Methodology for Economic Assessment of Green and Blue Infrastructure in Human Settlements



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Methodology submitters' statement
The methodology submitters state that the methodology does not infringe on other persons' rights to industrial or other intellectual property.

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List of Abbreviations:

CBA	Cost-benefit analysis
CO_2	Carbon dioxide
EC	European Commission
MEA	Millennium Ecosystem Assessment (a summary report assessing the present state of ecosystems and services they provide on Earth; more than 1,360 experts worldwide contributed to the report in 2001-2005)
O_3	Ozone
PM_x	Particulate matter
SO_2	Sulphur dioxide
SZKT	Czech Landscape and Garden Society (Czech: Společnost pro zahradní a krajinářskou tvorbu)
TEEB	The Economics of Ecosystems and Biodiversity (global initiative focused on recognition, promotion and identification of values provided by nature)
WTP	Willingness to pay
WWTP	Wastewater treatment plant

Objective of the methodology

In recent years, the Czech Republic and other parts of the world have been experiencing increasingly frequent climate change events, such as more intensive precipitation, heat waves, extreme wind or drought periods. These events have negative effects on our life quality, such as flash floods, urban heat islands and problems with electricity supply (e.g., Turner et al., 2017) or deteriorating conditions for agriculture (e.g., Pullens et al., 2019; Wheeler and Von Braun, 2013). Climate change events also have direct impacts on population health. At the same time, human behaviour and leisure activities change. People in cities increasingly search places for short-term recreation (e.g., Poudyal et al., 2009), and the importance of urban agriculture is increasing (for more, see, e.g., Kiesling and Manning, 2010; Smith and Jehlička, 2013).

Green and blue infrastructure is capable of resolving a range of these problems efficiently or even preventing them. In addition, it provides a wide range of synergic effects, which can be identified as benefits for human society. In this methodology, we focus on urban settings, an example of which is an urban park, which helps alleviate the urban heat island and cools its immediate surroundings and provides room for recreation, but also contributes to water infiltration and retention in the area, air quality improvement and noise level reduction, and performs an aesthetic function.

The objective of this certified methodology is to produce an unified comprehensive tool for economic assessment of the components of green and blue infrastructure in human settlements, which can be used for economic evaluation of specific measures in human settlements using green and blue infrastructure. The procedure proposed in this methodology is based on modified cost-benefit analysis (CBA), applied to a selected green and blue infrastructure feature or measure. The proposed modified CBA encompasses several consecutive steps. Methodology outcomes and financial valuation of green and blue infrastructure features may serve either in the case of construction of new public spaces such as squares, parks, playgrounds, streets and more, or in decision-making on land use and construction of specific features. Likewise, they are useful for renovation or revitalisation in cities, including buildings and parking areas (e.g., use of green roofs or green façades). Finally, they find use in negotiation with developers and other investors, including private owners and residents, who influence quality of life in cities with their activity.

In this context, strategic materials, municipal, regional and national strategic and policy documents as well as professional publications apply technical terms other than green and blue infrastructure, which sometimes have a narrower or broader meaning. Examples include nature-based solutions, adaptation measures, measures for provision of ecosystem services, and urban greenery (Escobedo et al., 2019). Besides, the term green and blue infrastructure itself encompasses several meanings and definitions, depending on the context in which it is used. For example, Benedict and McMahon (2006) define it as trees in streets which have ecological benefits, and Vítek (2018) speaks of engineering structures, such as rainwater management systems. The European Commission (2013, p. 3) uses the following definition: *"a strategically planned **network** of natural and semi-natural areas with other environmental features"*. Thus, the term is commonly understood broadly in terms of both a component measure and a system composed of measures.

For the purposes of this methodology, green and blue infrastructure refers to **all water features and green features in urban settings that provide people with a wide range of benefits in the form of ecosystem services**. The introduction to the methodology deals with defining green and blue infrastructure and introducing the various features. The following chapter speaks about ecosystem services, that is contributions of nature (ecosystems) to quality of human life. The next chapter is dedicated to the economic assessment procedure as such. The annex contains a model assessment on the case of a green roof, an overview of costs of selected measures, an overview of biophysical indicators of benefits and a more detailed description of valuation methods, and results of application of choice experiment to assessment of cultural services provided by selected green and blue infrastructure features.

Figure 1: Example measure – extensive green roof

Source: Pavel Dostal (2015)

The methodology is applicable at the level of public administration and self-government, as well as by other interest groups and citizens. The methodology provides relevant information necessary for decision-making of such concerned groups about supporting maintenance, renovation or new implementation of green and blue infrastructure in cities.

Methodology description

The methodology first briefly introduces green and blue infrastructure and makes an overview of basic features classified in 10 categories. Afterwards, it describes the concept of ecosystem services, including a listing of relevant services provided by green and blue infrastructure in human settlements. The next chapter describes the procedure of economic assessment using modified cost-benefit analysis (CBA). Finally, annexes contain an example of the assessment procedure, tables containing costs of implementation and maintenance of selected green and blue infrastructure features, and an overview of relevant biophysical indicators.

1. Green and blue infrastructure

Urban development and construction of transport and other grey infrastructure[1] has resulted in increasing competition for uses of public spaces in urban settings. As greenery in ecosystems is gradually decreasing, developed areas provide fewer benefits that humans obtain from nature in the form of ecosystem services (see Chapter 2). Fragmented and discontinuous natural systems in cities do not work efficiently. They provide fewer benefits than their potential would allow. Changes in land use and expansion of developed areas lead to reduced biodiversity, impaired air quality as well as reduction in groundwater supply, reduced water infiltration in the urban environment, increased flood risks and damage, and overheating of city centres.

These problems can be solved by construction and promotion of so-called green and blue infrastructure. The European Commission (2013, p. 3) defines green (and blue) infrastructure as *“a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings*.”

Green and blue infrastructure comprises numerous features, which can be natural, semi-natural and artificial. Table 1 contains examples of features or measures. The degree of benefits frequently varies depending on the origin (natural vs. semi-natural features; Daniels et al., 2018). Numerous green and blue infrastructure features are frequently combined with grey infrastructure features. These are typically green roofs and walls.

In urban settings in particular, where around 70% of the Czech Republic’s population live (CSO, 2018), where important economic activity and most of the socioeconomic activity are concentrated, construction of green and blue infrastructure is important and meaningful.

[1] The term grey infrastructure refers to single-purpose technical and technological solutions such as roads, railways, hydraulic structures, etc. They may include mechanical flood barriers, air-conditioning, etc.

Table 1: Examples of green and blue infrastructure features (measures)

Examples of features/measures
Water bodies (e.g., fountains, fishponds, lakes, pools, wetlands, watercourse revitalisation and uncovering, oxbow lakes)
Riparian vegetation (restoration along water bodies)
Polders (dry reservoirs)
Dikes (collector, retention, infiltration) and **infiltration strips**
Areas with permeable/semi-permeable surfaces (porous materials, such as infiltration paving, grassed tram tracks, etc.)
Trees (e.g., avenues, windbreaks, scattered vegetation)
Green roofs and walls (of buildings)
Urban agriculture and gardening (e.g., community gardens, garden allotments), front gardens, block courtyard greenery
Parks and forest parks (in city centres and on outskirts)
Reed fields (for wastewater treatment; water can be used for watering trees, etc.)

Source: Own listing based on McCarney (2009)

Green areas in cities are often viewed as territory that has not yet been developed and built upon. However, lack of quality green and blue infrastructure in cities leads to increasing vulnerability of cities in light of the ongoing climate change. It can manifest itself through events such as heat waves, extreme wind, more intensive precipitation as well as drought.

Therefore, in the ideal case, decision-making on the environment should be part of spatial planning so as to ensure identification of green and blue infrastructure features, their construction, restoration, protection, long-term strategic management and, most importantly, interconnection of both protected areas and all public spaces with green and blue infrastructure features. Such an approach can boost provision of ecosystem services and thus increase the benefits provided and improve the welfare of city inhabitants and visitors. Besides increasing knowledge and awareness of benefits of green and blue infrastructure at all levels of society, implementers and local administration, numerous other support tools can be used. Monetary expression of benefits is one of them. Monetary expression of the values of benefits that green and blue infrastructure features provide can help spatial planning to find (cost) effective and sustainable spatial development and maximisation of total benefits with respect to limited resources.

2. Ecosystem services

Nature in cities (greenery and water features) brings city inhabitants, workers and visitors alike numerous benefits and thus contributes to improving quality of life in cities. These contributions by nature, or various ecosystems, to human society are termed ecosystem services. The concept of ecosystem services focuses on identification of benefits that human society derives from natural systems and on methods of reflecting these benefits in decision-making processes of market economies. The term was established in the 1980s (Ehrlich and Ehrlich, 1981), but the application of the concept has been developing significantly since the early 21st century. There are dozens of different definitions of the term ecosystem services, but experts most commonly explain them as benefits that people obtain from ecosystems and that have a positive effect on their living standard (welfare). Ecosystem services influence the components of human welfare, which can be used as a measure for evaluation of quality of life. They include, among other things, linkages among ecosystem services and welfare components such as health, access to clean air and wildlife, safety, etc.

Figure 2: Example of measures – Park using rain water of roofs of surrounding buildings

Author: Petr Förchtgott (2015)

Examples of ecosystem services include cooling of overheating city centres (that is, alleviation of urban heat islands or, more generally, microclimate regulation)[2], water regulation in landscape (retention of water in urban landscapes and flood protection), noise reduction, and air quality improvement (due to greenery capturing dust particles). Nature in

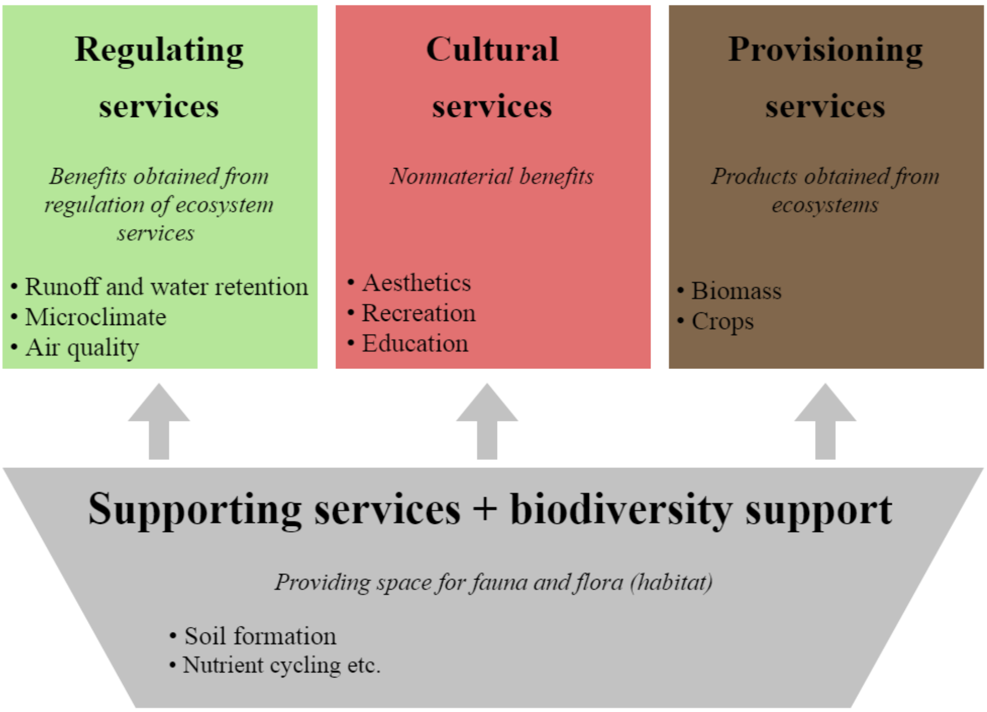
[2] The usual situation is that the city centre is much warmer than the city surroundings as a result of the large paved areas.

cities makes room for relaxation or short-term recreation. Provision of these services by urban nature ultimately has a positive effect on things such as health of inhabitants, work performance, community life, and property prices near the green areas. Many studies (e.g., Tomalty and Komorowski, 2010; Kolbe and Wüstemann, 2015) have confirmed that property prices near green areas are higher.

Contributions of urban nature to quality of life in cities are not invariable. According to Capistrano (2005), social welfare is influenced by changes in the structure and functioning of ecosystems and services provided by them. Balmford et al. (2002) found that the total (societal) value of unchanged natural habitats may exceed the private benefits of their change. However, since ecosystem services are frequently not traded on markets, or their value is not determined similarly to other goods and services in monetary units, their benefits tend to be underestimated in land-use decision-making processes (Bateman et al., 2013). For this reason, economists in cooperation with nature scientists try to valuate ecosystem services and so contribute to reflection of these benefits provided by nature in important strategic and political decision-making.

For assessment of nature's benefits to human society as well as for easier interpretation of relationships between these benefits and social welfare, MEA (2005) divides ecosystem services into 4 basic categories. These are regulating, cultural, provisioning and supporting services. Their classification is shown in Figure 3, and the categories are described below.

Figure 3: Division of ecosystem services into 4 basic categories



Source: Own depiction based on MEA (2005) and TEEB (2010)

Regulating services

They provide protection from negative environmental impacts on human society (even though the impacts may be caused by changes in nature originally made by human activity). The reason is that these services regulate air quality, water quality and quantity, soil erosion, diseases and pests or local and global climate. Nature's decreasing ability to provide selected regulating services may lead, e.g., to decreasing air and water purification ability, soil degradation, reduced ability to cool local climates, or more frequent flooding. Regulating services are characterised by the fact that if their natural provision decreases (as a consequence of damaged ecosystems), the society's costs of eliminating or mitigating damage caused by natural events (e.g, flood damage) increase, costs of avoiding such damage (e.g., flood protection measures) increase, or economic loss due to deteriorating environment occurs (e.g., lower agricultural production). Although there is no factual market for these services in the strictest sense of the word (in contrast with provisioning services), knowledge of said potential societal costs makes it possible to quantify these benefits to human society. In practice, however, this is very rarely done as part of spatial planning processes. Pollination is sometimes included among the regulating services.

Cultural services

They provide society with recreational benefits (nature provides room for short-term and longer-term recreation and relaxation), aesthetic values (e.g., in the form of inspiration for works of art) and spiritual and religious values (room for contemplation and meditation, holy places for various religions, etc.). This type of ecosystem services is of particular importance for urban dwellers, who frequently seek greenery in the form of parks, suburban forests and gardens as places of everyday relaxation. Expression of the value of these services in monetary units is the most difficult, but by no means does that mean that they are of no value for society. Resources expended on recreation in nature (be it a vacation or a one-day trip) indicate that people value nature and are willing to pay even relatively large amounts to be allowed to admire nature's beauty or relax there (e.g., the well-known Plitvice Lakes in Croatia are visited by approx. 1.5 million tourists annually despite the high-season entry fee of over 800 CZK per person).

Provisioning services

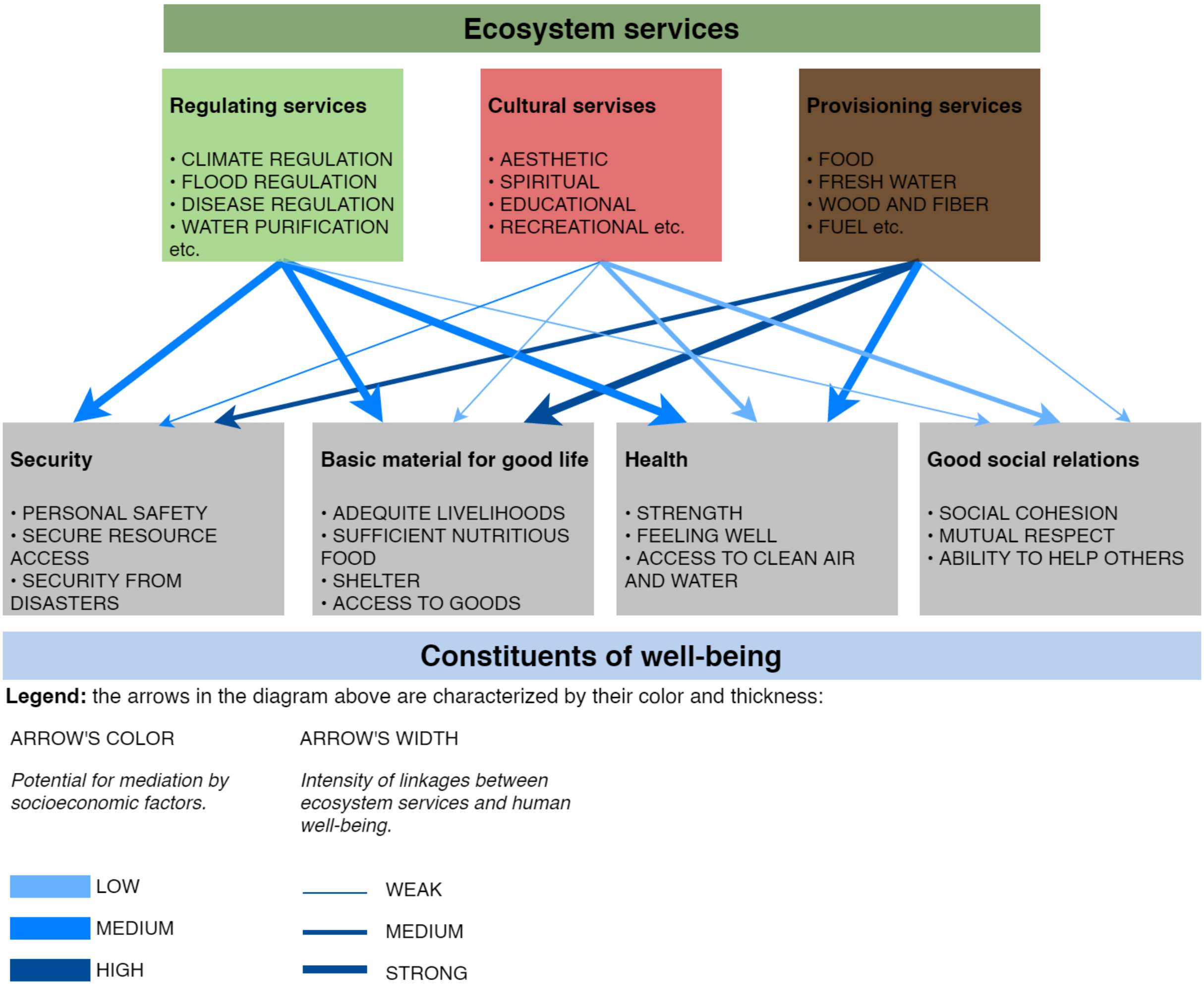
These include production of food, timber, other wood matter, water, etc. Outputs of these services are mostly traded on markets in the form of various goods, so there is no problem determining their value. We can also say that the more of these services nature provides, the more (natural) resources society has for its functioning.

Supporting services

Unlike the three previous categories of ecosystem services, they have an indirect effect on social welfare, and changes in their production are manifested more in the long run. These services support the production of all the other services provided by ecosystems. They include, e.g., soil formation, nutrient and water cycles in nature, photosynthesis or primary production (assimilation and accumulation of nutrients and energy in organisms). These services are not valuated in monetary units, because they are included in the valuation of the three previous types of services.

The following diagram (Figure 4) shows the **relationships between ecosystem services and human welfare**.

Figure 4: Relationships between services and their impact on welfare



Source: Own developed based on MEA (2005)

Economic assessment valuates provisioning, regulating, cultural and ecosystem services. Along with supporting biodiversity, supporting ecosystem services boost the ability of ecosystems to provide regulating, cultural and provisioning ecosystem services, which provide society with benefits. Table 2 contains a list and brief description of ecosystem services relevant to green and blue infrastructure in human settlements.

Table 2: Overview of ecosystem services and other benefits and their brief description

Regulating services

Runoff regulation	Leads to retention of water or slowing of runoff. The consequence is reduced drainage of precipitation water from areas. At the same time, the amount of water drained via sewerage decreases. In the case of combined sewerage, the amount of precipitation water transported to wastewater treatment plants is reduced.
Flood risk reduction	Closely related to runoff regulation. Connected primarily with water retention, which leads to reduced damage due to torrential rain or river flooding.
Water quality	Numerous measures have a positive impact on water quality by means of its filtration/purification. A number of pollutants are broken down. Along with runoff regulation, combined sewerage does not suffer from water dilution, i.e., overflowing of water out of sewers and directly into watercourses during excessive drainage.
Noise reduction	Contributes to absorption and interception of noise from the surroundings (e.g., from transport), or directly as acoustic insulation on buildings.
Air quality	Pollutants such as dust particles, nitrogen and sulphur oxides and ozone are intercepted from the air.
Soil erosion	The measure contributes to elimination of erosion activity by means of reinforcing soil with roots, grass, etc. Alternatively, the features are used to capture sediment.
CO_2 reduction	CO_2 from the atmosphere is deposited.
Microclimate regulation	Regulation of temperature, humidity and air flow at a local level.
Pollination	Increases the rate of pollination, makes room for bees and other pollinators.
Diseases regulation	Supports a healthy environment that eliminates or mitigates numerous diseases (asthma, lifestyle diseases, heart attacks, etc.).

Table 2: Overview of ecosystem services and other benefits and their brief description (continued)

Cultural services	
Recreational function	Green and blue infrastructure offer spaces for recreation and relaxation. It has an effect on the population's psychic and mental health.
Aesthetic value	Nature-based features frequently have a positive effect on the surroundings. They improve visual appearance and are reflected in property values in the surrounding areas.
Educational	Green and blue infrastructure contribute to environmental awareness and education of all society. It can also be used purposefully in combination with information boards or other tools.
Provisioning services	
Biomass production	Maintenance of green infrastructure is connected with production of waste biomass, which can be used as input raw material not only for urban greenery maintenance but also as an energy source in biogas stations, etc.
Timber production	Besides their other functions, trees produce wood matter, which can be used to a limited extent. This mostly concerns cases where old trees are naturally replaced with new ones.
Crop production	Besides wood and biomass, some features and measures also provide other crops. This applies primarily to so-called urban agriculture measures, such as garden allotments, community gardens, etc., where vegetables and fruits are grown. Crops can also be produced, e.g., by productive roof gardens.
Other benefits	
Energy savings on heating/cooling	This benefit is tightly linked to microclimate regulation, which may affect, among other things, thermal management of buildings, which are cooled in summer and thermally insulated in winter.
Property value increase	This benefit is closely linked to aesthetic value. Increases in aesthetic value may be reflected in increasing prices of properties around a feature/measure or the property on which the feature/measure is implemented (e.g., green roof, green façade).
Biotope formation	Implementation of green and blue infrastructure features/measures contributes to habitat formation.

Source: Own description based on MEA (2005) and TEEB (2010)

It is important to mention that benefits are understood in economics as anthropocentric, i.e., benefits for individuals (inhabitants, owners, users of public spaces, etc.) and are derived from specific values expressed by people (e.g., stated willingness to pay for a certain service). This notion of benefits is different from that in natural science, which also takes into account the intrinsic value of nature, which is independent on people's attitudes. In economic valuation, non-anthropocentric (ecocentric) values in the form of supporting services are thus regarded as values beyond the scope of human perception and knowledge, and remain without monetary value. That is the case of this methodology too, which adheres strictly to the anthropocentric perception of benefits and utilities.

The quality and quantity of ecosystem services provided depend not only on the sizes of the different green and water areas, but also their condition and interconnections. Therefore, we frequently speak about **green and blue infrastructure** – a comprehensive system of interconnected features of urban natural areas. Green and blue infrastructure in cities is able, to a greater or lesser extent, to substitute for the loss of ecosystem services in urbanised areas as a consequence of construction development, grey infrastructure, increasing traffic intensity, etc. The specific conditions always matter.

However, different green and blue infrastructure features cannot be understood as absolute equivalents or substitutes for grey infrastructure commonly used in many cities, but often as its complement. Typical examples include green roofs and building façades, a park in the middle of a housing estate, etc.

In many cases, green or blue infrastructure may replace grey infrastructure and society would simultaneously enjoy a number of positive side-effects while achieving similar goals. This is particularly true of goals of adaptation of cities to climate change, such as urban heat islands, heat waves, water shortages, etc. A typical attribute of grey infrastructure elements is that they usually perform a single function (flood barriers only prevent water permeation during floods), whereas green and blue infrastructure elements may perform several functions at once (or provide an array of auxiliary benefits in the form of ecosystem services). Examples include natural wetlands and nature-based retention reservoirs. Not only do they retain water from torrential rain and so reduce flood-related damage, but they also subsequently cool their surroundings by evaporating retained water, are an important sanctuary for many plant and animal species and, last but not least (with appropriate landscaping), they may be an attractive recreational location.

Moreover, if we compare the value of the above benefits that the measure (originally a flood-prevention measure) brings with the costs of its implementation and maintenance, we may often conclude that the value of their social benefits significantly outweighs the costs of their implementation and operation. Thus, investment in green and blue infrastructure may be socially more efficient than investment in grey infrastructure. This conclusion can be reached by applying the economic assessment procedure that is the subject matter of this methodology.

Generally, all the ecosystem service types can be identified for green and blue infrastructure to a greater or lesser extent, but regulating and cultural services are the most frequent, followed by a provisioning ecosystem services, mostly connected with parks, orchards, etc. A great potential is connected with the use of biomass for energy production.

Spatial planning and decision-making processes on removal/restoration/new establishment of green and blue infrastructure features should take into consideration all the benefits brought to society by nature-based measures. That is, even benefits manifested by direct financial flows due to goods and services traded on markets. The concept of ecosystem services (combined with application of cost-benefit analysis) may help significantly determine the values of benefits as contributions of different nature-based measures or green and blue infrastructure features to social welfare.

3. Economic assessment procedure

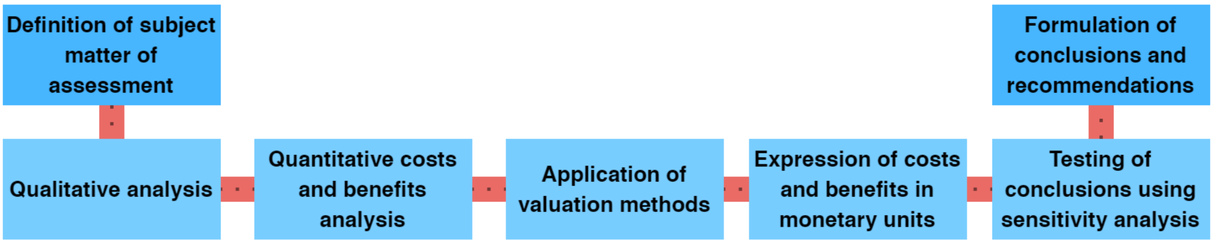
Based on a literature survey and existing experience of the team of authors (e.g., Slavíková et al., 2015; Macháč et al., 2017; Macháč et al., 2018a, Macháč et al., 2018b, Dubová et al., 2019), the economic assessment of green and blue infrastructure is grounded in cost-benefit analysis (CBA), modified by connection with the ecosystem service concept for the purposes of green and blue infrastructure assessment.

The economic assessment is analogous to financial analysis commonly performed in both the public and private spheres. The CBA also considers additional social costs and utilities beyond pure private financial benefits and costs. It takes into consideration costs and utilities that affect society and individuals (public administration and self-government, local inhabitants, tourists, property owners, entrepreneurs, public service providers such as water and sewerage utilities, etc.). Social costs and utilities frequently have no direct financial dimension, but have a considerable effect on quality of life in human settlements. The economic assessment applies an anthropocentric approach. All the values are derived from people's preferences, either in the form of market prices, if they exist for the goods and services in question and if they are traded on markets, or in the form of willingness to pay (WTP) for the goods/services. In this respect, the economic assessment differs from the ecocentric perspective applied in natural science, where a value can be attributed to a utility independent of people's preferences. All purely ecocentric values that go beyond human perception (intrinsic value of nature) thus remain unappraised (in monetary terms) in our approach.

Since only a very small quantity of utilities go through markets, the assessment needs to apply a number of methods capable of expressing their economic value. The utilities are defined and categorised using the ecosystem service concept, introduced in the previous chapter. According to CBA, green and blue infrastructure features are considered beneficial if their benefits outweigh the costs.

The procedure is broken down into a number of steps, including starting (definition of subject matter of assessment) and follow-up steps (application of results). The basic diagram is shown in Figure 5. The individual steps are then described in detail below.

Figure 5: Economic assessment procedure diagram



Source: Own processing

The procedure presented below is illustrated on an example of a green roof in Annex 1.

Starting step: Definition of subject matter of assessment

The key step is identification and definition of green and blue infrastructure features/measures that are the subject matter of assessment. Their cooperation and connection to other features has to be taken into account very often, since interaction among features and measures frequently leads to significant reinforcement of the overall effect of the features/measures. The resulting effect of two measures is usually more than their simple sum.

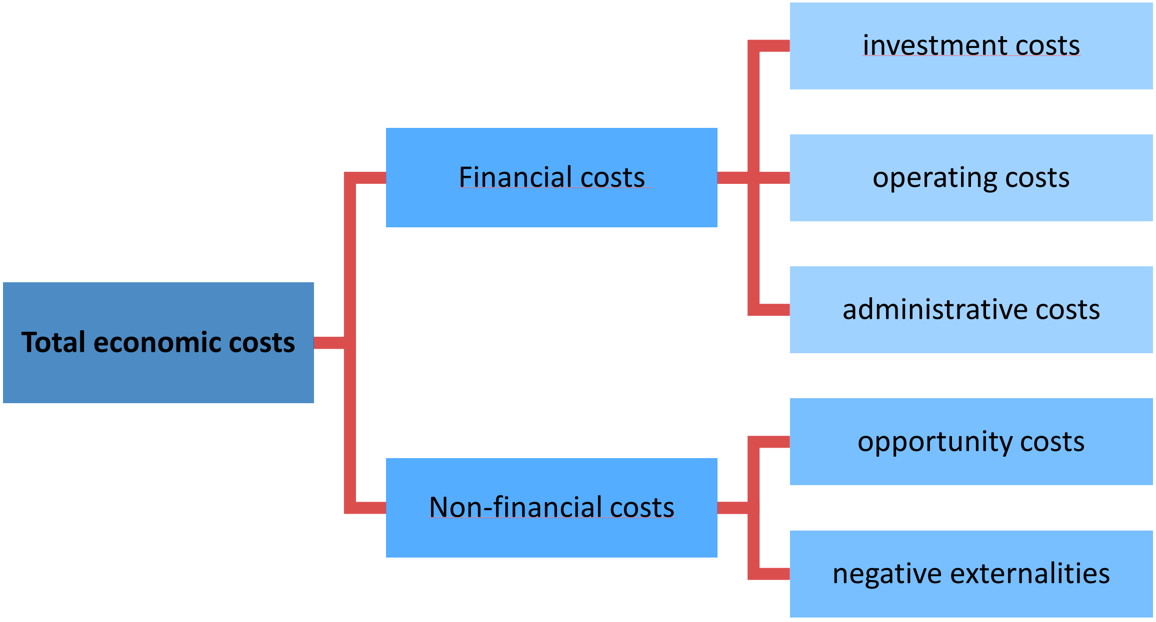
An integral component is the definition of the spatial extent of the measure impact, which has a significant effect on relevant identification of benefits connected with the feature. Many measures provide both local society-wide benefits (e.g., microclimate regulation) and benefits at the level of the whole human settlement (e.g., space for recreation) and global benefits (absorption of greenhouse gases, etc.). In the case of runoff regulation, there may be specific impacts lower downstream in the form of flood wave elimination.

At the same time, the initial situation as of which the assessment is made has to be defined. Thus, the first step frequently involves mapping of the area. If assessing green and blue infrastructure features that are still in planning, it is necessary to describe the current situation as of which the planned measures can be assessed. In the case of features and measures already implemented, we need to define what situation we regard as initial. This part is importantly connected with the next step, which identified the costs and benefits.

Step 1: Qualitative cost-benefit analysis

The definition of the subject matter of assessment is followed by a basic identification and qualitative description of costs and benefits. Costs refer to all the society-wide resources that have to be expended (Figure 6). The **costs include** both costs of green and blue infrastructure construction as such (investment costs) and all subsequent costs related to maintenance (operating costs). Frequently, implementation of a feature/measure thwarts other possible uses of the area in question. It is advisable to include these opportunity costs in the assessment, just as any other negative impacts of the measure (negative externalities or reduced production of some ecosystem services as a consequence of change in land use). The component costs also include administrative costs of measure implementation. However, these costs are difficult to define in practice, as are the transaction costs. The identification therefore produces a list of the above relevant costs. The qualitative analysis then makes a more detailed description of them, which is an input step for their quantification.

Figure 6: Structure of economic costs



Source: Macháč et al. (2018b)

The **benefit side** includes all positive benefits associated with implementation of green and blue infrastructure. As part of the methodology, we have introduced the ecosystem service concept, aimed to help identify and define corresponding services, including impacts on biodiversity. The identification involves a selection of ecosystem services that are relevant to the green and blue infrastructure feature in light of definition of subject matter of assessment. Afterwards, it is advisable to define the degree of provision of these services (low, medium, high). The degree of provision is useful, for example, when comparing two measures; at the same time, it can be a guide to which benefits (services) need to be valued in the next steps.

Step 2: Quantitative cost-benefit analysis

The costs and benefits defined in the previous step are subjected to quantitative analysis. This results in a definition of the extent of costs incurred (investment, periodic and one-off costs) and ecosystem services provided and other benefits.

The costs can usually be expressed in monetary terms already in this step, broken down into actions connected with the construction and maintenance of the feature/measure. As necessary, they can be expressed in different units, such as hours spent on construction and maintenance, quantities of materials used and amounts of externalities.

The basis for the quantitative benefit analysis is typically definition of biophysical units representing the amounts of ecosystem services provided, such as quantities of water retained, substances captured, carbon stored, energies saved, etc. These figures can be obtained by primary measurement, but that is time and money-consuming and usually goes beyond the capacities of the team doing the economic assessment. The starting point is therefore usually value transfer, based on available data, databases, standards or domestic and international literature surveys. An overview of selected values is contained in Annex 2. These values are only approximate, and have been used in the Czech context in previous assessments of selected measures. However, own values can be used, as can values provided by the measure designer or other experts. Values related to the specific site may be considerably more accurate than transferred values.

Step 3: Choice and application of valuation methods

The costs are usually valued in monetary terms based on market prices either in relation to costs already expended (ex-post analysis) for measures already implemented. In the case of ex-ante analysis (measures only planned), the cost estimate has to be made based on measure designs or by derivation from implementation of similar measures in the municipality or in other municipalities. It is necessary to adjust the estimates to local specifics such as property prices in the area or extent of works. Under operating costs, it is necessary to consider not only periodic annual costs but also one-off maintenance costs as expended either as needed or every few years. Mud removal costs are an example of irregular costs that still have to be included.

Market prices can be used to express opportunity costs (typically value of land property if used for construction of a family house/apartment building/office compound, etc.). The pricing of negative externalities proceeds analogously to benefits using additional valuation methods.

Annex 3 contains an overview of average investment and operating costs of selected measures, used for obtaining a basic picture of the requirements of the implementation and maintenance of the measures. As said above, the actual costs depend on local conditions and the specific form of the feature/measure. Facilities and other equipment may make up a significant part of the costs.

Valuation of benefits using market prices is only possible for some of the ecosystem services. This makes the monetary expression of benefits more complex than for the costs. Very often, it is necessary to apply one of the environmental goods and service valuation methods. To provide an overview of ecosystem services and other benefits (contained in Table 2), this section summarises examples of methods that can be used for valuating the different ecosystem services. This is not a complete overview but one of commonly used methods based on our own experience and literature survey. The overview is in Table 3, and the different methods are briefly introduced in Annex 4.

Table 3: Assignment of suitable valuation methods for individual ecosystem services (benefits)

Ecosystem service	Valuation method based on:
	Regulating services
Runoff regulation	market price (cost saving on wastewater treatment in WWTP, or cost saving on other methods of rainwater interception/drainage, incl. construction of separate sewerage)
Flood risk reduction	market price (as per damages), flood damage mitigation costs
Water quality	mitigation costs (i.e., costs of water treatment, improving water quality, or costs of alternative measures)
Noise reduction	mitigation costs (i.e., costs of alternative measures, e.g., noise reduction in flats)
Air quality	mitigation costs (costs of alternative measures, interception of pollutants from the air: dust particles, nitrogen oxides, sulphur oxides and ozone)
Soil erosion	mitigation costs and market price (cost saving on purchase of lost soil and cost saving on nutrient replacement and removal of sediment from watercourses)
CO_2 reduction	CO_2 emission mitigation costs (costs of alternative measures), or market price of CO_2 permits
Microclimate regulation	mitigation costs (costs of alternative measures – air-conditioning or other grey infrastructure measures)
Pollination	market price (crop production changes)
Diseases regulation	market price (cost saving on healthcare)
	Cultural services
Recreational function	choice experiment, travel costs
Aesthetic value	choice experiment, travel costs, property price increase (see below), often valuated together with recreational function
Educational	travel costs, substitution costs (other alternative education methods, e.g., visits to botanical gardens, etc.)

Table 3: Assignment of suitable valuation methods for individual ecosystem services (benefits) (continued)

Provisioning services	
Biomass production	Market price (biomass purchase price after subtracting necessary costs of transport, etc.)
Crop production	market price (crop purchase price)
Timber production	market price (value of timber in own processing/timber purchase price expressed in normal metres for the species)
Other benefits	
Energy savings on heating/cooling	market price (energy savings)
Property value increase	hedonic price, alternatively benefit transfer in combination with market price (based on expression of percentage of property price increase determined using value transfer)
Biotope formation	biotope assessment (e.g., using Hesse method)

Source: Own processing based on, e.g. Gómez-Baggethun et al. (2013), Dubová et al. (2019)

The choice of an appropriate method depends on data availability and the assessment author's time and financial capacities. An alternative method for monetary valuation is value transfer in the form of benefit transfer, or application of its advanced form of meta-analysis (see, e.g., Macháč et al., 2018a). Existence of relevant values is a necessary precondition for both these methods. Simple benefit transfer requires consideration of local specifics, which may differ significantly depending on climate conditions, substrate, etc. For transfer from abroad, it is more advisable to apply the advanced meta-analysis method, which involves factors such as price level difference, etc.

The project under which this methodology is produced included addition of some of the missing values using primary valuation. Attention was paid to the recreational and aesthetic functions of green infrastructure features (nature-based park, semi-natural park and urban garden), blue infrastructure features (nature-based stream, semi-natural stream and stream running in a pipe) and park facilities (benches, bins and toilets) as supports to the recreational function of parks. The choice experiment was carried out in 5 cities of the Czech Republic (Děčín, Pardubice, Liberec, Brno and Prague). The data collection in Pardubice only took place in June and July 2019, when the assessment will be made. Therefore, the methodology only contains results for Děčín, Liberec, Brno and Prague. Since they are not related directly to the economic assessment procedure described in this point, they are included as Annex 5.

Step 4: Expression of costs and benefits in monetary units

The costs and benefits are expressed in monetary units based on application of valuation methods. This information then has to be expressed for a predefined time horizon (or multiple horizons). Our methodology recommends using at least two time horizons. In light of previous experience (e.g., Macháč et al., 2018b), we recommend working with horizons of 25 and 50 years; alternatively, own time horizons can be chosen. They should always be chosen realistically with respect to the measure lifetime. If the period chosen exceeds the lifetime, the costs need to include expected costs of gradual renovation of the feature.

To cope with the temporal discrepancy[3] between the costs and benefits, the assessment may use either expression of costs and benefits by annualization (e.g., Slavíková et al., 2015; Macháč and Brabec, 2018), or the present value method (e.g., Macháč et al., 2018b; Dubová et al., 2019).

We **recommend using the net present value method** for green and blue infrastructure assessment. The method is built upon conversion of future costs and benefits to their cumulated value expressed as present value of money. Present value calculation is shown in Equation 1. Comparison of costs and benefits yields the so-called net present value (Equation 2).

Equation 1: Formula for calculation of present value

$$PV = \sum_{t=1}^{T} \frac{V_t}{(1+r)^t}$$

where PV is the present value,
V_t is the value (of cost or benefit) at the time t,
r is the discount rate (EC recommendation is to use a 4% discount rate, i.e., 0.04),
T is the assessment time horizon,
t is the year (in the range 1 – horizon T).

Equation 2: Formula for calculation of net present value

$$NPV = PVb - PVc$$

where NPV is the net present value,
PVb is the total net present value of benefits,
PVc is the total net present value of costs.

In the case of **annualization**, we try to convert the known value of present costs and benefits to a future flow of the same values based on annual costs that correspond to the known value at present with cumulation (Jacobsen, 2005). The formula for calculation of annualized

[3] Temporal discrepancy refers to a situation where the costs of green and blue infrastructure features/measures are usually the greatest in the first year, when the measure is implemented. In contrast to that, the benefits are obtained continuously, meaning a simple subtraction of the costs from the benefits is impossible.

value of investment and operating costs is shown in Equations 3 and 4. The calculation of total annualized costs is in Equation 5. The procedure for the calculation of annualized benefits is analogous to that for the costs. The last step is the calculation of the net annualized benefits: the annualized costs are subtracted from the annualized benefits.

Equation 3: Investment cost annualization

$$ACi = \sum_{l=1}^{L} ACi_l = \sum_{l=1}^{L} \left(PVi_l \times \frac{r \times (1+r)^l}{(1+r)^l - 1} \right)$$

where ACi is the total annual investment costs in the annualized form,
ACi_l is the investment costs with lifetime *l* of the measure,
PVi_l is the net value of investment costs connected with certain lifetime,
r is the discount rate (EC recommendation is to use a 4% discount rate, i.e., 0.04),
L is the maximum expected lifetime of the measure,
l is the lifetime of a part of the measure.

Equation 4: Operating cost annualization

$$ACm = \sum_{y=1}^{Y} ACm_y$$

where ACm is the total value of operating costs,
ACm_y is the annual operating costs in the year y,
Y is the assessment time horizon.

Equation 5: Calculation of total annualized costs

$$ACtot = ACi + ACm + ACo$$

where $ACtot$ is the total annualized costs,
ACi is the investment costs in the annualized form,
ACm is the operating costs in the annualized form,
ACo is the other costs[4] in the annualized form.

The outcome of this step is the total net benefit of measures from the society point of view. At the same time, the present value of costs and the present value of benefits can be used to **express the rate of return of a feature/measure from the society point of view**. It is the time (year) in which the cumulated valuated benefits exceeds the cumulated costs.

An alternative indicator may be the so-called benefit-cost ratio, which expresses how many times the benefits provided, expressed in monetary terms, exceeded the costs expended by the chosen time horizon. The formula for calculating this ratio is shown in Equation 6.

[4] Includes costs in other categories, i.e., administrative and opportunity costs and negative externalities.

Equation 6: Benefit-cost ratio

$$B/C = \frac{B}{C}$$

where B/C is the benefit-cost ratio,
B is the total benefits (in present value or annualized value),
C is the total costs (in present value or annualized value),

Step 5: Testing of conclusions using sensitivity analysis

It is advisable to test the results of the cost-benefit analysis (steps 1-4) to eliminate possible distortions caused by input data. A sensitivity analysis method is useful for that purpose.

Testing of the impact of the discount rate applied in step 4 should form the basis. A so-called scenario sensitivity analysis is applied in this case. Besides the default 4% discount rate, representing the baseline scenario, other scenarios are produced that apply different rates. The analysis in Macháč et al. (2018b) used 2% and 6% rates. Sometimes these scenarios are also referred to as the optimistic (2%) and pessimistic (6%) ones. The results are then compared to the default scenario. The difference is most clearly visible when expressing the results using the indicator of rate of return on the feature from the society point of view. Ideally, the numbers of years should not differ too much.

Alternatively, all the input parameters can be tested using a method that adjusts all the values by 1%. This is followed by examining the percentage change in the results and which values have the greatest impact on the results. It is advisable to focus attention on those values that affect the results the most and, if the conclusions need confirmation, perform a scenario sensitivity analysis again, using input values lower and higher than in the default calculation.

Moreover, we recommend considering costs and benefits that could not be expressed in monetary terms before formulating conclusions. They can be included as educated estimates. Alternatively, they can be balanced using a qualitative assessment and supported with a discussion of the degree of underestimation of costs and benefits due to impossibility of economic assessment of some of the values.

Follow-up step: Formulation of conclusions and recommendations

Based on the preceding steps, it is possible to formulate conclusions regarding the society-wide benefits of the green and blue infrastructure features/measures. Moreover, potential additional measures that would lead to greater benefits can be recommended based on the assessment of relevant ecosystem services. The procedure can also be used to compare multiple features or various methods of implementation of a measure, aiming to select the most effective measure (e.g., one that achieves the shortest rate of return, best benefit-cost ratio, etc.).

In addition, to the CBA results, it is advisable to provide a verbal summary of the main benefits and costs and to define the part of benefits and costs that could not be valuated. It is advisable to accompany this information with an assessment of their effect on the results.

Based on the methodology, the conclusions and recommendations should indicate the period of time when the total benefits exceed the total costs.

Figure 7: Example of measures – Community garden

Author: Jan Macháč (2018)

4. Common assessment mistakes

Economic assessment of green and blue infrastructure using cost-benefit analysis (CBA) and the ecosystem service concept is associated with numerous challenges, risks and uncertainties. For assessing measures correctly, it is advisable to keep the following weaknesses in mind.

The social utility of different measures differs from case to case. Some benefits only occur after a certain amount of measures has been implemented successfully (e.g., an increase in aesthetic and recreational functions only has an actual impact once the measure has covered a sufficient area). From a certain area threshold, users no longer value any additional square metres.

Conversely, some measures may take several years to start providing benefits such as dust interception, CO_2 absorption, etc. The degree of provision of ecosystem services by green features develops over time. This factor has to be included in the assessment.

Another frequent mistake in economic assessment is multiple inclusions of the same benefit/cost. This happens particularly when the same benefit/cost is valuated using several methods or auxiliary indicators. Thus, double counting of benefits should be avoided when using combinations of methods. Example include the costs of acquisition of land for a newly built park, which overlaps with opportunity costs to some extent. By purchasing the land, the original owner no longer incurs any damage/loss of income (it will be compensated by selling the land). The loss of income is transferred to the new owner, who acquires the land for the purpose of building the measure, however. Double counting may also occur since some methods lead to valuation of a wider range of benefits, resulting in a partial overlap. In this respect, therefore, it is advisable to choose an adequate combination of methods. A possible solution is to update the overview of costs and benefits and progressively mark the costs and benefits that have been valuated.

An alternative mistake is inclusion of secondary impacts that are closely related to the primary impacts already expressed in monetary terms. These may include impacts of adjacent activities, i.e., effect multiplication. This process also often leads to inclusion of the same impact but at a different level.

Numerous uncertainties are then associated with predicting development, discounting of costs and benefits (or using a discount rate to express net present value), application of values from other areas/countries, etc. Therefore, a sensitivity analysis is required when determining social utility to verify the impact of the different assessment input parameters on the analysis results.

Description of methodology applications

The present methodology is intended primarily as background information for planning, decision-making and communicating of construction and maintenance of green and blue infrastructure features in human settlements. As said in the introduction, the methodology is designed for assessment of green and blue infrastructure using monetary expression of costs and benefits and their comparison. A wide range of benefits can thus be expressed with a single figure, which is easier to grasp and imagine in many respects. The common unit (monetary expression) also makes it possible to compare different options of measures (when including identical benefits) or even different measures. When comparing different measures, there may be distortions caused by non-uniform assessment of benefits and differing inclusion of various ecosystem services.

The methodology also enables assessment of impacts of measures already implemented; these data can be used when promoting implementation of similar measures or assessing effectiveness of subsidies or other forms of support and intervention by public administration, self-government or private entities. Examples of other interventions include implementation of an action plan of climate change adaptation strategies at a municipal level.

In light of the above, the methodology has a wide range of applications, corresponding to a quantity of potential users. **At the mayor and municipal level**, methodology application results may be a **support tool for local self-governments** in both selection and planning of features/measures and communication and presentation of measures **towards their citizens**. The methodology procedure and application results are also an **economic argument for non-profit initiatives and private entities** dealing with implementation of green and blue infrastructure features in practice. The methodology is also widely applicable in analogous economic analyses, e.g., analyses assessing impact of regulation at the public administration level.

Although the methodology describes the assessment procedure step by step, it is advisable to entrust its application to someone with certain experience of similar analyses. Applications of cost-benefit analysis (CBA) is frequently connected with numerous methodological mistakes (see chapter 4), such as double-counting of benefits, leading to considerable distortion of results. The degree of relevance of the outcomes thus depends not only on input data quality but on the author’s approach as well.

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Annexes

Annex 1: Assessment procedure application example

The green and blue infrastructure assessment procedure is demonstrated for the purposes of this methodology on an example of a green roof. The procedure here follows the individual steps of chapter 3, from definition of subject matter of assessment to the assessment as such to formulation of conclusions and recommendations.

Description and definition of subject matter of assessment:

The assessment procedure is applied to an intensive green roof implemented as part of an office complex. It is a roof built at the centre of the complex in an inner courtyard over an underground parking garage. The area is situated between two office buildings. The total size of the roof garden is 1,100 m^2. The livable roof park contains garden beds, paths, 22 trees (red maples) and a café. The paths are lined with box shrubs. The substrate thickness is up to 1.5 metres in some places. The garden bed vegetation is grass carpet. The implementation uses two types of roof substrate: extensive as the foundation and intensive as the top vegetation layer. An automated irrigation system was installed due to the need for irrigation. The green roof is accessible not only for employees of companies located in the office buildings but other visitors as well.

For the purposes of green infrastructure measure assessment, the green roof is regarded as an alternative to other roofing types. The costs and benefits are thus derived from the layers above waterproofing. We thus do not deal with the benefits of the roof as such. Given the expected lifetime of green roofs, we set the time horizons at 25 and 50 years.

Qualitative analysis:

The qualitative analysis involves identification of costs and benefits associated with the implementation and operation of the green roof. The total costs comprise investment and operating costs. Opportunity costs and negative externalities are not relevant in this case. The administrative costs can be neglected since the green roof was built as part of the office complex development project. The assessment below makes a more detailed analysis of the investment and operating costs. The investment costs are connected with the protective layer, drainage, substrate, vegetation and the automated irrigation system. The operating costs include particularly the greenery maintenance and irrigation.

The benefits are defined by way of ecosystem services. Based on Table 2 in the methodology, we identified the individual services and other benefits associated with the green roof implementation and operation. A qualitative overview of ecosystem services and other benefits relevant for the green roof assessed is shown in Table 1.

Table 1: Overview of relevant ecosystem services

Ecosystem service	Importance of service/benefit
	Regulating services
Runoff regulation	high (rain water retention)
Noise reduction	low (noise reduction not beneficial due to placement over garage)
Air quality	medium (intensive roof capable of intercepting air pollutants to a degree corresponding to the amount of greenery)
CO_2 reduction	medium (intensive roof capable of reducing CO_2 to a degree corresponding to the amount of greenery)
Microclimate regulation	medium (intensive roof contributes to cooling of inner courtyard climate)
	Cultural services
Recreational function	medium (creates space for staying in greenery, place for breaks; this service is reinforced by the café, which has outside seating here)
Aesthetic value	medium (green roof makes an aesthetic building perception and resolves the problem of covering the underground garage)
	Provisioning services
Biomass production	low (grass material production, usable for composting or sending to a biogas station)
	Other benefits
Energy savings on heating/cooling	medium (prevents heat reflection from surrounding buildings and reduces structural cold bridge of the whole complex)
Property value increase	medium (greenery composition leads to increased attractiveness of the building, hence its price or rent)
Lifetime extension and saving on roofing	high (implementation of green roof leads to saving on roofing and extends the insulation lifetime)
Biotope formation	medium (creates additional living space particularly for insects)

Source: Own analysis

Quantification of costs and benefits:

The quantification of costs was made based on the green roof project design and the resulting budget and on data on operating costs expended in the first three years after the green roof implementation. Unlike an assessment of the measure prior to its implementation, we did not need to quantify the costs by compiling an estimated budget and quantities of work operations.

The quantification of benefits was made based on an analysis of local conditions (average annual precipitation total, sewerage charge and energy prices, price of land occupation) shown in Table 2. The local conditions were determined from data in available statistics (Czech Statistical Office, Czech Hydrometeorological Institute, water utilities and data shown on the Brno city website).

Table 2: Analysis of local conditions

Local conditions	Quantitative data
Average annual precipitation total on city territory	500 mm
Sewerage charge in Brno (2017)	38.66 CZK/m^3
Price of electricity (average price for consumers in Brno in 2017)	4.41 CZK/kWh
Land occupation(2017 data from Brno city website)	10 CZK/m^2/day

Source: Own analysis based on available sources

We also assessed the capacity (degree of provision) of the different ecosystem services and other benefits based on the parameters of the green roof implemented. Table 3 shows data on roof water runoff reduction; noise reduction; reduction of the pollutants NO_2, SO_2, O_3 and PM_{10} and CO_2 reduction; energy savings as one of the manifestations of improved microclimate inside the buildings; and savings on alternative roofing.

Table 3: Quantitative analysis of ecosystem service based on green roof parameters

Ecosystem service	Quantification of impact:	
	Regulating services	
Runoff regulation	rain water runoff reduced by 80% (reduction by 400 l/year/m^2 of roof)	
Noise reduction	noise reduction in the building reduced by 6 dB	
Air quality	**reduction trend derived from data in Annex 2:**	
	Trees	Beds
	NO_2: 0.18 - 0.22 kg/year/tree	NO_2: 16 - 23 kg/ha/year
	SO_2: 0.1 - 0.15 kg/year/tree	SO_2: 4 - 6 kg/ha/year
	O_3: 0.07 - 0.08 kg/year/tree	O_3: 30 - 44 kg/ha/year
	PM_x: 0.08 - 0.10kg/year/tree	PM_x: 8 - 12 kg/ha/year
CO_2 reduction	**reduction trend derived from data in Annex 2:**	
	Trees	Beds
	150 - 200 kg of CO_2/year/tree	700 - 900 kg of CO_2/year
	Cultural services	
Recreational function	75 m^2 of square used for café purposes	

Table 3: Quantitative analysis of ecosystem service based on green roof parameters (continued)

Other benefits	
Energy savings on heating/cooling	energy saving of 12 kWh per m^2 of roof area
Lifetime extension and saving on roofing	insulation lifetime extended by 50%, saving on roofing 360 CZK/m^2

Source: Own analysis based on data contained in methodology

Application of valuation methods:

The monetary expression of costs and benefits applied a wide range of valuation methods. The costs were determined from real market prices based on investment costs expended. The annual operating costs were derived as average maintenance and irrigation costs, including any extra expenditures. The average was determined based on real operating costs for the three years of the green roof existence so far.

Due to their importance and data availability, the following ecosystem services and other benefits were selected for the monetary valuation of benefits: runoff regulation, noise reduction, air quality, CO_2 reduction, recreational functions, energy saving and extended insulation lifetime. The different benefits were valuated using appropriate methods, detailed in Table 4.

Table 4: Assignment of suitable valuation method for individual ecosystem services (benefits)

Ecosystem service	Valuation method based on:
Regulating services	
Runoff regulation	market price (cost saving on wastewater treatment at WWTP)
Noise reduction	costs of alternative measures (noise reduction). Although the green roof contributes to noise reduction, the effect is negligible for a roof over a parking garage and is valuated at 0 CZK (the benefit is included for comprehensiveness and used further in Option 2).
Air quality	costs of alternative measures leading to interception of same amount of pollutants from the air: dust particles, nitrogen oxides, sulphur oxides and ozone
CO_2 reduction	average obtained using methods based on mitigation costs for the same amount of CO_2 emissions, costs of alternative measures and market price of CO_2 permits
Cultural services	
Recreational function	market price (land occupation for café)

Table 4: Assignment of suitable valuation method for individual ecosystem services (benefits) (continued)

Other benefits	
Energy savings	market price (energy saving on cooling and heating)
Lifetime extension and saving on roofing	mitigation costs and market price derived from costs of roofing acquisition and insulation replacement including associated work

Source: Own analysis

Expression of costs and benefits in monetary units:

The costs and benefits were determined in monetary units based on the application of the above methods; we calculated the net present value for the horizons of 25 and 50 years.

The total costs expressed in monetary terms comprise the investment costs of 3,392,400 CZK excl. VAT and the average annual operating costs of 85,946 CZK. The operating costs include costs of greenery maintenance and irrigation (drinking water consumption).

Table 5 shows the monetary expression of the benefits.

Table 5: Overview of benefits expressed in monetary units

Ecosystem service	Monetary expression:
Regulating services	
Runoff regulation	17,010 CZK/year
Noise reduction	CZK 0
Air quality	2,946 CZK/year
CO_2 reduction	15,806 CZK/year
Cultural services	
Recreational function	157,500 CZK/year
Other benefits	
Energy savings	58,212 CZK/year
Extended lifetime	726,000 CZK (one-off)

Source: Own analysis

Conversion of all the individual costs and benefits to present value using Equation 1 yields the economic assessment results. Table 6 shows the present value of the costs and benefits and their comparison and determination of the net social benefits for both time horizons. The results indicate that the valuated costs exceed the benefits expressed in monetary terms at the 25-year horizon. The benefits exceed the costs at the 50-year horizon. The rate of return on the investment from the society point of view, i.e., the time when the valuated benefits exceed the valuated costs, is 30 years.

Table 6: Overview of results of measure assessment

25 YEARS	TIME HORIZON	50 YEARS
CZK 4,604,572	Cumulative present value of COSTS	CZK 5,108,223
CZK 4,309,316	Cumulative present value of social BENEFITS	5,884,725 CZK
CZK -295,256	**Net present value of social benefits at the horizon**	**776,503 CZK**

Source: Own analysis

The results in Table 6 can be further expressed using the benefit-cost ratio. The ratio is 0.94 for the 25-year horizon; i.e., the costs exceed the benefits by 6%. In other words, costs of 1 CZK lead to provision of benefits worth 0.94 CZK. For the longer period, however, the benefits exceed the costs: 1 CZK of costs leads to 1.15 CZK of benefits. The higher the benefit-cost ratio, the more socially beneficial a measure is.

Testing of conclusions using sensitivity analysis:

Sensitivity analysis was used to identify the sensitivity of change in input parameters to the economic assessment results; in this case, the costs and benefits expressed in monetary units to rates of return on measures from the society point of view. The sensitivity analysis focused on testing the effect of the discount rate, and was made using scenarios (2% and 6% discount rates). Table 7 shows the results in the form of rates of return on measures from the society point of view and their change depending on the discount rate applied. For the green roof assessed, the results (rates of return) differ depending on the discount rate chosen by 7 years between the optimistic and baseline scenario, and more in the case of the pessimistic scenario. This indicates that the discount rate has a significant effect on the assessment results. The discount rate choice thus affects the results. We could test for other input variables analogously.

Table 7: Sensitivity analysis

RATE OF RETURN [YEARS] FOR SCENARIO		
OPTIMISTIC (2%)	BASELINE (4%)	PESSIMISTIC (6%)
23	30	>50

Source: Own analysis

Formulation of conclusions and recommendations:

The results indicate that the measure is beneficial for society in the longer time horizon. If we include a qualitative description benefits we were unable to valuate, the result is at least balanced even in the shorter period of 25 years. In the shorter horizon assumed in particular, the results are influenced primarily by the green roof type chosen and its location over a parking garage. The sensitivity analysis shows that the discount rate applied also plays an important role.

In the context of the results, therefore, the economic analysis was carried out on a modified project design in the other options. Beside the baseline option, assuming the green roof in its implemented form as assessed above (i.e., benefits from noise reduction and energy savings are limited by the fact that the roof is over a parking garage), we also made the assessment for an alternative option, where the green roof would be placed over a part of the complex that contains offices. Compared to the baseline option implemented, this would achieve greater benefits from energy savings on office space cooling and reduction of interior noise in the building, which would make a positive contribution to the assessment results and rate of return from the society point of view.

The rate of return from the society point of view is reduced from 30 years in the baseline option implemented to 12 years in the alternative option with the green roof over the offices. Table 8 shows the analysis results for the 25 and 50-year horizons, and Table 9 below shows the sensitivity analysis. The benefit-cost ratio is 1.4 at 25 years and 1.7 at 50 years. This means that 1 CZK of costs is compensated for by 1.40 and 1.70 CZK of benefits, respectively. This extension of the baseline assessment scenario thus demonstrates the applicability of the assessment procedure to selection between possible implementation scenarios and benefits of green and blue infrastructure measures.

Table 8: Modified project assessment

25 YEARS	TIME HORIZON	50 YEARS
CZK 4,604,572	Cumulative present value of COSTS	CZK 5,108,223
CZK 6,466,563	Cumulative present value of social BENEFITS	8,724,229 CZK
1,861,990 CZK	**Net present value of social benefits at the horizon**	**3,616,006 CZK**

Source: Own analysis

Table 9: Modified project sensitivity analysis

RATE OF RETURN [YEARS] FOR SCENARIO		
OPTIMISTIC (2%)	BASELINE (4%)	PESSIMISTIC (6%)
11	12	13

Source: Own analysis

As part of the conclusions and recommendations, therefore, it can be stated that both green roof implementation options are beneficial in the long run. It would be advisable to implement a green roof over the offices in order to optimise the society-wide impact. However, all the benefits were not fully valuated in either of the green roof options (over garage and offices); for this reason, the net present benefits can be regarded as rather underestimated, and the rate of return overestimated.

Annex 2: Catalogue of basic biophysical values

Measure name	Benefit expression method	Biophysical expression
Regulating services		
Runoff regulation		
Restoration of riparian vegetation	Share of volume of retained precipitation water in total precipitation	up to 60%
Polder	Share of volume of retained precipitation water in total precipitation	up to 50%
Infiltration strips	Share of volume of retained precipitation water in total precipitation	up to 90%
Permeable surface areas	Share of volume of retained precipitation water in total precipitation	depending on surface type and substrate, 57–80%
Trees in cities	Maximum water volume retained per tree	Small tree (H 6.7 m x W 6.4 m): 1,105 L/year
		Medium tree (12.2 m x 8.2 m): 4,273 L/year
		Tall tree (14.3 m x 11.3 m): 8,183 L/year
Extensive green roof	Share of volume of retained precipitation water in total precipitation	30–70%
Intensive green roof	Share of volume of retained precipitation water in total precipitation	70–95%
Garden allotment	Share of volume of retained precipitation water in total precipitation	up to 90%
Urban parks	Share of volume of retained precipitation water in total precipitation	up to 90%
Water quality		
Water bodies in cities	Average percentage of total phosphorus removal	up to 50%
	Average percentage of total nitrogen removal	up to 75%

Polder	Average percentage of pollutant removal (phosphates, nitrates, sulphates)	70-80%
Permeable surface areas	Average percentage of interception of total suspended sediments	approx. 90%
	Average percentage of zinc interception	up to 85%
	Noise reduction	
Extensive green roof	Reduced noise in the building (decibels)	up to 5 dB
Intensive green roof	Reduced noise in the building (decibels)	up to 6 dB
Green wall	Reduced noise in the building (decibels)	up to 5–40 dB, depending on wall type
	Air quality	
Trees in cities	Quantity of pollutants intercepted	Tall tree *(6.7 m x 6.4 m)*: NO_2: 0.18 kg/year SO_2: 0.1 kg/year O_3: 0.07 kg/year PM_X: 0.08 kg/year
		Medium tree *(12.2 m x 8.2 m)*: NO_2: 0.29 kg/year SO_2: 0.19 kg/year O_3: 0.09 kg/year PM_x: 0.12 kg/year
		Tall tree *(14.3 m x 11.3 m)*: NO_2: 0.50 kg/year SO_2: 0.31 kg/year O_3: 0.13 kg/year PM_x: 0.16 kg/year
Extensive green roof	Quantity of pollutants intercepted	NO_2: up to 16 kg/ha/year SO_2: up to 4 kg/ha/year O_3: up 30 kg/ha/year PM_X: up to 8 kg/ha/year
Intensive green roof	Quantity of pollutants intercepted	NO_2: up to 23 kg/ha SO_2: up to 6 kg/ha O_3: up 44 kg/ha PM_X: up to 12 kg/ha
Green wall	Quantity of pollutants intercepted	NO_2: up to 40% PM_X: up to 60%

	CO_2 reduction	
Trees in cities	Greenhouse gas reduction (CO_2) per tree	Tall tree *(6.7 m x 6.4 m)*: 150 kg of CO_2/year
	Greenhouse gas reduction (CO_2) per tree	Medium tree *(12.2 m x 8.2 m)*: 200 kg of CO_2/year
	Greenhouse gas reduction (CO_2) per tree	Tall tree *(14.3 m x 11.3 m)*: 330 kg of CO_2/year
Extensive green roof	Greenhouse gas reduction (CO_2)	up to 700 kg of CO_2/ha
Intensive green roof	Greenhouse gas reduction (CO_2)	up to 900 kg of CO_2/ha
	Microclimate regulation	
Solitary trees, tree avenues	Air temperature reduction around tree	0.35–5°C depending on current temperature and amount of greenery
	Reduction in physiologically equivalent temperature	0.5–27 °C depending on current temperature and amount of greenery
Extensive green roof	Roof (building envelope) temperature decrease	up to 25°C depending on green roof type (and roofing in the comparison)
Intensive green roof	Roof (building envelope) temperature decrease	up to 50 °C depending on green roof type (and roofing in the comparison)
Extensive green wall	Building interior temperature decrease	up to 2°C
Intensive green wall	Building interior temperature decrease	up to 5 °C
Urban parks	Air temperature reduction	up to 2.5 °C
	Cultural services	
Green and blue infrastructure elements	Property price increase (depending on element, its extent and initial situation)	5–15% of value of property and adjacent flats with a view of the trees (one-off benefit)

Provisioning services (crop production)		
Garden allotment	Average fruit and vegetable production	80 kg/100 m^2
Other services		
Energy savings		
Intensive green roof	Percentage savings on heating and cooling	10–50%
Extensive green roof	Percentage savings on heating and cooling	up to 10%
Green wall	Percentage savings on heating and cooling	up to 50%
Extended lifetime		
Green roofs	Extended insulation/roof lifetime	up to 20 years

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Annex 3: Catalogue of costs of measures

The methodology development included a data collection for costs of implementation of a selected set of measures. Each type of measure/feature was represented at least by 10 implemented measures.

INVESTMENT COSTS		OPERATING COSTS	
Fountains			
Investment costs of art, construction and process equipment	As per local conditions	Operating costs of maintenance and drinking water and electricity consumption (pump, evening lighting, etc.)	As per local conditions
Restoration and establishment of oxbow arms (pools and wetlands)			
Investment costs of material and construction work	Wetland, wetland pond, pool up to 1,000 m^2 (excl. land purchase costs): from 1,600 CZK/m^3	Operating costs include maintenance of greenery on the bank/dam, maintenance of any structures (inlet, outlet, overspill, etc.), technical and safety supervision of the structure and mud and sediment removal	Grass mowing: from 10 CZK/m^2 Mud removal costs: 200-350 CZK/m^3 of sediment

INVESTMENT COSTS		OPERATING COSTS	
Open water bodies in cities			
Investment costs of material and construction work	Small water reservoir up to 1,000 m^2 (excl. land purchase costs): from 1,900 CZK/m^3	Operating costs of grass mowing and seedling removal on the bank/dam, maintenance of structures (inlet, outlet, overspill, etc.), technical and safety supervision of the structure and mud and sediment removal	Grass mowing: from 10 CZK/m^2 Mud removal costs: 200-350 CZK/m^3 of sediment
Restoration of riparian vegetation			
Investment costs of restoration - cutting and planting of new woody plants	Cutting of grown trees: thousands of CZK/tree Removal of shrubbery, including vegetation trucking: 20-550 CZK/m^2 Planting of trees and shrubs: hundreds of CZK/plant	Operating costs of vegetation maintenance and restoration	Grassland mowing: 3-10 CZK/m^2 Rejuvenating pruning of shrubs and trees with small-scale thinning: 40–60 CZK/plant
Construction of polders			
Investment costs of material and construction work	from 500 CZK/m^3 (depending on size, excluding land purchase costs)	Operating costs of grass mowing and seedling removal on the banks and dyke and in the flooding part of the polder (2-3 times a year), maintenance of structures (dyke, outlet device, safety overspill, etc.), technical and safety supervision over the hydraulic structure and mud and sediment removal	Grass mowing: from 10 CZK/m^2 Mud removal costs: 200-350 CZK/m^3 of sediment

INVESTMENT COSTS		OPERATING COSTS	
Infiltration/retention ditch			
All investment costs (notably earth works and swale reinforcement) excluding land purchase costs and administrative costs	From 1,300 CZK/length metre (3x1 m)	Operating costs of grass mowing and seedling removal (2-3 times a year), cleaning and sediment removal	Grass mowing: from 40 CZK/length metre Cleaning: from 20 CZK/length metre
Permeable surface areas			
Investment costs of material and construction work depending on permeable surface type chosen, existing uses of the area and substrate composition and inclination	Gravel lawn: 300-900 CZK/m^2	Maintenance operating costs	Gravel lawn: 0-25 CZK/m^2
	Surface of gravel or aggregate: 290-800 CZK/m^2		Surface of gravel or aggregate: 0-25 CZK/m^2
	Vegetation pavers: 650-1,800 CZK/m^2		Vegetation pavers: 0-25 CZK/m^2
	Pavers with grassed joints: 750-1,850 CZK/m^2		Pavers with grassed joints: 0-25 CZK/m^2
	Porous pavers: 750-1,900 CZK/m^2		Porous pavers: 0-25 CZK/m^2
	Plastic grass blocks: 700-1,350 CZK/m^2		Plastic grass blocks: 0-25 CZK/m^2
	Grassy infiltration strips: 7,500-85,000 CZK/ ha		Grassy infiltration strips: from 10 CZK/m^2

INVESTMENT COSTS		OPERATING COSTS	
Solitary trees, tree avenues			
Planting into holes including substrate (assuming 100% soil replacement, incl. substitute substrate; i.e., including preparation, digging, planting, anchoring and transplant protection)	750 CZK/plant excl. VAT (bare-rooted tree up to sapling) to 5,000 CZK/plant excl. VAT (superior park tree)	Pruning (depending on difficulty category)	5,300–26,200 CZK/plant excl. VAT
Costs of tree seedling	from 320 CZK/plant excl. VAT (non-fruit half-sapling) to 8,400 CZK/plant excl. VAT (avenue tree, trunk circumference 16-18 cm, with root ball)	Binding in the crown, including installation	2,650 CZK/plant excl. VAT
Follow-up management of plantings	From CZK 150/plant	Tree cutting depending on trunk diameter (for tree replacement, depending on trunk diameter at the stump cut surface)	1,300 CZK/plant excl. VAT (trunk circumference 20-30 cm) to 28,000 CZK/plant excl. VAT (trunk circumference 90-100 cm)
Extensive green roof			
Investment costs of materials (insulation layer, sheet, fabric, substrate, vegetation) and execution	Ordinary standard (ordinary roof) from 700 CZK/m^2	Operating costs of waterproofing and greenery inspection (1-2 times a year)	Ordinary standard: 15-50 CZK/m^2
	Higher standard (slanting roof, >15°): 2,250 CZK/m^2		

INVESTMENT COSTS		OPERATING COSTS	
Intensive green roof			
Investment costs of materials (insulation layer, sheet, fabric, substrate, vegetation) and execution	Ordinary standard: 1,500 CZK/m^2	Costs of irrigation and periodic gardening care (frequency depending on vegetation demands)	40-800 CZK/m^2
	Higher standard (roof garden): 2,500 CZK/m^2 or more		
Intensive green wall			
Investment costs of growing containers or structures, substrate, irrigation and fertiliser system and plants, including installation on building	12,000-21,000 CZK/m^2	Operating costs of irrigation and fertiliser and costs of greenery maintenance (trimming, plant replacement, etc.)	Depending on green wall accessibility: 100-250 CZK/m^2/year
Extensive and semi-intensive green wall			
Investment costs of seedlings	Ivy (10-15 cm): 25-35 CZK/plant	Operating costs of gardening care and gutter cleaning	Depending on wall extent and height: 530-4,400 CZK/year
	Ivy (40-60 cm): 170-210 CZK/plant		
	Ivy – pre-grown wall (180x100x40 cm): 5,800 CZK/plant		
	Grapevine (2 L container): 230-370 CZK/plant		
Investment costs of making planting holes, costs of soil acquisition	As per local conditions		
Investment costs of support structure, incl. work	Metal espalier drilled in façade, or slat frame: 370-530 CZK/m^2		

INVESTMENT COSTS		OPERATING COSTS	
Garden allotment			
Investment costs of fencing the area and each garden, landscaping, adjustments to existing vegetation, building facilities, energy supplies, acquisition of garden tools, etc.	As per local conditions	The operating costs comprise land lease, costs of water (drinking and utility), energies, plantings, administrative costs of accounting, coordination of garden works, etc.	As per local conditions
Urban parks			
Investment costs of park implementation excluding costs of land purchase	As per local conditions	Maintenance costs:	from 10 CZK/m^2

Annex 4: Brief introduction to basic methods suitable for valuation

The (anthropocentric) monetary value of costs and benefits of green and blue infrastructure in urban settings can be determined using one of a wide range of quantitative valuation methods. They differ substantially in working with primary or secondary data. The most accurate expression is in monetary units based on market value; this can be used to valuate most costs, but only a part of benefits. Many cases require the use of another method or its combination with the market price method. We can also use primary surveys of manifestations of people's behaviour on existing markets or their hypothetical behaviour in model situations (questionnaires). Such methods are used to identify people's preferences or utility from green and blue infrastructure in the form of their willingness to pay or willingness to receive compensation (for provision or non-provision of ecosystem services, respectively).

If green and blue infrastructure produces ecosystem services that are purchased and sold on a market, the benefits of such measures and features can be valuated using the **market price method**. An application of this method is possible, e.g., for garden allotments, where production of crops such as fruit, vegetables and any other biomass can be easily valuated. Market price statistics are available for these goods and can be used for quantification of the value of this provisioning ecosystem service.

Market prices can also be used for blue infrastructure features and measures. For instance, if we know that implementation of features or measures will contribute to regulation of rain water runoff to the sewerage or if improvement in water quality is expected, we can express the benefit of the measure as a cost saving on wastewater treatment at WWTP or cost saving on sewerage construction or split sewerage maintenance.

Existing market prices of CO_2 emission permits can be used if we know that the implementation of a green measure such as a tree avenue or a green roof will lead to a CO_2 reduction. The product of the permit price and the CO_2 reduction represents the monetary expression of the measure benefit in relation to CO_2 reduction.

The **damage cost avoided method**, the **replacement cost method** and the **substitute cost method** are other methods that enable valuation of benefits from ecosystem services of green and blue infrastructure based on known costs. The methods are often confused due to their similarity.

The **damage cost avoided valuation method** makes it possible to valuate a benefit of green or blue infrastructure using costs of avoided damage that would occur if the measure was not implemented. In other words, the benefit of a measure or feature is expressed using potential costs that can be avoided if green or blue infrastructure is implemented.

For infrastructure reducing water runoff from an area (e.g., implementation of a wetland, permeable surfaces, etc.), the benefit of such measures can thus be quantified using quantification of expected damage that would occur on adjacent property in the event of (flash) floods, owner's costs of flood protection measures, costs of property insurance, etc.

The **replacement cost method** valuates green and blue infrastructure benefits based on potential costs of replacement of their ecosystem services with other means and methods.

For green and blue infrastructure reducing soil erosion, the benefit of such measures can be imagined as costs that would have to be expended on practical replacement of soil loss (soil acquisition, transport, etc.) and replacement of soil nutrient loss (price of fertiliser) in case the soil erosion was not reduced, e.g., by implementation of protective grassing.

The **substitute cost method** quantifies green and blue infrastructure benefits using costs of a different type of measure that would provide the same ecosystem services.

For green infrastructure such as green roofs or walls, the same results in relation to elimination of pollutants can be achieved by a different technical or investment solution.

Analogously, in the case of building of permeable surfaces or wetlands reducing the risk of (flash) floods, the same effect can be achieved using technical solutions such as flood barriers, etc. The costs of alternative solutions (substitute costs) with the same effect can be regarded in this method as an estimate of benefits provided by green or blue infrastructure. However, it is not advisable to use this valuation of other green and blue infrastructure features, as they usually provide a wide range of benefits as well.

Cultural ecosystem services can be valuated using the **hedonic price method**, which again considers the price of other goods traded on markets (most commonly property prices). It can be used to derive the aesthetic value of green and blue infrastructure features. It follows from a number of studies (e.g., Wolf, 2007; Tomalty and Komorowski, 2010; Kolbe and Wüstemann, 2015) that the value of a property is significantly affected by availability of green infrastructure in its surroundings.

The **travel cost method** is another type of method that can be used for valuating green and blue infrastructure benefits. The method is based on the assumption that the costs that people are willing to expend on travelling to see nature are an estimate of their willingness to pay for natural goods. It can be used for valuating the recreational function of individual features.

An example of the application is a situation where we examine the change in travel costs in the case of construction of new features, etc.

The **choice experiment valuation method** is appropriate for valuating recreational benefits, aesthetic value and change in biodiversity. The method is based on a questionnaire survey which offers the respondent a set of alternative choices/products from which the respondent chooses the most preferred option.

This method can be used, e.g., to valuate aesthetic value of urban greenery or recreation benefits of blue infrastructure. As part of a 2018 project, we implemented a choice experiment focused on urban parks, aiming to identify the recreational and aesthetic functions of parks and valuate selected attributes of parks. The description of application of this method and its results are shown in Annex 5.

If there is a sufficient number of studies on a feature or measure, dealing with valuation of its benefits using one of the above methods, **benefit transfer** can be used for time and money-saving reasons.

The benefit transfer method makes it possible to valuate green and blue infrastructure features such as ponds, wetlands or parks in urban settings in the Czech Republic if local conditions are specified (e.g., average precipitation, temperature, size, population, GDP rate, etc.). The method is typically used for transfer of recreational ecosystem services for types of measures and features frequently used in practice. Transferring secondary data from abroad and transferring of values into the Czech context requires consideration of local conditions. Transferring values from different vegetation zones without any consideration to local aspects is absolutely inappropriate. The greatest time savings are admittedly achieved in the assessment, but the result is distorted data with zero information value.

Annex 5: Choice experiment results

Besides developing the present methodology, the project also included valuation of missing aspects using primary valuation. The attention was focused on the recreational and attention functions of green and blue infrastructure features.

A choice experiment was developed and implemented in five cities (**Děčín**, Pardubice, **Liberec, Brno and Prague**) between 2017 and 2019. The literature survey and testing was followed by definition of 4 attributes, each with three levels. They were as follows:

- **annual voluntary contribution** (three levels of contribution, specific for each city),
- **greenery type** (nature-based park, semi-natural park and urban garden),
- **brook type** (nature-based stream, semi-natural stream and stream running in a pipe),
- **facilities** (benches, bins and toilets).

Illustrative photographs were selected for each attribute, a graphic design for the choice cards was made, a questionnaire was developed and transmitted into the electronic form. The collection was made using tablets, where the answers were recorded. Interviewers were trained and places for data collection were identified in each city so as to include various types of green and blue infrastructure. The collection was made on various days and times so as not to exclude any categories of respondents.

The results presented below are based on almost 900 interviews carried out in Děčín, Liberec, Brno and Prague. The results from Pardubice could not be included in the methodology due to the data collection timing.

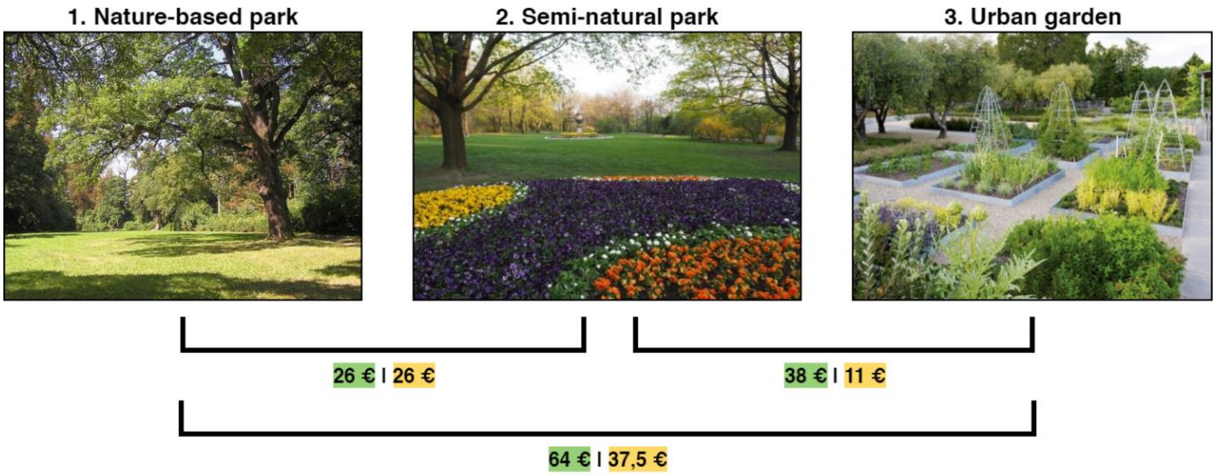
Choice experiment results

The results from the different cities indicate certain differences in local inhabitants' preferences. The model for Děčín, for example, indicates that a considerable part of the respondents disregarded the price in their decision-making. Compared to that, the other cities (where higher contribution amounts were used due to purchasing power) show negative price coefficients, which means that, ceteris paribus, a higher price is connected with a lower probability of choosing an option and with lesser utility.

Generally, it can be said that people prefer a natural form of both urban parks and brooks. The resulting coefficients are positive and statistically significant. Thus, people chose more frequently those options that contained natural features and are thus connected with higher utility for the citizens. Semi-natural parks and urban gardens are not preferred very much. People in Děčín are willing to pay 1,809 CZK (71 EUR) more a year for a nature-based park compared to a semi-natural one. Conversely, the preferences for nature-based parks in Brno are almost identical to those for semi-natural parks. The coefficients for semi-natural parks in Liberec and Prague are not statistically significant and comparisons are not advisable; nevertheless, the strong preference for nature-based parks remains in these cities as well. Results for the different greenery types and cities are shown in Figure 1 for Liberec and

Prague, Figure 2 for Děčín and Figure 3 for Brno. Three figures are chosen deliberately due to the different ranks of preferences.

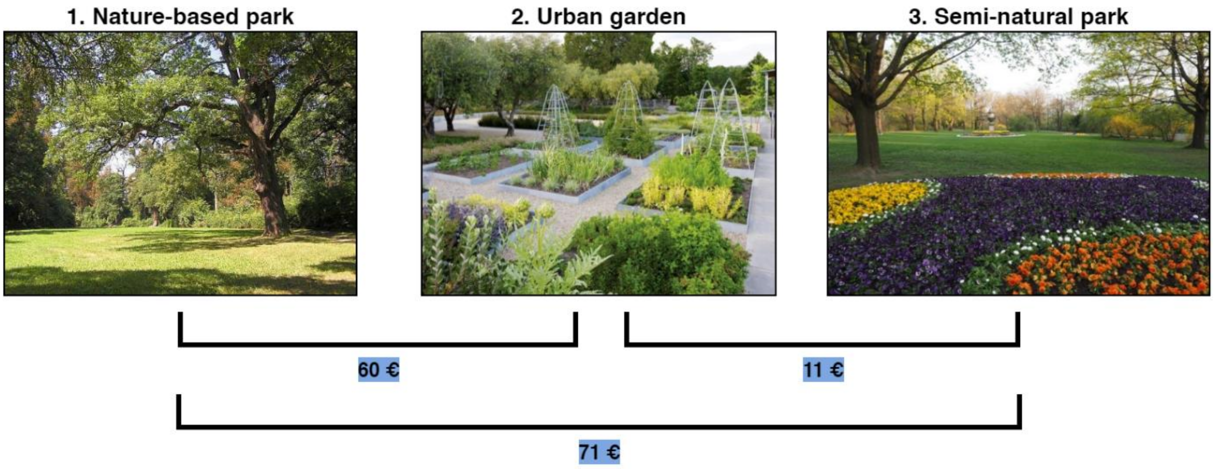
Figure 1: Relative willingness to pay for green infrastructure in Liberec and Prague



*Key: values are shown progressively for **Liberec** and **Prague**.*

Source: own processing

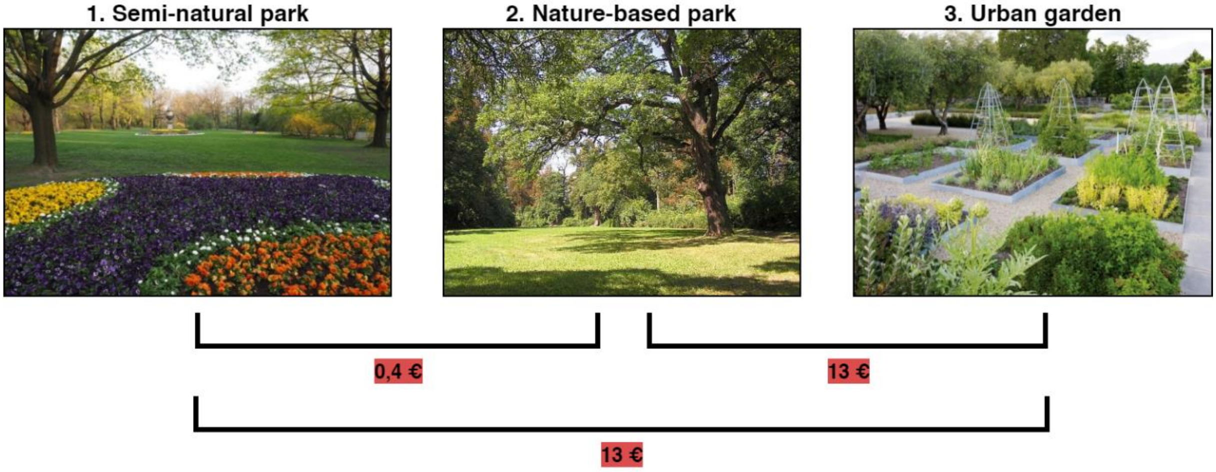
Figure 2: Relative willingness to pay for green infrastructure in Děčín



*Key: values shown are for **Děčín**.*

Source: own processing

Figure 3: Relative willingness to pay for green infrastructure in Brno

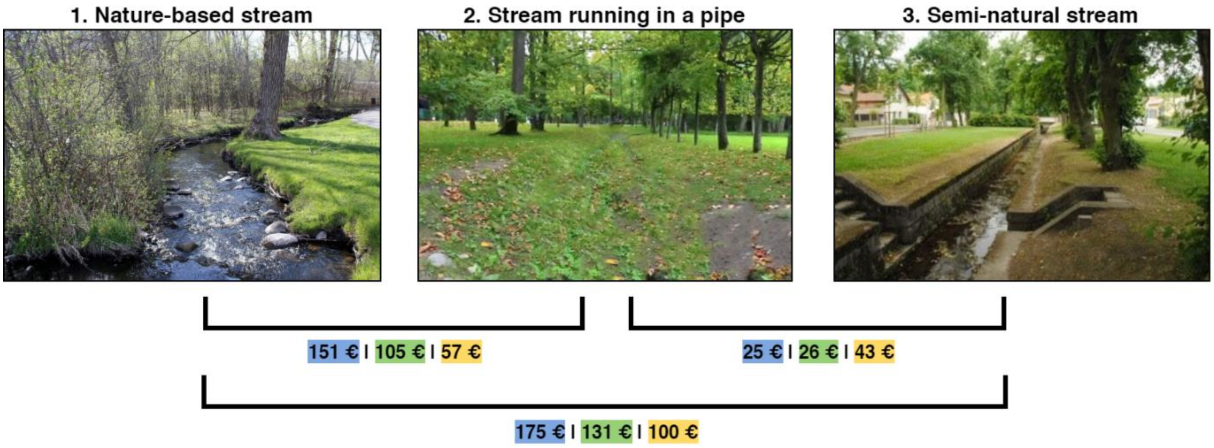


*Key: values shown are for **Brno**.*

Source: own processing

Even stronger positive preferences were identified for nature-based streams, which respondents in Děčín value 4,480 CZK (175 EUR) more than a semi-natural one; the values are 3,350 CZK (131 EURO) in Liberec, 395 CZK (15.5 EUR) in Brno and 2,563 CZK (100 EUR) in Prague. With the exception of Brno, a stream running in a pipe is surprisingly preferred a little over a semi-natural one. The results are shown in Figure 4 for Děčín, Liberec and Prague and Figure 5 for Brno. Two figures are chosen deliberately due to the different ranks of preferences in Brno compared to the other cities.

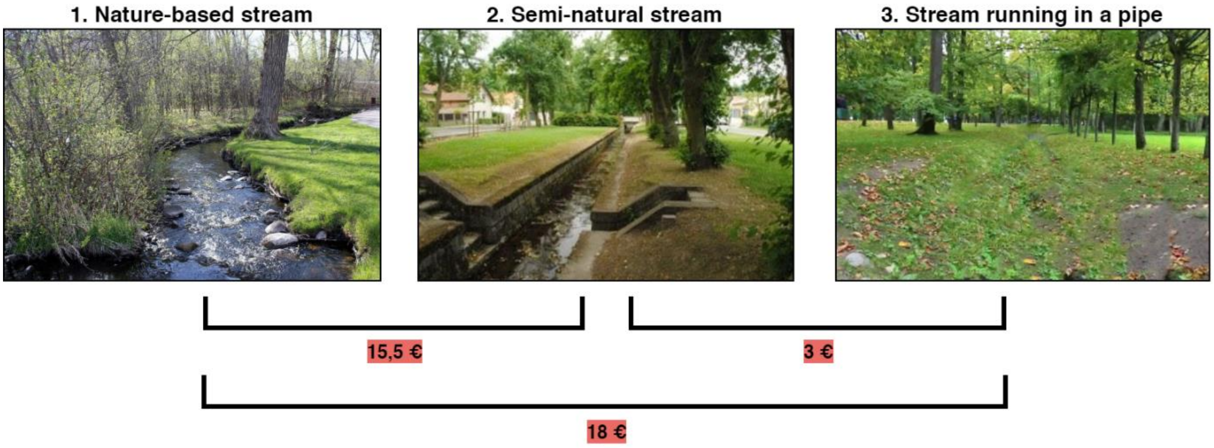
Figure 4: Relative willingness to pay for blue infrastructure in Děčín, Liberec and Prague



*Key: values are shown progressively for **Děčín**, **Liberec** and **Prague**.*

Source: own processing

Figure 5: Relative willingness to pay for blue infrastructure in Brno

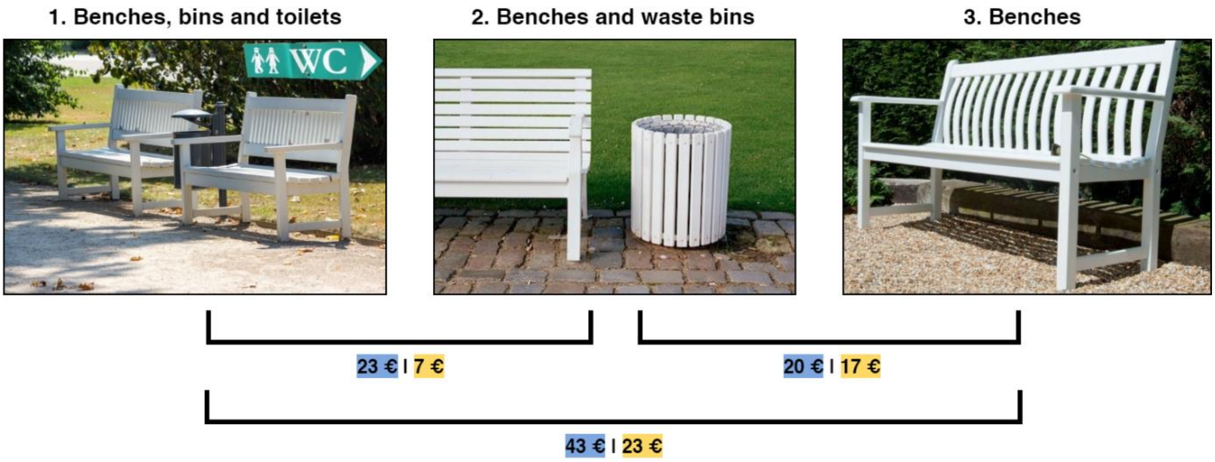


Key: values shown are for ***Brno****.*

Source: own processing

The results for park facilities are not quite unequivocal. Whereas people in Děčín and Prague showed preferences for more abundant facilities (benches, bins and toilets), Liberec and Brno prefer the option without toilets slightly more. Nevertheless, the differences in the coefficients are not as significant as in the previous cases, and are not always statistically different from zero. The results are shown in Figures 6 and 7.

Figure 6: Relative willingness to pay for urban park facilities in Děčín and Prague



Key: values are shown progressively for ***Děčín*** *and* ***Prague****.*

Source: own processing

Figure 7: Relative willingness to pay for urban park facilities in Liberec and Brno

*Key: values are shown progressively for **Liberec** and **Brno**.*

Source: own processing

The choice experiment also examined the effect of several sociodemographic variables on preferences regarding green and blue infrastructure in cities. It turns out that the willingness to pay for these features in cities decreases with age, namely by 15-73 CZK (0.6 – 2.6 EUR) a year, depending on the city. Conversely, willingness to pay increases with education, up to the order of several thousand CZK a year. However, this attribute is probably correlated with respondents' income, which was not included in the model, because many of the inhabitants refused to tell the amount of their income in the interviews. Higher education is typically connected with higher wages; therefore, more educated people are willing to pay higher amounts for green and blue infrastructure. Gender only affects the willingness to pay in the models for Brno and Prague; the effect is reversed in each city. Whereas women in Brno are willing to pay hundreds of CZK more for natural features than men, the situation is the reversed in Prague.

Generally, it can be said that people have a relatively strong preference for natural features in cities. Whether they are a natural form of a park or a naturally-looking brook, people are willing to pay more for such features. In this respect, the results do not differ among the cities very much. The perceptions of park infrastructure are different: toilets are not requested everywhere. Younger people with higher education are willing to pay more for the options chosen.

Summary

The methodology for economic assessment of green and blue infrastructure (GBI) in human settlements is a unified comprehensive tool for assessing GBI elements. It is designed primarily as a basis for planning, decision-making and communication concerning construction and maintenance of GBI elements and nature-based measures. In addition, it can be used for raising awareness of benefits of natural spaces in cities. GBI elements provide a wide range of utilities in the form of ecosystem services, on the monetary valuation of which the methodology focuses.

First of all, the methodology defines GBI and its elements. Then, it introduces the concept of ecosystem services, aimed at identification and specific definition of adequate regulatory, provisioning, cultural and supporting services of GBI in the urban environment.

The main part of the methodology deals with the assessment procedure itself. The assessment is based on modified cost-benefit analysis (CBA). The procedure consists of several consecutive steps, described in detail in the methodology.

The starting step of the assessment is identification and definition of green and blue infrastructure elements or measures that are subject to the assessment. This is followed by a basic identification and qualitative description of costs and benefits. On the cost side, the methodology analyses costs related to construction of green and blue infrastructure (investment costs) as well as all costs related to maintenance (operating costs). The methodology also describes potential costs of sacrificed opportunity and any other negative impacts of measures (negative externalities, administrative costs). On the benefit side, the methodology applies the concept of ecosystem services in order to help identify adequate services.

The next step is a quantitative analysis, closely linked to the choice of a suitable method of monetary valuation of costs and benefits. The costs (investment, operating – periodic and one-off) are valuated in monetary terms typically based on market prices. In the case of negative externalities, the procedure is usually identical to that for benefits. The methodology contains an approximate overview of average investment and operating costs of selected elements/measures.

The basis of the quantitative analysis of benefits is usually a definition of biophysical units representing the amount of ecosystem services provided. An annex contains an overview of selected values for individual ecosystem services, which can be used for value transfer. In case using existing market prices for the valuation is not appropriate or possible, the methodology describes options for pricing the individual ecosystem services (benefits) using specific methods.

The methodology recommends expressing the overall benefit of measures in the form of net present value of the benefits for two time horizons, namely 25 and 50 years. The methodology recommends testing the cost-benefit analysis results using a scenario

sensitivity analysis. In addition, there is a recommendation to consider costs and benefits that could not be priced in monetary terms before formulating any conclusions. Furthermore, the results can be displayed as a benefit-to-cost ratio and the indicator of return on investment in measures from a society point of view. The procedure can also be used for comparison of multiple elements or various methods of implementation of a measure in order to choose the most effective measure (e.g., one that has the fastest return on investment, best benefit-to-cost ratio, etc.).

In its conclusion, the methodology points out the most common mistakes, risks and uncertainties associated with economic assessment. In addition to the above, an annex to the methodology contains a template assessment application using the example of a green roof and results of application of the choice experiment to an assessment of cultural services provided by selected green and blue infrastructure elements.

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Methodology for Economic Assessment of Green and Blue Infrastructure in Human Settlements

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