Appraisal of adaptation to river flood at the Vltava river, Prague

Key Messages

- The study aims at the ex-post appraisal of adaptation to flood risks in the city of Prague, for which the corresponding investments and social benefits will be calculated through a cost-benefit analysis.
- The methodology presented includes a context analysis, hazard and impact assessment, followed by the economic assessment using cost-benefit analysis, and then the decision whether the investments promote economic efficiency.
- The cost-benefit analysis involves the systematic identification of project consequences, followed by the assessment of all social benefits and costs.
- Significant uncertainties arise at all stages of the methodology, and especially in the various steps of the economic analysis. Addressing these uncertainties is a priority, and is discussed throughout the case study.

Context

Mainstreaming adaptation in infrastructure development is a crucial component of building resilience to climate change impacts. This Insight presents the application of the methodology presented on the appraisal of economic projects to support the assessment of adaptation options to river flooding in the Vltava river basin in the Czech Republic. The methodology used for assessing adaptation options is a cost-benefit analysis . As the impacts incorporate low-probability high-damage flood events that are spread over a long-term horizon, key to the assessment is to incorporate uncertainties in the economic appraisal. Uncertainties under climate change variability were investigated as well further uncertainties with respect to different assumptions about input data and discount rate assumptions. Addressing these uncertainties is discussed throughout the case study.

Policy and methodological developments

Context analysis

The case study area is the capital city of the Czech Republic, Prague. It is located in the Lower Vltava river basin district, one of two river basin districts in the Vltava river basin that are both managed by the Povodí Vltavy, state enterprise, but planning is done for each of them separately. Prague is the absolutely dominant economic unit in the river basin, and the floodplain area encompasses residential areas as well as several important industrial areas, recreational zones such as urban parks and also agricultural areas in the south of Prague.

From an institutional standpoint, flood protection planning is widely developed by the public sector in the Czech Republic, and accounts mainly for flood protection measures that affect larger areas in the river basins. Local administrations play a role in allowing the development in floodplain areas by setting the territorial plan of the municipality and participating in the building-permit process. On the policy side, key documents include the EU Water Framework Directive and the EU Floods Directive, which are transposed at the national level through the Water Act. There are also numerous strategic and planning documents identified at the local and national level. The relevant stakeholders include state-level Ministries, local municipalities, the Czech hydro-electric power company (CEZ), and the state enterprise responsible for the management of the Vltava river basin, Povodí Vltavy, State Enterprise.

Hazard and Impact assessment

Information on current hazards related to flood risk is available in the form of GIS maps of administratively defined floodplain areas and active zones of floodplain areas. In line with the EU Flood Directive, maps of flood danger and flood risks have been created by the Povodí Vltavy, s. e. The focus in the estimation of future hazards is to simulate and relate spatially the potential losses, i.e., damages in each location. Several flood return periods are considered (5-, 20-, 100-, 500-year) and data were interpolated to cover 141 flood extents.

The impacts of climate change on floods, and the costs and benefits of flood protection adaptation measures in the Vltava river basin is simulated using a methodology that overarches climatic, hydrologic and economic aspects. The simulation of changes in maximum runoffs is based on the hydrological model Bilan run by T.G. Masaryk Water Research Institute. The model employs as input climate projections of precipitation and temperature that are simulated under two Representative Concentration Pathway scenarios until year 2100 using a set of regional climate models.

The outputs of the hydrological modelling are transferred to flood extent and depths. Assets under risk are identified and the direct economic damage as expected annual damage (EAD) is calculated for the following categories of damage: damage to immovable (including housing, commerce and public sector buildings; and road infrastructure) and loss of agricultural production). The adaptation benefits are then expressed using EAD that is avoided by the adaptation investments into flood protection.

Economic assessment

For the Vltava case study, cost-benefit analysis has been used for economics assessment. CBA involves the systematic identification of project consequences, followed by the assessment of all social benefits and costs and thereafter the application of appropriate decision criteria (Fuguitt and Wilcox, 1999).

The expected annual damage that is avoided by the adaptation measures serves as welfare measure of socioeconomic benefits attributed to the investment. EAD is calculated from an exceedance probability loss curve which represents a relationship between different levels of flood damage of a particular return period and the corresponding probabilities of flood events. The economic efficiency is estimated by a widely used decision criterion, the net present value (NPV), which can be applied when evaluating a single investment. A NPV above zero suggests that the adaptation project promotes economic efficiency.

Some variables considered in the calculation of the NPV are deterministic, i.e., there is no uncertainty involved in the lifespan of the measure. The EAD, the lump-sum / one-off of costs associated with the occurrence of a flood event and the discount rate under intertemporal risk aversion are random variables contributing uncertainty (and risk, from a certain point of view) into the CBA. Thus, instead of the simple NPV, the expected net present value (ENPV) which could be formulated for the Vltava case study was calculated as follows:

$$E[NPV] = -\sum_{t=ts}^{t=-1} CI + \sum_{t0=0}^{T} (\Delta EAD_t - CV_t - CL_t) \cdot \tau_t \cdot \prod_{to=0}^{T} (1 + \eta \cdot g_t)$$

where τ_t is the discount factor in year t with the social discount rate r_s, assumed to be:

$$\tau_t = \frac{1}{(1 + r_s)^t}$$

The costs of the adaptation measures include the initial investment cost *CI*, the yearly maintenance and variable costs CV_t and lump-sum costs CL_t. Lump-sum costs are spent when 50-year flood and higher will occur. The investment costs were incurred during the period 1997-2014. The social benefits in year t are measured by the ΔEAD_t indicator and represent the avoided flood damage in year *t*. The indicator ΔEAD_t, for a given year represents the increased flood protection standard in Prague, from 1 in 10-year flood to 1 in 500-year. The product in the third term adjusts real values of social benefits and costs for possible changes in income over time. Parameter η is the elasticity of marginal utility and g_t is the growth rate of consumption in year *t*.

Results show that average value of ENPV for all RCP scenario is € 626 million, if we assume 0% discount rate. The differentiation between RCPs will have a moderate impact on ENPV, the RCP2.6 scenario will decrease the value by 30%, RCP4.5 will increase ENPV by 6% and RCP8.5 decreases by 4%. When considering 4% discount rate, then the effect of RCPs on ENPV is larger, the change is -107%, 14% and -7% for RCP2.6, RCP4.5 and RCP8.5, respectively.

The variability in the estimation of ENPV among RCPs and climate simulations is clearly evident in Figure 1. The ENPV value varies among the RCP4.5 simulations in the range from -79% to 40% compared to the RCP4.5 average (at 4% is the range larger, from -221% to 91%). The variability of ENPV for the climate simulations of RCP8.5 is in the range from - 35% to 34 % (at 4% discount rate the range is from -238% to 91%).

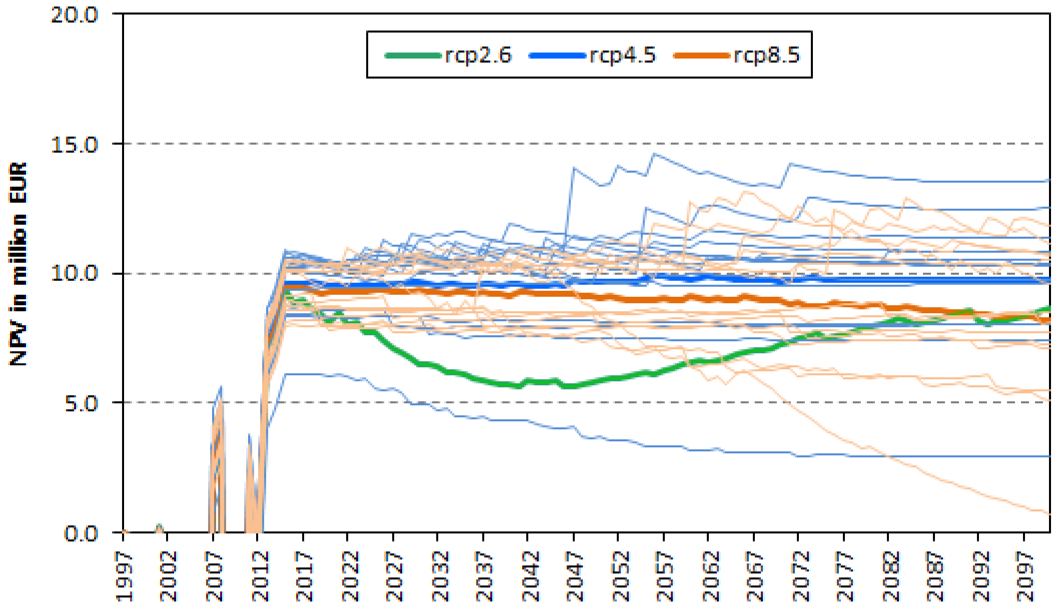

Figure 1. Annual net present value (not discounted values) of flood protection measure in Prague. The thin lines represent individual RCMs, and bold lines the average for each RCP scenario.

A sensitivity analysis was performed measuring the influence of changes in key input parameters when other parameters are held constant. This demonstrated that the ENPV varies significantly with the use of different discount rates and return periods while the choice of infrastructure cost variables, depth-damage functions are less significant. To investigate the effect of the choice of the discount rate on the results, four discounting approaches were applied and their influence was tested on the ENPV in a sensitivity analysis. The approaches were: the constant discount rates of 0% and 4%, the standard neoclassical Ramsey formula with scenario-dependant discount rates, the extended Ramsey formula with stochastic growth, and discounting under intertemporal risk aversion (Traeger, 2014). The results of sensitivity analysis indicated that the choice of the pure rate of time preference and consumption elasticity in the Ramsey formula of discount rate dramatically influenced CBA results, whereas the choice of the RIRA coefficient in expanded Ramsey formula with RIRA had a negligible effect.

As an example of the output of the sensitivity analysis on the use of scenario-dependent discount rate, Table 1 provides the ENPV estimates according to different methodological assumptions about parameters δ (pure rate of time preference) and η (consumption elasticity of marginal utility), type of GDP growth projections and the choice of SSP in Ramsey formula of discount rate. Selected plausible combinations of SSP and RCP are highlighted in bold in Table 1: RCP2.5 and SSP1; RCP4.5 and SSP3; RCP8.5 and SSP5.

The results show that there is a dramatically large difference in the value of discount rate, in the range 16-2802%, caused by different values of δ and η parameters. The discount rate for $\delta = 0.015$ and $\eta = 2$ and SSP5 reaches ca. 7.5%. There is only a relatively small difference in the range 0-61% between the two types of GDP growth projection (modelled by IIASA and OECD), depending on RCP and SSP scenario. The choice of SSP scenario has a moderate effect on NPV, when considering parameters $\delta = 0$ and $\eta = 1$. The range of variability caused by SSP scenarios is 9-282%. When we assume $\delta = 0.015$ and $\eta = 2$, the variability of NPV increases, with range 11-1141%.

Table 1. Sensitivity analysis of cumulative NPV (in million €) on different parameters assumed in Ramsey discounting, with the IIASA and OECD SSP-dependent growth rates. Plausible selected combinations of SSP and RCP are in bold.

		Shared Socioeconomic Pathways				
		SSP1	**SSP2**	**SSP3**	**SSP4**	**SSP5**
	Parameter values:	δ = 0%	η = 1			
Average discount r.	IIASA	0.0128	0.0106	0.0012	0.0069	0.0243
	OECD	0.0193	0.0195	0.0081	0.0175	0.0302
RCP2.6	IIASA	**440**	501	934	663	200
	OECD	**440**	400	876	500	207
RCP4.5	IIASA	664	747	**1312**	953	344
	OECD	664	615	**1232**	742	356
RCP8.5	IIASA	602	678	1188	862	**311**
	OECD	602	560	1116	672	**323**
	Parameter values:	δ = 1.5%	η = 2			
Average discount r.	IIASA	0.0407	0.0361	0.0174	0.0288	0.0636
	OECD	0.0536	0.0540	0.0311	0.0499	0.0753
RCP2.6	IIASA	**169**	229	785	392	7
	OECD	**170**	150	687	221	15
RCP4.5	IIASA	303	386	**1125**	600	78
	OECD	304	280	**991**	373	91
RCP8.5	IIASA	273	350	1021	543	**66**
	OECD	274	254	899	337	**78**

Decision making

The net benefits of the adaptation options are considered as the difference between the situation without new adaptation investment (with a 10-year protection) adaptation investment (with a 500-year protection) realized in the period 1999-2014. The value of interest is the incremental impact of the adaptation investment, which is described through the differences in the project option impacts in comparison to status quo (in terms of marginal costs and benefits). Therefore, the main interest is the reduction of potential food damage due to new flood protection system, which represents marginal social benefits, and incurred investments and corresponding maintenance and lump-sum costs, which represent marginal social costs. Following these decision rules, results support the adaptation project into flood protection because its net present value is positive in the order of millions of EUR, depending on the characters of input data and methodological assumptions.

Main implications and recommendations

The methodology of the study suggests how uncertainties in each of the phases of the adaptation assessment (modelling the climate, hydrologic modelling and economic modelling) may be addressed and the results show how serious are particular uncertainties for the final results of the CBA of adaptation options in Prague. An assessment of the uncertainties related to the case study is summarized below.

Table 2. Integration of uncertainties in assessment.

Source of uncertainty	**Degree of Uncertainty**	**How it was addressed**
Future emissions	Medium	Use of three RCPs: RCP 2.6; RCP 4.5; RCP 8.5
Regional climate	High	Use of 14 climate simulations from several RCMs for precipitation and temperature
Hydrological modelling	Low	Cut-off of the events with the highest return periods, to reduce uncertainty from the extrapolation of extreme values from limited observation series
Socio-economic developments	High	Application of SSP- and RCP-dependent discount rates for future values. Also, two different sources of GDP projections are used (OECD, IIASA)
Damage calculation	Medium/High	Inclusion of uncertainties on exposure of assets and on the vulnerability curves for buildings: min, max and mean values are considered for these datasets
Costs of adaptation	Low	Inclusion of a range of values for the cost of maintenance and for “one-off“ costs for protection operations
Method of EAD calculation	Medium	Trapezoidal rule using 6 return periods vs. using full range of 141 return periods
Discounting approach	Medium	Employing several approaches: constant rate; Ramsey formula with scenario-dependent discount rate; expanded Ramsey formula with uncertain growth; expanded Ramsey formula with RIRA. Also, two different sources of GDP projections are used (OECD, IIASA)
Discount rate	High	Two discount rates are used for the constant discounting approach

The sensitivity analysis shows that the critical factor in the CBA assessment is the selection of a discount rate. Discount rates in the range up to 3% still enable that the adaptation option generates positive ENPV. However, if discount rate is set at 4% and above, the project is no longer efficient.

It must be noted that the benefits, which were quantified as the avoided flood damage, are in all likelihood underestimated, because they cover only direct tangible damages on buildings, road infrastructure and agricultural crops, and the other damage categories are not included in the CBA. Consideration of intangible/non-monetary benefits would be important for a more complete assessment. This can be achieved through frameworks such as policy analysis, cost-effectiveness analysis or multi-criteria analysis. Where these methods may not be feasible, it is possible to resort to “expert judgement” to provide qualitative evaluation of adaptation measures.

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Further Information
Policy and decision context of case studies
Description of adaptation options and their costs and benefits
Description of uncertainties associated with planned investments and incorporation in decision rules
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