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Green Roof Cost-Benefit Analysis: Special Emphasis on Scenic Benefits

Abstract: This article presents a green roof cost-benefit analysis (CBA). Green roofs are roofs which are partially or completely covered by vegetation. We discuss the benefits and costs of light self-sustaining vegetated roofs. The benefits of the ecosystem services (ES) provided by green roofs can be classified into private and public benefits. We apply the selected valuation methods first in Helsinki, Finland and subsequently explain how results can be transferred to other urban locations. Past research and this study show that private benefits are usually not high enough to justify the expensive investment for a private decision maker. However, when the public benefits are added to the private benefits, social benefits are higher than the costs of green roofs in most cases.

Past research quantified most types of the benefits, excluding scenic and biodiversity benefits. Scenic benefits denote the intangible benefits that people derive from the presence of green space, including at least aesthetic and psychological ones. In this article, special emphasis is placed on the valuation of the scenic benefits; these are among the most challenging benefits to valuate in monetary terms. We employ hedonic pricing theory, implemented via spatial regression models, and green roof implementation scenarios in order to estimate the aggregate willingness to pay for a "unit" of green roof. The results show that the scenic benefits can be a significant attribute in cost-benefit calculations. Yet, the amount of benefits strongly depends on the green roof design.

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1 Introduction

Green roofs are roofs that are partially or (almost) completely covered by vegetation as a result of planned action rather than neglect. Green roofs are an increasing feature of cities' urban planning tool set. Local adaptation plans around the world list green roofs as a tool for both storm-water management and attenuation of the urban heat-island effect, as is the case for adaptation plans of Vancouver, Copenhagen, London, Melbourne, Singapore, Chicago and Barcelona (see Copenhagen, 2015, for a review and links). Green roofs also decrease the energy consumption in buildings (e.g., Berardi et al., 2014) and are identified as a valuable strategy to make buildings more sustainable, and increase urban green in cities while avoiding the negative effects of lowering densities. The inclusion of green roofs to the urban planning tool set creates a high demand for cost-benefit studies to support decision-making with regards to choosing the right implementation strategy, for example, choice of plant cover, needed incentives and efficient scale (U.S. Government, 2011). This article aims to contribute to this increasing demand, and convert the green roof benefits into monetary terms, aggregate monetary values over time and compare benefits to the costs of green roof installation. We focus on the benefits and costs of thin, lightweight, left-sustaining green roofs with minimal maintenance requirements – often labeled as extensive green roofs in the literature (e.g., Berardi et al., 2014).

The benefits and costs of green roofs have been studied for several sites, including New York (Rosenzweig, Gaffin & Parshall, 2006; Bianchini & Hewage, 2012), Toronto (Bantinget al., 2005), Atlanta, Georgia (Carter & Keeler, 2008; Whatley, 2011), Michigan (Clark, Adriaens & Talbot, 2008) and Seoul, South Korea (Shin & Kim, 2015). Additionally, the costs and benefits of green roofs have been studies in more general settings than a specific city context in Germany and Brazil by Porsche and Köhler (2003), in Belgium by Claus and Rousseau (2012), and in the USA by Porsche and Köhler (2003) and Sproul, Wan, Mandel and Rosenfeld (2013). All studies quantified benefits pertaining to membrane longevity, building energy savings, storm-water management and air-quality benefits, while many also quantified reduction of the heat-island effects, noise insulation and greenhouse gas reduction. Scenic benefits that include at least aesthetic and psychological benefits, and biodiversity benefits are usually left out of the analysis. The exceptions are a study by Rosenzweig et al. (2006) in which aesthetic benefits were included by assuming a certain willingness to pay (WTP) for New York residents, and a study by

Bianchini and Hewage (2012) in which percentual (2%–5%) increases in the value of the nearby properties were assumed. Taking into account the state of the art, our main contributions to the literature are (1) ease the transferability of the value estimates by providing detailed information on the valuation methods and the roles of different assumptions and parameter values in the estimates of benefit and cost items and (2) inclusion of scenic value benefit item into the analysis based on a formal and trackable analysis rather than a guess.

The paper is structured as follows: We first discuss the valuation of benefits that people obtain from the consumption of ES, and explain the choice of discount rate. Next, we present all the building blocks and benefit items of a CBA of green roofs and the options to assess them. The presentation is based on an application in Helsinki, Finland, but with added information on how the same item can be treated for another location. In this way we intent to contribute to the spread of benefit-transfer approaches so as to make CBA of green roofs affordable. One section has been dedicated to the valuation of scenic benefits since previous measures of the scenic value individuals place on green roofs are weak at best. Subsequently, we review the costs of green roofs, and finally we discuss the net present value (NPV) of green roofs and present a green roof implementation scenario in which 10% of the city's roof area is being greened, while a distinction is made between public and private costs and benefits. In the conclusion, we summarize the results and reflect on policy options such as needed incentives, and discuss the limitations of our approach.

2 Economic Background

Ecosystem services (ES) are benefits that people obtain from ecosystems (Millennium Ecosystem Assessment, 2005). The concept of ES is useful as it allows to separate different types of services provided by an ecosystem, in this case a collection of green roofs. This allows the valuation of each ecosystem service separately. Within urban areas, the primary issue from the perspective of human well-being is whether urban settlements are able to provide a healthy and satisfying living environment for residents. The emergence and growth of cities is (usually) based on the proximity of producers and consumers that creates common advantages in productions and consumptions. As a consequence, the productivity per acre in cities can get so high that it pushes up land and real estate prices (Brown, 1974). This creates pressure for ecosystems in terms of high opportunity costs of urban green space, while the benefits of ES are not often explicitly valued. The trade-off between ES and urban economic activity is not evenly weighted in the absence of such assessments. Consequently, the interest in ES is rising also for urban environments, which ties in with the need of revising the concept of sustainable urban planning. This article focuses on valuation of benefits of ES of an ecosystem that is not yet a standard solution in most cities: green roofs. The addition of green roofs to the green infrastructure portfolio is promising, as green roofs can raise the supply of ES while avoiding the negative effects of lowering densities.

2.1 Defining the economic value of ecosystem services

Based on the preferences of an individual, the “equivalent in money” can be calculated for a change in the quantity or quality of ES, where the sum of money represents the equivalent effect on the welfare of an individual (Freeman, Herriges & King, 2014). The valuation of urban planning realization effects, for example, trough changes in real estate value, is eventually based on the theoretical concepts of compensating variation and equivalent variation, first adapted to commodity (rather than the price) space by Mäler (1974):

$$v(\mathbf{p}, q_1, y - CV) = v(\mathbf{p}, q_0, y) \tag{1}$$

$$v(\mathbf{p}, q_1, y) = v(\mathbf{p}, q_0, y + EV). \tag{2}$$

The compensating variation, CV in equation (1), is the maximum amount of money that an individual would be willing to pay (WTP), so as to achieve the higher supply of ecosystem service q_1 as compared to $q_{0.}$ The equivalent variation, EV in equation (2), is the minimum compensation that an individual would accept (WTA) to forgo the raise of supply of ES from q_0 to q_1 associated with the enhancement of an ecosystem. The difference between the concepts is that the monetary “value” is measured at different points, either at q_1 or at q_0 in the ES quantity/quality dimension. In the case of green roofs, the correct welfare measure is CV – based on the property rights argument, as the beneficiaries of green roofs do not yet possess the higher level of ES. (The property rights argument is explained, for example, in Boadway, 2006; Arrow et al., 1993).

Hanemann (1991) showed that in the case the good q has a perfect substitute x_i that can be bought at the market place for a price p_i, and assuming interior solution so that $x_i > 0$, both at q_0 and at q_1, there are no income effects and the CV can be calculated by $(q_1 - q_0) * p_i$. Consequently, if the ES replaces a market good/service that would have been bought by the decision maker regardless, it is straightforward to use this avoided costs as a value measure. It should be noted that we do not claim that green roofs are a perfect substitute for conventional roofs but that some ES it provides are perfect substitutes for some market goods. In the subsequent chapters, we use this as a basis for our valuation methods and show that many of the benefits of green roofs are in the form of avoided costs, for example, energy costs or stormwater-related costs.

2.2 Applied valuation methods

There is a variety of methods developed for estimating the value of ES, discussed in detail in several articles (e.g., de Groot, Wilson & Boumans, 2002; Kaval, 2010). Valuation methods all share a target for attributing a monetized value to the benefits obtained from a change in quality or quantity of ES. We discuss only those we have applied in the green roof valuation. The choice of method is dependent on the function of the ecosystem service.

Green roofs are a technical solution that takes advantage of the regulating properties of the vegetation and substrate layers. Many of the ES they provide can be classified into regulating services. These services benefit people mainly by enabling avoidance of other costs. The natural choice of the valuation method is then "Avoided costs" as suggested by de Groot et al. (2002) or on more theoretical terms by Hanemann (1991).

Green roofs, however, benefit people also in subtler ways. There is evidence that green roofs can provide urban habitat for wild species and help to increase the local biological diversity (Coffman & Waite, 2011; Madre, Vergnes, Machon & Clergeau, 2014; Gabrych, Kotze & Lehvävirta, 2016). This "refugium" function of green roofs could be tackled with contingent valuation methods to some extent, but is left out of the scope of this study as it would suffer from lack of adequate quantitative input. Yet, green roofs can also provide aesthetic and psychological benefits for people in urban areas. These benefits have been grouped together in this article as "scenic benefits" for methodological reasons. Hartig, Mang and Evans (1991) proved that experiencing naturel has restorative outcomes and the effect can last for several weeks after the experience. It is widely known that property prices are positively affected by the view and closeness of green space. In Finland Tyrväinen and Miettineni (2000) have shown the positive relationship between the urban green and property prices. We confirm this relationship in our analysis. Hauru, Lehvävirta, Korpela and Kotze (2012) showed that changing the visual setting from urban built-up area to an urban forest offers restorative benefits, while Lee et al. (2015) show that restorative benefits are even elicited by a small urban green roof and are comparable to that of a small urban park. We use the results from the hedonic regression analysis to indicate an upper limit for the scenic value of urban parks, expressed as mark-up of the square meter price of involved real estate.

The scenic value can also be studied by means of the contingent valuation (CV) methodology. Our choice in favor of hedonic pricing (HP) is explained by: (1) HP is the appropriate methodology for valuation of services and disservices that are intrinsically dependent on the *location* of households (Brander & Koetse, 2011); (2) we are able to avoid the bias of stated preferences contained in CV (Brander & Koetse, 2011); (3) there are only a couple of green roofs installed in Helsinki and people lack experience to the extent of turning stated preferences into mere guesses (Murphy, Allen, Stevens & Weatherhead, 2005); and (4) we would expect the results to be of the same magnitude in the case of a CV study (Blomquist, 1988; Carson, Flores, Martin & Wright, 1996; Shabman & Stephenson, 1996; Bateman, Lovett & Brainardi, 2004; Ghermandi, van den Bergh, Brander, de Groot & Nunes, 2010). Expected differences and uncertainties in the hedonic estimates and the use of the proxy are handled by using lower and upper bounds for the value.

2.3 Choice of discount rate

Weitzman (2001) concluded – based on a survey of more than 2000 economists – that the appropriate discount rates for environmental BCA can be summarized in the following simplified scheme based on the project's lifetime: 4% for the immediate future (years 1–5), 3% for years 6–25, 2% for years 26–75 and 1% for years 76–300 and 0% for the benefits and costs for years after 300. The declining trend in the discount rates can be backed by the economic theory on uncertainty (see Gollier & Weitzman, 2010). However, for simplicity and to ease the interpretation of the results, we have applied a single interest rate of 3% which approximates the discount rate schedule above. This choice is also in line with the fixed long-term interest rates applied to mortgages and long-term investment loans. The same interest rate of 3% is also recommend by the U.S: Office of Management and Budget (2003) and by the German treasury. Slightly higher social interest rates are recommended by France (4%) and UK (3.5%) (EU, 2008).

3 The benefits of green roofs in Helsinki and the transferability of the results

In this section, we show how each benefit item of green roof CBA can be treated. We measure the benefits in Helsinki, the capital of Finland, with around 625 000 inhabitants, and a metropolitan area of around 1.1 million inhabitants. We compare our findings to results from the literature. We also divide the benefits between those that directly accrue to the property owner/resident and those that are shared by the wider public, such as savings on in public spending and health benefits. For each benefit, we also show how the results obtained from Helsinki change when changing the city-specific environmental or infrastructural parameters. Furthermore, the valuation methods described in this section can be applied to any other urban location. To ensure replicability and transferability, we take some space to describe the methods.

3.1 Membrane longevity

The historic experience built up with green roofs points at approximately doubling the lifespan of the roofing membrane. This amounts to an additional 20 years lifetime compared to a conventional roof. We use this assumption so that the life cycles are 20 and 40 years for conventional roofs and green roof respectively (Porsche & Köhler, 2003; Liu & Baskaran, 2003; TRC 2007). This is fairly conservative as 40 years is the minimum life cycle of a green roof in other cost-benefit analyses, for example, Bianchini and Hewage (2012). The price of installing a regular bitumen roof in Finland is around 43€/m^2, which includes the value-added tax, as this is a private cost (taxes are removed when analyzing the social benefit and costs). Hence, the NPV of the benefit is 23.8€/m^2 or the discounted price of the reference roof. The factor that determines this benefit is the local cost of the chosen reference roof that the green roof is compared to.

3.2 Energy cost savings

Green roofs have an effect on the heat transfer properties of the roof via three different phenomena (Berardi et al., 2014): (1) substrate increases thermal capacity and decreases thermal transmittance through the roofs, (2) foliage shades, under the foliage convection provokes heat thermal exchange but foliage absorbs part of the thermal energy for photosynthesis and (3) substrate and vegetative layers induce evaporative and evapotranspiration cooling. These phenomena have the potential to reduce the energy consumption for heating in the winter and for cooling in the summer. The benefits of these processes are determined by the type of vegetation, substrate depth, availability of water, local climate and building type (Liu & Baskaran, 2003). We employ the avoided cost method to estimate the savings in the energy costs for an extensive green roof in Helsinki. Our results below show that when moving toward warmer climates, the energy savings in total tend to increase as the cooling energy benefit increases considerably faster than the heating energy benefit decreases.

3.2.1 Energy cost savings for heating

We explore the impact of a green roof on the heating consumption of a building by comparing the heat loss of different types of roof. Green roofs reduce the thermal transmittance of a roof, thereby improving the insulation capacity. This effect is highly dependent on the building envelope characteristics on which the green roofs are placed. Generally, in non-insulated buildings, the impact of green roofs is much higher than in insulated ones, whereas the better the insulation of the roof, the lower the contribution of green roofs. In cold, heating dominated climates, the insulation properties of the roof carry the highest significance as the heating load benefits from a low U value (U is the coefficient of thermal transmittance). (Roche & Berardi, 2014). More complex models have been developed, most notably by Sailor and Hagos (2011) but the use of these models requires a vast amount of input data from local conditions to building characteristics. Based on Sailor's model, a web based calculator has been developed to quantify energy savings, but it is only available for U.S. cities. (Green Building Research Laboratory Websites, 2016). Here, we demonstrate the effects of added insulation of green roofs to reduce the heating load with a model suggested by a senior researcher in energy technology (personal communication, Jokisalo, 2012): We calculate the hourly heat losses of the green roof and the reference roof, and compare the differences between them. Hourly heat losses (q) are calculated as in equation (3), where U = Coefficient of thermal transmittance, A = Roof area, T_s = Target temperature °C inside the building, T_u = Hourly average temperature °C outside (Seppänen, 2001).

$$q = U_1 \times A \times (T_s - T_u). \tag{3}$$

Next, by taking the average of the difference in the annual heat losses of the chosen reference years, we get an estimate for the impact of the green roof on the annual heat loss of a building. To get the impact of the green roof on the energy consumption, we still need to divide the reduction in the heat loss by the combined efficiency of the heat supply and heat delivery system of the building, for example, 95% for a building with a radiator and 100% for an electric heating system (FEA, 2012). Finally, we get the annual savings on the energy use (kWh), converted into monetary savings by multiplication with the price of energy for those buildings heated by district heating (80% share) and with the price of electricity for those building heated by electricity (20% share). The average price of electricity per kWh in Helsinki is 0.115€ and the price of energy used for district heating is around 0.081€ (Energy Authority, 2016). The average price per kWh is then around 0.9€/kWh. Around 30% of the price (of both) are taxes (around 0.27€ per kWh).

We use the same price for both the private and the social benefits, albeit for different reasons. For private benefits, the taxes are included as costs for the private decision maker. On the other hand, external costs of energy production need to be accounted for in the social case. The district heat is produced for over 90% in fossil fuel power stations (∼40% coal; ∼50 natural gas). The origin of the supplied electricity is 50% nuclear, 33% natural gas and the remainder is renewables (mainly biomass as supplementary fuel). Finland takes part in the EU Emission Trade System (ETS), which affects both the production of district heat and electricity (for units beyond a minimum size). The so-called pass through of the ETS prices into power prices is high in Finland (Honkatukia, Mälkönen & Perrels, 2008), meaning that 50%–100% of the carbon price is captured in the end use price (with a higher percentage mostly during winter months). A similarly high pass through may be assumed for district heat, which is a regulated monopoly. This means that the external costs of carbon with respect to global warming are to a large extent captured in the energy price. Now the effects of NOx and SO2 remain to be included. The co-generation power stations are fitted with sulphur and nitrogen emission reduction technology, greatly reducing the emissions of these agents. The costs of these technologies are internalized in the energy prices. Nevertheless some emissions remain of which the costs may be in the order of magnitude 0.25 eurocent/kWh (EU eXterne study, 2005). The indicative external cost per kWh of nuclear power in the EU eXterné study is also rated at approximately 0.25 eurocent/kWh.

In Helsinki, we selected one year (2008) that was near to normal with respect to the observed climate, and one that was unusually warm (2010) to account for the warming of the climate and to be more conservative when estimating the benefits. For a new building ($U = 0.09$ for the reference roof, $U = 0.08$ for the green roof) we get a total discounted benefit of $2.9€/\mathrm{m}^2$. For an older building the benefit is much higher based on the poorer insulation properties of the roof (e.g., Berardi et al., 2014).

Simulations with the heat loss model show that an increase in the average temperature (Helsinki average temperatures: summer 16.2 °C, winter −3.5 °C (FMI, 2015)) by 1 degree reduces the difference in the heat losses between the green roof and the reference roof around 7% compared to the initial level in Helsinki. This corresponds to around 0.1 $\mathrm{kwh}/\mathrm{m}^2$ with thermal coefficient of heat loss $U = 0.09$ for the reference roof. The same trend continues when the average temperature is increased further.

The other determining factor on the heating energy savings is the energy insulation quality of the considered building stock, and more specifically the insulation properties of the roof. Each 0.01 increase in the coefficient of heat loss of the reference roof will increase the benefit by 100% compared to the original benefit when $U = 0.09$, assuming that with a green roof $U = 0.08$ is achieved. Decrease in the thermal transmittance can be achieved by green roof design, as demonstrated in Roche and Berardi (2014). Consequently, the effect of the building regulation has much more relative weight compared to the changes in the outside temperature. The heating energy savings do not need to drastically decrease when moving south from Helsinki if the building code is less strict in relation to the insulation properties of the roof. As an example, for Madrid in Spain, with average winter temperature of 9.7 °C (Saiz, Kennedy, Bass & Presnail, 2006) and heat loss coefficient U of 0.15, the benefit would translate into around 1.5€/m^2. However, the optimal design of a green roof in Spain would have less insulation to maximize the cooling benefits, as additional insulation could in fact increase the energy consumption by overheating the building. (Roche & Berardi, 2014). Consequently, in reality the heating savings in a warm climate are close to zero.

3.2.2 Energy cost savings for cooling

The cooling savings are estimated using results from the cooling energy simulations by Saiz et al. (2006) and Roche and Berardi (2014). Saiz et al. (2006) obtained results from an eight-story residential building located in Madrid (average temperatures, summer 19.4 °C, winter 9.7 °C) with a flat roof and total living area of 3381 m^2 and annual cooling energy use around 90,000 kWh or 27 kWh/m^2. The green roof was found to have a cooling impact on the five highest floors with a total effect of around 10% on these floors. For the highest floor or for a one-floor building, the cooling energy was reduced by around 25%. The green roof was a standard extensive green roof, with 9 cm substrate and plant types of sedum, cactus desert shrub. Roche and Berardi (2014) compared different types of green roofs in three different climate conditions for a one-story office building, and recorded annual cooling load reductions between 17% and 22% for optimal green roof designs in different climates.

In Finland, much more energy is used for heating buildings than for cooling them. Simulations show that a reference model building in southern Finland consumes around 3 kWh/m^2 per year for cooling in the current climate with a small expected increase in the future to at most 3.5 kWh/m^2 in 2030 (Jylhä et al., 2012). The benefit would then translate to 1.5–2.2€/floor m^2 (buildings are cooled with electricity) which in a building with one floor is roughly the same for the roof area for a flat roof. An example office building in Jylhä et al. (2012) uses relatively more energy for cooling than a residential building. The energy demand for cooling in southern Finland was estimated to be 7 kWh/m^2 per year at 2010 and 7.5 kWh/m^2 in 2030. For such a building, the reduction in the energy demand for cooling is then roughly 10%. The benefit is then 2€/floor m^2. For an office building with five floors, this roughly equates to 10€/m^2 per installed green roof. This is close to the maximum benefit as addition of more stores to the building does not increase the benefit since the marginal benefit per store is decreasing and approaches zero at the sixth highest floor.

For comparison in Madrid, the eight-story residential building would have a total discounted benefit of around 24€/m^2. As the benefit is calculated for a residential building, the benefit would be even larger for a commercial building that tends to use more energy for cooling.

It must be noted that these benefits are likely for green roof designs optimized for cooling the building and the maximum benefits of heating and cooling are hard to realize at the same time. Roche and Berardi (2014) proposed "active green roofs" to partly solve this dilemma, in which the cooling in the summer is increased with a plenum fan and variable insulation can be achieved.

3.3 Noise insulation

Lightweight vegetated roofs may increase transmission loss up to 10 dB at low frequency and up to 20 dB at mid-range frequencies (Connelly & Hodgson, 2013). Connelly and Hodgson (2013) show that the noise insulation benefits of green roofs are comparable or better to an additional, though unspecified, ceiling element. We use the cost of adding a plasterboard layer, a widely used technique to improve the noise insulation (personal communication, Helimäki, 2013), on a roof as the maximum sound insulation benefit of a green roof. We estimate that the benefit of a green roof is this avoided cost under flight routes. In other areas we assume that the benefit is zero, even though large amounts of green roofs in downtown areas may also affect the soundscape of the inner city, generally in the sense of attenuating mechanical noises (Irvine et al., 2009; Renterghem, Hornikx, Forssen & Botteldooren, 2013).

The total costs of plasterboard installation are around 20€/m^2 in Finland, of which around 50% is attributable to labor costs (net costs 50€/h) (prices for materials and contracts e.g., Gyproc, 2015; Kodinremontit.fi, 2015).

3.4 Storm-water management

Green roofs can reduce the demand on sewer system capacity by delaying water flows and reducing total runoff by retaining part of the rainfall and releasing it back to the atmosphere by evapotranspiration. Results from Berlin suggest that a light ($<$100 mm substrate) low-growth green roof on 10% of the building stock would result in a reduction of 2.7% in runoff for the region and 54% for the individual buildings (Mentens, Raes & Hermy, 2006). Rosenzweig et al. (2006) showed that a similar green roof infrastructure in New York could produce a 2% reduction in total runoff.

In Helsinki, the storm-water management can be divided into two main categories: combined storm-water–sewer systems and separated systems. In the combined systems both the storm water and sanitation waters are conveyed through the same pipes to the water treatment facility. In a separated system the different types of water are conveyed through separate courses. In the downtown area of Helsinki ($\sim$2200 hectares) the storm-water and sewer system is combined; in other parts of Helsinki mainly separate systems are in use. Of the over 1900 km of sewer pipes about 250 km are built as combined sewer system and 1650 km as separate system. The expansion of the sewer network (almost all new sewers are separate systems) incurs annual costs of 4 million € for the storm water alone. The repair of the existing storm-water pipes costs around 2 million € per year. The repair costs of combined systems are around 5–10 million € per year, of which 2–4 million € is allocated to storm-water-induced repair costs (personal communication Heinonen, 2012). The discounted total costs of rain water purification are shown in Table 1.

In the future, repair costs are estimated to rise to double or triple the current level, as a consequence of (over)aging of the sewer systems. The annual expansion costs of the network are expected to rise about 20%, since the new pipes should have larger sizes to account for the effects of climate change. In several cost-benefit analyses it has been assumed that there is a linear relationship between the amount of reduced runoff and the reduction in the capital and purification expenditures (e.g., Rosenzweig et al., 2006). However, based on our interview (personal communication Heinonen, 2012), some costs are fixed even in the long term and the amount of runoff has only a small effect on these costs.

Three kinds of capital expenditure are taken into account in our analysis: (1) the building of new (separate) sewer systems, (2) the repair of existing separate sewer infrastructure and (3) the repair of existing combined sewer system. We assume that at a 10% infrastructure scenario (10% of roof space is greened in Helsinki and uniformly distributed across the inner city), the resizing costs of the pipes would go down 10% (personal communication Heinonen, 2012). As for the other cost

Table 1 Expenditure categories and estimated avoided costs.

Cost type	Total discounted costs (million €)	Costs related to resizing of the pipes (million €)	Estimates for the avoided costs of 10 pct. infrastructure scenario (million €)
Rain water purification	26		0.5
Expansion of sewer network	100	10	1–4
Repair of separate sewer infrastructure	110	30	3–6.3
Repair of combined sewer infrastructure	110	23	2.3–5.6

reductions, we can also speculate that a 10% green roof scenario would reduce other costs by 2%–3% with the usual assumption of a linear runoff reduction–cost-reduction relationship (e.g., in Rosenzweig et al., 2006).

Our cost-reduction estimates based on the 10% infrastructure scenario are shown in Table 1.

These assumptions would result into benefits between 6.8 and 16.4 million € . The range of the green roof benefit for storm-water reduction is then 3.9€–9.4€/m^2. It must be noted that compared to some earlier estimates (e.g., Bianchini and Hewage, 39$–100$/m^2), these figures are on relatively low level. The realization of the higher figures would mean that savings around 20%–30% should be achieved with 10% green roof infrastructure scenario. This does not seem plausible based on the literature or the interview (personal communication, Heinonen, 2012).

Out of the different cost types in Table 1, only the annual water purification costs are directly related to the amount of precipitation and only in those areas where combined sewer system is used. The annual average precipitation is around 7000 mm in Helsinki (FMI, 2015).

The capital expenditure benefits are affected by more complicated relationships between rainfall patterns (e.g., return periods of extreme rainfall events) and city-specific storm-water and sewage system infrastructure. An important factor is the current state of the sewer infrastructure: the capacity is usually designed for a return period of a certain extreme rainfall event. In the future, sewer systems in many parts of the world will be under ever more stress due to expected increase in extreme rain events due to climate change (e.g., IPCC, 2014).

The storm-water benefit is then positively dependent on (1) the amount of precipitation (2) backlog of the current sewer system, the more outdated the system, the larger the benefit (3) occurrence and intensity of extreme rain events and (4) expected changes in extreme rainfall events due to climate change. All these need to be evaluated separately in each site. As mentioned, the figures in Helsinki are relatively low compared to other estimates, and the benefits are likely to be much higher in other cities.

3.5 Air-quality improvements

Tan and Sia (2005) found that the levels of fine particles (PM_x) and sulphur dioxide (SO_2) decreased by 6% and 37% in the immediate surrounding air space after a green roof was installed. Currie and Bass (2008) estimated that 109 ha of green roofs in Toronto could remove about 8 tons of unspecified air pollutants per year. Peck (2003) estimated that current roof greening in Toronto (cover over 6.5 million m^2) results in a 5–10% reduction in nitrogen dioxide (NO_2) and SO_2, and in a reduction of 30 tons of PM_x. Yang, Yu and Gong (2008) showed that a total of 1675 kg of air pollutants was removed by 19.8 ha of green roofs in one year in Chicago with the following distribution: 52% of ozone (0_3), 27% of NO_2, 14% of PM_{10} and 7% of SO_2. The annual total removal per ha of green roof was then 85 kg, of which 44 kg of 0_3, 23 kg of NO_2, 12 kg of PM_{10} and 6 kg of SO_2. Yang et al. (2008) reported that their estimate was 18% higher compared to above cited estimates from Toronto (Currie & Bass, 2008). In this article, we utilize proportions of gas reductions from Yang et al. (2008) and use their estimate of total removal as our high estimate and the result from Toronto (Currie & Bass, 2008) as our low estimate for green roof air purification potential.

The average costs of different emissions were studied in a report by the Finnish Transport Agency (Tervonen & Ristikartano, 2010). The calculations include negative effects on health (e.g., cancer, heart and lung diseases), environment, infrastructure (e.g., corrosion) and climate change (of GHGs). The costs were significantly higher in urban areas since there pollutants have an effect on a higher number of people. Their valuation is based on methods dealing with valuing reduced mortality risks and valuing reduced morbidity risks (Freeman et al., 2014). The results of the air-quality benefits are shown in Table 2. Summing up the effects regarding each agent in Table 2, the total air-quality benefit in Helsinki is between 4.8€ and 6.9€/m^2.

Results show, that at least 95% of the air-quality benefits can be attributed to the removal of particulate matter. Consequently, the air-quality benefit is positively dependent on the uptake potential of green roofs for PM_x and the (local) marginal cost of the PM_x. The exact concentration-response function for PM_x

Table 2 Green roof emission reduction benefits.

Type of emission	**Uptake (kg $\mathbf{ha^{-1}yr^{-1}}$)**	**Benefit (€ $\mathbf{ha^{-1}yr^{-1}}$)**	**NPV Benefit/$\mathbf{m^2}$ (€)**
O_3	30–44	not quantified	not quantified
NO_x	16–23	20–30	**0.05–0.07**
PM_x	8–12	1920–2780	**4.57–6.62**
SO_2	4–6	60–90	**0.15–0.21**

is unknown, but based on current evidence, the marginal social cost of PM_x is increasing with the concentration (Beelen et al., 2015; Wyzga & Rohr, 2015). Consequently, air-quality benefits are expected to be higher in those sites with higher concentration of particulate matter compared to Helsinki. Compared to most cities across Europe, Helsinki ranks as one of the lowest for concentrations of particulate matter (visualization and statistics available at EEA website, 2015). As the concentration-response function is unknown, local estimates of marginal costs need to be employed to give more accurate results. In Helsinki, a marginal social cost of 232 800€ for a ton of particulate matter was used (Tervonen & Ristikartano, 2010). The benefits of air-quality improvements are prone to changes in the transport fuel mix. The pace of change is however too speculative to take into account.

3.6 Heat-island effect

In urban environments, vegetation has largely been replaced by impervious and often dark surfaces. These conditions contribute to the urban heat-island effect, wherein urban regions are significantly warmer than the surrounding suburban and rural areas, especially in the nighttime. One of the benefits of green roofs is mitigation of the urban heat-island effect (Berardi et al., 2014). A study by Santamouris (2014) reviewed urban heat-island mitigation techniques, and remarked that large-scale application of green roofs could reduce the ambient temperature by 0.3 K to 3 K.

The value of the benefits and costs of the heat-island effect in Helsinki or other cities in cold climates has not been estimated or even comprehensively qualitatively listed. Some impacts are positive (such as reduced energy demand in the winter) and some negative (increased mortality during heat waves is shown by Ruuhela, Lahtinen, Haga, Fronzek and Carter (2012)). The value of the urban heat-island benefit/cost is not included in the cost-benefit calculation of Helsinki.

By only considering the price of saved cooling energy, Bianchini and Hewage (2012) considered that extensive green roofs could generate a benefit of 1.2$–3$ and Rosenzweig et al. (2006) that the energy savings of the cooling costs could be in the range of 0.7–10%. As the difference between the low and high estimates is high, and only the decrease in energy consumption has been taken into account, it can be noted that the monetary benefit of green roofs for urban heat-island mitigation is still largely unknown.

4 Valuation of scenic benefits

All of the reviewed articles of green roof economics stated that green roofs offer amenity, aesthetic, psychological or other cultural benefits to urban residents. Nevertheless all but two left these benefits out of the cost-benefit calculations. The first exception was a study in New York (Rosenzweig et al., 2006) in which it was assumed that between 0.9 and 3.4 million residents of New York City would enjoy having half of city's roofs greened, with each resident willing to pay $10, $25 or $50 for the installation. These estimates were not supported by any valuation study. The second exception was the study by Bianchini and Hewage (2012) in which it was assumed that "the aesthetics benefit obtained from extensive green roofs varies from 2% to 5% of property value. For intensive green roofs the aesthetics benefit is considered that varies from 5% to 8% of the property." These numbers were based solely on assumptions. A review article on green roof economic benefits by the U.S. Government (2011) stated that: "... studies are not specifically related to green roofs and the methodology is open to debate; productivity, absenteeism, aesthetics, and views were not accounted for in the cost-benefit analysis (CBA). The overall evidence, however, is that green roofs have the capacity to provide significant value in terms of productivity and absenteeism to the tenants (and thus the owner) as well as to the community at large who benefit from the improved aesthetics and views of the green roof."

4.1 The study method and discussion of the proxy

White and Gatersleben (2011) compared the aesthetic quality of different roof types and found that people prefer view to a nonvegetated roof. Fernandez-Cañero, Emilsson, Fernandez-Barba and Machuca (2013) argue that green roofs with similar appearances to conventional green areas are most valued by citizens and the closer their design is to that of conventional urban green, the more comparable the aesthetic quality is to conventional urban green. Jungels, Rakow, Allred and Skelly (2013) showed that positive attitudes toward green roofs increased as the green roofs became more familiar. Lee, William, Sargent, Farrell and Williams (2014) confirm that green roofs carry aesthetic quality over concrete surfaces; aesthetic quality is however strongly dependent on green roof characteristics, such as choice of vegetation and diversity. Lee et al. (2015) confirm in a later study that green roofs have restorative effects comparable to conventional urban green – a view to a green roof can restore attention in the same way as a view to conventional urban green. Based on the literature, the scenic quality of green roofs may be lower than that of conventional urban green, but with good design the scenic quality approaches that of small pockets of conventional urban green. Consequently, we use the scenic value of small urban areas with green cover (referred as "small parks" from here) as the high estimate and zero as the low estimate for the scenic value of green roofs. Even though this is quite a wide range, it will define the limits based on which the scenic value can be added to the CBA.

Next, we need to (1) find the value that inhabitants place on small parks (2) isolate the scenic value from other values of urban green, for example, recreational values. To this end, we use evidence from housing transactions in Helsinki and analyze the values that individuals have placed on different proximities to different types of parks and, based on this evidence, we infer the effects of increasing urban green in Helsinki. For robustness, we also repeated the analysis in another city in Finland (Table 4c)

A spatial hedonic specification was estimated on a sample of approximately 6500 apartment transactions that took place in Helsinki's city center between 2008 and 2011. The observed dependent variable in this context is the purchase price/m^2 of the property, which can be interpreted as the present value of the stream of expected rental values; rental price is a function of a vector of amenities, of which the view to urban green is one component (Freeman et al., 2014). In our analysis, we define the scenic value to be the value that residents in the immediate vicinity (defined below) of urban green receive compared to those farther from it.

Previous work on the dataset showed that the value of urban green is highest in the city center and diminishes rapidly when moving away. For this reason, we focused on Helsinki's center in which there is the greatest potential for incremental value. We defined the point of highest density of commercial establishments as Helsinki's central business district (CBD) and then selected property transactions within 3 km from the CBD.

Urban parks are the predominant type of urban green in the study area; for Helsinki, the term refers to areas with a mix of trees, other vegetation, and artificial configurations like walkways and playgrounds. We split parks into two categories

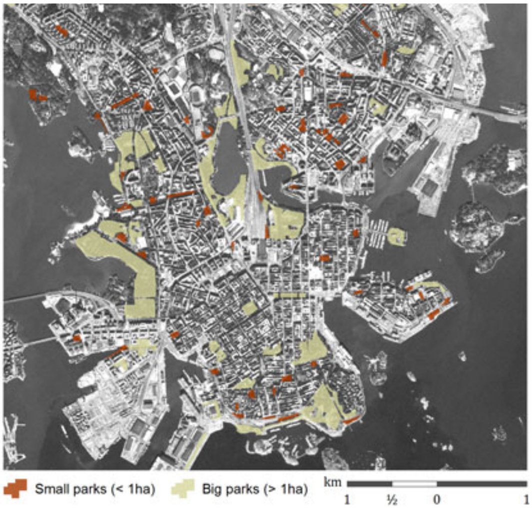

Figure 1 Helsinki's CBD and park categories.

("big parks" larger than 1 ha and "small parks" 1 ha or smaller), since we wanted to find out whether even small areas devoted to urban green can have positive effects on the housing market. Dummy variables were created for properties that are within 30, 50, and 70 meters from big and small parks. These alternative distances to a park were tested to see how varying the distance to a park affects the average WTP. Figure 1 displays the study area and park categories. The variables connected to each transaction are listed in Table 3.

For this estimation, we have used a spatial error regression specification:

$$y_i = a + \sum_{k=1}^{n} \beta S_{ki} + \sum_{j=1}^{n} \gamma N_{ji} + \sum_{l=1}^{n} \gamma E_{li} + \lambda W u_i + e_i. \tag{4}$$

In equation (4), W is a spatial weights matrix (in this case produced by a 1st order Moore neighborhood rule), Wu a spatially autocorrelated error term, e a random error term, α the intercept, and β, λ coefficients. The beta coefficients are interpreted as in nonspatial OLS regressions. The spatial error term lambda (λ) is treated in this analysis as an uninterpretable instrument that clears residuals from spatial autocorrelation. Equation (4) includes structural, neighborhood, and environmental attributes of housing (Dubin, 1992): $\boldsymbol{S}$ is a vector of k structural attributes of a property, $\boldsymbol{N}$ is a vector of j attributes describing the neighborhood of the property, and $\boldsymbol{E}$ is a vector of l attributes describing aspects of the natural environment in

Table 3 The variables of the analysis and their mean values in Helsinki's CBD.

Variable	Description	Unit	Mean
PRICE	Selling price per m^2, 2011 prices	€ thousand per m^2	4.7
DEBT	Debt component(a), 2011 prices	€ thousand per m^2	.18
MAINT	Monthly maintenance cost, 2011 prices	€ per m^2	3.36
ROOMS	Rooms, excluding kitchen	Multinomial (1–9 rooms)	1.96
FLOOR	The floor on which the apartment is situated	Multinomial (1st–9th floor)	3.53
ELEVATOR	Elevator available in the apartment block	Dummy (1: yes, 0: otherwise)	.77
AGE	Dif. between selling and construction year	Years	70.83
BADCND	Bad condition	Dummy (1: bad, 0: otherwise)	.058
AVGCND	Average condition	Dummy (1: avg., 0: otherwise)	.33
CBD	Proximity to the central business district	Meters	1692
SEAVIEW	Within 100 m from the coastline	Dummy (1: within, 0: otherwise)	.038
PARK	Within 30/50/70 m from any park	Dummy (1: within, 0: otherwise)	.21(b)
SMPARK	Within 30/50/70 m from a small park (<1 ha)	Dummy (1: within, 0: otherwise)	.14(b)
BGPARK	Within 30/50/70 m from a big park (>1 ha)	Dummy (1: within, 0: otherwise)	.067(b)
YEAR	Transaction year	Multinomial (2008–2011)	2010

(a) Refers to loans undertaken by the housing committee for large maintenance tasks (e.g., roof, pipes or structural renovations), distributed to each property usually according to its size.
(a) Figures for the "within 30 m" category.

the vicinity of the property. Vector E contains the target variables of this analysis (direct view to small and big parks). Equation (4) was estimated on the previously described sample and variables of Table 3. Pre- and post-estimation tests verified the assumption of spatially autocorrelated residuals and indicated that the spatial error model of equation (4) as the preferred specification as compared to a nonspatial OLS regression or alternative spatial specifications.

4.2 Estimation results and interpretation

First, we estimated the value of any urban park, regardless of its size, within 30, 50 and 70 m of a building (Table 4a). The value of a presence of urban green is significant in all of the tested distances. The average marginal value is highest for buildings within the 30 m radius from a park and decreases when increasing the allowed distance from the park. The average values for the respective distances are 134€, 122€ and 94€ per m^2 of living space. It has been empirically shown (Crompton, 2001) that the incremental of value attributable to the park significantly

Table 4a–c Hedonic regression results for the CBDs of Helsinki and Pori (dependent variable: Price/m^2 in € thousand, 2011 prices)

	Coefficient ***(std. error and significance)***								
	(4a) Helsinki, any park			**(4b) Helsinki, small and big parks separately**			**(4c) Pori, small and big parks separately**		
	30 m	**50 m**	**70 m**	**30 m**	**50 m**	**70 m**	**30 m**	**50 m**	**70 m**
INTERCEPT	−479.322	−482.076	−481.22	−479.895	−482.31	−481.156	−128.042	−128.287	−126.852
	*(15.806***)*	*(15.797***)*	*(15.768***)*	*(15.807***)*	*(15.793***)*	*(15.77***)*	*(16.086***)*	*(16.0781***)*	*(16.0523***)*
DEBT	−.384	−.384	−.374	−.384	−.385	−.375	−.811	−.81	−.817
	*(.022***)*	*(.0222***)*	*(.0225***)*	*(.022***)*	*(.0222***)*	*(.0225***)*	*(.017***)*	*(.0167***)*	*(.0167***)*
MAINT	−.00959	−.0101	−.00879	−.0105	−.011	−.00921	.0263	.025	.028
	(.00934)	*(.00932)*	*(.00932)*	*(.00935)*	*(.00932)*	*(.00931)*	*(.0123*)*	*(.0124*)*	*(.0122*)*
ROOMS	−.193	−.195	−.199	−.193	−.196	−.199	−.0911	−.0911	−.0932
	*(.0095***)*	*(.0095***)*	*(.00951***)*	*(.0095***)*	*(.0095***)*	*(.00951***)*	*(.00919***)*	*(.0092***)*	*(.00917***)*
ELEVATOR	.0345	.0309	.0293	.0345	.0314	.0301	.0213	.0223	.0295
	(.0279)	*(.0278)*	*(.0279)*	*(.0279)*	*(.0278)*	*(.0279)*	*(.0205)*	*(.0203)*	*(.02)*
AGE	−.0187	−.0188	−.0189	−.0188	−.019	−.0189	−.0322	−.0324	−.0326
	*(.00191***)*	*(.0019***)*	*(.0019***)*	*(.00191***)*	*(.0019***)*	*(.0019***)*	*(.00105***)*	*(.00105***)*	*(.00104***)*
[AGE]^2	.000164	.000164	.000163	.000164	.000165	.000164	.000202	.000203	.000205
	*(.0000148***)*	*(.0000147***)*	*(.0000147***)*	*(.0000148***)*	*(.0000147***)*	*(.0000147***)*	*(.00000847***)*	*(.00000845***)*	*(.00000838***)*
FLOOR	.0858	.086	.0851	.0858	.0862	.0853	.0256	.0252	.0259
	*(.00473***)*	*(.00473***)*	*(.00472***)*	*(.00473***)*	*(.00472***)*	*(.00472***)*	*(.00475***)*	*(.00473***)*	*(.00472***)*
BADCOND	−.669	−.668	−.674	−.67	−.668	−.673	−.418	−.416	−.416
	*(.0357***)*	*(.0357***)*	*(.0356***)*	*(.0357***)*	*(.0357***)*	*(.0356***)*	*(.0534***)*	*(.0534***)*	*(.0534***)*

Continued on next page.

Table 4a–c (Continued).

AVGCOND	−.323	−.323	−.326	−.323	−.323	−.326	−.197	−.196	−.198
	(.018***)	(.018***)	(.018***)	(.018***)	(.018***)	(.018***)	(.0218***)	(.0218***)	(.0218***)
log [CBD]	−.911	−.915	−.914	−.909	−.903	−.905			
	(.0432***)	(.043***)	(.0429***)	(.0431***)	(.043***)	(.0429***)			
SEAVIEW	.447	.455	.462	.438	.436	.453			
	(.0872***)	(.0869***)	(.0868***)	(.0874***)	(.087***)	(.0866***)			
RIVERVIEW							.0319	.0304	.0286
							(.0651)	(.0649)	(.0641)
PARK	.134	.122	.094	.134					
	(.043**)	(.0394**)	(.0371*)						
SMPARK				.132	.05	.0583	.0311	.00147	.054
				(.0518*)	(.0477)	(.0433)	(.0305)	(.0274)	(.0232*)
BGPARK				.203	.249	.183	.0653	.0791	.0773
				(.0682**)	(.0612***)	(.055***)	(.0268*)	(.025**)	(.0237**)
YEAR	.245	.246	.245	.245	.246	.245	.0651	.0652	.0645
	(.00787***)	(.00787***)	(.00785***)	(.00787***)	(.00787***)	(.00785***)	(.00801***)	(.008***)	(.00799***)
Number of obs.	6882	6879	6859	6882	6879	6859	1361	1361	1361
Pseudo-R^2	.554	.554	.555	.554	.555	.555	.756	.756	.757
AIC (OLS AIC)	14967 (17208)	14943 (17176)	14853 (17057)	14963 (17171)	14932 (17129)	14850 (17018)	604 (675)	602 (672)	595 (660)

Significance ranges: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1.

increases with the size of the park; for instance, in an early study by Coughlin and Kawasima (1973) it was found that a 5-acre park (2 ha) had almost five times the increase in the price of a dwelling unit than a 1-acre park (0.4 ha) and it was also found that the incremental value attributable to a small park decreased more quickly as the distance to the park increased. Our findings were similar regarding the effects of park size (Table 4b). The value of a big park for buildings within 30 m from the park was in average 200€ per square meter while the value of a small park was 130€. However, when increasing the distance radius including also buildings within 50 m from the parks, the average value of a big park was almost 250€ while the average value of a small park was around 50€. We interpret that this shows that the recreational value of a big park is still available when allowing a longer distance, but the presence of a small park bears mainly scenic value that goes down quickly as the view gets blocked.

Based on GIS analysis, small parks are mainly visible to those building within 30 m radius, and the view is more or less blocked when increasing the radius. However, all of the services related to recreational or other use values of the parks are still present and (almost) as easily available at the radius between 30 and 50 m from the small parks. Consequently, we take the value that is attached to small parks at 30–50 m radius and deduct that from the total value of the parks available between 0 and 30 m radii. We define the residual as the "scenic value" of small parks. This is around 110€ per square meter as the value of a small park decreases fast when increasing the distance as expected from the literature, and the mean value attached to a small patch of urban green is only around 20€ per square meter at the distance between 30 and 50 m from the park.

In percentage terms, the range for the scenic benefit of the green roofs is 0–2.3% without taking the vertical location of the green roof into account. However, this undermines the fact that compared to a park, the view to a green roof is limited, as only those neighbors that live on a higher floor compared to the green roof, are able to actually enjoy the view. Consequently, the building heights distribution needs to be taken into account. As in figure 2, around 37% of the buildings in the study area are buildings with 1–2 floors, and 63% of the buildings have three or more floors. If all the green roofs are installed on the buildings with either one or two floors, we assume that out of the buildings with 1–2 floors 25% of the residents live on a higher level than the green roofs, and 66% of the residents on a 3+ building live on a higher level than the green roofs. In total, the vertical location of the green roof would limit the view from 46% of those apartments that would have had a view to an urban park. To take this into account, the high estimate for the value of having a green roof within 30 m from the building drops to 1.2%.

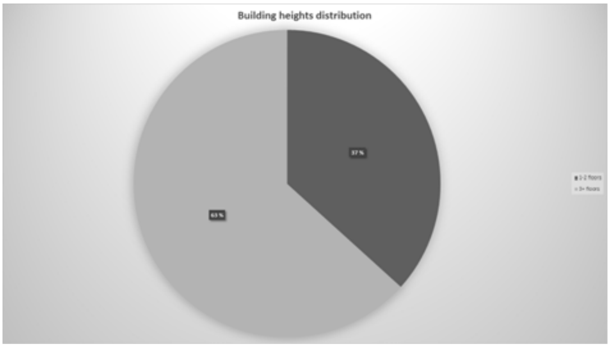

Figure 2 The distribution of building heights in Helsinki, Finland.

The only comparison in the literature is Bianchini and Hewage (2012) in which the value of properties was assumed to be 2%–5% higher for extensive green roofs. Based on our results, we recommend to use value increases between 0% and 1.2% for those properties in the immediate vicinity (within 30 m) of a green roof.

4.3 Simulation of the scenic value in Helsinki

We analyze two scenarios (Figure 2): (1) high benefit simulation (Simulation 1) in which all the roofs that are greened are placed in the CBD, which would result in 50% of roofs in the CBD being green and would yield the highest pay-off and (2) low benefit simulation (Simulation (2) with equal distribution of green roofs across the broader urban area of Helsinki in which 10% of the CBD roof tops are greened. In both of the cases we assume that (i) the average marginal value of increase in urban green drops linearly to zero once the last simulated green roof has been installed, and (ii) the average marginal value of the scenic value of a green roof is between 0% and 1.2% as explained above.

We start by surveying the current green cover in Helsinki and adding green space to those areas with the least green space. Before the simulation (1) 26% or 629 buildings out of 2415 in our delineation of Helsinki's CDB were situated within 50 m from a big park or within 30 m from a small park. The total amount of roof area in the city of Helsinki is around 1740 ha, approximately 19% of 334 ha of which is located in the study area (CBD). In simulation 1, 174 ha green roofs would all be located in the CBD. We simulated this additional green cover by placing green roofs in a GIS software in those areas that currently exhibit the

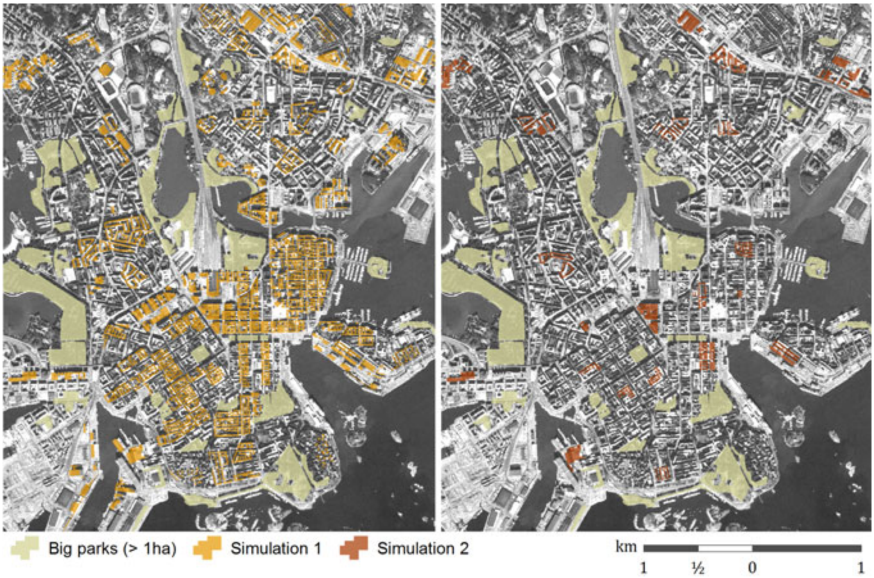

Figure 3 The simulations (1) and (2) of green roof cover in Helsinki CBD.

highest distances to urban parks. We selected adjacent rooftops that would generate large green cover areas. Our selection for simulation (1) is shown in figure 3 on the left hand side. After the simulation, 68% of the buildings or 1652 of the buildings in the CBD had a presence of either a green roof or a small park within 30 meters, or a big park within 50 meters. The residential living area in the CBD is around 550 ha. (Helsinki Statistics). With assumptions (i) and (ii), the benefit of a green roof would be between 0 and 37€/m^2. The 37€/m^2 can be seen as the upper limit for the value of the scenic benefit of green roofs in Helsinki as it relies on the assumptions that (1) green roofs are optimally placed in those areas with the least amount of urban green and highest property values, (2) green roofs carry the same scenic value as small urban parks and (3) they are optimally placed on the low-rise buildings.

The second simulation was done by assuming a uniform distribution of green roofs across the city of Helsinki, so that only 10% of the CDB roofs were greened. We again, simulated green roof cover by placing green roofs to those areas of CBD with the lowest proximity to urban green depicted in figure 3 on the right hand side. After the simulation, 38% of the buildings had either a green roof or a small park within 30 m, or a big park within 50 m from the building. With assumptions (i) and (ii), the value of the increase per installed green roof would be 0–17€/m^2.

This range can be regarded as more realistic, as it relies only on assumptions that (1) green roofs would carry value on those areas with the lowest amount of urban green (CBD), (2) the scenic value would be close to that of a small park without its use values, and (3) the value of the green roofs last green installed last green roofs would approach zero as the supply of urban green is less scarce.

Out of the other benefits, only the air-quality benefits can be partly included twice if the scenic benefits are fully incorporated into the CBA. If air-quality benefits are conservatively – to avoid double counting – reduced from the scenic benefits of the green roofs, the scenic benefits of green roofs are between 0 and 10€/m^2

5 Costs of green roofs

The main barrier for green roof implementation is the additional costs compared to standard roof solutions (e.g., Berardi et al., 2014; Clark et al., 2008). The cost levels for extensive green roofs exhibit significant differences across the world. The high estimate of the literature can be found in Sproul et al. (2013) in which cost level of 150€/m^2 for extensive green roofs is assumed. Almost as high figures were reported in Bianchini and Hewage (2012) in which the costs of extensive green roofs were approximated to be 90€/m^2–113€/m^2 in British Columbia, Canada. However, neither of the aforementioned studies elaborate whether the costs were additional costs compared to reference roof or total costs. Additional costs of 68€/m^2 were applied in a study by Carter et al. (2008) in City of Atlanta. In a literature review report from 2007, Toronto Region Conservation (Toronto Region Conservation (TRC), 2007) confirms the wide range of initial capital costs across the world. In North America, with very low implementation rates of green roofs across the continent, the additional costs of extensive green roofs ranged from 45€/m^2 to 190€/m^2. However, in Germany with established green roofs industry and higher implementation rates, the additional costs were only around 13€/m^2–41€/m^2.

To get an appreciation of the cost level in Finland, green roof suppliers were interviewed. Our example roofs are built on a supporting structure and the cost estimates are based on the assumption that the roof will be built on an existing building or to a new building with sufficient loading capacity. This section is an updated version of chapter 5 of a project report by Nurmi, Votsis, Perrels and Lehvävirta (2013).

- The standard bitumen roof costs are around 35€/m^2 (+VAT 24%, = 43€/m^2). This includes rubber bitumen layers, waterproofing and installation. These installations are needed also under green roofs (with some modifications, the costs remain approximately the same).

- The additional costs to install a green roof are on average around 50€/m^2 (+VAT 24 %, = 62€/m^2). The additional costs include the sedum mats (53% of the additional costs), the installation costs (around 24% of the additional costs) and taxes (23%).

The least expensive green roof is achieved by installing a drainage layer, filter fabric, substrate, and plants from cuttings and seeds. These green roofs may allow for more plant diversity if a deeper substrate is used, but require more structural capacity to hold the weight of the soil. They are generally at least 20% less expensive than ready-made green roof sedum mat systems, the total extra costs being around 40€/m^2 (+ VAT 24%).

Cost estimates from Finland are very high in comparison with estimates in those countries with established green roof industries, such as Germany. The low price level in Germany is a result of more than thirty years of market development. In Switzerland low cost solutions cost only around 20€/m^2 (personal communication Brenneisen, 2013) despite the high price level of the country. In new markets competition is scarce and no economies of scale exist, labor is more expensive since installers lack experience, and there is a tendency to use custom-design systems. Obviously, adopting low cost techniques would support the proliferation of green roofs. The additional costs of a green roof have gone down by 33%–50% (Toronto Region Conservation (TRC), 2007) since the industry has established itself. In our scenarios we assume that the same would happen in Finland if 10% of roof top area in Helsinki was greened. For comparison in Basel, of which around 30% of flat roofs or 3% of total roof area is green, the additional costs have gone down from around 80 euros to only around 15 euros per square meter (ZHAW, 2013), making our cost-reduction estimate fairly conservative.

6 Results of the cost-benefit analysis

In this section, we wrap up the estimates of benefits and costs in Helsinki, Finland. First, we discuss the private incentives to build green roofs. Next, we take a look at the public benefits assuming that 10% of Helsinki's roofs are converted to green roofs. By modifying the values of different ES based on the target cities characteristics as described in Section 4, it is then easy to see how the cost-benefit ratio would change when replacing Helsinki for another case-study location.

Table 5a Private Cost-benefit analysis, with 90%–110% sensitivity analysis.

	Low benefit, high cost scenario (€/m^2)	**High benefit, low cost scenario (€/m^2)**	**Relevant factors affecting the value**
Additional costs of installation	62	50	Lower costs possible for buildings with strong structural capacity
Private benefits:			
Energy savings for heating	2.7 (90%)	3.3(110%)	Isolative properties of the alternative roof; Green roof design
Energy savings for cooling	1.4 (90%)	11 (110%)	Use of the building, used A/C-method; Green roof design
Membrane longevity	21.4 (90%)	26.2 (110%)	Service life of a green roof vs. that of conventional roof
Sound insulation	0	20	Benefits for those in air-traffic noise zones
B/C-ratio	**0.4**	**0.8** (1.2 with sound insulation benefits)	

6.1 Private benefits versus private costs

Only a part of the aforementioned benefits accrue to the owner of the property where the green roof is installed, however all the costs are levied on the private decision maker (Table 5a). A higher price of the roof also increases the value-added tax burden on the investor. The private benefits and costs also include avoided and incurred tax costs (namely VAT) for the property owner.

In Table 5a we list the private costs and benefits. All of these benefits are of the same nature – they are avoided costs for the property owner and represent the WTP. These kinds of benefits can be summed together (as shown in Section 2) and are the same for any building owner. The analysis shows that the current level of costs is too high compared to the benefits for a private decision maker to have an incentive to install a green roof, the B/C-ratio is between 0.4 and 0.8 and the NPV is -36.5–-9.5€/m^2. The expected value for NPV is -257€/m^2, assuming uniform distribution for other benefits except sound insulation (0 for 98.5%; 20€/m^2 for 1.5% population under flight routes) and taking into account that both cooling and heating benefits are hard to achieve with the same design of the green roof. These results are in line with results from other cities as indicated by the literature review.

Table 5b Social Cost-benefit analysis.

	Low benefit, High cost scenario (€/m^2)	**High benefit, Low cost scenario (€/m^2)**	**Relevant factors**
Additional costs of installation	33.5	25	Calculated for the current standard solution – sedum mats, market structure
Private benefits	21	54	High scenario includes sound insulation benefits
Public benefits:			
Storm-water management	3.5 (90%)	10.3 (110%)	Assumptions on the reduction of storm-water infrastructure
Air-quality benefits	4.3 0%)	7.6 (110%)	The green roof performance in the climate conditions of southern Finland
Scenic benefits		11€ (110%)	Green roof design and visibility
Social B/C-ratio	**0.9**	**2.5** (3.5 with sound insulation benefits)	

We present both the lower and higher bounds for the benefits and vice versa for the costs.

6.2 Social cost-benefit analysis with 10% installation scenario in Helsinki

Next, we take a look at the social costs and benefits in a scenario in which green roofs have been installed in 10% of the building tops in Helsinki. In addition to the private ones, public benefits are expected to emerge. We assume that higher implementation rates would lower the additional costs of green roofs by at least 33% and at most 50%, as explained in Section 5. In Table 5b we list the social benefits including both private and public. Here we also exclude taxes (from the membrane longevity and sound insulation benefits) from the calculations – unlike in Table 5a – as we are interested in the social benefits instead of private incentives. The social B/C-ratio is between 0.9 and 2.1, and NPV is between −4.7 and 37.9€/m^2 and possibly even higher on those areas with air-traffic noise. The expected value for the social NPV is 13.4€/m^2 with the same assumptions as for the private benefits. The focus of this study – the scenic benefits – represent 13% of the total benefits in the high estimate case, or around 13% of the expected value of the benefits. Consequently, while not insignificant, the addition of the scenic benefits only strengthens the conclusion that while the private benefits are not high enough to cover the installation costs, the social CBA shows positive results.

7 Conclusions

The aim of this article was to discuss the economic benefits and costs of thin, lightweight green roofs with special emphasis on the previously unmeasured benefit of the increase in the scenic value.

The main conclusions of green roof CBA in Helsinki are:

(1) As the reviewed literature would suggest, the private benefits are usually not high enough to cover the current level of additional private costs. In Helsinki, even in the low cost-high benefit scenario the private B/C-ratio is under 1. However, in some circumstances, in warm climates the cooling energy savings can drive even the private B/C-ratio slightly over 1. The most important parameters determining the private benefits are: (1) cost of the reference roof so that higher reference roof price increases the benefits, (2) temperature profile of the location so that higher temperatures increase the benefits, (3) energy price so that higher energy price increases the benefits and (4) building code of the roof so that higher coefficient of heat loss increases the benefit.

(2) When adding up private and public benefits, the benefits would surpass the costs in most of the cases, especially if a higher implementation rate drives down the costs. The factors that have a positive effect on the public benefits, which are at a relatively low level in Helsinki, are: (1) the average annual precipitation and frequency of extreme rainfall, (2) the maintenance backlog of the current sewer system and (3) the concentration of particulate matter. As also the cost level of green roofs is high in Finland, the social B/C-ratios can be expected to be higher than those reported in this study in most other cities of similar size or larger.

(3) Scenic benefits have a potential to be a significant factor in green roof CBA; the increase in the property values in the buildings within 30 m of a green roof was assessed to be between 0% and 1.2%. Helsinki is a green city compared to many other cities, thus benefits are likely to be higher in many other cities with less vegetation cover. Compared to other benefits, scenic benefits represent 13% of the total benefits of the high estimate case for social benefits, or around 13% of the expected value of the benefits.

In this study, we were able to quantify several green roof benefits, including membrane longevity, sound insulation, energy cost savings, air-quality, storm-water management and scenic benefits. Many studies also indicate that green roofs have the potential to increase urban biodiversity, but this benefit was not in the scope of this article. The level of benefits was found to be positively correlated with outside temperature (Section 3.2), level of precipitation and frequency of extreme downpours (Section 3.4), level of urbanization, and proximity to city center (Section 4). Presumably climate change and urbanization will drive the level of benefits higher in the future.

The costs of green roof installation were gathered by supplier interviews. The additional costs of a green roof in Finland are around 50–60€/m^2 making them more than two times more expensive than the reference roof. Cost estimates were significantly higher than in countries with long traditions in green roof implementation, namely Switzerland and Germany. The cost-benefit calculations together with the reviewed literature show that private benefits are usually not high enough to justify a green roof installation for a private decision maker. It can be expected that the level of implementation stays low in most cities with comparable climatic and ambient conditions as Helsinki without corrective policy instruments. Policy instruments could include supportive policies that turn part of the public benefits into private ones (e.g., reduction in storm-water fee). In addition, research projects and demonstration projects could drive the benefits up and the costs down.

The two main limitations of this article are related to scarcity of evidence of the impacts of green roofs in different environments. First, many of the natural processes of green roofs have been studied only in a few sites, for example, we had to rely on figures of the emission uptake in Toronto and Chicago. More research is needed in local climate conditions to obtain more reliable figures. The second limitation is of the same nature: we had to estimate the upper limit of the scenic value of green roofs by indirect means by looking at the value people attach to the presence of an urban park. We assumed that the value of the presence of an urban park is comparable to that of a presence of a green roof but took into account the reduction in the visibility.

Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/bca.2016.18.

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References

Arrow, Kenneth J., Solow, Robert M., Portney, Paul R., Leamer, Edward E., Radner, Roy & Schuman, Howard (1993). *Report of NOAA Panel on Contingent Valuation*, January 11, 1993, http://www.economia.unimib.it/DATA/moduli/7_6067/materiale/noaa%20report.pdf.

Banting, Doug, Doshi, Hitesh, Li, James, Missios, Paul, Au, Angela, Currie, Beth & Verrati, Michael (2005). *Report on the environmental benefits and costs of green roof technology for the city of toronto*, Toronto City Working Paper http://www1.toronto.ca/city_of_toronto/city_planning/zoning_environment/files/pdf/fullreport103105.pdf.

Bateman, Ian J., Lovett, Andrew & Brainardi, Julii (2004). *Applied Environmental Economics: a GIS Approach to Cost-Benefit Analysis*. Cambridge: Cambridge University Press.

Beelen, Rob et al. (2015). Natural-Cause Mortality and Long-Term Exposure to Particle Components: An Analysis of 19 European Cohorts within the Multi-Center ESCAPE Project. *Environmental Health Perspectives*, *123*(6), 525–533.

Berardi, Umberto, Hosein, Amir, Hoseini, Ghaffarien & Hoseini, Ali Ghaffarian (2014). State-of-the-Art Analysis of the Environmental Benefits of Green Roofs. *Applied Energy*, *115*(115), 411–428.

Bianchini, Fabricio & Hewage, Hasun (2012). Probabilistic Social Cost-Benefit Analysis for Green Roofs: A Lifecycle Approach. *Building and Environment*, *58*(58), 152–162.

Blomquist, Glenn (1988). Valuing Urban Lakeview Amenities Using Implicit and Contingent Markets. *Urban Studies*, *25*(25), 333–340.

Boadway, Robin (2006). Principles of Cost-Benefit Analysis. *Public Policy Review*, *2*(1), 1–44.

Brander, Luke M. & Koetse, Mark J. (2011). The Value of Urban Open Space: Meta-Analyses of Contingent Valuation and Hedonic Pricing Results. *Journal of Environmental Management*, *92*(10), 2763–2773.

Brenneisen, Stephan (2013). Personal email comment regarding Green roof costs in Switzerland. Professor in ZHAW Life Sciences and Facility Management, Research Focus in Green Roofs in Switzerland.

Brown, Douglas M. (1974). *Introduction to Urban Economics*. London: Academic Press Inc.

Carson, Richard, Flores, Nicholas, Martin, Kerry & Wright, Jennifer (1996). Contingent Valuation and Revealed Preference Methodologies: Comparing the Estimates for Quasi-Public Goods. *Land Economics*, *72*(1), 80–99.

Carter, Timothy & Keeler, Andrew (2008). Life-Cycle Cost–Benefit Analysis of Extensive Vegetated Roof Systems. *Journal of Environmental Management*, *87*(3), 350–363.

Clark, Corrie, Adriaens, Peter & Talbot, Brian (2008). Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits. *Environmental Science and Technology*, *42*(6), 2155–2161.

Claus, Karl & Rousseau, Sandra (2012). Public Versus Private Incentives to Invest in Green Roofs: A Cost-Benefit Analysis for Flanders. *Urban Forestry and Urban Greening*, *11*(4), 417–425.

Coffman, Reid R. & Waite, Tom (2011). Vegetated Roofs as Reconciled Habitats: Rapid Assays Beyond Mere Species Counts. *Urban Habitats*, *6*(1).

Connelly, Maureen & Hodgson, Murray (2013). Experimental Investigation of the Sound Transmission of Vegetated Roofs. *Applied Acoustics*, *74*(10), 1136–1143.

Copenhagen (2015). Websites of City of Copenhagen, http://en.klimatilpasning.dk/media/704006/1017_sJ43Q6DDyY.pdf.

Coughlin, Robert & Kawasima, Tatsuhiko (1973). *Property values and open space in Northweast Philadelphia: An empirical analysis*, Discussion Paper 4, Philadelphia: University of Pennsylvenia, Regional Science Research Institute.

Crompton, John L. (2001). The Impacts of Parks on Property Values: A Review of the Empirical Evidence. *Journal of Leisure Research*, *33*(1), 1–31.

Currie, Beth A. & Bass, Brad (2008). Estimate of Air Pollution Mitigation with Green Plants and Green Roofs Using the UFORE Model. *Urban Ecosystems*, *11*(4), 409–422.

Dubin, Robin A. (1992). Spatial Autocorrelation and Neighborhood Quality. *Regional Science and Urban Economics*, *22*(3), 433–452.

EEA (European Environment Agency) (2015). Websites, http://www.eea.europa.eu/themes/air/interactive/pm10.

Energy Authority (2016). Websites of the National Energy Association, Energy price statistics, https://www.energiavirasto.fi/en/web/energy-authority/.

EU (2008). Guide to cost-benefit analysis of investment projects, http://ec.europa.eu/regional_policy/sources/docgener/guides/cost/guide2008_en.pdf, p. 208.

EU eXterne study (2005). Summary report e.g. https://ec.europa.eu/research/energy/pdf/externe_en.pdf.

Fernandez-Cañero, Rafael, Emilsson, Tobias, Fernandez-Barba, Carolina & Machuca, Miguel (2013). Green Roof Systems: A Study of Public Attitudes and Preferences in Southern Spain. *Journal of Environmental Management*, *128*(128), 106–115.

Finland's environmental administration "FEA" (2012). Meluselvitykset 2012 (Noise Reports 2012, only in Finnish), http://www.finavia.fi/ymparisto/ymparistojulkaisut/selvitykset.

FMI (2015). Finnish Meteorological Institute Websites, http://ilmatieteenlaitos.fi/kesatilastot and http://ilmatieteenlaitos.fi/talvitilastot.

Freeman, Myrick A., Herriges, Joseph A. & King, Catherina L. (2014). *The Measurement of Environmental and Resource Values*. (3rd ed.). London: RFF Press.

Gabrych, Malgorzata, Kotze, Johan & Lehvävirta, Susanna (2016). Substrate Depth and Roof Age Sternly Affect Plant Abundances on Sedum-Moss and Meadow Green Roofs in Helsinki, Finland. *Ecological Engineering*, *86*(86), 95–104.

Gollier, Christian & Weitzman, Martin (2010). How Should the Distant Future be Discounted when Discount Rates are Uncertain? *Economics Letters*, *107*(3), 350–353.

Ghermandi, Andrea, van den Bergh, Jeroen, Brander, Luke, de Groot, Henri & Nunes, Paulo (2010). Values of Natural and Human-Made Wetlands: A Meta-Analysis. *Water Resources Research*, *46*(12), 1–12.

Green Building Research Laboratory Websites (2016). Green roof Energy Calculator v2, http://greenbuilding.pdx.edu/GR_CALC_v2/grcalc_v2.php#retain.

de Groot, Rudolf S., Wilson, Matthew A. & Boumans, Roelof M. J. (2002). A Typology for the Classification, Description and Valuation of Ecosystem Functions, Goods and Services. *Ecological Economics*, *41*(3), 393–408.

Gyproc (2015). Gyprof.fi/Plasterboard manufacturer websites.

Hanemann, Michael W. (1991). Willingness to Pay and Willingness to Accept: How Much Can they Differ? *The American Economic Review*, *81*(3), 635–647.

Hartig, Terry, Mang, Marlis & Evans, Gary W. (1991). Restorative Effects of Natural Environment Experiences. *Environment and Behavior*, *23*(1), 3–26.

Hauru, Kaisa, Lehvävirta, Susanna, Korpela, Kalevi & Kotze, Johan D. (2012). Closure of View to the Urban Matrix has Positive Effects on Perceived Restorativeness in Urban Forests in Helsinki, Finland. *Landscape and Urban Planning*, *107*(1), 361–369.

Heinonen, Tuomo (2012). Interview by Nurmi, V. (E-mail and phone communication). HSY (Helsinki Environmental Center) Manager of Investments Mr. Tuomo Heinonen.

Helimäki (2013). Interview by Nurmi. V. (E-mail communication). Acoustic Consulting Company.

Honkatukia, Juha, Mälkönen, Ville & Perrels, Adriaan (2008). Impacts of the European Emissions Trading Scheme on Finnish Wholesale Electricity Prices. In Francesco Giulio (Ed.), *Markets for Carbon and Power Pricing in Europe – Theoretical Issues and Empirical Analysis* (pp. 160–192). Cheltenham UK: Edgar Elgar publishers.

IPCC (2014). Intergovernmental Panel on Climate Change, Summary for Policymakers. https://ipcc-wg2.gov/AR5/images/uploads/WG2AR5_SPM_FINAL.pdf.

Irvine, Katherine N., Devine-Wright, Patrick, Payne, Sarah R., Fuller, Richard A., Painter, Birgit & Gaston, Kevin J. (2009). Green Space, Soundscape and Urban Sustainability: An Interdisciplinary, Empirical Study. *Local Environment*, *14*(2), 155–172.

Jokisalo, Juha (2012). Interview by Nurmi, V. (E-mail communication). Aalto Yliopisto Senior Researcher Juha Jokisalo.

Jungels, Jeremy, Rakow, Donald A., Allred, Shorna B. & Skelly, Sonja M. (2013). Attitudes and Aesthetic Reactions Toward Green Roofs in the Northeastern United States. *Landscape and Urban Planning*, *117*(117), 13–21.

Jylhä, Kirsti, Kalamees, Targo, Tietäväinen, Hanna, Ruosteenoja, Kimmo, Jokisalo, Juha, Hyvönen, Reijo, Ilomets, Simo, Saku, Seppo & Hutila, Asko (2012). Rakennusten Energialaskennan Testivuosi 2012 ja Arviot Ilmastonmuutoksen Vaikutuksista. *Ilmatieteen Laitos Raportteja*, *6*, 1–110.

Kaval, Pamela (2010). *A summary of ecosystem service economic valuation methods and recommendations for future studies*. Working paper series #10 Department of Economics, University of Waikato.

Kodinremontit.fi (2015). www.kodinremontit.fi, realized contract prices in Finland.

Lee, Kate E., William, Kathryn J., Sargent, Leisa, Farrell, Claire & Williams, Nicholas (2014). Living Roof Preference is Influenced by Plant Characteristics and Diversity. *Landscape and Urban Planning*, *122*(122), 152–159.

Lee, Kate E., William, Kathryn J., Sargent, Leisa, Farrell, Claire, Williams, Nicholas & Johnson, Katherine (2015). 40-Second Green Roof Views Sustain Attentions. The Role of Micro-Breaks in Attention Restoration. *Journal of Environmental Psychology*, *42*(42), 182–189.

Liu, Karen & Baskaran, Bass (2003). *Thermal Performance of Green roofs through Field Evaluation—Ottawa* Ottawa (Canada): National Research Council Canada, Institute for Research in Construction. Report no. NRCC-46412.

Madre, Frederic, Vergnes, Alan, Machon, Nathalie & Clergeau, Philippe (2014). Green Roofs as Habitats for Wild Plant Species in Urban Landscapes: First Insights from a Large-Scale Sampling. *Landscape and Urban Planning*, *122*(122), 100–107.

Mäler, Karl-Göran (1974). *Environmental Economics: A Theoretical Inquiry*. Baltimore: Johns Hopkins University Press.

Mentens, Jeroen, Raes, Dirk & Hermy, Martin (2006). Green Roofs as a Tool for Solving the Rainwater Runoff Problem in the Urbanized 21st Century? *Landscape and Urban Planning*, *77*(3), 217–226.

Millennium Ecosystem Assessment (2005). Current State and Trend Assessments, Full report, http://www.unep.org/maweb/en/Condition.aspx.

Murphy, James, Allen, Geoffrey, Stevens, Thomas & Weatherhead, Darryl (2005). A Meta-Analysis of Hypothetical Bias in Stated Preference Valuation. *Resource and Environmental Economics*, *30*(3), 313–325.

Nurmi, Väinö, Votsis, Athanasios, Perrels, Adriaan & Lehvävirta, Susanna (2013). *Cost-benefit Analysis of Green Roofs in Urban Areas: Case Study in Helsinki* Finnish Meteorological Institute - Reports 2013:2.

Peck, Steven (2003). Towards an Integrated Green Roof Infrastructure Evaluation for Toronto. *The Green Roof Infrastructure Monitor*, *5*(5), 4–5.

Porsche, Ulrich & Köhler, Martin (2003). Life Cycle Costs of Green Roofs: A Comparison of Germany, USA, and Brazil. In *Proceedings of the World Climate and Energy Event*; 1–5 December 2003., Rio de Janeiro, Brazil. (22 October 2007 www.gruendach-mv.de /en/ri03_461_u_porsche.pdf).

van Renterghem, Timothy, Hornikx, Maarten, Forssen, Jens & Botteldooren, Dick (2013). The Potential of Building Envelopre Greening to Achieve Quietness. *Building and Environment*, *61*(61), 34–44.

La Roche, Pablo & Berardi, Umberto (2014). Comfort and Energy Savings with Active Green Roofs. *Energy and buildings*, *82*(82), 492–504.

Rosenzweig, Cynthia, Gaffin, Stuart & Parshall, Lily (2006). *Green Roofs in the New York Metropolitan Region: Research Report*. Columbia University Center For Climate Systems Research and Nasa Goddard Institute for Space Studies. New York.

Ruuhela, Reija, Lahtinen, Matti, Haga, Lisa, Fronzek, Stefan & Carter, Timothy (2012). *Investigating the Relationship Between Mortality and Temperature and a Possible Acclimatization Effect in Finland* poster at the Second Nordic International Conference on Climate Change Adaptation, Helsinki 29–31.9.

Sailor, David J. & Hagos, M. (2011). An Updated and Expanded set of Thermal Property Data for Green Roof Growing Media. *Energy and Buildings*, *43*(9), 2298–2303.

Saiz, Susana, Kennedy, Christopher, Bass, Brad & Presnail, Kim (2006). Comparative Life Cycle Assessment of Standard and Green Roofs. *Environment Science and Technology*, *40*(13), 4312–4316.

Santamouris, Mattheos (2014). Cooling the Cities – A Review of Reflective and Green Roof Mitigation Technologies to Fight Heat Island and Improve Comfort in Urban Environments. *Solar energy*, *103*(103), 683–703.

Seppänen, Olli (2001). *Rakennusten lämmitys* (Heating of buildings, in Finnish) Suomen LVI-liitto ry. 2001.

Shabman, Leonard & Stephenson, Kurt (1996). Searching for the Correct Benefit Estimate: Empirical Evidence for an Alternative Perspective. *Land Economics*, *72*(72), 433–449.

Shin, Eunha & Kim, Heungsoon (2015). Analysing Green Roof Effects in an Urban Environment: A Case of Bangbae-Seoul. *Journal of Asian Architecture and Building Engineering*, *14*(2), 315–322.

Sproul, Julian, Wan, Man P., Mandel, Benjamin H. & Rosenfeld, Arthur H. (2013). Economic Comparison of White, Green, and Black flat Roofs in the United States. *Energyy and Buildings*, *71*(71), 20–27.

Tan, Puay & Sia, Angelina (2005). A Pilot Green Roof Research Project in Singapore. In *Proceedings of Third Annual Greening Rooftops for Sustainable Communities Conference,* Awards Trade Show, Washington, DC, May 4–6.

Tervonen, Juha & Ristikartano, Jukka (2010). Unit-costs of different cost elements in road traffic 2010 (in Finnish), Finnish Transport Agency, Liikenneviraston ohjeita 21/2010, Helsinki.

Toronto and Region Conservation (TRC) (2007). An Economic Analysis of Green Roofs: Evaluating the Costs and Savings to Building Owners in Toronto and Surrounding Regions pdf available at http://www.sustainabletechnologies.ca/wp/wp-content/uploads/2013./03/GR_Econ.pdf.

Tyrväinen, Liisa & Miettineni, Antti (2000). Property Prices and Urban Forest Amenities. *Journal of Environmental Economics and Management*, *39*(2), 205–223.

U.S: Office of Management and Budget (2003). Circular A-4. Available at: www.whitehouse.gov/sites/default/files/omb/inforeg/regpol/circular-a-4_regulatory-impact-analysis-a-primer.pdf.

U.S. Government (2011). Benefits of Well-Designed, Well-Maintained Green Roofs, Available at: http://www.gsa.gov/portal/mediaId/167843/fileName/Benefits.action.

Weitzman, Martin (2001). Gamma Discounting. *American Economic Review*, *91*(1), 260–271.

Whatley, Melvin B. (2011). Life-Cycle Cost-Benefit Analysis of Green Roofing Systems: The Economic and Environmental Impact of Installing Green Roof on all Atlanta Public Schools.

White, Emma V. & Gatersleben, Birgitta (2011). Greenery on Residential Buildings: Does it Affect Preferences and Perceptions of Beauty? *Journal of Environmental Psychology*, *31*(3), 89–98.

Wyzga, Ronald E. & Rohr, Annette (2015). Long-Term Particulate Matter Exposure: Attributing Health Effects to Individual PM Components. *Journal of the Air and Waste Management Association*, *65*(5), 523–543.

Yang, Jun, Yu, Qian & Gong, Peng (2008). Quantifying Air Pollution Removal by Green Roofs in Chicago. *Atmospheric Environment*, *42*(31), 7266–7273.

ZHAW (2013). School of Engineering in Switzerland. http://pd.zhaw.ch/publikation/upload/203013.pdf.