LIFE LOCAL ADAPT | Integration of climate change adaptation into the work of local authorities

Assessment of benefits and co-benefits of particular urban adaptation measures

Deliverable to Sub-Action C4.4

Authors: Helena Duchková

Eva Horváthová

Simeon Vaňo

Affiliation: Global Change Research Institute of CAS

Due date: 30.11.2020

Transmission date: 03.03.2021

Project start: 01.07.2016

Project end: 30.06.2021

Version: Final

TECHNISCHE UNIVERSITÄT DRESDEN | Das Land Steiermark | CzechGlobe | GERICS Climate Service Center Germany | VALGA · VALKA | LANDESAMT FÜR UMWELT, LANDWIRTSCHAFT UND GEOLOGIE | Freistaat SACHSEN

Content

List of figures

List of tables

1 Introduction

Climate change is a complex problem in the present time. It represents a rapid development of alterations in the Earth's system cycles and atmospheric conditions, like the changes in temperature and precipitation averages and variability. This is further amplified by ever-increasing human activities including land take, resource exploitation, production and consumption. Altogether the situation contributes to further environmental degradation and negatively affects human health and wellbeing (Sachs, 2015). Moreover, the annual economic damage caused by climate impacts can be as high as 1.1 trillion EUR[1]. The climate crisis poses a major challenge to humanity and to the environment that we need to respond to by developing new comprehensive approaches and strategies to strengthen climate-resilience[2].

Two broad strategies are applied when tackling climate change, *climate mitigation* and *climate adaptation* (Kabisch *et al.*, 2016). The first one, *climate mitigation*, aims to reduce the causes of climate change and so the overarching objective is cutting down the greenhouse gas emissions produced by industrial and household energy consumption and by transportation. Emission cuts could be achieved for instance by implementing energy-efficient technologies, technologies for utilisation of renewable energy, industry processes improvements, or sustainable modes of mobility. The technological approaches best define mitigation strategies. However, enhancing local agricultural capacity can reduce the need for the import of supplies over long distances that result in high emission levels. Moreover, mitigation takes place also through enhancing green and blue infrastructure either by planting trees or creating new water bodies that act as greenhouse gas (or carbon) sinks. Green and blue infrastructure is a nature-based solution that reinforces not only mitigation but also climate adaptation.

The second strategy, *climate adaptation*, makes adjustments in natural and human systems to moderate harm or exploit beneficial opportunities from changing climate. Building resilience to unstable and extreme weather events and improving our ability to thrive under such conditions is then the main objective of adaptation. Increasing adaptive capacity is especially important in cities. Cities accumulate most of the world's population, technology, infrastructure and economic assets ((World Bank, 2010; McPhearson *et al*., 2015). Adjustments in infrastructure and building design, adopting strategies for flood protection and water management, or enhancing and protecting nature - these all increase adaptive capacity and can harness additional ecosystem benefits for both society and nature.

This report was developed under action *C4 Improvement of local policies* of LIFE LOCAL ADAPT project. Particularly, it is produced as a part of the sub-action *C4.4 Estimation of benefits of certain measures*. This report aims to provide a wide range of information regarding the benefits and co-benefits of adaptation measures and demonstrate the effects of adaptation on example case studies. It offers an introduction to adaptation conceptual approaches and a view into the benefits of adaptation measures through the lenses of ecosystem services, followed by the chapters on adaptation

[1] Source: Dara Group and Climate Vulnerable Forum, 2015.
[2] https://ec.europa.eu/clima/policies/adaptation/what_en

measures' effectivity and methods of economic assessment, assessment of benefits of planting project in Cheb municipality (Czech Republic) and its various alternative planting scenarios, and a cost-benefit analysis of rainwater catchment project in Kadaň (Czech Republic).

References

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Haase, D., Knapp, S., Korn, H., Stadler, J., Zaunberger, K., and Bonn, A. 2016. Nature-based Solutions to Climate Change Mitigation and Adaptation in Urban Areas: Perspectives on Indicators, Knowledge Gaps, Barriers, and Opportunities for Action. Ecology and Society, 21(2): 39.

McPhearson, T., Andersson, E., Elmqvist, T., Frantzeskaki, N. 2015 Resilience of and through urban ecosystem services. Ecosystem Services. 12: 152–156.

Sachs, J., D. 2015. The age of sustainable development. Columbia University Press.

UN. 2018.The World 's Cities in 2018 - Data Booklet, The World 's Cities in 2018 - Data Booklet.

World Bank. 2010. Cities and climate change: an urgent agenda. (English). Urban development series knowledge papers; no. 10. Washington, DC: World Bank.

2 Adaptation approaches, measures and their benefits

2.1 Conceptual approaches to adaptation

Collaboration across disciplines and actors are the essence of efforts in developing effective climate actions and measures. Scientists, policymakers and practitioners, proposed several concepts with the intention to introduce common solutions based on enhanced ecosystems and their benefits. *Ecosystem services*, *ecosystem-based adaptation*, *green infrastructure* or *nature-based solutions* emerged as the most influential concepts in the arena of climate change adaptation over the last decades.

Ecosystem services (ES) is the core concept that provides a basis for all other concepts. It defines the different services and benefits that humanity obtains from natural ecosystems (Daily, 1997). Fig. 1 presents provisioning of goods produced by ecosystems, benefits gained through regulation of processes, supporting essential processes for producing other services, or cultural - nonmaterial benefits (MAE, 2005; Braat and de Groot, 2012), which are increasingly being studied in urban areas (e.g. Barthel *et al.*, 2017). It is generally agreed that maintaining the supply of ES is critical for human health and wellbeing (e.g. Tzoulas et al., 2007) and enhancing the ecosystems is a fundamental predisposition for sustainable and climate-resilient cities (McPhearson *et al*., 2015).

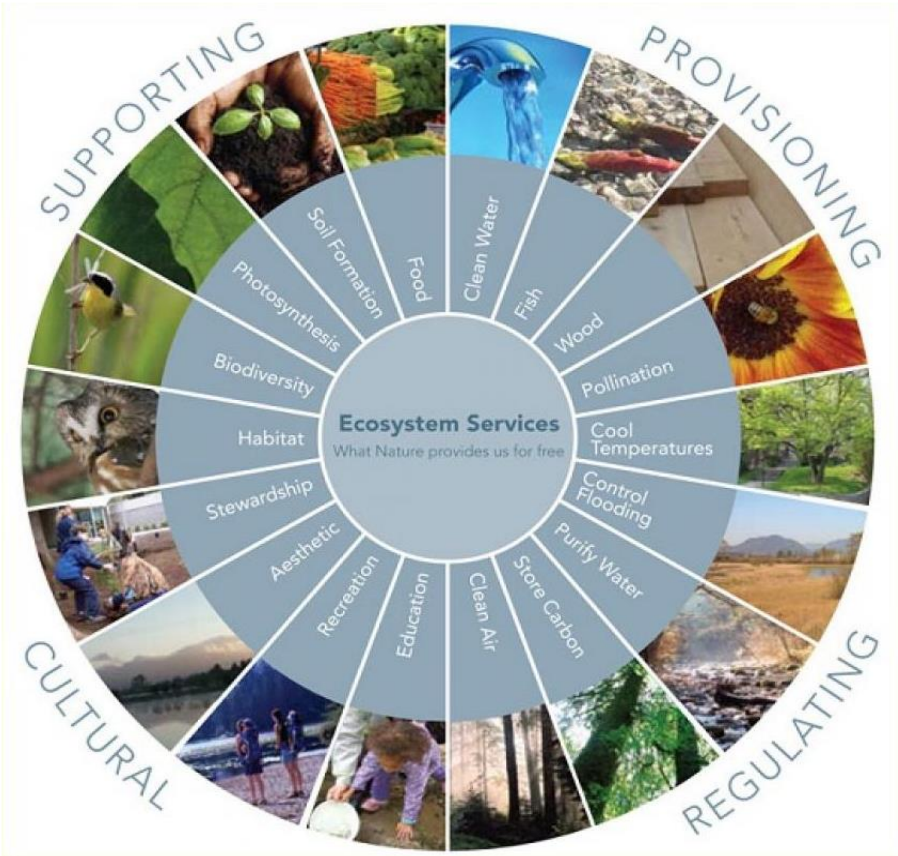

FIG. 1. ECOSYSTEM SERVICES (MAES, 2005)

Ecosystem-based adaptation then builds on the ES concept and is focused on the integration of biodiversity and ES through the adaptation actions. Though in some instances it proved to be a cost-effective and comprehensive approach for urban planners (Brink *et al.,* 2016), it greatly overlaps with the other concepts like ES and green infrastructure (Geneletti and Zarado, 2016) that are already well-established concepts for urban adaptation. The application of the concept remains more relevant for sectors of agriculture and forestry - in the settings of rural communities (Doswald et al., 2014).

The other two concepts - *green infrastructure* and *nature-based solutions* - have become popular approaches to climate adaptation in urbanized areas and were embraced by researchers and policymakers across Europe (European Commission, 2013; Eggermonnt et al., 2015).

Nature-based solutions, defined as 'actions which are inspired by, supported or copied from nature' (European Commission, 2015), is understood as an umbrella concept for adaptation policies and actions. The word 'solutions' is a clear indication of an action-oriented approach, which, besides establishing policy support, is tasked to provide physical adaptation measures carrying the biodiversity and natural elements at their core (Kabisch et al., 2016).

Green infrastructure has evolved as a 'tool' by which policymakers, planners and practitioners, are able to operationalize ES on the ground (Baró, 2016; Lovell and Taylor, 2013). Being defined as a 'planned network of natural and semi-natural environments' (Benedict and McMahon, 2006), the concept's key feature is its spatial orientation that influences planning. It offers an integrative and proactive approach for the identification of ecologically sound areas and enhancing open spaces in and around urbanized landscapes (Lafortezza et al., 2013). Pauleit et al. (2017) have comprehensively described the relationship between these concepts where *nature-based solutions* are positioned as an umbrella term and green infrastructure as an operational approach (Fig. 2.).

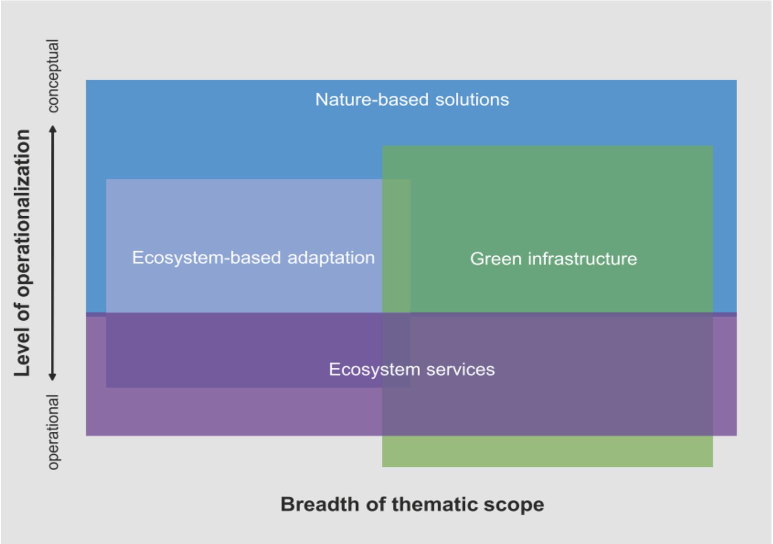

FIG. 2. THE FOUR CONCEPTS, THEIR THEMATIC SCOPE AND POSITION WITHIN THE CONCEPTUAL-OPERATIONAL SCALE (PAULEIT ET AL., 2017).

Despite the variances in conceptual approaches, the key message here is that they all integrate adaptation measures based on and developed with nature to secure critical ecosystem services and benefits. These services are then essential for climate-resilient and liveable cities.

2.2 Adaptation measures and benefits

Ecosystems provide multiple services or functions that can help people adapt to both current and future climate hazards. Gómez-Baggethun and Barton (2013) have identified important ecosystem services and functions that should be considered in urban planning. Among the most important, in regard to adaptation, are microclimate regulation (e.g., cooling), flood control, and supporting services such as soil formation, hydrological cycles or biodiversity, but also cultural services can play a role through e.g., education. If a city targets to harness these - so the benefits can be rendered directly in urban environments - physical implementation of certain actions that we call adaptation measures is required.

Several adaptation measures have been developed throughout different collaborations between researchers, practitioners, policymakers and other agencies, to match them with specific goals and contexts[3] [4]. A context can be defined by factors like location (geography and biophysical settings), situation (site's character - e.g., building, industrial site), and scale (from a building to a city) while goals relate to specific functions or benefits that planners wish to enhance.

Generally, we distinguish three main typologies of adaptation measures according to their character: (1) nature-based ('green and blue'), (2) technical ('grey') and (3) soft measures as displayed in Table 1.

Each type of measure differs in its functional, physical and contextual appearance. Nature-based measures provide the broadest range of benefits, and thus, should be prioritized in adaptation efforts. Technical measures are useful in cases where nature-based measures on their own are not viable - parking lots and constructions being good examples - while combined 'grey-green' solutions as green walls and facades should be promoted. Finally, soft measures represent institutional, political or other types of interventions that relate to the dimension of human processes.

Harnessing the adaptive capacity of ecosystems is generally considered as economically viable (Munang *et al*., 2013), however the effectiveness can differ between adaptation measures.

[3] https://www.urbangreenbluegrids.com/
[4] https://naturvation.eu/atlas

Table 1. Typologies of adaptation measures with examples and benefits that they provide. (Based on Naturvation Atlas, 2017; Urban Green-Blue Grids, 2016).

Type of measure	Adaptation measure	Ecosystem services (ES) or other benefits and functions
Nature-based (blue and green)	**Enhancing green areas** (tree planting, new green spaces, urban forests, meadows, or brownfield revitalization)	High uptake of all ES
	Urban agriculture	Provisioning and regulating ES
	Revitalizing river systems and water bodies	Supporting, regulating and cultural ES
	Rain gardens Swales Rainwater retention ponds	Supporting and regulating ES
	Replacing impervious surfaces by natural elements	Regulating and cultural ES
	Greenspace management and planting techniques (e.g. native species, mowing regimes)	Supporting, regulating and cultural ES
Technical (green-grey)	**Green roofs and facades**	Regulating, supporting and cultural ES
	Reflective materials and surfaces	Surface temperature regulation
	Technical alternatives for Impervious surfaces (e.g. parking lots, tram rails)	Runoff and temperature regulation
	Dams and polders	Flood control
	Rain water retention technologies and collectors	Water retention and runoff control
	Shading elements	Surface temperature regulation, cooling
	Fontains	Cooling, water provision
Soft (instrumental)	**Policies** **Implementation standards**	Legislative support and planning regulation for adaptation and mitigation measures; for implementation of environmental and climate goals
	Awareness-raising and communication **Information and nugging**	Public education and transparent decision-making

References

Baró, F. 2016. *URBAN GREEN INFRASTRUCTURE: Modeling and mapping ecosystem services for sustainable planning and management in and around cities. Ph.D. Dissertation, Universitat Autonoma de Barcelona.*

Nikodinska, N., Paletto, A., Pastorella, F., Granvik, M., and Franzese, P., P. 2018. Assessing, valuing and mapping ecosystem services at city level: The case of Uppsala (Sweden). *Ecological Modelling,* 368: 411-424.

Benedict, M., A., McMahon, E. 2006. *Green infrastructure: linking landscapes and communities.* and Conservation Fund. Sprawl Watch Clearinghouse: Washington, DC.

Braat, L. C. and de Groot, R. 2012. The ecosystem services agenda: bridging the worlds of natural science and economics, conservation and development, and public and private policy. *Ecosystem Services,* 1(1): 4–15.

Brink, E., Aalders, T., Adam, D., Feller, R., Henselek, Y., Hoffman, A., Ibe, AK., Matthey-Doret, A., Meyer, M., Negrut, N., L., Rau, A.-L., Riewerts, B., von Schickmann, L., Tornros, S., von Wehrden, H., Abson, D., J., and Wamsler, C. 2016. Cascades of green: A review of ecosystem-based adaptation in urban areas. *Global Environmental Change*. 36: 111–123.

Daily, G. C. 1997. *Nature's services: societal dependence on natural ecosystems*. Island Press.

Doswald, N., Munroe, R., Roe, D., Giuliani, A., Castelli, I., Stephens, J., Moller, I., Spencer, T., Vira, B., and Reid, H. 2014. Effectiveness of ecosystem-based approaches for adaptation: review of the evidence- base. *Climate and Development*, 6(2): 185–201.

Eggermont, H. et al. 2015. Nature-based Solutions: New Influence for Environmental Management and Research in Europe', *GAIA - Ecological Perspectives for Science and Society,* 24(4): 243–248.

European Commission. 2013. *Green Infrastructure (GI) — Enhancing Europe's Natural Capital.* Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels.

European Commission. 2015. *Towards an EU research and innovation policy agenda for nature-based solutions and re-naturing cities.* Final Report of the Horizon 2020. Brussels. (21)

Geneletti, D., Zardo, L. 2016. Ecosystem-based adaptation in cities: an analysis of European urban climate adaptation plans. *Land Use Policy*, 50:38–47.

Gómez-Baggethun, E., and Barton, D., N. 2013. Classifying and valuing ecosystem services for urban planning, *Ecological Economics*, 86: 235–245.

Kabisch, N., Stadler, J., Korn, H., and Bonn, A. 2016. *Nature-based solutions to climate change mitigation and adaptation in urban areas.* BfN-Script 446', BfN: Bonn.

Lafortezza, R., Davies, C., Sanesi, G., Konijnendijk, C., C. 2013. Green Infrastructure as a tool to support spatial planning in European urban regions*. iForest - Biogeosciences and Forestry*, 6: 102–108.

Locatelli, B. 2016. Ecosystem Services and Climate Change. In Potschin, M., Haines-Young, R., Fish, R., and Turner, R., K. (eds). *Routledge Handbook of Ecosystem Services.* Routledge: London and New York, 481-490.

Lovell, S., T, Taylor, J., R. 2013. Supplying urban ecosystem services through multifunctional green infrastructure in the United States. *Landscape Ecology*, 28: 1447–1463

MAE. 2005. *Millennium Ecosystem Assessment*. Island Press: Washington, DC.

McPhearson, T., Andersson, E., Elmqvist, T., and Frantzeskaki, N. 2015. Resilience of and through urban ecosystem services. *Ecosystem Services*, 12: 152–156.

Munang, R., Thiaw, I., Alverson, K., Liu, J., Han, Z. 2013. The role of ecosystem services in climate change adaptation and disaster risk reduction. Current Opinion in Environmental Sustainability, 5(1): 47-52.

Naturvation. 2021. Urban Nature Atlas. Available at:
https://naturvation.eu/atlas [Assessed 3/3/2021]

Pauleit S., Zölch T., Hansen R., Randrup T.B., van den Bosch C., K. 2017. Nature-Based Solutions and Climate Change – Four Shades of Green. In: Kabisch N., Korn H., Stadler J., Bonn A. (eds) *Nature-Based Solutions to Climate Change Adaptation in Urban Areas. Theory and Practice of Urban Sustainability Transitions.* Springer, Cham.

Tzoulas, K., Korpela, K., Vrnn, S., Yli=Pelkonen, V., Kazmierczak, A., Niemela, J., and James, P. 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review, *Landscape and Urban Planning*, 81(3), pp. 167–178.

Urban Green Blue Grids. 2021. Measures. Available at: https://www.urbangreenbluegrids.com/measures/?themeorder=2-3-4-5-6-7-8&theme=3&goal=heat#list [Assessed 3/3/2021]

3 Effectivity of adaptation measures: assessing the benefits (co-benefits) and disservices, synergies and trade-offs.

Adaptation measures can deliver multiple ecosystem services alongside climate change risk mitigation (as described in the previous section). Evaluation, including the adequacy, effectiveness and acceptability, is a crucial part of the formulation and implementation of adaptation (Smit et al., 1999). For the success of adaptation efforts, adequate measures need to be selected and placed in suitable environmental settings. This is particularly true in complex socio-ecological systems such as urban areas, where the effectivity of measures is determined by many variables (natural and cultural aspects) of a specific site in a given time (Cohen-Shacham et al., 2016). The selection of adaptation measures should be, hence, always context-specific as not all the measures, e.g., to mitigate overheating, are suitable and effective in all urban areas. To determine the effects of adaptation measures, benefits and co-benefits should be assessed, for instance, by their contribution to ecosystem services or environmental, economic and social benefits (Millennium Ecosystem Assessment, 2005).

A presumption of effective adaptation is answering three questions proposed by Smit et al. (1999): *adaptation to what, who or what adapts and how does adaptation occur* (Fig. 3)? While answering the question on *adaptation to what*, it is necessary to conduct a thorough analysis of current and future risks. This should set goals (e.g., to reduce flood risks, increase the air quality, mitigate heat island) of adaptation, leading to a selection of measures that respond to current or expected future climatic stimuli and can provide ecosystem benefits that minimise the risks and increase the resilience of an area. This question also considers a scale of time and space. The second question, *who or what adapts*, refers to a system that needs adaptation. It may refer to a city district and its residents or various business sectors and it considers the specific characteristics of that particular system. The answers to these two questions provide the basis for the last one, *how adaptation occurs*. Here, it is necessary to consider the essential processes and also the outcomes of a measure. Additionally, criteria and principles to evaluate the adaptation should be set to determine its effectiveness.

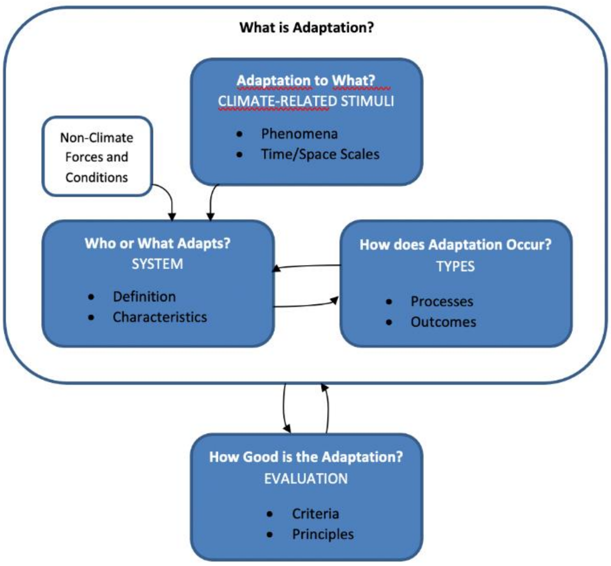

FIG. 3. ADAPTATION TO CLIMATE CHANGE (ADOPTED FROM SMIT ET AL., 1999)

Several frameworks for the assessment of adaptation measures (and nature-based solutions) have been developed, for example, as demonstrated by Smit et al. (1999) by posing the questions, more advanced frameworks capturing also co-benefits of measures alongside biodiversity and well-being by Raymond et al. (2017) or an innovative approach including the system analysis and backcasting, supporting the selection between more traditional and nature-based solutions proposed by Calliari et al. (2019). Despite the framework for the assessment of benefits of measures is not unified, adaptation measures, and especially nature-based solutions, are becoming more popular for the positive effects they can provide. However, if adaptation measures are not properly chosen for a risk area, they can also deliver disservices or trade-off one (or more) benefit for the others, further increasing the vulnerability of an area (von Dohren and Haase, 2015). There are often multiple risks challenging a location, hence, selecting a measure that would enhance the synergies of ecosystem services and address various risks is favourable. Adaptation, nevertheless, often crosses sectoral boundaries which makes it challenging to collect data and assess the overall effectiveness (Craft and Fisher, 2016).

Ecosystem disservices, as opposite to ecosystem services, represent the negative effects of nature impacting human well-being (Blanco et al., 2019). Some natural aspects of adaptation measures, if inappropriately designed, may lead to worsening of the environment. For example, urban trees can negatively impact air quality as they can produce biogenic volatile organic compounds and allergens, which may impair human health and well-being (Raymond et al., 2017). Therefore, it is crucial to select species adequate for the specific environment. Other disservices provided by nature can be view blockage (e.g. road view or view of historical buildings; Lyytimaki and Sipila, 2009), cause of accidents (e.g. tree branches fall on a property; Gomez-Baggethun and Barton, 2013), infrastructure damage (e.g. roots penetrating pavements; Lyytimaki and Sipila, 2009). Nature-based adaptation measures can also create fear and/or stress (e.g. dark unmanaged park creating fear at night; Ibes, 2016). Despite disservices nature can provide, the positive services are often of better value while understanding disservices provides stakeholders with a great basis for adaptation planning, including an adequate selection of NbS, monitoring and appropriate management; moreover, targeting a reduction of ecosystem disservices rather than an increase in services may be more effective in pro-nature behaviour (Blanco et al., 2019).

It is important to differentiate between ecosystem disservices and trade-offs. While disservices can increase and decrease alongside the services, trade-offs are referring to a decline in one service while gaining another at the same time and place (Cord et al., 2017). They may create a situation where stakeholders have to prioritise one service over another and decide if the increase of one ecosystem service is worth in resource, cost and sustainable terms (Haase et al., 2012). Trade-offs often appear between regulating and provisioning ecosystem services because when extracting the benefits of material provisioning (e.g. fibre, food), the integrity of the ecosystem is impaired and so are the regulating services (King et al., 2015). Other trade-offs can appear among biodiversity and habitat provisioning and cultural services. Biodiversity can downgrade as the experience of cultural benefits of nature as the human presence increases in an area. However, the loss of biodiversity from cultural services is less than from provisioning ones, while the increased demand for cultural and regulating services may provide an incentive to rather preserve nature and its biodiversity (Guo et al., 2010). Promoting such synergies, when the increase of one ecosystem service simultaneously increases the other, is a prerequisite to successful spatial planning and development (Haase et al., 2012). Understanding and identification of trade-offs and synergies of ecosystem services and the effects they have while choosing one service over another, contributes to achieving the goals set in the planning of nature-based solutions as adaptation measures. Hence, they are a key component in the assessment of the effectiveness of adaptation measures.

Measurement of adaptation has become a priority for policy- and decision-makers, local stakeholders and practitioners who all need to ensure that their goals are being met. Besides the evaluation of adaptation measures' effectiveness towards the risks and its (co-)benefits, trade-offs and synergies, the effectiveness can also be evaluated based on other important criteria which need to be considered in adaptation planning, such as implementability and cost (Smit et al., 1999). The economic assessment is, thus, another important part of an effective adaptation.

References

Blanco, J., Dendoncker, N., Barnaud, C., and Sirami, C. 2019. Ecosystem disservices matter: Towards their systematic integration within wcosystem service research and policy. *Ecosystem Services,* 36: 100913.

Raymond, C., M., Berry, P., Breil, M., Nita, M., R., Kabisch, N., de Bel, M., Enzi, V., Frantzeskaki, N., Geneletti, D., Cardinaletti, M., Lovinger, L., Basnou, C., Monteiro, A., Robrecht, H., Sgrigna, G., Munari, L. and Calfapietra, C. 2017. *An Impact Evaluation Framework to Support Planning and Evaluation of Nature-based Solutions Projects*. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas. Centre for Ecology & Hydrology, Wallingford, United Kingdom.

Haase, D., Schwarz, N., Strohbach, M., Kroll, F., Seppelt, R. 2012. Synergies, Trade-offs, and Losses of Ecosystem Services in Urban Regions: An Integrated Multiscale Framework Applied to the Leipzig Halle Region, Germany. *Ecology and Society,* 17(3): 22.

Cord, A., F., Bartkowsku, B., Beckmann, M., Dittrich, A., Hermans-Neumann, K., Kaim, A., Lienhoo, N., Locher-Krause, K., Priess, J., Schroter-Schlaack, C., Schwar, N., Seppelt, R., Strach, M., Vaclavik, T., and Volk, M. 2017. Towards systematic analyses of ecosystem service trade-offs and synergies: Main concepts, methods and the road ahead. *Ecosystem Services,* 28: 264-272.

King, E., Cavender-Bares, J., Balvanera, P., Mwampamba, T., H., and Polasky, S. 2015. Trade-offs in ecosystem services and varying stakeholder preferences: evaluating conflicts, obstacles, and opportunities. *Ecology and Society,* 20(3): 25.

Guo, Z., Zhang, L., and Li, Y. 2010. Increased Dependence of Humans on Ecosystem Services and Biodiversity. *PLoS ONE,* 5(10): e13113.

Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. 2016. *Nature-based Solutions to address global societal challenges*. Gland, Switzerland: IUCN. xii +97pp.

Raymond, C., M., Frantzeskaki, N., Kabish, N., Berry, P., Breil, M., Nita, M., R., Geneletti, D., and Calfapietra, C. 2017. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science and Policy,* 77: 15-24.

Calliari, E., Staccione, A., and Mysiak J. 2019. An assessment framework for climate-proof nature-based solutions. *Science of the Total Environment,* 656: 691-700.

Millennium Ecosystem Assessment. 2005. *Ecosystem and Human Well-being: Synthesis.* Island Press: Washington, DC.

Smit. B., Burton, I., Klein, R., J., T., and Street, R. 1999. The Science of Adaptation: A Framework for Assessment. *Mitigation and Adaptation Strategies for Global Change,* 4: 199-213.

Ibes, D., C. 2016. Integrating Ecosystem Services Into Urban Park Planning and Design. *Cities and the Environment,* 9(1): 1-39.

Gomez-Baggethun, E., and Barton, D., N. 2013. Classifying and valuing ecosystem services for urban planning. *Ecological Economics,* 86: 235-245

Lyytimaki, J., and Sipila, M. 2009. Hopping on one leg – The challenge of ecosystem disservices for urban green management. *Urban Forestry and Urban Greening,* 8: 309-315.

Craft, B., and Fisher, S. 2016. Measuring effective and adequate adaptation. IIED: London.

von Dohren, P., and Haase, D. 2015. Ecosystem disservices research: A review of the state of the art with a focus on cities. *Ecological Indicators,* 52: 490-497.

4 Methods of economic assessment of adaptation measures

There is a variety of techniques that can be applied to the economic assessment of adaptation measures in cities. Some techniques are only monetary-based e.g., cost-benefit analysis, other techniques combine monetary and biophysical indicators e.g. cost-effectiveness analysis and multi-criteria analysis, other techniques are solely indicator based e.g. impact analysis. Cost-benefit analysis (CBA), Cost-effectiveness analysis (CEA) and Multi-Criteria Analysis (MCA) are the most widely used techniques for comparing the pros and the cons of different investment options in the field of environmental economics.

4.1 Cost-benefit analysis

Cost-benefit analysis (CBA or Benefit-cost analysis, BCA) has been traditionally applied as a tool for guiding public policy. CBA is based on the following principles. First, costs and benefits are expressed in monetary terms, which enables their direct comparability. Moreover, the monetary expression is familiar and understandable for the general public. Second, costs and benefits are valued from the point of view of all members of the society on whose behalf the CBA is undertaken, so it requires a complete analysis of all benefits and costs involved. The third aspect of CBA is inter-temporal discounting. When all effects are quantified in monetary units, the future costs and benefits are compared with present costs and benefits using discounting. To support the project the net present value of the total benefits must be higher than the present value of the total cost of the project.

The major shortcoming and at the same time the main strength of CBA is that all benefits and costs are quantified in monetary terms and aggregated to a single number. On one hand, monetary terms are well understood and enable comparison of different benefits with costs but on the other hand, the monetization of some benefit is very complicated or even impossible. Another advantage of the CBA is its long history which enables comparability of CBA studies and the learning-by-doing process because the CBA studies share a common methodology. For ensuring comparability of CBA studies some countries apply guidelines to perform sound CBA (Sartori et al., 2015, EPA, 2014). All in all, CBA provide a sophisticated means for comparing various investment projects and outcomes.

4.2 Multicriteria analysis

Multi-criteria analysis (MCA) is an alternative assessment approach to CBA which is helpful when we want to prioritize investment options or policies and each option delivers different outcomes. MCA enables to identify goals or priorities of investment or policy and trade-off among those priorities in different investment projects or policies. MCA is especially suitable when the investments or policies have competing objectives and when the outcome has both monetary and non-monetary benefits.

The first step in MCA is an identification of the policy objectives and criteria that show the achievement of these objectives. Stakeholders and public participation are essential in setting the objectives and the criteria as well as for the determination of weights for criteria to reflect their comparative importance. The overall value of each project is given by the sum of the weighted criteria.

A particular advantage of MCA is its ability to deal with both qualitative and quantitative criteria and the possibility of prioritizing some policy objectives. Unlike CBA or cost-effectiveness analysis, MCA is rarely compulsory in national decision making (Gamper and Turcanu, 2007).

References

EPA. 2014 Guidelines for Preparing Economic Analyses (updated May 2014) U.S. Environmental Protection Agency

Gamper, C.D., Turcanu, C. 2007 On the governmental use of multi-criteria analysis. Ecological Economics 62. 298-307

Sartori D., Catalano, G., Genco, M., Pancotti, C., Sirtori, E., Vignetti, S., Del Bo, C. 2015 Guide to Cost-Benefit Analysis of Investment Projects. Economic appraisal tool for Cohesion Policy 2014-2020. European Commission. Directorate-General for Regional and Urban policy.

5 Planting trees and shrubs in fortification moat park, Cheb, Czech Republic

5.1 Introduction

We evaluated a project of vegetation revitalization in the park located in the central area of the city of Cheb. The main goal of the project is to increase the share of vegetation serving as food for squirrels and songbirds, nevertheless, the project also provides other benefits e.g., educational and regulating benefits. Using the Multi-Criteria Analyses - like approach to assessing the benefits, we concluded that tree planting delivers the most benefits on places originally without trees. Yet, the cost analysis has to be included in the evaluation that is likely to make a case for tree planting in the existing park.

5.2 Description of the project

The project entails planting shrubs and trees in the park located in the western part of the built-up area of Cheb city. The park is adjacent to Brandlova and Hradební streets (Fig. 4) and concerns a revitalization of public green space with an area of approximately 6,500 m2. Mainly slopes in the fortification moat are proposed to plant (Jiřinová, 2020).

FIG. 4. LOCATION OF THE EVALUATED PROJECT IN CHEB CITY (THE PARK IS MARKED IN RED). (SOURCE: MAPY.CZ)

The main aim of the project is the planting of shrubs and trees serving food and shelter for red squirrels and songbirds. The population of red squirrels has lived in the park for many years. During the previous reconstruction and renewal of the park, many old trees and almost all shrubs e.g., elderberries and arrowwood Viburnum were replaced by new plantings, mostly non-native species, which do not provide food and nesting places for local fauna. Due to the lack of food, squirrels often cross the nearby street to collect food in the adjacent garden and they are endangered by passing cars.

The park revitalization involves treatment of current trees, felling about 7 trees in poor living conditions and planting shrubs and developed deciduous trees. It is proposed to plant 5 new trees of English walnut (*Juglans regia*) with a trunk circumference of 14-16 cm at breast height, 21 pieces of hazelnut bush (*Corylus avellana*) and 14 pieces of serviceberry (*Amelanchier laevis*). Next, the planting of 84 pieces of shrubs into groups is proposed. The shrub groups will consist of cornelian cherry (*Cornus* *mas*), wild privet (*Ligustrum vulgare*), guelder rose (*Viburnum opulus*) and barberry Thunberg's (*Berberis thunbergii*). The selected shrub and tree species attract insects by their flowers and serve as food for squirrels and birds. Bushes will be planted on the slope of the moat. The steep slopes in the park are bare, shaded and are subject to erosion, hence planting the slopes will strengthen the slopes. A horticultural company will plant the trees and shrubs and provide regular maintenance care for 3 years after planting.

Furthermore, the project includes the installation of 5 nest boxes and 5 feeders for the squirrel, 20 nest boxes for songbirds and an information board at the entrance to the moat from Hradební Street. The expected costs amount to CZK 279,842 (Jiřinová, 2020).

5.3 Benefits of the project

The primary aim of the project is biodiversity support (mainly squirrels and songbirds). Moreover, the planting of shrubs and trees will support other services (Table 1). The most important benefits are regulating services, e.g., climate change adaptation and mitigation, slowing down and storing rainwater runoff, air pollution removal, soil erosion and noise control. The project will also deliver cultural (educational and aesthetic) and provisional services (production of walnuts and hazelnuts). The assessment of the project benefits (Table 1, Table 2, Table 3) is based on the expert elicitation and extensive literature study including but not limited to e.g. (Berland et al., 2017; Dwyer et al., 1992; Hegetschweiler et al., 2017; Kuehler et al., 2017; Morani et al., 2011; Mullaney et al., 2015; Norton et al., 2015). The level of added benefits is influenced by the relatively small extent of the project and by the fact that the planting will take place in the existing park which decreases the added value of planting.

The most important project benefit (both planned and realised) is supporting biodiversity due to the creation of habitats and securing food sources. The impact of the project on climate change adaptation and mitigation is medium and low respectively. The extent of planting is relatively small to have significant impacts on carbon storage and the planting will be realised in the existing park so the marginal benefits of the planting shrink. Nevertheless, gradual renewal of the greenery in the park is necessary for sustainable delivery of all ecosystem services by the whole park and micro-climate regulation is one of the most important ecosystem services of the park as a whole. The planting will positively impact rainwater management in the area (medium-high impact) mainly by increasing the amount of stored runoff and by slowing down the runoff. The project will contribute to groundwater recharge as well, but the marginal benefits of the project will be negligible. The runoff slowdown and strengthening of the moat slope will decrease soil erosion as well. The strengthening of the moat slope will be achieved particularly with planting shrubs on the slope and the upper edge of the moat. The project will provide high educational services (installation of the nest boxes, feeders and an information board) and medium impact on aesthetic value improvement. Last but not least the project will deliver provisioning ecosystem services (walnuts and hazelnuts production).

TABLE 2. ECOSYSTEM SERVICES OF THE PROJECT.

Services	Level of added benefits
Supporting services	
Biodiversity support (squirrels, songbirds, insect)	high
Regulating services	
climate change adaptation - micro-climate regulation	medium
climate change mitigation - carbon storage	low
storing runoff	medium
rainwater purification	medium
slowing down runoff	high
soil erosion control - strengthening of the moat slope	high
air pollution removal	low
noise reduction	low
Cultural services	
educational	high
aesthetic	medium
Provisioning services	
walnuts and hazelnuts	medium

5.4 Assessment of alternative planting scenarios

To show how the benefits of planting vary with the place of planting we compare ecosystem services of the project on three different locations (the location of the project and two theoretical locations). We compare benefits from planting in the existing park (the assessed project), a new planting on a playground in a housing estate originally without trees and a new planting along a road and (bike) path. The different benefits of planting in these three places are indicated in Table 2. The higher benefits of planting on a playground and along a road compared to planting in the park are caused mainly by planting on places originally with no trees because the added value of planting trees in new places is higher than the added value of tree planting in the park. Added value for climate change adaptation, storing and slowing down runoff and aesthetic improvement will be higher for new planting on the playground and along a road. Planting trees is likely to bring higher educational benefits on playgrounds than alongside roads while noise reduction and air quality improvement will be more important along roads than on playgrounds. The importance of soil erosion control will strongly depend on local conditions e.g., the slope of the terrain or the type of soil.

To simply and clearly compare the overall benefits of the three projects we assigned values to benefits according to the magnitude of the benefits and compared the total benefits (sum of the benefits points) of the projects (Table 3). We assigned 3 points to the high impact benefits, 2 points to the medium impact benefits and 1 point to the low impact benefits and we found that the new planting along a road delivered the highest benefits (28 points) although the new planting on a playground delivered nearly the same benefits (27 points). Planting into the existing park delivered the smallest benefits (25 points).

However, the priorities of planting likely differ among locations. For example, microclimate regulation is likely to be of the high priority of planting on playgrounds and along roads but of the low priority in an existing park. To assess the benefits of planting in different places with different priorities we assigned each benefit on each place its priority or importance (Table 4). This approach (weighting benefits according to their importance) is regularly applied in the Multi-Criteria Analyses (Cegan et al., 2017; Ellen et al., 2016; Huang et al., 2011; Janssen, 2001). The priorities for the Multi-Criteria Analyses are usually found through analysis, stakeholder engagement or expert elicitation. We applied expert elicitation in this case study.

The benefits of the projects (Table 3) were multiplied with their respective priorities (Table 4) to find the weighted benefits of the projects (Table 5). Total weighted scores (sum of all weighted benefits of the projects) were compared to find the most beneficial project as is commonly applied in the Multi-Criteria Analyses (Janssen, 2001).

TABLE 3. BENEFITS OF PLANTING IN THREE DIFFERENT LOCATIONS IN A CITY. CLASSIFICATION OF THE IMPACTS WAS INSPIRED BY THE CLASSIFICATION APPLIED IN THE NATURAL WATER RETENTION MEASURES PROJECT (DG ENVIRONMENT EUROPEAN COMMISSION, 2015).

Services	**Planting in an existing park**	**New planting on a playground in a housing estate**	**New planting along a road and (bike) path**
Supporting services			
biodiversity support	high	high	high
Regulating services			
climate change adaptation	medium	high	high
climate change mitigation	low	low	low
store runoff	medium	high	high
rainwater purification	medium	medium	medium
slow down runoff	high	high	high
soil erosion control	high	low	low
air pollution removal	low	low	medium
noise reduction	low	medium	high
Cultural services			
educational	high	high	medium
aesthetic	medium	high	high
Provisioning services			
walnuts and hazelnuts	medium	medium	medium

Table 4. Benefits of planting expressed in the point scale (3 - high impact, 2 - medium impact, 1 - low impact).

Services	**Planting in an existing park**	**New planting on a playground in a housing estate**	**New planting along a road and (bike) path**
Supporting services			
biodiversity support	3	3	3
Regulating services			
climate change adaptation	2	3	3
climate change mitigation	1	1	1
store runoff	2	3	3
rainwater purification	2	2	2
slow down runoff	3	3	3
soil erosion control	3	1	1
air pollution removal	1	1	2
noise reduction	1	2	3
Cultural services			
educational	3	3	2
aesthetic	2	3	3
Provisioning services			
walnuts and hazelnuts	2	2	2
SUM	**25**	**27**	**28**

TABLE 5. DIFFERENT PROJECT PRIORITIES OF THE PROJECTS (1 – LOW PRIORITY, 2 – MEDIUM PRIORITY, 3 – HIGH PRIORITY).

Services	**Planting in an existing park**	**New planting on a play-ground in a housing estate**	**New planting along a road (and bike) path**
Supporting services			
biodiversity support	3	2	2
Regulating services			
climate change adaptation	1	3	3
climate change mitigation	1	1	1
store runoff	1	3	3
rainwater purification	1	1	1
slow down runoff	2	3	3
soil erosion control	3	1	2
air pollution removal	1	3	3
noise reduction	1	3	3
Cultural services			
educational	2	3	1
aesthetic	2	3	3
Provisioning services			
walnuts and hazelnuts	1	1	1

TABLE 6. WEIGHTED BENEFITS OF DIFFERENT PLANTING PROJECTS.

Services	**Planting in an existing park**	**New planting on a playground in a housing estate**	**New planting along a road and (bike) path**
Supporting services			
Biodiversity support	9	6	6
Regulating services			
climate change adaptation	2	9	9
climate change mitigation	1	1	1
store runoff	2	9	9
rainwater purification	2	2	2
slow down runoff	6	9	9
soil erosion control	9	1	2
air pollution removal	1	3	6
noise reduction	1	6	9
Cultural services			
educational	6	9	2
aesthetic	4	9	9
Provisioning services			
walnuts and hazelnuts	2	2	2
Total weighted score	**45**	**66**	**66**

Planting on playgrounds and along roads deliver the highest benefits according to the analysis but for a complete comparison of the alternative plantings, the costs have to be considered too because the Multicriteria analysis consists of an assessment of both costs and different benefits e.g., environmental, social, institutional, economic (Scrieciu et al., 2011). Since we lack cost estimates for the two theoretical plantings (on a playground and along a road) we cannot compare the full costs and benefits of the alternative plantings. The costs (both planting and maintenance) are much higher for planting outside a park with a very high probability. For example, a tree planting in a park and its yearly maintenance costs are 5,000 Kč and 6,000 Kč, respectively, while a street-tree planting costs amount to 35,000-120,000 Kč and 40,000 Kč, respectively, in Prague (*Akční plán výsadby stromů v Praze (Milion stromů pro Prahu)*, n.d.). Hence taking costs into account will probably increase the total weighted score of planting in the park and make a case for planting in the park.

5.5 Conclusions

Planting trees and shrubs in a park located in the central area of the city of Cheb was assessed. The main purpose of the project is to increase the share of vegetation serving as food for squirrels and songbirds, but the project will also deliver other important benefits e.g., soil erosion control, enhanced rainwater retention or educational benefits. The benefits of tree planting in three places were compared to show how the benefits of tree planting vary among places of planting. The Multi-Criteria Analysis was applied to assess the benefits and the different priorities of planting in the three places. New planting on a playground and along a road is likely to deliver the most benefits (both weighted and unweighted) if the planting costs are similar in all places. However, the planting costs are likely to be the lowest in a park which will increase the total benefits of planting in the park.

References

Akční plán výsadby stromů v Praze (Milion stromů pro Prahu), n.d.

Berland, A., Shiflett, S.A., Shuster, W.D., Garmestani, A.S., Goddard, H.C., Herrmann, D.L., Hopton, M.E., 2017. The role of trees in urban stormwater management. *Landsc. Urban Plan.* 162: 167–177.

Cegan, J.C., Filion, A.M., Keisler, J.M., Linkov, I., 2017. Trends and applications of multi-criteria decision analysis in environmental sciences: literature review. *Environ. Syst. Decis*. 37: 123–133.

DG Environment European Commission, 2015. Natural Water Retention Measures [WWW Document]. Available at: http://nwrm.eu/about-nwrm-project/about/project [Aaccessed 23/11/20].

Dwyer, J.,F., McPherson, E.,G., Schroeder, H.,W., Rowntree, R.,A. 1992. Assessing the Benefits and Costs of the Urban Forest. *J. Arboric*., 18: 227–234.

Ellen, I., G., Yager, J., Hanson, M., Bosher, L., 2016. Planning for an Uncertain Future: Can Multicriteria Analysis Support Better Decision Making in Climate Planning? *J. Plan. Educ. Res.,* 36: 349–362.

Hegetschweiler, K., T., de Vries, S., Arnberger, A., Bell, S., Brennan, M., Siter, N., Olafsson, A., S., Voigt, A., Hunziker, M. 2017. Linking demand and supply factors in identifying cultural ecosystem services of urban green infrastructures: A review of European studies. *Urban For. Urban Green*., 21: 48–59.

Huang, I.B., Keisler, J., Linkov, I. 2011. Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. *Sci. Total Environ.,* 409(19): 3578-3594.

Janssen, R., 2001. On the use of multi-criteria analysis in environmental impact assessment in the Netherlands. *J. Multi-Criteria Decis. Anal.,* 10, 101–109.

Jiřinová, V., 2020. Mega nápady. Cheb 2020. *Výsadba v ulici Brandlova-hradební příkop.* Průvodní zpráva (Mega ideas. Cheb 2020. Planting in the Brandlova street-fortification moat. Project documentation) [in Czech].

Kuehler, E., Hathaway, J., Tirpak, A. 2017. Quantifying the benefits of urban forest systems as a component of the green infrastructure stormwater treatment network. E*cohydrology*, 10: 1–10.

Morani, A., Nowak, D.J., Hirabayashi, S., Calfapietra, C., 2011. How to select the best tree planting locations to enhance air pollution removal in the MillionTreesNYC initiative. *Environ. Pollut*., 159: 1040–1047.

Mullaney, J., Lucke, T., Trueman, S., J. 2015. A review of benefits and challenges in growing street trees in paved urban environments. *Landsc. Urban Plan*., 134: 157–166.

Norton, B., A., Coutts, A., M., Livesley, S., J., Harris, R., J., Hunter, A., M., Williams, N., S., G., 2015. Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landsc. Urban Plan.*, 134: 127–138.

Scrieciu, Ş., Bristow, S., Puig, D., 2011. MCA4climate: *A Practical Framework for Planning Pro-Development Climate Policy.* UNEP.

6 Cost-benefit analysis of rainwater collection system, Kadaň, Czech Republic

6.1 Introduction

The subject of this analysis is a project concerning the use of rainwater for irrigation on the premises of 3. ZŠ Sluníčková [Sluníčková Third Primary School] at Chomutovská No 1683, a school founded and financed by the city of Kadaň. Rainwater from buildings on the school premises is currently discharged into combined public sewers which empty into the municipal wastewater treatment plant. Rainwater is drained into accumulation tanks installed below ground (2 × 10 m^3 and 1 × 15 m^3). The collected water is used for irrigation of the school playground and areas used for growing crops. So far, the school only used drinking water to irrigate the land.

6.2 Project description

Rainwater is collected from one half of each of the roofs covering the two school buildings and the roof of the gym. Only the adjacent saddle roof halves covering the two school buildings (with a total usable area of about 660 m^2) is used for rainwater collection under the project, as it is difficult to connect the more distant rain gutters to the accumulation tanks due to the large distance and the need to keep the pipe reasonably sloped. These remote gutters, therefore, continue to be drained using the existing method. However, the entire area of the gym roof (744 m^2) can be used for rainwater accumulation. The total area of the roofs used for rainwater accumulation is 1404 m^2. The project's basic parameters are shown in Table 1.

The expected volume of rainwater collected over 1 year is 294.1 m^3 for both school buildings and 331.5 m^3 for the gym building. This calculation is based on a runoff coefficient for plastic roofing of 0.9, an annual precipitation level for Kadaň of 550 mm and an efficiency factor for a mechanical dirt filter of 0.9. The volume of the proposed tanks depends on the amount of rainwater collected as well as the interval between rains and the amount of water used for irrigation (as of yet unknown). The theoretical size of the accumulation tanks has been calculated at 16.1 m^3 for the two school buildings and 18.2 m^3 for the gym (with 15 m^3 and 20 m^3 tanks implemented, respectively). One plastic accumulation tank with a volume of 15 m^3 (diameter 3.4 m; height 2 m) is located next to the school building. Two plastic accumulation tanks with a total volume of 20 m^3 (diameter 2.84 m, height 2 m) are located next to the gym building. A new pipeline is used to drain rainwater from parts of the school roofs and the entire gym roof into the accumulation tanks. Excess rainwater is fed to soakaways (infiltration facilities) using an overflow system.

TABLE 7. BASIC PARAMETERS OF THE PROPOSED PROJECT

Total usable roof area (school buildings and gym)	1404	m^2
Total amount of precipitation potentially collected (school buildings and gym)	625,6	m^3/ year
Total volume of retention tanks	35	m^3

To prevent overfilling, accumulation tanks are connected to underground infiltration facilities (located behind the rainwater accumulation tanks). The infiltration facility for the school buildings has a surface of 30 m^2 and a gravel buffer thickness of 1.3 m. The infiltration facility at the gym has a surface of 33 m^2 and a gravel buffer thickness of 1.4 m.

Water from the accumulation tanks is used to irrigate the school grounds. Excess water is also used by the city (e.g. for watering decorative flower beds). Submersible pumps with suction strainers are installed in the rainwater tanks. A valve for connecting a garden hose and a distribution switch for connecting a mobile sprinkler is installed on the exterior of the gym. The water distribution point comprises a faucet connected to a garden hose. The hose is used by pupils and school caretakers to water plants and perform other maintenance duties. It can also be connected to a mobile irrigation sprinkler. A covered pit equipped with a garden hose connector is installed in the garden. The irrigation water distribution point for the garden and the greenhouse (supplied from the accumulation tanks collecting rainwater from the roofs of the two school buildings) is located in the western corner of plot No 1986.

Water is expected to be distributed from the tanks throughout the growing season, lasting about 6 to 8 months. In winter, the service water supply system is drained and winterized.

The main aims of the project, as per its documentation, are to reduce the financial costs of rainwater drainage and drinking water and to improve the flow conditions in the city's sewers.

The total construction area needed for the underground pipelines, accumulation tanks and infiltration facilities is 269 m^2. The company and persons responsible for the construction project are TZB ATELIER s.r.o., Prague, and Ing. Eva Sýkorová and Ing. David Sýkora. The implementation is projected to take place from June to August 2020.

6.3 Expected costs and benefits of the project

Rainwater collection provides a number of benefits both for the investor and for society in general. The expected benefits of the project are summarized in Table 2.

TABLE 8. EXPECTED BENEFITS OF THE PROJECT FOR THE INVESTOR AND SOCIETY IN GENERAL

Societal benefits	**Private benefits**
Reduction of the amount of drinking water consumed for watering (especially important in times of drought)	Savings on costs for rainwater drainage into the sewer system
Groundwater recharge	Savings on the supply of water for watering
Flash flood mitigation	
Educational benefits (the proposed facility will be located on the premises of a primary school)	
Improving outflow form the city's sewers	
Prolonged life of sewer system elements due to lower flow intensity	
Improved efficiency of the wastewater treatment plant due to reduced dilution of sewage with rainwater	

The most significant benefits of the project are societal. The reduced consumption of drinking water used for watering is a very important benefit, especially given the increasing frequency of dry periods. Another significant benefit is the reduction of the amount of rainwater discharged into the city’s sewer system. This will help to mitigate flash floods and extend the life of sewer system elements as well as improve the efficiency of wastewater treatment due to reduced dilution of sewage with rainwater. The project also has a very significant educational benefit, as it is to be implemented on primary school grounds. The school's pupils will be able to gain hands-on practical knowledge of rainwater management and carry this knowledge over to their family homes; an increased interest in rainwater accumulation by the students' families is, therefore, be expected. These societal benefits, however, are difficult to quantify in monetary terms.

The private benefits of the project consist of savings on the cost of drinking water needed for watering and of rainwater drainage into the sewer system. Thus far, about 168 m^3 of drinking water have been used each year to water the school playground and growing areas. The water used for watering was available for a water supply charge (CZK 49 per m^3 in 2019). The annual charges for draining rainwater from the roofs (to be used for rainwater collection under the project) into the sewer system amounted to about CZK 31,000.

The amount of precipitation that falls and is collected from the entire usable surface over 1 year significantly exceeds the amount of water consumed so far for watering the school playground and growing areas (with 168 m^3 water currently needed for watering vs. 625.6 m^3 potentially collectable from precipitation), and it is therefore assumed that further savings will be generated on the costs of water needed for watering of other areas. Since rainfall occurs throughout the year, including periods when watering is not needed, the entire volume of precipitation collected cannot be used for this purpose to generate savings on irrigation water. As stated in the project documentation, only 6 to 8 months' worth of precipitation (available over the growing season) are assumed to be used for watering. Based on the distribution of precipitation throughout the previous years, 50% of the average annual precipitation is assumed to occur from April to September (a growing season of 6 months), and 70% of the average annual precipitation is assumed to occur from March to October (a growing season of 8 months). Project benefits are calculated for both of these options.

Savings on rainwater drainage into the sewer system are calculated for the entire drained area of the roofs and according to applicable legislation. A sewer charge increase of 3% is assumed.

As the impact of climate change on precipitation is uncertain (some models show a slight increase in precipitation while others show a decrease), the long-term precipitation average for Kadaň (550 mm/year) is assumed to remain unchanged for the following period.

The total cost of the project, encompassing the preparation of project documentation, is CZK 4,185,403.69 including VAT. Annual maintenance costs, including cleaning, winterizing and the operation of pumps, are expected to amount to CZK 5,000 in 2021 and to subsequently increase in line with projected inflation.

A 3% annual increase in prices is assumed throughout the evaluated period, including an increase in water and sewer charges. In order to compare costs and revenues arising in different periods, all data is expressed in 2020 monetary units. Real rates of 2% and 3% are used for the conversion. The period considered for the project is up to and including 2050. Table 3 contains a summary of the basic assumptions used to evaluate the benefits and costs of the project.

TABLE 9. ASSUMPTIONS USED FOR ANALYSING FUTURE COSTS AND BENEFITS GENERATED BY THE PROJECT

Total volume of precipitation collected	625.6	m^3/year
Increase in precipitation	0	
Sewer charges in 2020*	50.32	CZK incl. VAT/m^3
Water charges in 2020*	53.07	CZK incl. VAT/m^3
Increase in water and sewer charges	3%	p.a.
Real discount rate	2%	3%
Inflation	3%	
Portion of collected rainwater used	50%	70%
Annual maintenance costs	5,000	CZK
Period considered	2020–2050	
Year of construction	2020	

* Data from Severočeské vodovody a kanalizace a.s. (WSS company)

6.4 Project costs and benefit analysis

The cost-benefit analysis considers two different options for the volume of rainwater used for irrigation. In a shorter growing season, the use of collected water for irrigation is assumed to take place only over 6 months, which corresponds to 50% of average annual precipitation used. In a longer growing season, the use of collected water for irrigation is assumed to take place over 8 months of the year, which corresponds to 70% of the average annual precipitation used. The cost-benefit assessment was performed for a discount rate of 2% and a discount rate of 3%. Tables 4 a 5 list the project's expected costs and revenues in 2020 Czech korunas, using a 2% discount rate and a 3% discount rate, respectively.

TABLE 10. COST AND BENEFITS OF RAINWATER USE ON THE PREMISES OF 3. ZŠ SLUNÍČKOVÁ, KADAŇ (2% DISCOUNT RATE)

	Portion of collected water used			**Portion of collected water used**	
	50%	**70%**		**50%**	**70%**
Costs			**Revenues**		
Invest-ment costs	CZK 4,185,404	CZK 4,185,404	Savings on drinking water	CZK 388,388	CZK 543,743
Mainte-nance costs	CZK 108,721	CZK 108,721	Savings on rainwater drainage costs	CZK 736,525	CZK 736,525
Total	CZK 4,294,124	CZK 4,294,124	**Total**	CZK 1,124,913	CZK 1,280,268
Costs/revenues	3.82	3.35			

Implementation costs are significantly higher than the benefits for all evaluated options of the project. The most favourable cost-benefit ratio is generated for the long growing season (70% of collected rainwater used) using a 2% discount rate. The largest difference between costs and revenues arises for the short growing season (50% of collected rainwater used) using a 3% discount rate. This result is not surprising, as greater use of retained rainwater results in greater savings on water used for irrigation. At the same time, lower discount rates produce relative increases in the value of future benefits.

TABLE 11. COST AND BENEFITS OF RAINWATER USE ON THE PREMISES OF 3. ZŠ SLUNÍČKOVÁ, KADAŇ (3% DISCOUNT RATE).

	Portion of collected water Used			**Portion of collected water used**	
	50%	**70%**		**50%**	**70%**
Costs			**Revenues**		
Investment costs	CZK 4,185,404	CZK 4,185,404	Savings on drinking water	CZK 341,973	CZK 478,763
Maintenance costs	95,148 CZK	95,148 CZK	Savings on rainwater drainage costs	CZK 648,506	CZK 648,506
Total	CZK 4,280,551	CZK 4,280,551	**Total**	CZK 990,479	CZK 1,127,269
Costs/revenues	4.32	3.80			

The relatively large difference between the projected benefits and costs is caused by several factors. Firstly, not all project benefits can be assessed in monetary terms (see Table 2 Expected benefits of the project for the investor and society at large) as it is impossible to quantify all of them in monetary units. Education is a very significant benefit as this project is implemented on the premises of a primary school, and this effect cannot be expressed in monetary terms. Another important benefit, also difficult to quantify in monetary terms, is the mitigation of flash floods and their impact on the city's sewer system (reduced use, extended life, improved sewage treatment).

In addition to the difficulties in expressing the benefits of the project, the resulting cost-benefit ratio is also affected by the way the project is implemented. The accumulation tanks are being added onto a completed structure, resulting in higher costs than if they had been part of the original construction. Adding the tanks *ex post* increases costs, including due to the need for additional wiring and piping. Another factor affecting the costs is the choice of underground accumulation tanks. The cost of installing the accumulation tanks could have been reduced by building them above ground. Before choosing either solution (aboveground or underground tanks), benefits and costs associated with both should have been carefully considered.

6.5 Conclusion

The expected cost and benefit analysis for the construction of rainwater retention tanks on the premises of the 3. ZŠ Sluníčková [Sluníčková Third Primary School], Kadaň shows that the costs of building underground retention tanks significantly exceed the expected benefits in the form of savings on the cost of drinking water used for watering and on the cost of rainwater drainage into the sewer system. However, this result is negatively influenced by the fact that some of the project's benefits, such as educational benefits, flash flood mitigation and the positive effect on the city's sewer system, cannot be expressed in monetary terms. The choice of underground retention tanks is another negative factor.

References

Dokumentace pro využití srážkových vod u 3.ZŠ (Sluníčková) B – SOUHRNNÁ TECHNICKÁ ZPRÁVA [Documentation for the use of rainwater at 3.ZŠ (Sluníčková) B – SUMMARY TECHNICAL REPORT]. TZB ATELIER s.r.o., Praha – Ing. Eva Sýkorová, Ing. David Sýkora

7 Summary

This report provides a wide range of information on the benefits and co-benefits of adaptation measures. It offers an introduction to adaptation conceptual approaches of ecosystem services, ecosystem-based adaptation, green infrastructure, and nature-based solutions. It provides a view into the benefits of various types of adaptation measures (nature-based, technical, instrumental) through the lenses of the concept of ecosystem services.

Further, the deliverable provides a discussion of adaptation measures' effectivity and the importance of an appropriate selection of adaptation measures regarding the context and characteristics of a given location selected for implementation. These specific characteristics can determine the effectiveness of an adaptation measure, its benefits, co-benefits, disservices, synergies, and trade-offs. Therefore, they need to be thoroughly considered before implementation to ensure effectiveness and avoid maladaptation.

The text also provides an introduction into methods of economic assessment of adaptation measures that can contribute to better adaptation and urban planning and support the implementation of climate change adaptation measures (often providing support for nature-based solutions over technical measures). The assessment of benefits and co-benefits is demonstrated on two case studies from pilot municipalities in Czechia - (1) Assessment of benefits of alternative planting scenarios in Cheb, and (2) cost-benefit analysis of rainwater collection system project in Kadaň.

Assessment of alternative planting scenarios in Cheb

The first case study used a multi-criteria analysis-like approach to assess the benefits of planting trees and shrubs in a fortification moat park in Cheb (CZ). The main aim of the planting project was to increase the food provision for local animals (birds, squirrels and improve the habitat and biodiversity in the park. Three different scenarios of planting the same amount of trees and shrubs in slightly different locations were assessed based on an expert elicitation in regard to supporting, regulating, cultural and provisioning ecosystem services. – (a) planting in an existing park, (b) planting on a playground in a housing estate, (c) planting along a road and (bike) path. The resulting scores were weighted in line with the priorities of the planting project. Planting scenarios (b) and (c) scored the same and both are suitable for the project's aim. However, if costs of planting would be considered, scenario (b) would most probably be more cost-effective (the data regarding costs estimates were not available).

Cost-benefit analysis of rainwater collection system project in Kadaň.

The second case study deals with an assessment of costs and benefits of rainwater collection system (underground water tanks) installed on the premises of ZŠ Sluníčková (Sluníčková Primary School) in Kadaň (CZ). The project aimed at the reuse of rainwater for irrigation of school premises.

Rainwater collection provides various benefits. For the investor these are (private benefits): reduction of costs for a) rainwater drainage and b) for freshwater used for irrigation (at school's playground). Social benefits are: a) reduction of water consumed for watering (especially important in times of drought), b) groundwater recharge enhancement, c) flash flood mitigation, d) educational benefits, e) prolongated life of sewer system due to lower flow intensity, and f) improved water quality due to better-performing wastewater treatment plant. Since social benefits are difficult to monetise, only private benefits were calculated in the cost-benefit analysis for the period of 2020-2050.

The amount of collected rainwater exceeds the annual usage for school premises watering; however, it is used by the city to water, e.g., decorative flower beds. Since watering is needed only during the growing season, which lasts between 6 (50% of annual rainfall) and 8 (70% of annual rainfall) months, the savings were calculated for these two options. The results were calculated for 2% and 3 % discount rates. Implementation costs resulted significantly higher than the benefits for all evaluated options of the project. The large difference between projected benefits and costs is caused by various factors, one of which being that several benefits that the project provides were not possible to assess in monetary terms (e.g. education, mitigation of flash floods) in this case. Another reason for the costs being higher in the assessment is the implementation of the project which consisted of the addition of a rainwater collection system to an already existing and completed structure and choosing underground water tanks which are typically more expensive than aboveground tanks.