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Environment Center
Charles University in Prague

# CBA of flood adaptation measures in Prague and the role of uncertainties

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# Aim and objectives

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- Explore the **boundaries** of cost benefit analysis
  - well-established method that has become routine in many contexts in the EU
- Explore the **methodological challenges** connected with dealing with large and diverse uncertainties typical of investments in adaptation to CC
  - relevant uncertainties rarely explicitly included in economic appraisal
  - cascade models spanning several disciplines
  - relative importance of each source of uncertainty on the CBA results
- Deliver **lessons-learnt & recommendations** for further use of CBA in CC context
  - how uncertainties may be treated in CBA so that the results are more robust

# Case study

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- **Flood adaptation measures in Prague**
  - ex-post CBA
  - carried out in the period 1999 – 2014
  - 5300 $m^3/s$ ($Q_{2002}$) + 30cm freeboard
  - involves:
    - line measures
      - fixed anti-flood earth dikes
      - reinforced concrete walls
      - mobile barriers
    - barriers in the waste-water system
      - backflow preventors etc.

# Why CBA?

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- At present the most sophisticated tool used for major budgetary decisions in the Czech Republic & other countries incl.USA *(Chichilnisky, 2011)*
- Particularly important to private investment projects and public programmes that **involve large expenditure** with **high environmental impacts**
- **Floods:** low-probability, high damage events (hazard events)
- **Assessment of hazard events**
  - imperfect knowledge on distribution of future avoided damage
  - requires the researcher to make several assumptions that may dramatically affect the results (e. g. discount rate)

# CBA methodology

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- **General practice of CBA**
  - all consequences of a project to **all individuals of society** (i.e., stakeholders) at **multiple scales** are considered
  - these costs and benefits are quantified in **monetary terms**
  - aggregate all **social costs and benefits** of the project **over time**

$$PV(C) = \sum_{t=0}^{N} \frac{C_t}{(1+s)^t} \qquad PV(B) = \sum_{t=0}^{N} \frac{B_t}{(1+s)^t}$$

  - the project is evaluated to determine if it provides net economic benefits to society

- **Comparison may be done**
  i. Between given project and status quo

$$NPV = PV(B) - PV(C)$$

  ii. Between competing alternative projects

$$NPV = PV(B) - PV(C) > 0$$

# Methodological framework

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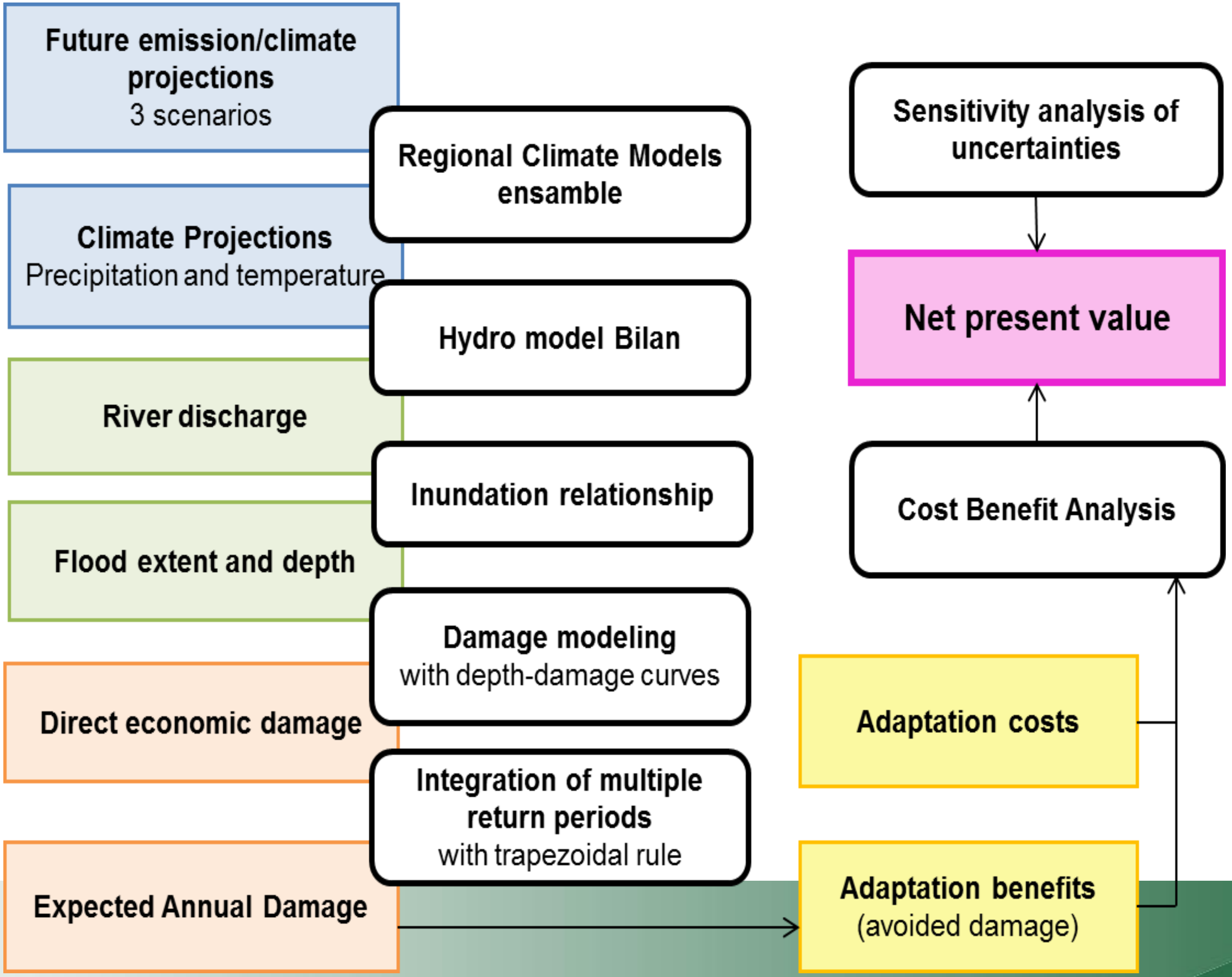

# Climate data

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- Daily time series of precipitation and temperature until 2100
- 14 simulation sets from the WCRP CORDEX database *(Jacob et al., 2014)*
- For the whole Vltava river basin, resolution 12 sq. km

| Regional climate models and simulation sets | RCP2.6 | | RCP4.5 | | RCP8.5 | |
|---|---|---|---|---|---|---|
| | pr | temp | pr | temp | pr | temp |
| CNRM-CERFACS-CNRM-CM5_CLMcom-CCLM4-8-17 | | | 6.3 | 14.0 | 9.5 | 19.8 |
| CNRM-CERFACS-CNRM-CM5_CNRM-ALADIN53 | | | 13.7 | 11.0 | 19.5 | 19.7 |
| CNRM-CERFACS-CNRM-CM5_SMHI-RCA4 | | | 4.7 | 19.6 | 11.2 | 26.6 |
| ICHEC-EC-EARTH_KNMI-RACMO22E | | | 2.9 | 21.1 | 6.3 | 33.3 |
| ICHEC-EC-EARTH_DMI-HIRHAM5 | | | 3.4 | 18.3 | 5.7 | 28.2 |
| ICHEC-EC-EARTH_CLMcom-CCLM4-8-17 | | | 4.6 | 16.0 | 5.1 | 25.4 |
| ICHEC-EC-EARTH_SMHI-RCA4 | 3.5 | 15.2 | 5.6 | 23.8 | 5.8 | 35.5 |
| IPSL-IPSL-CM5A-MR_IPSL-INERIS-WRF331F | | | 9.5 | 22.4 | 18.6 | 30.2 |
| IPSL-IPSL-CM5A-MR_SMHI-RCA4 | | | 7.2 | 24.3 | 10.1 | 35.0 |
| MOHC-HadGEM2-ES_CLMcom-CCLM4-8-17 | | | 4.9 | 26.7 | 6.2 | 36.4 |
| MOHC-HadGEM2-ES_KNMI-RACMO22E | | | 10.9 | 26.7 | 12.3 | 37.0 |
| MOHC-HadGEM2-ES_SMHI-RCA4 | | | 9.1 | 25.3 | 9.7 | 35.4 |
| MPI-M-MPI-ESM-LR_CLMcom-CCLM4-8-17 | | | 6.2 | 10.7 | 6.3 | 21.0 |
| MPI-M-MPI-ESM-LR_SMHI-RCA4 | | | 5.8 | 14.8 | 7.7 | 24.4 |
| **Average annual change** | **3.5** | **15.2** | **6.8** | **19.6** | **9.6** | **29.1** |

**Mean percentage changes by year 2100** (with respect to historical baseline) in anual values of daily precipitation (in mm/day) and temperature (in °C) in the Vltava river basin. Source: DMI (2014)

# Hydrological modelling

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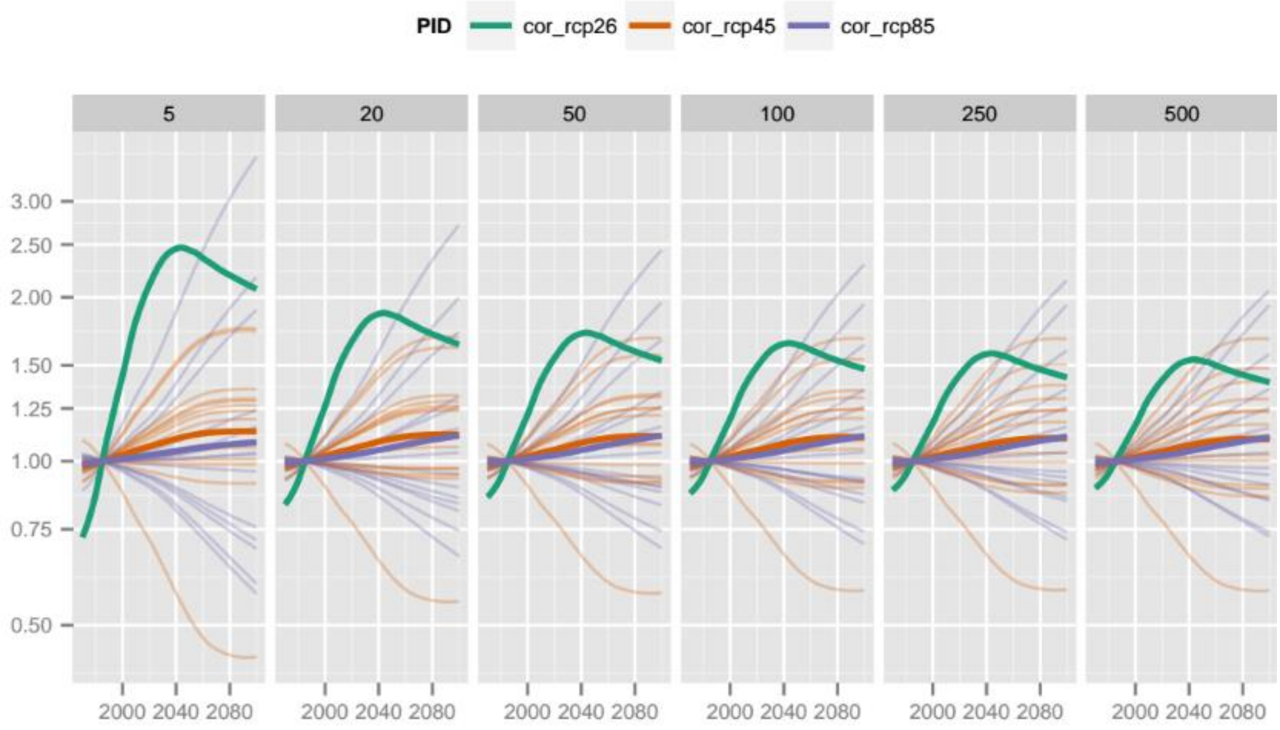
- Simulation of changes in max runoffs based on BILAN model (← bias-corrected time series of climate data)
- Simplified approach: observed relationship between runoff and flood extent
- Prediction of occurrence of N-year period floods based on climate data




**Relative changes (in factor units) of the maximum runoffs**, simulated with data from the ensemble of RCMs, for the assessed period (thin lines represent individual RCMs, and bold lines the average for each RCP scenario) and for floods of six return periods (5- to 500-year), compared to base year 1985. Source: Hanel and Vizina (2015)

# Damage and risk modelling

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- **Boundaries of CBA system**
  - Prague
- **Benefits = avoided flood damage**
  - direct tangible damage categories *(Foudi et al., 2015)*
  - using depth-damage functions *(TGM WRI, 2009)*

1. Damage to immovables
   - buildings (housing, commerce and public sector)
   - infrastructure (roads)
2. Loss of agricultural production

$$D_{total(e)} = D_{build(e)} + D_{road(e)} + D_{crop(e)}$$

$$D_{build(e)} = \sum_{i=1}^{m} \sum_{j=1}^{n} f_{DR}(w) \cdot A_{ij} \cdot F_{ij} \cdot P_i$$

# Floodplain areas in Prague and assets under risk

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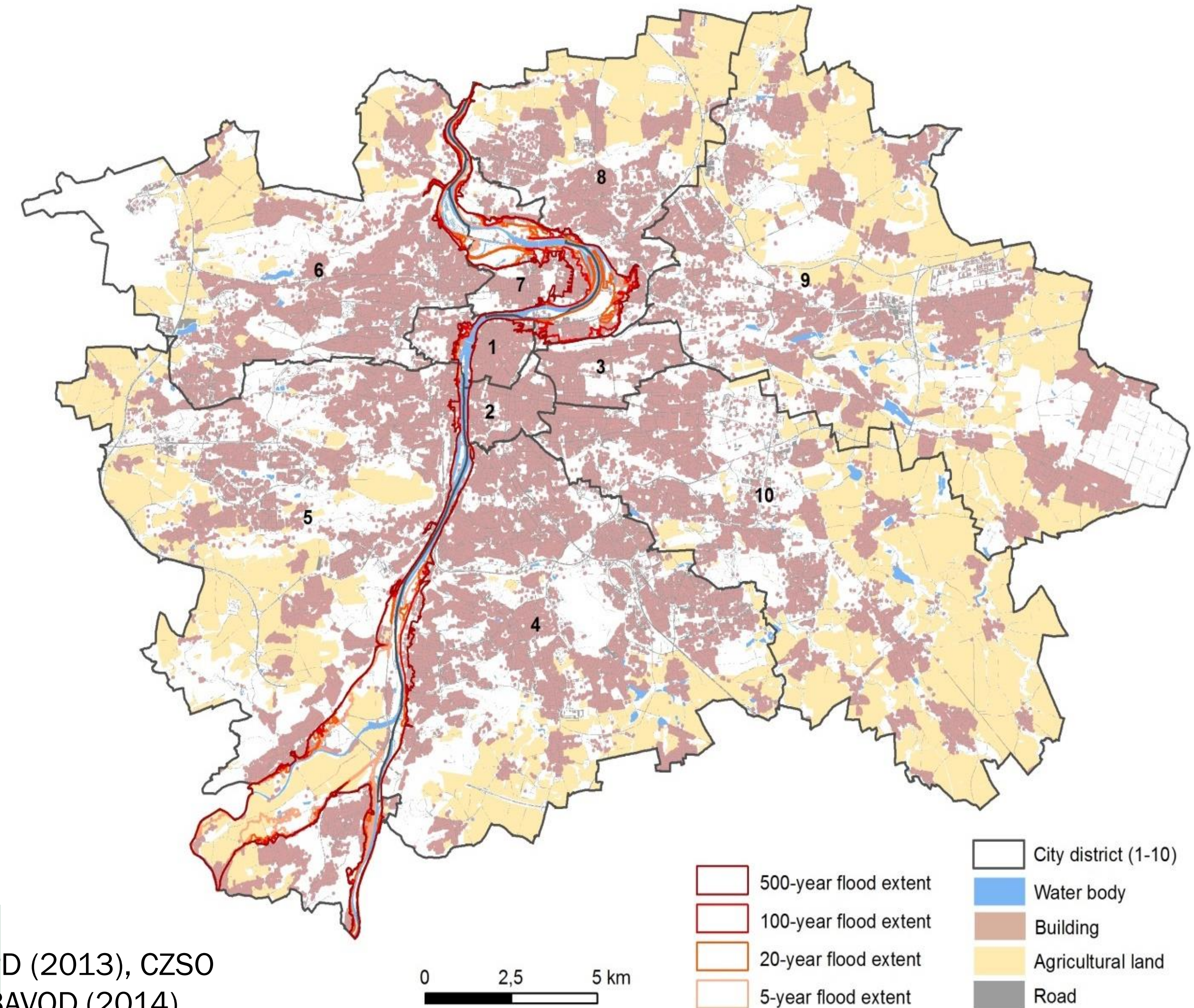


Source: PIPD (2013), CZSO (2011), DIBAVOD (2014)

# Method of damage assessment

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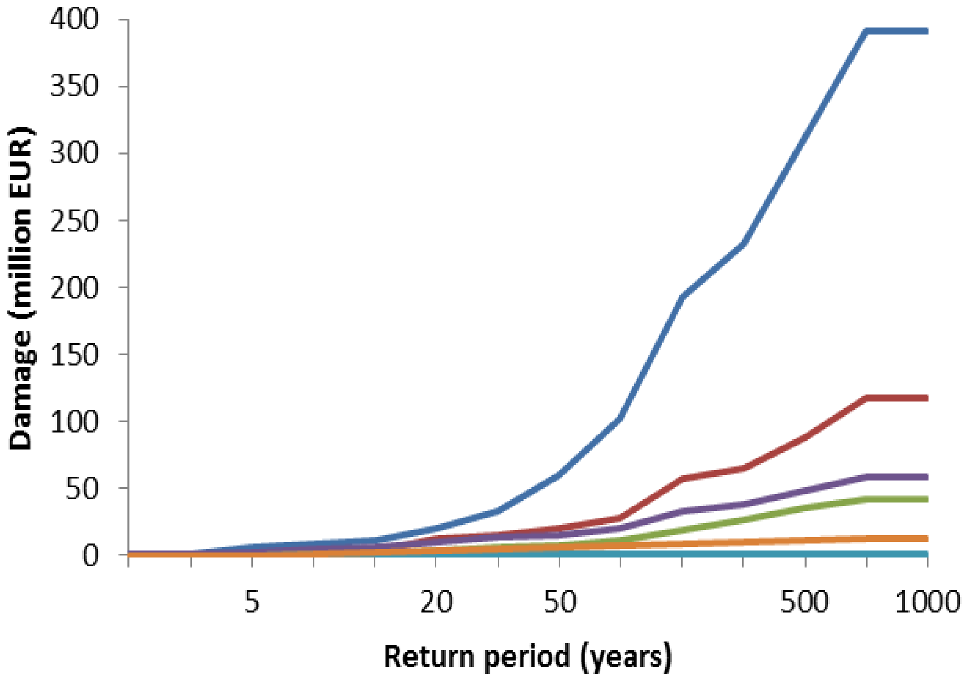
- **Expected annual damage (EAD; *Arnell, 1989*)**
  - = indicator that measures potential flood damage over a certain level of floodplain inundation (EUR/year)
  - – trapezoidal rule (*Olsen et al., 2015*): $$EAD = \frac{1}{2}\sum_{i=1}^{n}\left(\frac{1}{RP_i} - \frac{1}{RP_{i+1}}\right)(D_i + D_{i+1})$$
  - – avoided EAD compared to the status quo: $$\Delta B = \Delta EAD = EAD_{adapt} - EAD_{sq}$$



# Risk as Expected Annual Damage (EAD)

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- Estimated vs. observed damages on buildings in Prague (millions EUR; recalculated to € 2015 using EU HICP deflator and PPP exchange rate )

| Return period | 5-year | 20-year | 50-year | 500-year |
|---|---|---|---|---|
| Estimated average damage | 2.8 | 46.6 | 85.2 | 596.6 |
| Actual historic damage (2002-13) | 0.8* | 80.7* | | 570.3 |

Source: Own calculations, TGM WRI (2002), TGM WRI and CHMI (2006), CHMI (2013).

* *The actual damages related to historic floods in 2006 (5-year) and 2013 (20-50-year) were estimated from the reported total damage under assumption that the share is similar to the share of damages on buildings on total damage in year 2002 (500-year)*

# CBA application – case study

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- **Avoided EAD** = socioeconomic benefit of the adaptation investment
  - (a) The situation without the new adaptation investment, the *status-quo* situation)
  - (b) The adaptation investment (with a 500-year protection), which was realized in the period of 1999-2014.
- **Costs** = investment, operational, „one-off“
- → NPV: $$E[NPV] = -\sum_{t=ts}^{t=-1} CI + \sum_{t0=0}^{T} (\Delta EAD_t - CV_t - CL_t) \cdot \tau_t \cdot \prod_{to=0}^{T} (1 + \eta \cdot g_t)$$

**Discount factor** in year *t*: $$\tau_t = \frac{1}{(1 + r_s)^t}$$

Social discount rate

# Social discount rate

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- **Uncertain parameter** *(Heal and Milner, 2014)*
  - lack of information on future economic growth
  - normative disagreements about the values of welfare parameters
- Most recent approaches favour **more complex and flexible ways** than constant discount rate (HM Treasury, 2013)
  - Do not lower the importance of the benefits occurring in far future so much as constant DR (case of CC adaptation – long-term benefits)
- **Four approaches tested**
  - The constant discount rate (0, 1, 2, 3 and 4%)
  - The standard neoclassical Ramsey formula $r_s = \delta + \eta \cdot g_t$
  - The extended Ramsey formula with stochastic growth $r_s = \delta + \eta \cdot \mu - \eta^2 \cdot \frac{\sigma^2}{2}$
  - Discounting under intertemporal risk aversion $r_s = \delta + \eta \cdot \mu - \eta^2 \cdot \frac{\sigma^2}{2} - RIRA \cdot |1 - \eta^2| \cdot \frac{\sigma^2}{2}$

+ Adopting scenario-dependent GDP growth projection (5 **SSPs**)

+ Testing for a **range of values** for **welfare parameters**

# Results

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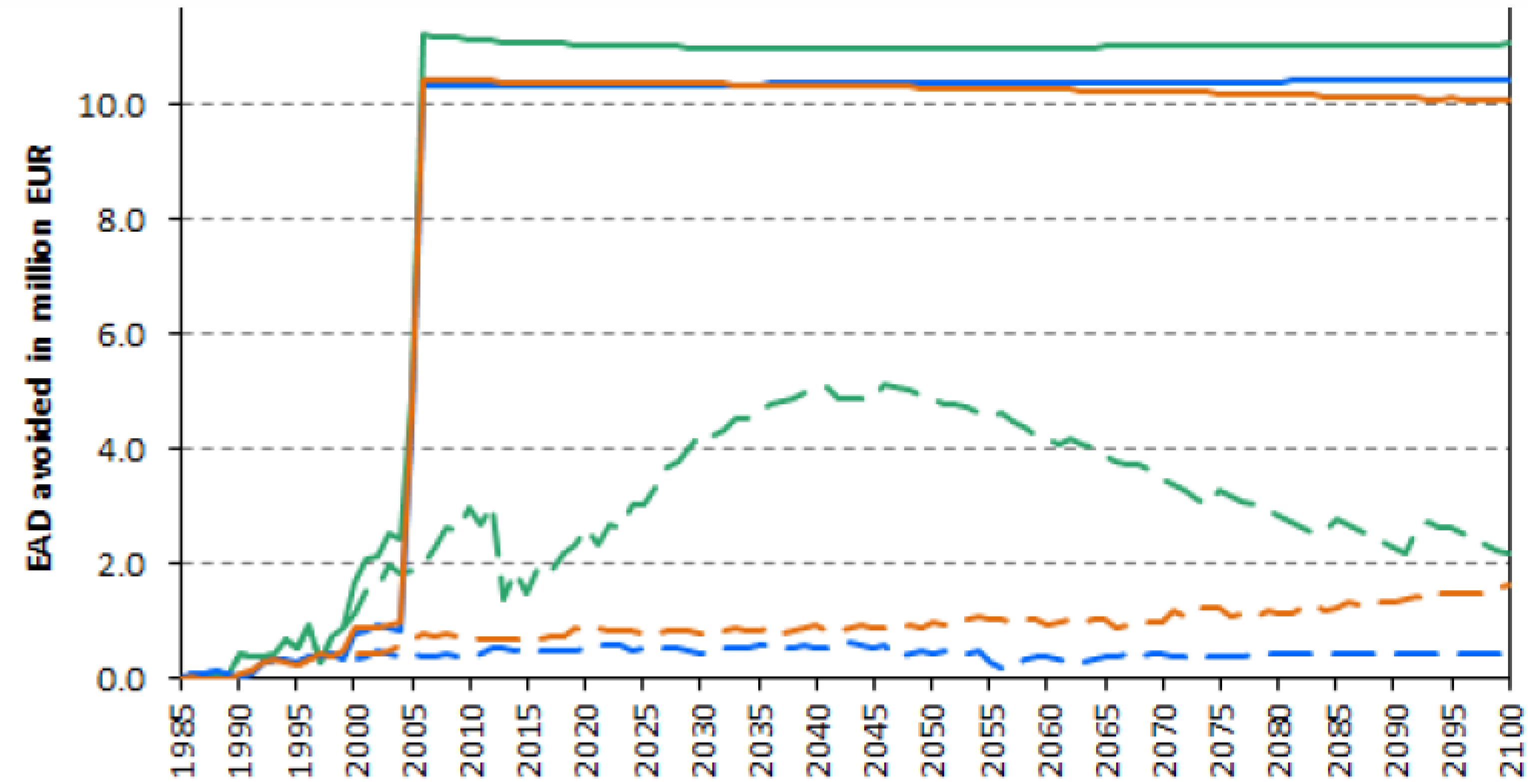
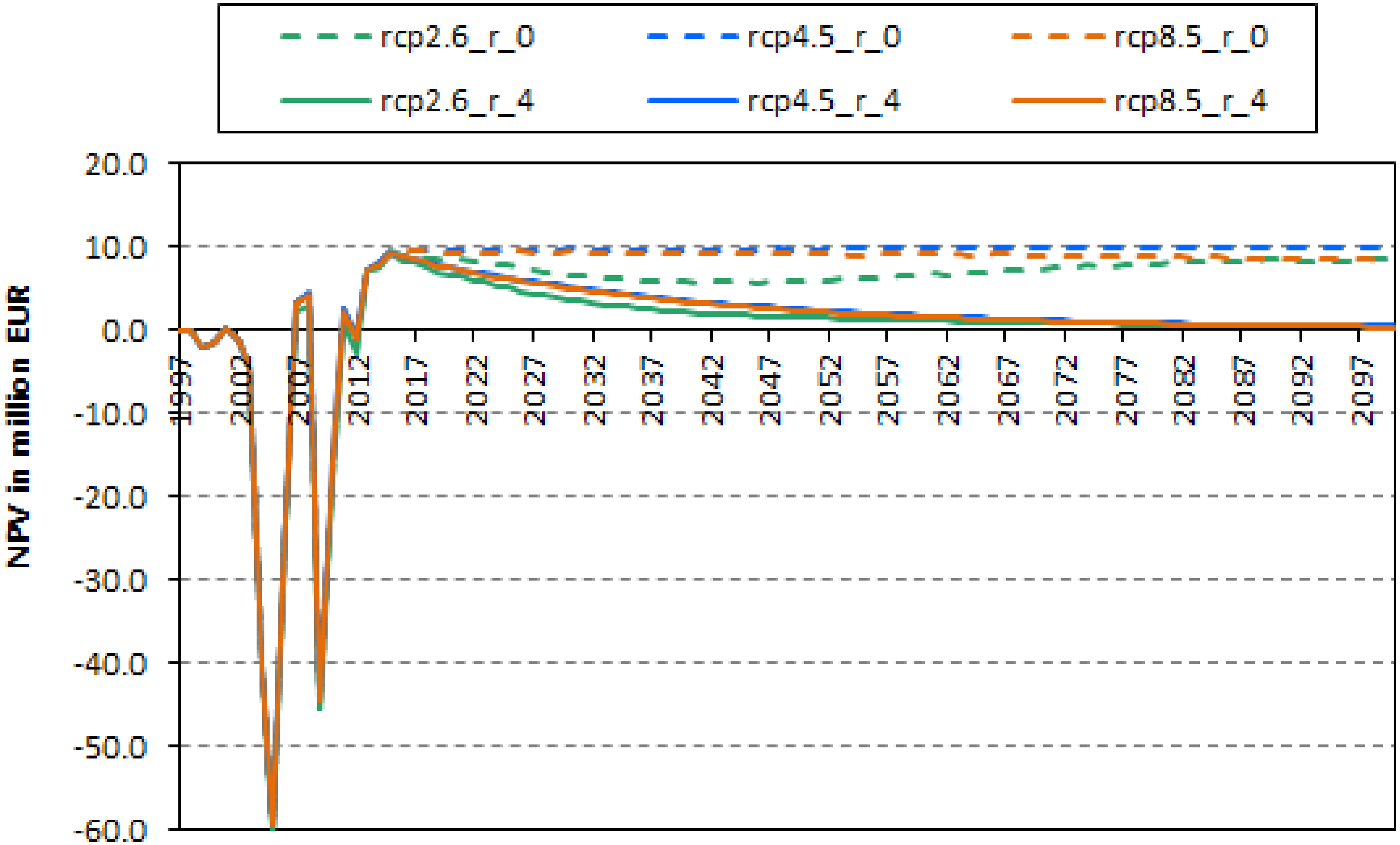
- **Avoided expected annual damage** (**not discounted**) according to RCP scenarios, compared to the EAD of the base year 1985
  - RCP2.6, RCP4.5, RCP8.5
  - <u>with adaptation investment</u>, <u>status quo</u>



# Results



- Annual NPV of flood protection measures in Prague according to RCP scenarios, compared to climate of the base year 1985 without flood protection
  - 0% discount rate and 4% discount rate



# Results

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- Sensitivity analysis of cumulative NPV (in million €) on different parameters assumed in discounting under intertemporal risk aversion with RIRA coefficient

| | Values of parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| discount rate | 0.015 | 0.015 | 0.014 | 0.014 | 0.045 | 0.045 | 0.044 | 0.043 |
| RRA | 1 | 2.5 | 5 | 10 | 1 | 2.5 | 5 | 10 |
| δ | 0 | 0 | 0 | 0 | 0.015 | 0.015 | 0.015 | 0.015 |
| η | 0.99 | 0.99 | 0.99 | 0.99 | 2 | 2 | 2 | 2 |
| μ | 0.0150 | 0.0150 | 0.0150 | 0.0150 | 0.0150 | 0.0150 | 0.0150 | 0.0150 |
| σ | 0.0110 | 0.0110 | 0.0110 | 0.0110 | 0.0110 | 0.0110 | 0.0110 | 0.0110 |
| ημ | 0.0149 | 0.0149 | 0.0149 | 0.0149 | 0.0301 | 0.0301 | 0.0301 | 0.0301 |
| standard risk term (SR) | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0002 | 0.0002 | 0.0002 |
| RIRA | 1 | 151 | 401 | 901 | -1 | 0.5 | 3 | 8 |
| intertemporal risk aversion (IRA) | 1.2E-06 | 1.8E-04 | 4.9E-04 | 1.1E-03 | -1.8E-04 | 9.1E-05 | 5.5E-04 | 1.5E-03 |
| magnitude of IRA/SR contribution | 0.020 | 3.066 | 8.142 | 18.294 | -0.750 | 0.375 | 2.250 | 6.000 |
| RCP2.6 | 439 | 447 | 456 | 473 | 170 | 174 | 179 | 190 |
| RCP4.5 | 662 | 673 | 684 | 707 | 305 | 309 | 317 | 332 |
| RCP8.5 | 600 | 610 | 620 | 641 | 275 | 279 | 286 | 300 |

# Conclusions

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- Prague flood measures: ΔB = ΔNPV generally > 0
- The choice of constant discount rate has a significant impact on the ENPV
  - Discounts of 4% and above entail ΔNPV < 0 under RCP 2.6
    - If we use min damage function rate, also under RCP 4.5 and RCP 8.5
  - Even under RCP 4.5 and 8.5 NPV 10 times lower than under RIRA
  - For RIRA discounting NPV always >0
- Also, very important uncertainty is related to climate prediction and socio-economic development
- The other parameters (costs, damage function used, hydrological modelling) have moderate effect on NPV
- Benefits included only avoided direct tangible damages → potential underestimation of ΔNPV

# THANK YOU FOR YOUR ATTENTION!

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**FULL REPORTS:** econadapt.eu/resources

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## RESOURCES

### BRIEFING DOCUMENTS

- Download a fact sheet about the project (PDF 0.5MB)
- Download ECONADAPT Newsletter 1 (PDF 2.8MB)
- ECONADAPT Policy Report on Costs and Benefits of Adaptation – Full draft report (PDF 4.6MB)
- ECONADAPT Policy Report on Costs and Benefits of Adaptation – Summary (PDF 2.8MB)
- ECONADAPT Policy Brief on Rwandan Case Study (PDF 0.6MB)

### DELIVERABLES

Links to documents will be added here as they become available.

| No. | Title of Deliverable |
|---|---|
| D1.1 | Stakeholder selection and survey results (PDF 1.4MB) |
| D1.2 | Design of policy-led analytical framework (PDF 2.8MB) |
| D1.3 | Documentation of the socio-economic scenarios and adaptation narratives developed and used in the case study WPs (PDF 944KB) |
| D1.4 | Documentation of the climate scenarios and data developed and used in the case study WPs (PDF 552KB) |
| D1.5 | Multi-scale integration and sythesis of scenarios and adaptation narratives (PDF 704KB) |

# FULL REPORTS: econadapt.eu/resources

| | |
|---|---|
| D6.3 | Report: Description of uncertainties associated with planned investments and incorporation in decision rules (PDF 4,164KB) |
| D6.4 | Report: The economic appraisal of adaptation investments under uncertainties: Policy recommendations, lessons learned and guidance (PDF 643KB) |

# METHODOLOGICAL & PRACTICAL GUIDANCE:

## econadapt-toolbox.eu

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# ECONADAPT/TOOLBOX

POLICY CHALLENGES | METHODS | INSIGHTS | DATA SOURCES | EASY ACCESS GUIDE

Climate change impacts are increasing and becoming widespread. Decision makers need adequate support tools to inform about climate change adaptation actions.

Assessments of adaptation actions can provide valuable information on the value, efficiency and feasibility of adaptation projects and strategies.

This toolbox provides easy accessible information on the economic assessment of adaptation.

## EASY ACCESS GUIDE

Find relevant information for your adaptation action

**POLICY CHALLENGES** — Are you interested in implementing or evaluating a specific policy or project?

**METHODS** — Are you interested in a specific economic method to evaluate your adaptation activity?

**INSIGHTS** — Are you interested in practical examples and methodological developments?

**DATA SOURCES** — Are you interested in concrete cost and benefit estimates?