrofitting existing infrastructure concerning increased precipitation (drainage systems)

Costs of retrofitting road transport infrastructure concerning increased precipitation

The cost calculation can be found in chapter 4.2.5.2.

Benefit for retrofitting road transport infrastructure concerning increased precipitation

Definition

As one consequence of climate change, higher amounts of precipitation are expected in some parts of Europe (especially in the north), as well as a higher intensity and frequency of extreme weather events (Frei et al 2006, IPCC 2007, Nikulin et al 2009). Such events can lead to flooding of roads and other transport infrastructure, thereby interrupting transport networks.

A number of technical options are available to address these anticipated changes and to limit the impacts on transport networks, but it is also clear that technical solutions (increasing the capacity of drainage systems, better flood protection for existing transport infrastructure) can only provide limited protection against extreme weather events. To a certain degree, increasing the capacity of drainage systems for roads can especially help to limit the adverse effects of flash floods and intensive precipitation events.

The benefit estimation considers the avoided detours due to road closures following extreme precipitation events. The estimation includes the value of delayed freight transports and delays in passenger traffic. Beyond the delay, precipitation and flooding may also result in further damages to the sub-base and the road itself. Due to lack of data, the estimation does not include benefits in terms of avoided maintenance costs or avoided accidents.

Calculation

The estimation of the benefits of adapted drainage systems follows a similar approach as the calculation of benefits of heat resistant asphalt. The estimation is based on the cost of road closures as a result of strong precipitation. For the assessment, the duration for detours and the Value of travel time savings (VTTS) is used.

The estimation differentiates between four different road types (motorways, state roads, provincial roads and communal roads). The increased frequency of extreme precipitation events are discussed on the basis of projections of Nikulin et al (2009) which show that the number of events in Northern Europe will increase, Southern Europe will have less events, and Central Europe will be affected by a slightly higher number of events.

Passenger traffic:

- BP_{Fi}: Benefit of adaptation measure to avoid flooding through higher capacity of drainage systems for passenger traffic per different country *i*

- BP_{Pi}^{M} : Benefit of adaptation of motorways in country *i* in Euro per year
- BP_{Pi}^{SR} : Benefit of adaptation of state roads in country *i* in Euro per year
- BP_{Pi}^{PR} : Benefit of adaptation of provincial roads in country *i* in Euro per year
- BP_{Pi}^{CR} : Benefit of adaptation of communal roads in country *i* in Euro per year

- $VTTS_{worki}$: Value of travel time savings for passenger trips during work per different country *i* (Source: HEATCO)
- $VTTS_{non-worki}$: Value of travel time savings for passenger-non-work trips per different country *i* (min, max value used) (Source: HEATCO)
- P_{Ri} : Passenger km Road Transport per different country *i* (Source: Eurostat)
  - P_{Ri}^{M} : Passenger km traveled on motorways in country *i* (own assumption: 40% of total passenger km travelled in country *i*)
  - P_{Ri}^{ST} : Passenger km traveled on state roads in country *i* (own assumption: 30% of total passenger km travelled in country *i*)
  - P_{Ri}^{PR} : Passenger km traveled on provincial roads in country *i* (own assumption: 20% of total passenger km travelled in country *i*)
  - P_{Ri}^{CR} : Passenger km traveled on communal roads in country *i* (own assumption: 10% of total passenger km travelled in country *i*)
- L_{Ri}: Length of road in country *i* in km (Source: Eurostat)
  - L_{Ri}^{M}: Length of motorways in country *i* in km
  - L_{Ri}^{SR}: Length of state roads in country *i* in km
  - L_{Ri}^{PR}: Length of provincial roads in country *i* in km
  - L_{Ri}^{CR}: Length of communal roads in country *i* in km
- ST : Share of work and non-work time of traveled km (13.6 % work, 86.4% non-work, Source: German Federal Ministry of Transport, Building and Urban Development 2010)
- NDP_i : Number of disruptions due to precipitation in country *i* (Own assumptions)
  - NDP_i^{M} : Number of disruptions on motorways in country *i*

- NDP_i^{ST} : Number of disruptions on state roads in country *i*
- NDP_i^{PR} : Number of disruptions on provincial roads in country *i*
- NDP_i^{CR} : Number of disruptions on communal roads in country *i*

- DDP : Duration of disruptions due to precipitation (one day per disruption; own assumptions)
- DE : Duration of detour per road (Source: Tröltzsch et al. 2011, own assumptions)
  - DE^{M} : Duration of detour on motorways (30 minutes, Source: Tröltzsch et al. 2011)
  - DE^{ST} : Duration of detour on state roads (30 minutes, own assumption)
  - DE^{PR} : Duration of detour on provincial roads (15 minutes, own assumption)
  - DE^{CR} : Duration of detour on communal roads (15 minutes, own assumption)

Calculation for motorways:

$$BP_{Pi}^{M} = \left(P_{Ri}^{M} / L_{Ri}^{M} * NDP_i^{M} * DDP * DE^{M} * ST_{work} * VTTS_{worki}\right) + \left(P_{Ri}^{M} / L_{Ri}^{M} * NDP_i^{M} * DDP * DE^{M} * ST_{non-work} * VTTS_{non-worki}\right)$$

Analog:

Calculation for state roads:

$$BP_{Pi}^{SR} = \left(P_{Ri}^{SR} / L_{Ri}^{SR} * NDP_i^{SR} * DDP * DE^{SR} * ST_{work} * VTTS_{worki}\right) + \left(P_{Ri}^{SR} / L_{Ri}^{SR} * NDP_i^{SR} * DDP * DE^{SR} * ST_{non-work} * VTTS_{non-worki}\right)$$

Calculation for provincial roads:

$$BP_{Pi}^{PR} = \left(P_{Ri}^{PR} / L_{Ri}^{PR} * NDP_i^{PR} * DDP * DE^{PR} * ST_{work} * VTTS_{worki}\right) + \left(P_{Ri}^{PR} / L_{Ri}^{PR} * NDP_i^{PR} * DDP * DE^{PR} * ST_{non-work} * VTTS_{non-worki}\right)$$

Calculation for communal roads:

$$BP_{Pi}^{CR} = \left(P_{Ri}^{CR} / L_{Ri}^{CR} * NDP_i^{CR} * DDP * DE^{CR} * ST_{work} * VTTS_{worki}\right) + \left(P_{Ri}^{CR} / L_{Ri}^{CR} * NDP_i^{CR} * DDP * DE^{CR} * ST_{non-work} * VTTS_{non-worki}\right)$$

Calculation of the total benefit:

$$BP_{Pi} = BP_{Pi}^{M} + BP_{Pi}^{SR} + BP_{Pi}^{PR} + BP_{Pi}^{CR}$$

The number of disruptions (NDP_i) is estimated on the following basis:

- EP_i : Change in frequency of extreme precipitation (1961-2100) (Source: Nikulin et al 2009)

- PF : Frequency of flooding problems at roads (every year – one problem every 1500 or 3000 km, Own assumptions, basis wet days/precipitation Germany)
- $WD_{Germany}$: Wet days in Germany per year (1961-1990) (Source: Tyndall Centre 2003)
- WD_i : Wet days in country *i* per year (1961-1990) (Source: Tyndall Centre 2003)
- $RP_{\min/\max}$: Ratio of precipitation which leads to drainage problem with drainage system and flooding per length of road (minimum every 3000 km, maximum every 1500 km, Tröltzsch et al. 2011)

For motorways:

$$NDP_i^M = EP_i * PF * L_{Ri}^M / RP_{\min/\max} * WD_i / WD_{Germany}$$

Correspondingly for other road types:

$$NDP_i^{SR} = EP_i * PF * L_{Ri}^{SR} / RP_{\min/\max} * WD_i / WD_{Germany}$$

$$NDP_i^{PR} = EP_i * PF * L_{Ri}^{PR} / RP_{\min/\max} * WD_i / WD_{Germany}$$

$$NDP_i^{CR} = EP_i * PF * L_{Ri}^{CR} / RP_{\min/\max} * WD_i / WD_{Germany}$$

The benefit of adaptation measures was estimated per country for the different roads: motorways, state roads, provincial roads, and communal roads. For these different roads the number of disruptions was calculated on the basis of assumptions from Tröltzsch et al. 2011 and own assumptions.

High floods occurred in Germany in the last decade on average every second year (UBA 2006, WWF 2007, Helmholtz Gesellschaft 2011, Müller 2004). There are numerous smaller and localized flooding events, which may also lead to road closures, however these are not documented systematically. The following estimations use different assumptions on the frequency and ratio of street flooding per length of road kilometer:

Minimum: every year one road closure for one day per 6.000 km road (based on the current number of wet days in Germany)

Maximum: every year one road closure for one day per 3.000 km road (based on the current number of wet days in Germany)

The traffic disruptions occur because of extreme precipitation events. It is assumed that the disruptions could be minimized through the use of drainage systems with a higher capacity. Regional differences in weather conditions are measured by the number of wet days in the EU-27 countries, based on data from the Tyndall Centre (2003).

The number of disruptions per country and road type are combined with passenger traveled per km road, with the duration of disruption and detour. The total kilometers per passenger in a country divided by the length of the road type result in the passenger per km road. The duration of disruption is an own assumption on the basis of Tröltzsch et al. 2011, which defines the disruption by one day for motorways. The same amount was taken for the other road types. Tröltzsch et al. 2011 assume a time loss per detour of 30 minutes for motorways. For state roads, the same value was used. For provincial and communal roads, the detour durations was assumed at 15 minutes because of denser network of such roads. In line with the estimation of heat-resistant asphalt, the Value of travel time savings (VTTS) was based on HEATCO values. Regarding the purpose of journeys, accordingly to data from Germany 13.6% work travel and 86.4% non-work travel was assumed (German Federal Ministry of Transport, Building and Urban Development 2010).

For the length of different road types per country and for passenger travel volumes, Eurostat and EEA data were used. The same caveats apply as in the previous chapter, regarding the accuracy and timeliness of the road network data.

Freight transport:

The calculation for freight transport is similar to passenger travel. The same assumptions are used for the number of disruptions, duration of detour and disruption duration.

The Value of travel time savings for freight transport is combined with the number of disruption and the estimated goods transported by road-km.

The estimation for freight transport uses the following approach:

- BP_{Fi}: Benefit of adaptation measure to avoid flooding through higher capacity of drainage systems for freight transport per different country *i*
    - BP_{Fi}^{M} : Benefit of adaptation of motorways in country *i* in Euro per year
    - BP_{Fi}^{SR} : Benefit of adaptation of state roads in country *i* in Euro per year
    - BP_{Fi}^{PR} : Benefit of adaptation of provincial roads in country *i* in Euro per year
    - BP_{Fi}^{CR} : Benefit of adaptation of communal roads in country *i* in Euro per year
- $VTTS_{freight}$: Value of travel time savings for freight transport per different country *i* (Source: HEATCO)
- FR_{Ri} : Freight per km per different country *i* (in tones) (Source: Eurostat)
    - FR_{Ri}^{M} : Freight per km motorway per different country *i* (in tones) (own assumption: 40% of total freight per km in country *i*)
    - FR_{Ri}^{SR} : Freight per km state road per different country *i* (in tones) (own assumption: 30% of total freight per km in country *i*)
    - FR_{Ri}^{PR} : Freight per km provincial road per different country *i* (in tones) (own assumption: 20% of total freight per km in country *i*)
    - FR_{Ri}^{CR} : Freight per km communal road per different country *i* (in tones) (own assumption: 10% of total freight per km in country *i*)

Calculation for motorways:

$$BP_{Fi}^{M} = FR_{Ri}^{M} / L_{Ri}^{M} * NDP_{i}^{M} * DDP * DE^{M} * VTTS_{freight}$$

Correspondingly:

Calculation for state roads:

$$BP_{Fi}^{SR} = FR_{Ri}^{SR} / L_{Ri}^{SR} * NDP_i^{SR} * DDP * DE^{SR} * VTTS_{freight}$$

Calculation for provincial roads:

$$BP_{Fi}^{PR} = FR_{Ri}^{PR} / L_{Ri}^{PR} * NDP_i^{PR} * DDP * DE^{PR} * VTTS_{freight}$$

Calculation for communal roads:

$$BP_{Fi}^{CR} = FR_{Ri}^{CR} / L_{Ri}^{CR} * NDP_i^{CR} * DDP * DE^{CR} * VTTS_{freight}$$

Calculation of total benefit:

$$BP_{Fi} = BP_{Fi}^{M} + BP_{Fi}^{SR} + BP_{Fi}^{PR} + BP_{Fi}^{CR}$$

5.9.4.3 Results

The following tables show the estimated results for passenger travel and freight transport.

Table 5-21: Benefit of higher capacity of drainage systems for passenger transport

Country	Minimum (in million Euro)	Maximum (in million Euro)
Austria	0.30	0.88
Belgium	0.53	1.53
Bulgaria	0.09	0.26
Cyprus	0.01	0.02
Czech Republic	0.20	0.59
Denmark	0.26	0.80
Estonia	0.03	0.09
Finland	0.28	0.86
France	2.90	9.63
Germany	3.42	9.94
Greece	0.12	0.41
Hungary	0.09	0.27
Ireland	0.28	0.88
Italy	2.15	6.51
Latvia	0.03	0.11
Lithuania	0.05	0.15
Luxembourg	0.05	0.13
Malta	0.00	0.00
Netherlands	0.61	1.77
Poland	0.65	2.08
Portugal	0.12	0.49
Romania	0.21	0.64
Slovakia	0.06	0.18
Slovenia	0.06	0.19
Spain	0.86	3.51
Sweden	0.32	0.99
United Kingdom	3.27	10.36
EU	**16.93**	**53.25**

The benefit thus comes to 17 to 53 million Euros per year. It should be kept in mind that, as described above, this estimation only quantified some of the benefits of the described measure (cost of avoided traffic disruptions in the form of detours and delays), but did not assess e.g. the avoided cost of maintenance and repair, or avoided the cost of accidents. From the estimated result the highest benefit would be observed in Germany, followed by the United Kingdom and France. In line with the projections for the increase in precipitation, Northern Europe tends to be more affected. Obviously, countries with a longer road network are more vulnerable to the described impacts, and thus have a larger expected benefit from adaptation.

Freight Transport

The results for freight transport are calculated for all EU countries (excluding Malta, for which no data was available).

Table 5-22: Total Benefit of drainage systems with higher capacity for freight transport

Country	Minimum (in thousand Euro)	Maximum (in thousand Euro)
Austria	36.39	80.06
Belgium	49.99	109.97
Bulgaria	9.66	21.46
Cyprus	0.28	0.84
Czech Republic	38.81	85.39
Denmark	22.35	52.82
Estonia	4.34	10.26
Finland	41.33	97.68
France	194.81	476.21
Germany	405.89	892.96
Greece	9.48	23.69
Hungary	18.67	41.48
Ireland	18.41	44.18
Italy	133.08	295.73
Latvia	7.74	18.30
Lithuania	7.89	18.65
Luxembourg	15.65	34.42
Netherlands	96.45	212.19
Poland	164.49	388.81
Portugal	15.03	45.08
Romania	20.73	46.08
Slovakia	18.49	40.67
Slovenia	10.77	23.93
Spain	139.63	418.90
Sweden	37.67	89.03
United Kingdom	214.11	513.88
EU	**1,732.12**	**4,082.65**

According to these estimations, the total benefit of increasing the capacity of drainage systems comes to about 1.7 to 4.1 million Euros per year for freight transportation in EU 27 (without Malta).

The results show that Germany benefits most, followed by United Kingdom and France, reflecting the likely distribution of increased precipitation as well as the length of road networks in these countries.

Passenger and Freight transport:

Taken together, the benefits of the measure (in terms of passenger and freight transport) add up between 19 and 57 million Euro per year for the EU-27. Again, it should be kept in mind that only part of the overall benefits was captured in monetary terms.

5.2.4.5 Comparison costs and benefits

As described in the previous chapter, the costs of better drainage systems with a higher capacity are between 50 and 240 million Euro per year. The highest costs are assessed for France, Germany and United Kingdom.

The benefits of this measure are estimated between 19 and 57 million Euro per year.

Keeping in mind that the benefit estimate only captures part of the overall benefits, there is no guarantee that the benefits of the measure will exceed its costs. If the costs are at the lower end of the estimated range, and the benefits at the upper end, there is a chance that the measure will deliver a net benefit. If the costs are at the upper end of the estimated range, they will exceed the benefits – at least that share of the benefits that was quantified above.

5.2.5 Side effects

5.2.5.1 Economic side effects

Major effects on employment would not be expected from the measure, if it is assumed that the upgrading of infrastructures (heat resistant asphalt or improved drainage capacity) is integrated into the regular reinvestment cycle. In this case, there would be no substantial effects, since the required labour input does not differ depending on the type of asphalt used. This would be different if existing infrastructure was retrofitted before the end of its economic life span; but this would also incur significantly higher cost than anticipated in this estimation.

5.2.5.2 Environmental side effects

Following the same rationale as with employment cost, negative environmental impacts during the construction phase are not anticipated: compared to normal road works, the construction of heat-resistant road surfaces or increased drainage capacity does not create significantly different environmental impacts.

There is a positive environmental benefit of the measures insofar as they helps to reduce congestion and avoids additional travels. Without the measures, additional kilometers for detours are driven resulting in additional emission of greenhouse gases, other air emissions like NO_x, particulate matter (PM) and SO_2, and noise. Therefore, adaptation measures that help to avoid congestion and detours would also avoid the associated emissions (Barth & Boriboonsomsin 2008, Barth & Boriboonsomsin 2009, Kompfner & Reinhardt 2008).

5.2.5.3 Social side effects

The measures do not have particular distributional impacts. Obviously, by its nature, the measures will especially benefit people that are mobile, and in particular car-owners. However, this group includes a large share of the EU population, and a group that is heterogeneous in itself.

Stakeholder involvement during the planning and implementation of the measure is generally recommended. But stakeholder involvement is generally conducted for larger transport infrastructure projects. The “adaptation component” of road infrastructure projects is relatively small compared to the overall impacts and costs of such projects, and it is not conceivable that the type of asphalt used or the dimensioning of the drainage system would become highly contentious points.

5.3 Urban Areas

5.3.1 Climate Proofing' measures for Urban Areas – Adaptation in Urban Areas

Urban Areas in Europe will be affected by different climate change impacts.

- Increased temperature and heat waves have impacts, for instance, on human health, air quality, urban transport, and vegetation. Due to the high energy demand during heat waves the maximum capacity of the energy infrastructure could be reached.
- Higher river floods, flash floods or storm surges lead to, inter alia, higher damages on buildings, higher health risk for inhabitants, consequences on urban transport. Additionally, the water and energy supply can be affected by floods.

Various adaptation measures exist to mitigate the expected impact of climate change. The following chapter focuses on the protection against increased temperature and heat waves through the use of green infrastructure, more specifically green spaces and green roofs. . According to chapter 4, a green space is defined as a green area, such as a park, an urban forest, or a blue area (e.g. a river or a lake inside a city). A green roof is defined as vegetation on a roof top. Both measures also protect against precipitation, of course green spaces do so on a larger scale than green roofs.

5.3.2 Basic information

Increased occurrences of heat waves and increased temperatures in general due to climate change call for the implementation of adaptation measures. Especially in urban areas where conditions create a heat island effect, a temperature increase has impacts on the residents or vegetation. The increase in temperature is a consequence of climate change for which projections are relative reliable. Changes are already being observed. The heat wave of summer 2003 showed tremendous impacts. Throughout Europe it has been estimated that between 25,000 and 35,000 more deaths occurred that summer than in the previous years(with a higher incidence in Southern and Western Europe) with almost 10,000 victims in Italy and 15,000 in France (Koppe et al. 2003, WHO Europe 2005, Conti et al. 2005, EEA 2004).

The adaptation measures green spaces and green roofs focus on reducing the impact of climate change (increased temperature) (ARL 2009, Amt für Umweltschutz Stuttgart 2010). Different estimates for large cities show that the measures can influence the heat island effect. Toronto Banting et al (2005) discussed a reduction of 1 ° C for a green roof percentage of 50%. Rosenzweig et al. (2006) modeled for New York a decrease of 0.4 °C when 75% of all flat roofs are grassed or planted.

5.3.3 Effectiveness of adaptation

The measures are important-to-have measures which address an area of special concern: health impacts which occur during heat waves. The measures show effects, but are only two of a series of potential measures. For example, high efficient or indirect cooling systems in buildings could serve as additional measures.

The damage avoided using these measures is not insignificant but limited, can be stated as medium. The measure will only address parts of the impacts (e.g. the impact described above was a reduction of up to 1 ° C). Therefore, o ther measures are needed to have additional impacts, for instance for office buildings, hospitals, nursing and retirement homes, and schools. It should be noted that measure effectiveness will suffer during periods of prolonged drought.

For the measure green space no or very low windfall profits are expected. The installation of parks and lakes is a task for public authorities. Green roofs are already profitable, so a high risk for windfall profits exist. Depending on the scale at which the measure is implemented scope of effects is local. The implementation is possible also at the regional or national level.

The measures become necessary in short to medium-term. Heat waves are already problematic today. A gradual increase for average and maximum temperatures is foreseeable. For instance, EPSON's climate projections show for Portugal and Spain over 40 additional summer days in 2100 (compared to 1961).

For green roofs, the time-lag between implementation of the measure and effects is short to medium. The measure is effective immediately after construction, technologies are available. Many existing buildings can be retrofitted with available technologies. The implementation of green spaces needs more time due to long planning processes, e.g. the necessary involvement of stakeholders as well as the concrete installation need time. The capacities are limited for green spaces as well as for green roofs. The lifetime of the measures is long. For green roofs, the lifetime is equal to the lifetime of buildings. Literature on green roofs suggests this measure increases the lifetime of roofs and lowers the need for renovation. Green spaces must have a long life time to justify the costs for implementation (Mann n.d.).

Installation of green roofs is a no-regret measure. The green roofs appear more economical even in the absence of climate effects. Higher investment and maintenance costs occur, but green roofs have a longer life expectancy. Additionally, green infrastructure (including green roofs and green spaces) has many positive side-effects e.g. for biodiversity, for well-being of residents. Due to these side effects green spaces are low-regret. The land has to be occupied up now, resulting of their long time for implementation. No other use is possible for the green and blue area.

The scenario-variability is generally low, due to the increase in heat days in all climate scenarios. But risks exist in case of reduced effect during periods of prolonged drought because the projections for precipitation are not so clear. After implementation the measures show little potential for adapting or reversing.

5.3.4 Efficiency/ costs and benefits

5.3.4.1 Green Space

Costs of green space

The cost calculation can be found in chapter 4.3.3.

Benefit for green space

Definition

The adaptation measure "Expanding green spaces" has for objective to reduce the heat island effect in urban areas through more parks, urban forests, or other vegetated areas. According to the cost estimation in the previous chapter, the estimation also includes water surfaces (sometimes called blue areas). Some vegetated areas in cities do not count as green space, like agricultural land in cities or private gardens are excluded.

Green spaces can help mainly against increasing temperatures and also with the impacts of higher intensity and frequency of precipitation. Climate projections show that in large regions in Europe the average temperature will rise and heat waves will appear more intense and more often. The calculation of benefits concentrates on avoided damages due to heat, especially on avoided deaths.

A large heat wave impacting several European countries happened in summer 2003. Estimations and statistical data show that in Europe between 25000 and 35000 deaths are connected with the heat wave (Koppe et al. 2003). Especially impacted was France with almost half of these deaths (14.800) (EEA 2004). The data show that heat waves can yield a significant increase in mortality rate:

Table 5-23: Number of cases of heat mortality in heat wave 2003 (Huebler et al 2007)

Place	Number of cases of heat mortality	Source
Europe	25,000 – 35,000	Koppe et al. (2003)
Germany	7 000	Zebisch et al. (2005)
Baden-Württemberg	1 100; 16 - 24 % increase	Koppe et al. (2003)
England	2,091; 17 % increase, 23 % increase among people aged 75 years or older, 85 % of victims older than 75 years	Johnson et al. (2005)
London	616; 42 % increase, 59 % increase among people aged 75 or older	Johnson et al. (2005)
France	14,800; 16 % increase, 80 % of victims older than 75 years	EEA (2004)
Netherlands	650	WHO Europe (2005)
Switzerland	975; 6.9 % increase	WHO Europe (2005)
Italy	9,704, 92 % of victims older than 75 years	WHO Europe (2005), Conti et al. (2005)
Portugal	1,854; 40 % increase, 58 % up to 96.6 % of victims older than 75 years	Calado et al. (2005), Kovats and Jendritzky (2006)

The data for the following calculation is taken from different literature sources. The data on cities is taken from the Urban Audit database of Eurostat. The statistical data on European country wide information for European countries is from Eurostat. The other data is from research projects like PESETA or CAFÉ, or from our own assumptions.

For the benefit quantification, reports are published on willingness-to-pay for a good climate in urban areas. Brandt (2007) conducts a questionnaire on willingness-to-pay for improvements on air and climate quality in cities. The results are very contradictory. The average willingness to pay to avoid hot and sleepless summer nights is 16 Euro per night while the willingness-to-pay for avoidance of health damages nears 0. Consequently, the willingness-to-pay-concept for climate in urban areas is not used for the study.

Calculation

The calculation of benefits is based on the following parameters:

- B_i^{AD}: Benefit adaptation measure: green space: avoided deaths per city *i*
- $VOLY_i$: Value of lost years (VOLY) min/max per city i (own estimation, based on Hurley et al. 2005)
- LY : Lost life years through deaths due to heat (Assumption: Ciscar 2009)
- P_i: Total population living in the city *i* (Eurostat)
- P_{55i}: Total population aged over 55 years in city *i* (Eurostat)
- P_{DE}: Total population living in Germany (Eurostat)
- P_{55DE}: Total population aged over 55 years in Germany (Eurostat)
- AD_j: Avoided death rate through green space (per 1000 inhabitants, own estimation)
- L_i: Total area of city *i* in km^2 (Eurostat)
- L_{bluei}: Blue area of city *i* in km^2 (Eurostat)
- L_{greeni}: Green area of city *i* in km^2 (excluding private gardens, green roofs and agricultural area) (Eurostat)
- L_{target}: Target share of blue and green area (in % of total area) (assumption: 20% of area should be blue and green area, taken from chapter 4)

$$B_i^{GP} = \left[L_{target} - L_i / \left(L_{bluei} + L_{greeni}\right)\right] * \left[VOLY_i * LY * \left(P_i / P_{55i} * P_{DE} / P_{55DE}\right) * AD_j * P_i / 1000\right]$$

The target of green and blue area with 20 % of total area is taken from chapter 4 of this report. The sum of existing green and blue area is deducted from the target area. A benefit is not estimated for cities which already have more than 20 % green and blue area. Given this condition and existing data gaps the calculation was possible for only 57 European cities.

The benefits are calculated based on the Value of life year (VOLY). The VOLY is a concept which attributes a constant value to each life year lost due to premature death. It is mainly used for cost-benefit analysis with regards to security aspects, for example in road traffic (HEATCO 2006, Hurley et al. 2005). The Value of life years is used here, due to the higher impacts on elderly people, which would be overscored by the value of statistical life years. . For the 2003 heat wave it was analysed that in Italy almost 90% of the affected people were older than 75 years. In France this figure was estimated at 80% (WHO Europe 2005, Conti et al. 2005, EEA 2004).

Different VOLYs exist in literature. For our purposes, figures from Hurley et al. (2005) from the CAFÉ-project were used. The latter estimated average values for all EU countries. The minimum value is 52.000 Euro/a, maximum value: 120.000 Euro/a. The VOLY of CAFE is adapted to the city via the relation of GDP per capita of the city.

Calculation for the VOLY-adaption:

- $VOLY_{CAFE}$: Value of lost years (VOLY) min/max, average for EU countries (Hurley et al. 2005)
- GDP_{EU} : GDP per capita (PPP) (Eurostat)
- GDP_i : GDP per capita (PPP) per city *i* (Eurostat)

$$VOLY_i = VOLY_{CAFE} / GDP_{EU} * GDP_i$$

Estimations from PESETA are used for the number of lost life years. Ciscar estimates eight lost life years, due to the high number of affected elderly people (Ciscar 2009).

The number of elderly people living in different European cities is included via the proportion of total population in the cities related to people older than 55 years, this quotient is estimated against the quotient of Germany because the increase of mortality rate is assumed for the German age structure.

The avoided deaths per 1000 inhabitants are based on the estimation on country level. The national rate is used for all the cities in the country.

The following equation is used:

- PC_j : Total population per country *j* (2009) (Eurostat)
- D_j : Number of deaths per country *j* (2009) (Eurostat)
- SD_j : Change in annual mean number of summer days in summer in country *j* in number of days (1961-2100, Source: ESPON)
- RHD_r : Percentage of heat days based on summer days per regions r (regions: Northern = 25%, Central =50%, Southern Europe = 75%) (own assumptions)
- MRS: Projected increase of mortality rate for Germany for strong heat load (9.3%) (based on estimations of Koppe & Jendritzky 2004)
- $MRE_{\min/\max}$: Projected increase of mortality rate for Germany for extreme heat load, two cases: minimum (12.0%) and maximum (12.4) (based on estimations of Koppe & Jendritzky 2004)

$$AD_j = D_j * 1000/(PC_j * 365) * (SD_j / RHD_r) * \left[(SD_j / SD_{DE} * MRE_{\min/\max}) - (SD_j / SD_{DE} * MRS)\right]$$

For the calculation, it is assumed that the heat load during heat days can be reduced through green spaces from an extreme heat load to a strong heat load (used in Ecologic Institute 2011). Koppe et al. (2003) estimate for Germany a 9.3 % increase in mortality rate for a strong heat load, and a minimum and maximum value for an extreme heat load of 12 % and 12.4 % respectively. The past heat event in the summer of 2003 is the basis for these results, but further adjustments were included. Due to lacking data the estimations are adapted via the above equation for other European Countries. To adapt to higher or lower summer temperatures, the difference between the higher number of summer days in 2100 in Germany is compared to that of other countries and combined with the mortality rate.

The rate is related to the higher number of heat days (in 2100). The change in the number of summer days (1961-2100) (ESPON) is the basis for the heat day calculation. It is assumed that the number of summer days corresponds with the number of heat days. The ratio is defined via our own assumptions for different European regions: Northern Europe (heat days are 25% of summer days), Central Europe (50%), Southern Europe (75%). The value for Germany is checked with the projections on the webpage Regionaler Klima-Atlas (2011). For the average projection of heat (plus 15 days) and summer days (30 days) in 2100, the ratio is 50% for Germany. The reduced mortality rate for heat days is combined with the mortality rate of different European countries. Unfortunately, mortality rates or death numbers are not available at the city level. The mortality rate (per 1000 inhabitants per year) of the country is based on the number of deaths and the total population in 2009 per country (Eurostat).

The cities in Northern regions are not excluded, but they show a very low number of heat days, so their values are low.

The additional economic value of green spaces is estimated as follows:

- B_i^{EV} : Benefit adaptation measure Green Space of additional economic value per city *i*
- $EV_{\min/\max}$: Economic value per km^2 green space (minimum/maximum value estimated by case studies, min: 22 Euro/km^2, max: 2200 Euro/km^2)

$$B_i^{GP} = \left[L_{target} - L_i / \left(L_{bluei} + L_{greeni}\right)\right] * EV_{\min/\max}$$

Data for added value of green space were taken from two British studies and one German study on national parks. The economic value in the reports were divided by the size of area of the national parks, an economic value per m^2 is the result.

Obviously, national parks have another potential for economic activities. They are tourist attractions and destination for vacationers. Furthermore, it was assumed, that a minimum of 1 % and a maximum of 5% of total economic value per year in national parks can be generated by green spaces, like parks, etc.

Results

The results of the benefit estimation for green space are presented in this chapter. The estimation is based on strong assumptions regarding the number of heat days in different European cities. Furthermore, the increase in mortality rate as a result of heat waves is taken from a German study, which relates to the heat wave of 2003. Different adjustments are done to adapt this increase for different regions in Europe, for instance, adjustment of the proportion of elderly people. For the monetisation, a European average VOLY-amount is taken and adjusted to the GDP per capita for cities included in the present report. Due to lacking statistical data the condition to exclude cities which have already more than 20% green and blue space, the estimation is possible for 50 European cities

The ten cities with the highest benefits are shown in the following Table 5.24.

Table 5-24: Value of avoided deaths for Green Space of ten cities with highest benefit (out of 58 cities)

Cities	Value of avoided deaths min (in Euro per year)	Value of avoided deaths max (in Euro per year)
Bucuresti	2,011,394	5,329,335
Paris	1,575,565	4,174,574
Lille	869,024	2,302,544
Valletta	864,268	2,289,942
Lyon	744,733	1,973,226
Bruxelles / Brussel	566,924	1,502,108
Bologna	556,968	1,475,728
Thessaloniki	533,058	1,412,378
Padova	514,762	1,363,899
Sevilla	512,79	1,358,674

The highest benefit of green space is estimated for Bucuresti at approximately 2 to 5.3 million Euros per year in 2100 and Paris 1.6 to 4.2 million Euros per year. The total benefit of green space for the 58 cities amounts to 12.4 to 40 million Euros per year from avoided deaths during heat waves.

For additional economic values the results are between 18,755 to 1.9 million Euros per year.

Table 5-25: Additional Economic Value for ten cities (in €) (with highest values)

Cities / Countries	Additional Economic Value, min (in Euro)	Additional Economic Value, max (in Euro)
Lille	2,374.7	243,038.9
Aarhus	1609.8	164,749.7
Krakow	990.2	101,340.5
Lyon	846.9	86,679.8
Toulouse	804.2	82,306.3
Bucuresti	769.4	78,741.7
Caen	725.7	74,272.2
Wroclaw	718.6	73,541.0
Lodz	647.7	66,288.3
Lens - Liévin	642.5	65,753.6

Comparison of benefits and costs

Costs for green space are calculated in chapter 4 at 2.6 billion Euro per year for about 100 European cities, where data was accessible.

The total benefit through avoided deaths is estimated to be between 12.4 and 40 million Euro per year (for 58 cities). Green space accounts for an estimated additional economic value of between 19,000 and 1.9 million Euro (for the 58 cities which are vulnerable and data was provided). The benefits include here only the avoided deaths and an increased economic value for cities' parts near to green space.

Other positive effects like higher recreation values are not calculated, due to unserious data for recreation value of green space in cities. It can be assumed that the benefits also on biodiversity and water management are much higher, both are also impacted by climate change.

5.3.4.2 Green roofs

Costs of green roofs

The cost calculation can be found in chapter 4.3.4.

Benefit of green roofs

Calculation

The calculation is based on the estimation in the previous chapter for green space. Further description of estimation and variables can be found in previous chapter.

- B_i^{GR}: Benefit adaptation measure Green roofs per city *i*
- L_i: Total area of city *i* in km^2 (Eurostat)
- G_{Poti}: Total potential area of green roof in city i in km^2 (estimated in chapter 4)

$$B_i^{GR} = G_{Poti} * L_i * \left[VOLY_i * LY * \left(P_i / P_{55i} * P_{DE} / P_{55DE}\right) * AD_j * P_i / 1000\right]$$

The estimation of avoided deaths through green roofs is based on the reduction of heat load from extreme to strong heat load on hot days. The avoided deaths correspond with the reduced mortality rate due to lower heat load. The monetization is prepared by value of life year-concept (VOLY). For the calculation, the loss of eight years from deaths due to heat waves is assumed.

The calculation was possible for 84 cities, for that data on different types of areas in the cities exits.

Results

The following table shows the ten cities with the highest estimated value of avoided deaths.

Table 5-26: Value of avoided deaths for Green roofs of ten cities with highest benefit (in €) (out of 58 cities)

Cities	Value of avoided deaths, min (in Euro per a)	Value of avoided deaths, min (in Euro per a)
Madrid	653,699	1,732,023
Roma	482,501	1,278,421
Barcelona	325,647	862,825
Milano	286,087	758,010
Budapest	210,520	557,789
Bucuresti	162,452	430,429
Torino	150,566	398,935
Lisboa	126,968	336,412
Zaragoza	115,316	305,538
Valencia	114,164	302,488

The cities with the highest value of avoided deaths are Madrid, Roma and Barcelona. Madrid has a value of 600.000 to 1.7 million Euro per year (in 2100), Roma between 500,000 and 1.3 million. The total value of avoided deaths for all 84 estimated cities is between 5 and 13 million Euro per year (in 2100).

Comparison of benefits and costs

Costs for green roofs are estimated in chapter 4 to total 5.2 bn Euro per year for the analysed European cities that are vulnerable and where data was accessible.

The benefit through avoided deaths is estimated at 5 to 13 million Euro per year (for 84 cities).

For both estimations many own assumptions have to be used in the report. The calculation shows a methodology with which estimations should be prepared, if more relevant research data and statistical is available.

5.3.5 Side effects

5.3.5.1 Economic side effects

For the measures the effects are divided for different areas in Europe. Particularly green space with high amount of occupied land that cannot be used in other ways has a high potential only in cities in Southern Europe. For Northern Europe, change in number of summer days is not significant. The projections for Northern Europe show also an increasing temperature during heat waves, but an extreme heat load will still be seldom. Therefore, all side effects will only be relevant for Southern Europe or partly Central Europe.

The measures show low effect on innovation and competitive advantage. The scope of the measures is very local. The techniques are already well known, with no foreseeable further developments with potential for innovation. For the effect on employment, no information could be found, but major positive effects are not expected. The installation of green roofs replaces employment for regular roofs. The implementation of green space has a small employment effect, but compared with the potential for other economical use of the areas, no positive effects can be stated.

The measures do however increase the value of areas near to parks and other green and blue areas. Buildings and land near to recreational areas show a higher value, with higher rents and property prices. Studies have found general increases of about 3 to 10% in residential property values associated with the presence of trees and vegetation on a property. Wolf (2007) indicates from different studies increases of property prices of 2 to 37%. Analyses of Portland show that trees added US $8,870 to the sale prices of residential properties (Foster et al 2011). Furthermore the value added of local commerce will increase, due to the higher attractiveness near to green space.

Further economic effects occur due to positive health impacts. Through green areas the quality of life for residents and the possibilities for recreation increase, which leads to lower healthcare costs. More positive effects are seen from the increase of air quality, for instance, reduced ozone concentration would lead to fewer respiratory diseases (Livingroofs 2004, Foster et al 2011). Clark et al (2007) calculated that the benefit for Detroit and Chicago of the greening of ten percent of metropolitan roofs would result in a reduction of healthcare costs of between $25.8 million to $97.7 million per year in Detroit and between $31 million to $118 million per year in Chicago (Livingroofs 2004, Clark et al 2007, Foster et al 2011).

Foster et al (2011) names the New York City's 2010 Green Infrastructure Plan as an example. The plan estimates that every fully vegetated acre of green infrastructure would provide total annual benefits of $8,522 in reduced energy demand, $1,044 in improved air quality, and $4,725 in increased property value.

5.3.5.2 Environmental side effects

Synergies can be seen for mitigation of climate change. Some potential for sequestration of CO2-emissions is stated for green areas. Foster et al (2011) describe a value from urban forestry in Chicago with a total carbon sequestration rate of 25,200 tons/year. In 2005, total carbon storage in urban trees in the US was approximately 700 million tons.

Furthermore, the energy demand for active cooling will decline. Especially in the regions where heat waves will not regularly or only for low number of days occur, an installation of active cooling may no longer be necessary. The lower energy consumption can have a significant effect for a lower amount of CO_2-emissions (Livingroofs 2004, Hallegatte et al 2007). Foster et al (2011) analysed different studies, which showed energy savings from green roofs at 15-45% of annual energy consumption, mainly from lower cooling costs.

Positive environmental effects are expected for urban biodiversity. For a larger green area, a higher diversity of species is also possible. Such aspects, like a high diversity, should be included already in the planning process for green area. Also, expected climate change impacts should be included in the planning process, so heat- and drought resistant plants are recommended. A larger area of green space also shows a higher vulnerability to climate change, for instance, dense vegetation protects more against storm events. (Livingroofs 2004, Clark et al 2007, Foster et al 2011)

A further environmental effect is improved air quality in urban areas. Fine dust particles and NOx can be reduced via growth in plants. The reduction of NOx would lead to a lower ozone concentration in cities. With better air quality, health impacts for the residents also decrease, which would lead to economical effects of lower healthcare costs. Furthermore, green roofs act as noise barriers and are sufficient to provide noise insulation for buildings under flight paths and around airports (Livingroofs 2004, Foster et al 2011).

5.3.5.3 Social side effects

The measures benefit especially vulnerable groups (elderly, infants) and groups in urban areas with high population density. No specific "losers" of the measure are found. For green roofs the tax payers can perhaps be seen as losers, due to the profitability of the measure.

The measures, especially developing green space, have generally positive effects on well-being. Green areas in cities have a recreational function. They increase the quality of life in the district or city, which could lead again to lower healthcare costs. (Livingroofs 2004, Clark et al 2007, Carter & Keeler 2007, Foster et al 2011)

An extensive stakeholder involvement is indispensable. Especially for green space, the discussion is also about large areas, for which normally other alternative uses are also possible. The alternative uses could also have strong advantages for the surrounding residents, as businesses with higher economic value and newly created job opportunities are attractive.

5.4 Agriculture

5.4.1 'Climate Proofing' measures for Agriculture – with a focus on irrigation as an adaptation measure

5.4.1.1 Irrigation as adaptation measure

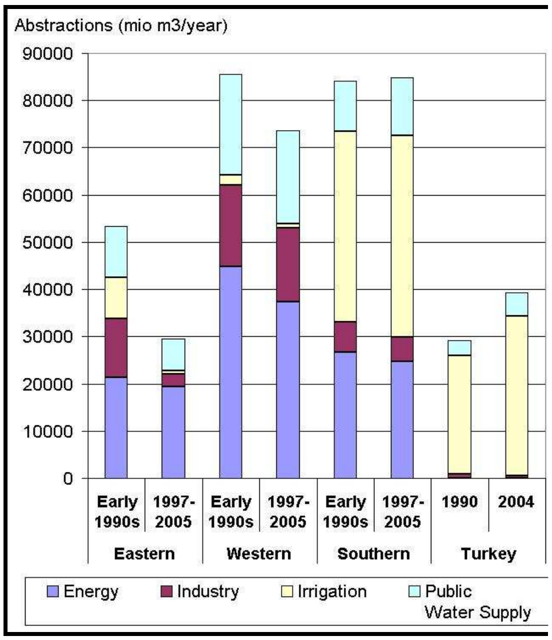
The main issue associated with increasing irrigation as an adaptation measure is that the water abstracted will in its majority no longer be available to other competing demands of the resource. This is especially relevant in water scarce areas in Europe, where the demand for the resource will be only exacerbated by longer periods of droughts as a result of climate change. It is under this scenario that water allocation policies should promote highest-value use, rather than in ill-defined property rights routed in historical allocations or political decisions.

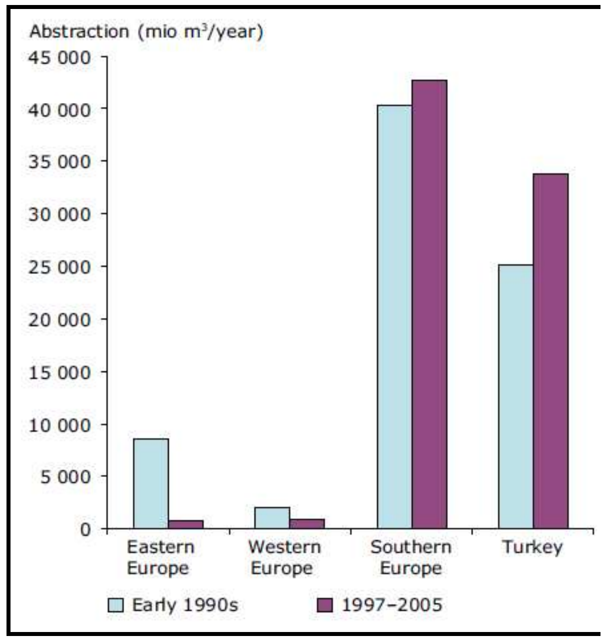
In addition increasing irrigation as an adaptation measure would jeopardize the objectives of other policies. Evidence is clear that agriculture is the most significant and controversial water user in most EU countries, as it is a sector associated to both water quality environmental concerns and problems of poor water use management. Across the EU, agriculture is seen as the sector that creates the biggest challenges to meeting the requirements of the Water Framework Directive. These challenges relate to the reduction of diffuse pollution from agricultural sources and to the regulation of agricultural water consumption.

Irrigation even though it has largely improved farmers' competitiveness, has been the source of a number of environmental problems, such as water table depletion and salinisation of coastal aquifers. Such problems also create significant competition between farming and other water users.

Competing uses of water resources include sectors such as agriculture, domestic energy, industry and tourism (figure 5.1 below). Agricultural water use across Europe has increased over the last two decades, accounting now for around 24% of total water abstraction mainly due to irrigation practices. In some parts of southern Europe, where crop irrigation has been practiced for centuries and is the basis of economic and social activity, this figure can reach up to 80% or even higher (see EEA 2009), see Figure 5.1:

Figure 5-1 (left): Water Abstractions in Europe and Turkey. Figure 5-2(right) Water abstracted for Irrigation in 1990 and 1997-2005 (source : EEA, 2009)





The sharp increase in irrigation in Southern Europe (Figure 5.2) is mainly due to the region's dry climatic conditions and low summer precipitation which results in a further need of water abstractions for agricultural irrigation; without irrigation in some southern locations crop production would be severely limited and could cause great economic hardship or even land abandonment. As matter of fact, agricultural water use is expected to increase due to future demand for energy crops, world population growth and increased water stress pressures resulting from climate change and drought events. Other drivers of agricultural water use include adverse subsidies such as prices not reflecting the full financial cost of water provision, pricing structures that do not incorporate the full costs (inc. environmental) of the service, or CAP regulations fostering in some cases the production of water-intensive crops.

To add to the problem, national and European (e.g. CAP) agricultural policies continue to promote irrigated agriculture to minimize perceived risks in food supply and distribution (even though recent modifications of the CAP have increased the support for environmentally friendly farm practices, intensive agriculture is still supported in the EU). The promotion of agricultural activity is considered strategic in fixing and developing rural economies and in many cases the existing systems of water use rights are reinforced by specific property rights that benefit agricultural water use over other sectors.

Irrigated agriculture accounts for a large share of final farming production and still plays an important role in the economic activity within some areas in Europe. This is the case in Spain where agriculture constitutes a 3% of the total GDP (26 billion euro) and employs 5% of the economically active population (1 million jobs). The irrigation sector is mainly located in the Southern part of the country where it imposes a high political influence. In Andalucia for example, agriculture is responsible for 5.5% of GVA, and it is relevant for part of the associated industry and tertiary sector, in particular, for the agroindustry sector (e.g. olive oil bottling or packaging of agricultural products) which generates 29% of the industrial GVA and 22% of employment in this sector (Guadalquivir dRBMP Annex 3:18).

A major issue with respect to agricultural water use is its highly consumptive nature, as only around 30% of the water used is returned to ground- or surface waters for downstream usage (EEA 2009). Agriculture is thus a user of “raw” water and water that is allocated to the sector has limited value to other users. This is often realised by subsidised water pricing schemes for irrigation and the support of certain agricultural practices which are harmful to the environment.

The management of water is and has been an economic, social and political issue encompassing to different degrees of involvement all sectors of an economy. The management involves trade-offs between these sectoral users, as well as between additional economic growth and further water resource depletion, degradation and related environmental concerns. Regarding the water scarcity problem, economics defines the conditions required to secure the most efficient allocation of scarce resources in a variety of contexts. Water resources provide important commodity and environmental benefits to society and any particular use of water is associated with opportunity costs, which are the benefits foregone from possible alternative uses of the resource. Decision-makers are faced with balancing, for example, water demands from agricultural irrigation for food production with the desire to preserve wetlands for fish and wildlife habitat. Economics contributes towards improved allocations by informing decision-makers of the full social costs of water use and the full social benefits of the goods and services that water provides.

5.4.1.2 Agriculture is not the highest value water user

In theory, a sustainable use of water would be achieved when the full costs of supply equal its full price (value). Water would normally be first allocated to high value users.

The economic value of freshwater availability for productive activities varies over time and space, as well as between sectors. Table 5.27 presents estimates for the value of water for various economic activities across the United States in the 1990s.

Table 5-27 Water value estimates by type of use in the USA (USD per acre-foot*)

Use	Average	Median	Minimum	Maximum
'Instream' uses				
Waste disposal	3	1	0	12
Recreation / habitat	48	5	0	2,642
Navigation	146	10	0	483
Hydropower	25	21	1	113
'Withdrawal' uses				
Irrigation	75	40	0	1,228
Industrial processing	282	132	28	802
Thermoelectric power	34	29	9	63
Domestic	194	97	37	573

** 1 acre-foot is about 1234 m^3.*

Source: Frederick et al., 1996.

Table 5.27 reflects the wide sectoral variety for the value of water in the USA. In relation to irrigation the sector is marked by a very low value for water in comparison to other sectors. However, it is the sector that shows the highest variability between the minimum and maximum values. This value is likely to be associated among other factors to the productivity of the land, cost-efficiency of production and to the availability of water resources among other geographical conditions. This variety is present in Europe as well. Normally, economic activities that are dependent on (clean) water will be located and scheduled so as to benefit from (relative) abundant supply as much as possible. Problems arise when expectations regarding water supply are not met, for instance due to climate change or as a result of competing water use by other actors.

5.4.1.3 Droughts can hit harder productivity levels in other sectors.

Table 5.28 provides a European illustration of the direct economic cost caused by drought: the case of Catalunya in the years 2007 and 2008, as reported by Martin-Ortega and Markandya (2009). These costs were estimated at 540 million Euros per year.

Table 5-28: Summary of direct costs of main economic agents due to the 2007-2008 drought event in Catalunya

Sector	Direct costs (M€ per year)	Description	Reliability	% of Catalan GDP
River Basin Authority	77.41	Expenses for drought related measures	High	0.04
Water suppliers	17.79	Expenses for drought related measures (extrapolation)	Medium	0.01
Irrigators	62.76	Production losses	Medium to low	0.03
Gardening and flower companies	210.00	Production losses	Very low	0.10
Swimming pool and related companies	45.00	Sales losses	Medium	0.02
Hydroelectric production	127.30	Production losses	Medium	0.06
Total	**540.26**		**Medium**	**0.27**

Source: Martin-Ortega and Markandya, 2009.

The annual direct costs of the 2007-2008 draught for the irrigation sector in Catalunya were estimated at around 60 Million Euro. Agriculture did not suffer the highest losses. Gardening and flower companies and hydroelectric energy generation were hit harder. In addition to the direct costs, indirect costs were calculated using input-output tables. These were estimated at another € 358 million per year, with the main part of the burden falling in the industry sector. On top of that, non-market welfare losses were estimated at € 762 million per year, leading to a total cost estimate of € 1661 million per year or 0.83% of the Catalan GDP. Actions taken by the authorities were, both in terms of demand reduction (e.g. restrictions on the use of drinking water for gardens, swimming pools and street cleaning) and increased supply (groundwater pumping, desalination, shipping water from France).

5.16.4 Increased irrigation can affect directly other economic activities

In Western Europe, an important economic impact of low water levels is the increase in inland shipping costs on the river Rhine (due to the inability of the vessels to use their full capacity). Jonkeren *et al*. (2007) estimated that in the period 1986–2004 this has led to an annual average welfare loss of €28 million. The estimated loss in 2003 was as high as €91 million due to the very dry summer in that year. Although these results are based on historical data, they have clear consequences for the inland shipping sector under climate change. Climate change scenarios for Western Europe show that the incidence of low water levels will increase.

5.16.5 Example of competing uses for water resources

In 2009, there were a total of 19 golf courses in Spain's Júcar River Basin. They consume on average around 500 000 m3 annually for a single course. The accompanying influx of tourists puts an even greater strain on public water supplies — mainly during the summer months when water resources are most scarce. At first glance it could be argued that this may well be an unsustainable use of the resource. But ultimately, a golf course uses no more water than a comparable area of irrigated corn and yields a much better financial return. Turnover at the Júcar's courses is estimated at EUR 1.5–9 million annually and each has an average of 150 employees (EEA, 2009).

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[i] Exchange rate from 2003: 1 Australian Dollar converts to 0.61 Euro.