COST-BENEFIT ANALYSIS OF GREEN ROOFS IN URBAN AREAS: CASE STUDY IN HELSINKI

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Cost-benefit analysis of green roofs in urban areas: case study in Helsinki

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Abstract

This report presents a green roof cost-benefit analysis. Green roofs are roofs that are partially (or almost completely) covered with vegetation; between the roofing membrane and the vegetation there may be several technical layers. In this report we discuss the benefits and costs of lightweight self-sustaining vegetated roofs that do not require structural modifications from the building. The costs and benefits have been analysed in Helsinki, Finland.

Green roofs offer various kinds of ecosystem services that are often scarce especially urban areas. These services accrue benefits to urbanites. However, ecosystem services do not generally have a market price, thus we had to use ecosystem valuation methods to estimate the benefits. Based on the valuation, the most significant benefits were: an increased lifespan of the roof, energy savings due to increased isolation and cooling, improved storm-water management, better air-quality and sound insulation especially in the air craft noise zones. In addition, other potentially significant benefits include aesthetic benefits, health benefits and improved biodiversity.

Only a share of the green roof benefits accrues to the owner of the property while other benefits are distributed among the population of a larger area. Thus, benefits can be classified into private and public benefits. In the cost-benefit analysis we found that private benefits are in most cases not high enough to justify the expensive investment of a green roof instalment since the costs are incurred solely by the private decision makers (e.g. developers, real estate buyers). The cost estimates are based on supplier interviews and the additional costs of green roof were compared to a reference bitumen roof.

The cost-benefit calculations hint that with a higher rate of implementation and realization of public benefits, the green roofs would be a good investment. However, because the private benefits are not high enough to justify a green-roof installation for a private decision-maker at the current cost level, the rate of implementation can be expected to stay low without corrective policy instruments. Policy instruments could include supportive policies that add incentives for private decision-makers to install green roofs and/or administrative orders.

ILMATIETEEN LAITOS

Julkaisija	Ilmatieteen laitos, (Erik Palménin aukio 1)
	PL 503, 00101 Helsinki Julkaisuaika 2013

Tekijä(t)	Väinö Nurmi, Athanasios Votsis, Adriaan Perrels ja Susanna Lehvävirta

Nimeke	Viherkattojen kustannushyötyanalyysi Helsingin kaupunkiolosuhteissa

Tiivistelmä

Raportissa esitetään viherkattojen kustannus-hyötyanalyysi. Viherkatoiksi kutsutaan yleisesti sellaisia kattoja, joiden päälle on istutettu kasvillisuutta; kattopinnan ja kasvillisuuden välissä on lisäksi useita erilaisia teknisiä kerroksia. Tutkimuksessa keskityttiin kevyisiin ja helppohoitoisiin viherkattoihin, joiden asentamiseen ei yleensä vaadita rakenteellisia muutoksia. Kustannuksia ja hyötyjä on arvioitu Helsingin kaupunkiolosuhteissa.

Viherkatot tarjoavat erilaisia ekosysteemipalveluita, joista voi olla varsinkin kaupunkiolosuhteissa niukkuutta. Näistä palveluista saadaan erilaisia hyötyjä kaupungin asukkaille. Hyödyille ei ole olemassa markkinahintaa, joten arvioimme hyötyjä ekosysteemipalveluiden arvottamismenetelmien avulla. Arvioimistamme hyödyistä merkittävimmät olivat kattopinnan pidentynyt käyttöikä, energiansäästö paremman eristävyyden ja viilentävän vaikutuksen ansiosta, hulevesien imeytyminen ja hulevesipiikkien hallinta, ilmanlaadun parantuminen ja äänieristävyys lentomelualueilla. Näiden lisäksi merkittäviä hyötyjä ovat myös esteettiset hyödyt, viherympäristön luomat terveyshyödyt ja parantunut biodiversiteetti.

Ekosysteemipalvelut hyödyttävät joiltain osin viherkattojen rakennuttajaa, asukasta tai kiinteistön omistajaa ja joiltain osin laajempaa joukkoa. Viherkattojen hyödyt voidaankin jakaa rakennuksen omistajan tai asukkaan hyötyihin (yksityiset hyödyt) ja koko yhteisön hyötyihin (julkiset hyödyt). Havaitsimme, että yksityiset hyödyt eivät ole monessa tapauksessa tarpeeksi suuret perustelemaan kallista alkuinvestointia. Alkuinvestoinnin eli viherkaton kustannukset selvitimme kattavalla viherkattojen toimittajien haastattelukierroksella, jossa selvitimme yleisimmin tarjolla olevan esikasvatettuihin maksaruohomattoihin perustuvan viherkaton hinnan verrattuna referenssikattoon eli bitumikattoon.

Mikäli koko yhteisön saavuttamat hyödyt lasketaan mukaan, viherkatot voivat varsinkin tiheästi rakennetuilla alueilla olla kannattava investointi koko yhteisön kannalta. Koska yksityisten päätöksentekijöiden kustannukset ovat usein suuremmat kuin hyödyt, jää viherkattojen käyttöönottoaste luultavasti hyvin pieneksi. Tästä syystä erilaisten kannustimien kehittäminen varsinkin kantakaupungin alueella voisi olla järkevää.

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1 INTRODUCTION

This report discusses the economic benefits and costs of thin, lightweight green roofs with minimal maintenance requirements. In general, green roofs are roofs that are partially or (almost) completely covered with vegetation. Between the roofing membrane and the vegetation there may be several technical layers such as a root barrier, drainage and water retention layers and substrate. There are different types of green roofs depending on the choice of vegetation, the water retention capacity, the thickness and quality of the substrate layer and the intensity of maintenance. In this study, we focus on the benefits and costs of lightweight self-sustaining vegetated roofs in an urban system and emphasize that the values can be essentially different for different kinds of green roofs in different systems. Most of the methods applied in this study can however be applied to similar studies with different settings. The urban system we focus on is Helsinki, the capital and the largest city of Finland. It is located in southern Finland, on the shore of the Gulf of Finland. Helsinki has a population of over 600,000, with a metropolitan population of over 1.1 million, making it by far the most populous municipality and urban area in Finland.

Because most of the potential benefits of green roofs are not directly measureable in economic terms, we have to use valuation methods developed for the conversion of different types of benefits of ecosystem services (ES) into commensurable (monetary) units. Many of the benefits such as improved biodiversity are intangible and hard to valuate. For this reason, various benefits of ES are often neglected in cost-benefit analysis of green roofs. In this study, we try to overcome these problems and arrive at an estimate of the benefit/cost –ratio (B/C-ratio) under different green roof infrastructure scenarios. An extensive literature search and expert interviews showed that – at least preliminary – estimates can be found for most benefits of those ES that are relevant for green roofs. These estimates can be easily updated to be coherent with the research on the actual green roof performance in Helsinki when more empirical evidence is available.

The study also deals with the dichotomy between predominantly public benefits and private costs. Green roofs generate a great deal of public (shared) benefits, while without additional policies their costs are private, i.e. mainly carried by the involved real estate owners. Without corrective policy instruments, this dichotomy normally leads to an undersupply of green roofs and consequently a

lower level of implementation than what is optimal from socio-economic viewpoint. We also show that, precipitation, outdoor temperature and level of urbanization are all positively correlated with the value of ES provided by green roofs, and thus the location of the green roof is an important determinant of the potential value.

This report is part of a research program called Fifth Dimension – Green Roofs in Urban Areas which is carried out by Urban Ecology Research Group at the University of Helsinki and funded by Regional Council of Uusimaa. The study also ties in with research carried out in the RECAST project (part of the FICCA programme of the Finnish Academy) and in ENSURE (research programme coordinated by HENVI) regarding sustainable urban planning and climate change resilient cities.

2 ECOSYSTEM SERVICES IN URBAN AREAS

2.1 Introduction – The rise of ecosystem services in new concepts of sustainable urban planning

Cities and urban systems are dependent on ecosystems existing both beyond and within the city limits. Bolund and Hunhammar (1999) identified seven types of different urban ecosystems: street trees, lawns/parks, urban forests, cultivated land, wetlands, lakes/sea and streams. Within urban areas, the primary issue from the perspective of human well-being is whether the urban settlements are able to provide a healthy and satisfying living environment for residents. Living ecosystems are recognized as a key to well-being as ecosystem services are increasingly acknowledged to increase the quality of life for urbanites e.g. by improving air quality, reducing noise and providing recreational services (see e.g. Niemelä et al., 2010). Many problems that are present in urban areas are locally generated and often the only or the most effective way to deal with these local problems is through local solutions. These local problems include for example poor air quality, heat island effect and urban flooding. Climate change is expected to further increase some of these problems (Bolund and Hunhammar, 1999).

Ecosystems provide services that can tackle some of the problems caused by urbanization - or rather the local undersupply of various ecosystem services that is at the root of the problem. Roofs represent a large share of the horizontal surface of built-up areas, but the roof area has scarcely been capitalized on. The addition of vegetation and the growing substrate on roof surfaces creates an ecosystem that provides services. These ES can mitigate several negative externalities (costs for the third party such as air pollution) of built-up areas and can reduce the energy consumption of the buildings (Oberndorfer et al., 2007). Green roofs represent an opportunity to increase the coverage of living ecosystems in cities. However, the extent on which green roofs can be justified to compensate for the ground-level ecosystems and the extent on which green roofs serve as a complementary solution needs to be studied, as their structure and many functions differ profoundly from ground-level ecosystems.

Ecosystem services have been categorized in a number of different ways. Millennium Ecosystem Assessment popularized the concept, thus the classification used most often is from the final report of MEA (MEA, 2005). In this study, the ES were grouped into four broad categories: 1) provisioning, 2) regulating, 3) cultural and 4) supporting function, bearing in mind that some of the categories overlap. In their widely cited article Costanza et al. (1997) identified 17 groups of ES and de Groot et al. (2002) extended the list to 23 main services (that they called functions). Some of these services have a major importance in urban areas including at least emissions regulation, microclimate regulation, noise disturbance prevention, water regulation, waste treatment, aesthetics and educational benefits.

Once the functions of a specific ecosystem are known, the nature of the benefit and its potential value to human society can be estimated through the goods and services provided by the functional aspects of the ecosystem (de Groot et al., 2002). Green roofs for example provide ES that include improved storm-water management, regulation of building temperatures, reduced urban heat-island effect, aesthetic and health benefits and increased urban wildlife. How beneficial a certain service is depends not only on the service but also on the system where it is located. For example storm-water management provided by a green roof can be highly beneficial in a city with a high level of precipitation and a high proportion of impermeable surfaces; naturally the benefits vary within cities as well. The ES provided by green roofs derive from the three main components of the roof system: vegetation, substrate (growing medium) and the membranes under them (affecting the water retention capacity, cooling effect, biodiversity value etc.).

The existence of cities is based on concentration and agglomeration advantages. This means that the proximity of various producers and consumers creates common advantages in production and consumption as comparison to a dispersed settlement pattern. With all agglomeration factors present, a more dynamic set of agglomeration advantages emerges, which can lead to further accumulation of population and economic activity. As a consequence at least in some parts of the urban area the productivity per acre gets so high that it also significantly pushes up land prices and hence real estate prices. Consequently, a process of selective expulsion (from economic core areas) starts up. In turn this implies that, in the absence of further measures, the city starts to expand over an ever larger area and to show more spatial segregation in functions. Depending on landscape, climate, hydrology, economic structure, and urban form all kinds of environmental external effects may occur in such an expanding city, e.g. pollution of the air, soils, and water, as well as noise and degradation of natural habitats.

From a socio-economic viewpoint, a sustainable city requires sufficient maintaining of agglomeration advantages on which the existence of the city is based (see Glaeser, 2010; Söderman et al., 2011). The concentration of and the proximity of various producers and consumers creates common advantages in comparison to a dispersed settlement pattern. If many favorable factors are present a more dynamic set of agglomeration advantages emerges, which can lead to further accumulation of population and economic activity. In expanding and consolidating urban areas, diverse environmental external effects occur, e.g. pollution of the air, soils, and water, as well as noise and fragmentation and degradation of natural habitats, and productivity of ecosystem services per area is very likely to decrease. However, this decrease has until recently been overlooked or at least the consequent substitution solutions have been planned with little consideration of the lost value of ecosystem services.

The rise in attention to ecosystem services in urban environments ties in with the need of revising the concepts of sustainable urban planning. Sustainable urban development tended to emphasize higher building densities as a central paradigm (Newman and Kenworthy 1999, 2007). The underpinning has leaned mostly on minimized distances and urban metabolism approaches (Carlsson-Kanyama et al., 2005) based on impacts related to material consumption by urban dwellers (Rees and Wackernagel, 1996). In this paradigm, urban areas are primarily understood as social-economic-technical systems, for which environmental conditions (e.g. air quality) can be relevant to enable good socio-economic conditions or – in less formalised terms – to enable attractive and healthy living environments. The significance of urban green can be taken into account but is often only assessed in terms of its amenity value (e.g. Cho et al., 2008), not in terms of all the services it could provide.

The valuation of ecosystem services requires an interdisciplinary approach, but so far the integration of social, economic, ecological and engineering theories and methods has been meager (MEA, 2005). Furthermore, research results have seldom offered feasible guidelines for urban planning. Thus studies on urban biota, and the benefits and values it provides for humans, are often ignored in planning and management (Yli-Pelkonen and Niemelä, 2006). At the same time, urban planning has been criticized for neglecting the social space, the lived and experienced city (Lehtovuori, 2009), yet residents' experiencing their environment is a key process in the identification of cultural ecosystem services such as opportunities for recreation, learning, aesthetic enjoyment and health benefits. Resident experiences, attitudes, values and understanding also affect

the implementation of ecologically sustainable solutions, making it important to understand the acceptability of possible solutions beforehand.

Finally, while the sustainability of ecosystem services in urban areas depends on biological boundary values for ecosystem functioning, and interactions between ecosystem services, it also depends on the interplay of these services with urban economic functions. The rising interest for valuation of ecosystem services in urban planning and management is reinforced by the need to better prepare for natural hazards exacerbated by climate change. This acknowledgement has boosted a widely shared interest in the resilience of social and natural systems, including cities (Walker et al., 2004), and sustainable urban development will be increasingly based on the notions of resilience. The challenge is, however, that there are trade-offs between different ecosystem services and their interaction with the economic system. For example, increasing the share of urban green in the entire city could improve air quality, the inhabitants' living environment, and storm water retention (and hence attenuate flooding risks). Yet, for a given population size, a higher share of green area may mean an expansion of the total urban area, which inter alia would increase emissions from transport, or – under strict regulation – could lead to higher densities outside green areas, which may have major impacts on real estate costs (Cho et al., 2010; Conway et al., 2010). With these trade-offs in mind the addition of green roofs to the green infrastructure portfolio is promising, as green roofs can raise the supply of ecosystem services while avoiding the negative effects of lowering densities. When applied at a notable scale, there may even be positive spatial spillover effects, but the assessment of that effect goes well beyond the remit of the current study. All in all it means that a societal cost-benefit analysis of green roofs, as a facilitator of various ecosystem services, can be carried out as a comparison between alternative roof solutions (e.g. conventional, solar and wind energy oriented, and a green roof), i.e. substituting purely manmade solutions by a mixture of ecosystem services and some engineering.

2.2 Ecosystem services provided by green roofs

Storm-water management

Urban areas largely consist of hard, impervious surfaces of streets, driveways and buildings. These conditions create problems as nonporous surfaces greatly intensify storm-water runoff, diminish groundwater recharge and enhance stream channel and river erosion (Mentens et al., 2005). One of the major environmental problems in urban areas is that hydrological systems have to cope with

highly fluctuating amount of surface runoff water. Climate change will further increase these problems at least in the northern Europe where both the amount of precipitation and the number of extreme precipitation events are expected to increase in the future (Jylhä et al., 2009). Consequently, also the risks of city floods are going to increase significantly. When heavy runoff overburdens existing storm-water management facilities, it can cause (besides city flooding) also combined sewage overflow into the lakes and rivers. Combined sewage overflows (CSO) occur when sewage and storm water are discharged from sewer pipes without treatment. Urban runoff that is high in pollutants harms wildlife habitats and contaminates drinking water reserves. CSOs are a significant source of environmental pollution in urban areas (Rosenzweig et al., 2006). To be able to cope with increased amount of urban runoff (due to both increased urbanization and climate change impacts), storm water management has to be resized according to the increased levels of precipitation. However, resizing sewage systems usually comes at a high cost (analyzed in Chapter 4.2.), thus other ways to manage water flows may be more cost-effective.

During heavy rainfall in cities, the amount of surface water may increase up to ten or twenty-fold compared to a normal situation. Underground storage tanks are one example of an engineering approach that stores overflows for later introduction to the sewer system. Another approach is to use vegetated surfaces such as green roofs as an alternative or a complementary solution to other available storm-water management measures. Green roofs store water during rainfall events, delay runoff and return precipitation to the atmosphere through evapotranspiration (reviewed in Oberndorfer et al., 2007). The reduction of runoff consists of:

- (i)   the delay of the initial time of runoff due to the absorption of water in the green roof system;
- (ii)   reduction in the total runoff by retaining part of the rainfall; and
- (iii)   distribution of the runoff over a longer time period through a delayed release of excess water (Mentens et al., 2005).

The annual rainfall-runoff ratio for green roofs is strongly determined by the depth of the substrate layer, roof slope and type of vegetation. Results from Berlin suggest that light-weight (<100 mm substrate) low-growth roof greening on just 10% of the buildings would already result in a runoff reduction of 2.7% for the region and of 54% for the individual buildings (Mentens et al., 2006). In another study, simulations from New York showed that thin, lightweight green roofs planted with sedums could reduce the annual storm water runoff at the sewage shed level by as much as 10%

with 50% green roof infrastructure, while a 10% green roof infrastructure produced a 2% reduction in total runoff (Rosenzweig et al., 2006).

Membrane longevity

Green roofs extend the lifespan of the roofing membrane by protecting against thermal stress, diurnal fluctuations and UV radiation. The exposure of the roof materials causes breakdowns of the roof materials. Most studies indicate that green roofs at least double the lifespan of the roofing membrane to 40 or 50 years, while literature estimates for non-vegetated roof longevity ranged from 10 to 30 years (reviewed in Toronto Region Conversation, 2007 and Oberndorfer et al., 2007). Thus, although green roofs in Finland are twice as expensive to install (or even more if the implementation rate remains very low, as will be shown in Chapter 5.), most studies indicate that the service life of the roof will be at least doubled.

Noise insulation

Noise pollution is an increasingly severe problem in urban systems. Noise disturbs people and causes economic problems through decreased efficiency amongst employees as well as lowered property values due to less demand. Over 170 million people in the EU are estimated to live in areas where noise is a source of irritation. About 80 million people, or 20% of the European population, are exposed to noise levels that are unacceptable. The effects of exposure include irritation, sleep disturbances and other risks for negative health impacts (Lagström, 2004). Over 300,000 people in Uusimaa (the province where Helsinki is located) are exposed to daily noise levels above Lden > 55 dB (a common threshold for noise exposure in residential areas; threshold values can be found at the website of Finland's environmental administration). Road transportation is the major cause for noise exposure, while air traffic causes noise exposure to at least 14,000 inhabitants (Finland's environmental administration, 2012).

To improve the noise insulation properties of a building, green roofs can be used to increase the transmission loss of the roof. Based on a field study in Canada (Connelly and Hodgson, 2008) light-weight green roofs (substrate depth 40-150mm, drought-tolerant plants) provide a higher transmission loss than an additional ceiling element albeit the design of the hypothetical ceiling element was not specified in the study. However, this property is specifically desirable in residential occupancies that are near highways or are located below aircraft flight paths. Transmission losses

were found to increase from 5 to 13 dB on low and mid frequency rate (below 2000 Hz) and from 2 to 8 dB in higher (over 2000 Hz) frequency rates.

Lagström (2004) studied the sound insulation properties of moss-sedum green roofs. He estimated the costs of disturbing noise levels in Europe: a conservative estimate is that noise leads to an annual cost of approximately 10 billion euros in Europe each year. However, the exact method of valuation of the costs is not properly explained. Lagström's study shows that moss-sedum vegetation and the layers below it decrease noise levels by 5 to as much as 25 dB, depending on the frequency of the noise, with an average of around 10 dB. This is in the same order of magnitude as found by Connelly and Hodgson (2008).

Building heat regulation

During warm weather, green roofs reduce the amount of heat transferred through the roof thereby lowering the energy demand of the cooling system of the building (Connelly and Baskaran, 2003). Green roofs reduce heat flux through the roof via evapotranspiration, by physically shading the roof and by increasing the insulation and thermal mass. Green roof impact on energy demand for cooling is a difficult parameter to estimate because it is highly dependent on the building type, the ratio between roof and floor areas, geographical location and type of vegetation. The benefit is naturally increased in warmer environments and in buildings with poor insulation but may again decrease in hot arid areas with scarcity of water. Thus, the aggregate cooling demand depends on building type, location and use, among other factors (Rosenzweig et al., 2006).

A report about energy savings of a light-weight green roof with succulent drought resistant plants (sedum, cactus and desert shrub) in Madrid (Saiz et al., 2006) showed that a green roof reduced the energy used for cooling by approximately 10% for the entire building and by 25%, 9%, 2% and 1% for the four consecutive floors directly below the green roof, as compared to a gray gravel roof. A field study in Vancouver (Connelly and Liu, 2005) compared the heat flows of two green roofs (one with 75mm growing medium with sedums and a one with 150mm growing medium with grass) to a bitumen reference roof over a 30-day observation period in British Columbia in October 2004. During the observation period, both green roofs reduced the heat flow of the roof over 70% compared to the reference roof (with no significant difference between the test roofs).

Green roofs also increase the insulation properties of a roof. However, new buildings in Finland that are built according to the current building regulations are already by default very well insulated. Thus, the isolative benefit of installing a green roof is much higher for older buildings than for new ones. In Chapter 3.4, we show a method of converting the improved insulation properties into a monetary benefit.

Microclimate regulation

In urban environments, vegetation has largely been replaced by impervious and often dark surfaces. These conditions contribute to an urban heat island effect, wherein urban regions are significantly warmer than the surrounding suburban and rural areas, especially at nighttime (first discovered by Howard 1818; more specifically Oke, 1973). A simulation in New York (Rosenzweig et al., 2006) showed results that green roof infrastructure (50% of roof area covered with vegetation) could reduce average surface temperatures in New York City by as much as 0.8 °C.

Drebs (2011) studied the heat-island-effect in Helsinki. He found out that 1) the city center of Helsinki is warmer than its surroundings, both on a monthly basis, and for the annual mean; however, there are only a few grid points which display a temperature difference of more than 1 °C; 2) if the monthly spatial variation in air temperature differences is small, then usually the temperature difference between the city and the surroundings is also small; and 3) isolated large buildings and suburban centers create their own individual heat islands. The value of the benefits and harms of the heat-island-effect in Helsinki has not been estimated or even 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 et al., 2012). Thus, green roofs' potential value as a reducer of the heat-island-effect is not included in the cost-benefit calculation, because reliable estimates for the scope of different benefits and harms are not available.

In architectural design and site planning, Givoni (1998) provides a considerable amount of evidence and design recommendations for effectively regulating microclimate inside and around a building by the use of vegetation.

Emission regulation

Individual lightweight green roofs are low in biomass and thus have only a small potential to offset carbon emissions from cities. However, a widely adopted green roof infrastructure could make a significant contribution as an urban emissions (and particle) regulator, thus having an impact on the air quality of urban systems. Clark et al. (2008) suggest that green roofs could work well to the mitigation of nitrogen oxide, and they estimated that the uptake potential of NO_2, for a lightweight green roof (with a substrate of 5-15 cm) would be $0.27 \frac{kgNO_2}{y\,m^2}$. Clark et al. (2008) pointed out, however, that as the estimate is on data from greenhouses, further research is needed to understand the performance on the roof and species specific uptake potential. Tan and Sia (2005) provided estimates for the gas uptake potential of lightweight green roofs in Toronto and Yang et al. (2008) for a mix of different kinds of green roofs (63% short grass and other low growing plants, 14% large herbaceous plants, 11% trees and shrubs, and about 12% various structures and hard surface) in Chicago. These studies show, that next to nitrogen dioxide NO_2, green roofs can also reduce the concentrations of ozone O_3, particulate matter PM_x and sulfur dioxide SO_2.

Aesthetic and psychological benefits

Green roofs provide aesthetic and psychological benefits for people in urban areas. A well-known article by Hartig et al. (1991) proved that experience with nature has restorative outcomes; greater levels of happiness were recorded still three weeks after the experience. Even a short-term exposure to green spaces was found to have salutary effects on people. Yet more interesting, the study showed that restorative effects can be realized in a wide range of natural settings which include urban parks and urban wilderness areas. However, these benefits are among those that are the hardest to valuate. For the Finnish context, Hauru et al. (2012) showed the positive effects of partially or completely hiding direct views to the urban matrix by the use of urban green, and it inspires a hypothesis that green roofs may also have such effects.

Urban green has been found to positively affect property prices in smaller towns in Finland (Tyrväinen, 1997 for Joensuu; Tyrväinen and Mietinen, 2000 for Salo). This effect is composite and highly dependent on the context (e.g. location within the city, presence/absence of several other urban economic factors), but it nevertheless reflects in part the positive aesthetic and psychological value of urban green and it is reasonable to extend it to green roofs that are physically or visually accessible.

From a design perspective where the aesthetic dimension is an important factor, the use of natural elements is frequently recommended in architectural and planning guidelines as a necessary element of sound urban design, both inside and outside the sustainable development context (e.g. Hedman and Jaszewski, 1984; the LEED and Earthcraft design standards). Historically, urban green has been at the core of significant planning movements such as the City Beautiful movement, Ebenezer Howard's Garden City, and Frank Lloyd Wright's conception of the ideal city, which all reacted to the mode of life in a highly industrialized and polluted built environment (Hall, 2002; Fishman, 2003). Green roofs and the natural landscape have been a frequent element in Friedensreich Hundertwasser's architectural and urban design projects.

Urban habitat

Green roofs provide habitat for wild species within cities and can help increase local biological diversity. However, creation of habitat is seen usually only as a bonus to more quantifiable benefits. As a response, incentives and regulations for designing vegetated roofs with biodiversity goals have been implemented at least Switzerland and England (Coffman and Waite, 2011). To quantify the increase in biodiversity is not easy and the methods vary between different studies. Most of the studies show promising results as an increase in urban biodiversity.

Köhler (2006) studied two dry-meadow green roofs with 10 cm substrate in Berlin over twenty years and found a relatively wide range of flora (in total 110 vascular plant species, 7% of those that had been observed on the region). Another study in Basel (where green roofs are mandatory for flat roofs) found that a single green roof supported 79 beetle and 40 spider species of which 20 species were endangered. Brenneisen (2006) concluded that low-maintenance green roofs provide suitable habitat for those animal and plant species that are able to adapt to such conditions and are mobile enough to reach the habitats on the roofs. A study in London (Kadas, 2006) observed a high abundance of invertebrates on the roofs. At least 10% of the species collected at the study sites were designated nationally rare or scarce. Another kind of example can be found in England where green roofs have been designed to mimic the conditions found on the derelict sites favored by the black redstart which is a rare species of bird in the U.K. (Grant, 2006). In a more recent study, Coffman and Waite (2011) observed a high diversity of three taxa: insects, spiders, and birds on two separate green roofs (one with sedums and no higher than 7.6cm and one with installed container-grown nursery plants with depth between 30 cm – 60 cm). Even though both of the roofs were abundant with small species, the degree of similarity between the roofs was low. It was also found that even

systems constructed without conservation objectives contained wild species of insects, spiders, and birds. Coffman and Waite (2011) used methods called a *rapid assessment method* and *Rényi entropy equation* for quantifying diversity and to allow comparison between different sites. These methods are of interest as efforts to quantify the biodiversity benefits and thus made them more comparable across studies.

2.3 Private and public benefits

Generally, only a part of the benefits of ecosystem services accrues to the owner of the property where the considered (section of the) ecosystem is located. It is rarely feasible for the owner to charge other beneficiaries for the benefits they receive from the ES. For example, an owner of a building with a green roof cannot charge neighbors a fee for improved air quality or more pleasant scenic view. Attempts have been made to develop markets or payment schemes for a very small proportion of the ES (MEA, 2005). Green roofs are not an exception in this respect. Most of the aforementioned benefits relevant to green roofs fall into the category of public benefits, while most of the costs are incurred by the private decision makers (e.g. developers, real estate buyers).

A setting like this can lead to an inefficient situation in which the level of implementation of green roofs (or other ecosystem services) is at a lower level than would be societally desirable. A problem like this requires other kinds of solutions such as payments for negative externalities or subsidies for positive externalities. One example with respect to storm water management is a reduction in the storm-water fee of a property owner with a green roof installation. These kinds of tax abatement programs are scarce in Finland where storm-water fees are charged by municipalities. With a scan across the websites of Finnish municipalities, the basis of calculation for storm-water management is usually directly related to the piped water consumption (e.g. in Turku) or the fee is partly (e.g. Helsinki) or fully (e.g. Kouvola) based on the area of impenetrable surfaces of the considered lot. However, in some municipalities it is possible to reduce the fee thanks to storm-water solutions such as green roofs (e.g. Vaasa, the range of the fee 0-1230 €/year.)

Private benefits include at least membrane longevity, reduced energy costs and potentially sound insulation benefits, scenic value and less damage incurred from city floods. In addition, in some municipalities (e.g. Vaasa) it is possible to get a reduction in storm-water fee for building owners with less impervious surfaces. For companies, improvement of public image with the adoption of

green infrastructure may bring extra return on investment. Public benefits include at least reduced storm water runoff expenditures, reduced urban heat island effect, improved air quality, improved public health, scenic value and urban habitat for various creatures such as birds and insects. Currently all the costs (the net cost of green roof and maintenance costs) are private costs.

3 VALUING ECOSYSTEM SERVICES

The economic valuation of ES is important for at least four different purposes which include awareness raising, support for decision-making, environmental liability and sustainable financing (Costanza et al., 1997). In this study, the valuation of ES can be viewed as an input to a cost-benefit analysis aiming at more efficient land-use, ecosystem payment schemes and other decisions related to urban planning. The benefits of ecosystem services are often neglected in ordinary cost-benefit analysis. However, the lack of commensurate valuation restrains from the comparison of where scarce resources should be allocated. The systematic undervaluation of the ecological dimension in decision making can be partly explained by the fact that the services provided by the natural capital are not adequately quantified in terms comparable with economic services and manufactured capital (Costanza et al., 1997).

Cost-benefit analysis is a decision-support tool that aims to convert the range of benefits and costs surrounding a decision to commensurable units, aggregating the effects over time by discounting future euros into present euros, and then arriving at a present value that can be compared with other uses of scarce resources. Thus, when the valuation has been done properly, the benefits of ecosystem services can be more explicitly incorporated in the cost benefit analysis and the results of cost-benefit analysis on the infrastructure will change. In this particular case, it is also important to communicate potential cost savings and other private benefits to developers and home-owners. Developers can market their buildings with a beneficial green-technology and a relatively higher investment can be at least partly justified with the benefits provided by the ecosystem services.

The concept of ecosystem services has developed from one basic principle in a sense that ecosystem services are considered necessary for human welfare. The framework of the valuation is based on three basic principles: it is *utilitarian*, *anthropocentric*, and *instrumentalist* in the way that it treats ecosystem services. It is utilitarian in that things count to the extent that people want them; anthropocentric in that humans are assigning the values; and instrumentalist in that ecosystem services are regarded beneficial only to the extent they increase human satisfaction (Randall, 1988).

The total economic value of ecosystem services can be divided into five categories: direct use value, indirect use value, option value, bequest value and existence value. The first two categories are

tangible and easy to evaluate and they include services like food and timber production or coastal protection. Option value includes potential future use values such as genetic prospecting and it pertains to the possible use of a resource in the future (e.g. new medicines from tropical rainforests). Intangible bequest and existence values are the hardest to valuate. Valuation of abstract concepts such as cultural heritage and indigenous rights can sometimes be better tackled with other decision-making methods such as multi-criteria analysis. Existence value is derived from human satisfaction for having a certain species or ecosystems to exist; bequest value is derived from the satisfaction to pass the environmental benefits to future generations (Brouwer, 2012).

Even though all dimensions of ecosystem services should be covered in the valuation studies, current research has mainly focused on the use values of ecosystem services (Brouwer, 2012). Broader valuation of ecosystem services is not a simple task and a variety of different methods has been developed for different purposes and situations. The next chapter presents the different valuation methods found in the literature.

3.1 Valuation methods

Economic valuation methods fall into four main categories (De Groot et al., 2002): 1) direct market valuation, 2) indirect market valuation, 3) contingent valuation and 4) group valuation.

Direct market valuation

This is the exchange value that ecosystem services may have in trade, mainly applicable to the goods but also some for cultural services (e.g. recreational services if there is a charge to get into a national park etc.). This is applicable to a very limited scope of ecosystem services since only few of them are exchanged in the markets.

Indirect market valuation

When there are no explicit markets for ecosystem services, indirect methods must be used to assess the values. These include (at least) the following methods:

1) Avoided Cost – services that allow people to avoid costs that would have been incurred without these services, examples from the green roof include energy savings

2) Replacement Cost – some ecosystem services could be replaced with human-made systems

3) Factor Income – ecosystem services that enhance income – for example the product of roof gardens

4) Travel Cost – sometimes the use of ecosystem services requires travel and no other costs. The travel costs can in these cases be seen as the reflection of the revealed value of the service for an individual.

5) Hedonic Pricing – service demand may be reflected in the prices that people are paying for associated goods; e.g. how much people pay more for housing that is located next to a park or some other green. The hedonic pricing method is based on the idea that people prefer and will pay more to live in areas with good environmental quality and thus, the marginal value of environmental quality is embedded in housing prices.

Contingent valuation

Contingent valuation (CV) is a demand-based method of determining values for non-market goods and services. Contingent valuation relies on hypothetical market-like scenarios to provide data that are then used to estimate values that people assign e.g. to various ecosystem services. One of the contingent valuation methods is the *stated value* (SV) method. In this method, data are collected by surveys that try to estimate the maximum amounts people would be *willing-to-pay* (WTP) or would be *willing-to-accept* (WTA) to forgo a specific level of an ecosystem service. There are several important points that need to be taken into account when conducting a SV study. Studies need to clearly define the ecosystem service to be valued (e.g. the existence of a specific species) and respondents need to be informed about the framework of the hypothetical situation. It has also been shown that WTP and WTA surveys might give very different results from each other with otherwise similar settings (Kahneman and Tversky, 1984). Thus, revealed preference studies (often RV in literature – stands for revealed value) are likely to give more consistent results, since they are based on the actual behaviour of people; however, they are also more difficult to carry out.

Group valuation

Group valuation is another contingent valuation method which is based on a stated preference of a group. In this method, a group of stakeholders is brought together to discuss values of ecosystem

services (de Groot et al., 2002). The idea behind the method is that ecosystem services are (usually) public goods and decisions that affect them have an effect on a large group of people. Some believe that valuation of these services should come from public discussion instead of individual based values. This method can also be used in conjunction with any of the aforementioned methods.

3.2 The preferred valuation method

Each valuation method has its strengths and weaknesses. Costanza et al. (1997) went through over one hundred articles and gave an overview of which valuation methods are usually applied to different ecosystem functions. For each ES, several valuation methods are usually applicable but for each service only one or two methods have primarily been used (Costanza et al., 1997). Furthermore there is a relationship between the main type of service and the preferred valuation method. Regulation services are mainly valued through indirect market valuation techniques (avoidable cost and replacement cost), habitat services through indirect market pricing (money donated for conservation purposes), production services through direct market pricing and factor income methods, and cultural services are mainly valuated through contingent valuation (cultural and spiritual information) and hedonic pricing (aesthetic information). Market pricing can be applied to those services that bear a market price (food, tourism). De Groot et al. (2002) showed that for all types of ecosystem functions it is possible, in principle, to arrive at a monetary estimation of human preferences for the availability and maintenance of the related ecosystem services.

3.3 Net present value

After the valuation, the benefits (accrued sometimes in the distant future) and costs (which usually need to be covered right away) need to be converted into a common currency of equivalent present terms by the means of discounting. The choice of an appropriate discount rate is one of the most critical issues in environmental economics. The result of an environmental cost-benefit analysis is usually extremely sensitive to the choice of the discount factor, thus almost any answer to a CBA question can be defended by the choice of an appropriate discount rate. The rationale of discount factors for the distant future has been studied extensively by economists Martin Weitzman and Christian Gollier (e.g. Gollier and Weitzman, 2010). They concluded that when future discount

rates are uncertain but have a permanent component, then the effective discount rate must decline over time toward its lowest possible value.

In this study, the time horizon extends up to 40 years. For practical reasons, we use a constant discount factor for all the future benefits independent on the type of the benefit. Upon a survey of over 2000 economists, Weitzman concluded that the appropriate discount rates (for environmental CBA) are the following: 4% for the immediate future (years 1-5), 3% for years 6-25, 2% for years 26-75, 1% for years 76-300, and 0% for benefits and costs for years after 300. For the relevant time horizon in our study and taking the duration (the weighted average duration until the benefits are received) of the benefits into account, we choose 3% as the single discount factor. This is in line with the fixed long-term interest rates (http://www.swap-rates.com/EUROSwap_extended.html) which reflect the nominal rates (+ premium) that borrowers have to pay to finance their activities.

4 THE VALUE OF BENEFITS OF GREEN ROOFS

4.1 Membrane longevity

Most studies indicated that green roofs will at least double the lifespan of the roofing membrane to 40 or 50 years while literature estimates for conventional roof longevity ranged from 10 to 30 years according to a review article that had gathered estimates from the available literature (Toronto and Region Conservation, 2007). As the green roof industry in Finland is relatively new, we were unable to obtain green roof performance data over a long-period. Thus, we have to rely on literature estimates. The estimates are mainly gathered from German literature such as Porsche and Kohler (2003).

The available literature (Liu and Baskaran, 2004; Porsche and Kohler, 2003) suggests that conventional dark roofs will last around 20 years and the green roof at least 40 years. The benefit of installing a green roof is then the cost of installing some other type of a roof 20 years in the future. We assume a real discount rate of 3% so that inflation does not need to be taken into account. From the industry survey (see Chapter 4) we found that the price of a regular bitumen roof is around 43 €/m² including value added tax.

$$\text{Present value of the benefit} = \frac{43 \text{ € / m}^2}{e^{20 \text{x} 0.03}}$$
$$= 23.6 \text{ €/m}^2$$

This is a private benefit (avoided cost) for the owner of the building.

4.2 Storm-water management

Storm-water management is getting more and more attention in Finland. Already 80% of Finns live in urban areas and almost 20% live in the metropolitan area of Helsinki. Urbanization creates more and more impervious surfaces which prevent the storm water absorption in to the ground. Also the

amount of precipitation is expected to rise in the future as well as the frequency of extreme downpours (Jylhä et al., 2009). The sewage infrastructure of already constructed areas is hard or expensive to alter, while in many parts of Finland the infrastructure already lags behind the current requirements (Aaltonen et al., 2008). Thus, green roof technology that reduces the runoff has potential to be a beneficial way to mitigate the harmful effects of storm water.

Storm-water management in Finland is not even designed to dissipate the runoff of the heaviest rain events because of the high price of the required infrastructure. A usual design for the storm water system capacity in Finland is based on a 10-minute rain event that takes place on average every second year. Thus, sometimes the capacity is exceeded which causes floods and combined sewer overflows. Floods damage building structures, urban developments and destroy items that are stored in the basements. The damage risks related to urban flooding have not been evaluated in detail so far in Finland (Aaltonen et al., 2008).

Storm-water management systems in Finland can be divided into two main categories: combined sewer systems and separate sewer systems. In combined sewer systems the storm-, waste- and drainage waters are conveyed in the same pipes. A separate sewer system is a system in which different types of water are conveyed in their own separate pipes. In the downtown area of Helsinki (~2200 hectares), the sewer system is a combined system, in other parts of Helsinki mainly separate sewers systems are in use.

Green roofs can reduce the demand on sewer system capacity by retaining as much as fifty to seventy percent of annual rainfall precipitation depending on regional climate, and even more importantly, by retaining water during heavy rain events, and slowing down water fluxes from surfaces into the sewer. It is quite evident that a single green roof or some scattered roofs here and there have a little or no impact on the storm-water management expenditure. However, storm-water modeling has shown that there are potential benefits for large-scale roof greening projects in urban areas (e.g. Obernhorfer et al., 2007; Rosenzweig et al., 2006 and Deutsch et al., 2006). As stated in Chapter 2, a 10% green roof scenario is estimated to reduce the total annual runoff by 2-3% and 50% green roof scenario by more than 10% when the installed green roofs are lightweight, thin and planted with sedums.

To obtain reliable figures on the costs of sewer system infrastructure, an interview with the manager of the investment unit in Helsinki Region Environmental Services Authority was conducted

(Heinonen, 2012). In Helsinki, there are over 1900 km of sewer pipes of which about 250 km belong to the combined sewer system and 1650 km to the separate system. In Helsinki, the expansion of the sewer network (almost all new sewers fall into the category of separate sewer systems) costs about 12 million euros per year of which about 4 million euros can be allocated to the storm water pipes. The repair of existing storm water pipes costs around 2 million euros per year. There are no accurate figures available on how much money is spent yearly to repair existing combined sewer systems (or what is the relevance of storm water in the attrition of the pipes), but this was estimated to be 5-10 million euros of which 40% can be allocated to the storm water induced repair costs.

In addition to the capital expenditure, the storm water that is conveyed in the combined pipe system needs to be purified at the water treatment plant along with the wastewater. The cost of the purification is around 3-4 million euros per year (of which about 1 million euros is directly dependent on the amount of storm water). Usually the capacities of the treatment plant are sufficient but in the case of a long period of heavy rainfall, there is a risk of combined sewage overflow and a combination of storm and sewage water needs to be conveyed straight to the Baltic Sea. This happened in a larger scale for example in the summer of 2005. In the future, the costs of repair work are estimated to be two- or triple-folded as the sewer system gets older. In addition, both the repair and the expansion of the network is going to be about 20% more expensive in the future since the pipes need to be resized due to the climate change which is expected to bring more precipitation.

The question of how much of these costs can be reduced with a green roof infrastructure is more complex. In several cost-benefit analyses it has been assumed that there is a linear relationship between the amount of runoff and the capital expenditures (e.g. Rosenzweig et al., 2006). In another study (Clark et al., 2008) it was assumed that the reduction in storm water fees due to a green roof is normally-distributed at fifty percent of the storm water fee for the building footprint; impacts to storm water infrastructure costs were only assessed at scale. However, according to our interview (Heinonen, 2012), some costs are fixed even on in the long term and the amount of runoff has only a small effect on these costs. In addition, we cannot use storm water fees as a basis for our analysis, since not all municipalities charge storm water fees and only a few of them assign a reduction to the fee for the green roof owners. Despite these challenges, we try to give some range of the potential benefits, which can then be updated when more information is available.

The total operational costs of rain water purification for the next 40 years are estimated to be ~26 million euros. The operational costs of water purification would go down around 100 000 (current yearly average) – 120 000 (as the precipitation increases) euros per year with a 50% green roof scenario (direct relationship between the amount of water and variable costs) or about 2.6 million euros (3% discount rate) during the life-cycle of a green roof and around 0.5 million euros with a 10% green roof scenario. This translates into a benefit of 0.15 €/m^2.

The total capital expenditure (next 40 years) for Helsinki for the storm water management is estimated as follows for the new sewer systems: first ten years 4 million euros (current system) annually, second ten year period 4.4 million euros annually (resizing pipes in more critical areas) and 4.8 million euros annually for the last twenty years (resizing all new pipes which means 20% increase in the costs). The total capital expenditure for the expansion of the sewer network is then around 100 million euros of which around 10 million euros can be allocated to the resizing of the pipes.

For the repair of the existing separate sewer infrastructure, the costs are estimated as follows: 2 million euros annually for the first 10 years (current system), 4.4 million euros annually for the second ten year period (resizing of the pipes and doubling of the demand for repair) and 7.2 million euros annually for the last twenty years; the total cost being around 110 million euros of which 30 million euros can be allocated for the resizing of the pipes.

For the repair of existing combined sewer infrastructure the costs are estimated as follows: 3 million euros annually for the first 10 years (40% of the current overall costs), 4.4 million euros annually for the second ten years, 5.75 million euros annually for the third ten year period and 7.2 million euros annually for the fourth (doubling of the repair costs and 20% for the resizing of the pipes). These figures translate into the total costs of 110 million euros of which 23 million euros for the resizing of the pipes. The capital expenditure for each cost group is shown in table 4.2.

	Operational costs of rain water purification	Expansion of the (combined) sewer system into new areas	Repair of existing (separate) sewer network	Repair of existing (combined) sewer network
Total costs million euros (period 2012-2052)	**26**	**104**	**110**	**110**
Costs (million euros) of increased precipitation and resizing of the pipes	**2**	**9**	**29**	**23**

Table 4.2. Sewer network capital expenditure

The costs of resizing of the pipes are directly related to the peak runoff during heavy rain events. The peak outflow of runoff was significantly reduced ($p < 0.05$) from the green roof (the average peak flow reductions of more than 75% were observed from each green roof), and each green roof substantially delayed runoff (Hathaway, 2008). Another study from North Carolina (Moran and Hunt, 2004) on actual green roof performance found that test green roofs reduced runoff from peak rainfall events by more than 75% and that the roofs temporarily stored and then released, through evapotranspiration, more than 60% of all rainfall. With a 50% infrastructure scenario, we only assume that the resizing costs would go down by 50% and other costs stay fixed. With a 10% infrastructure scenario, we assume that the resizing costs would go down by 10%. In other words, it is assumed that part of the increase in the expected costs due the climate change would be mitigated with green roofs, resulting in a benefit of 31 million euros. As for the other costs, in the higher range of the benefit calculation it is also assumed that green roofs would reduce the costs by 10% for the 50% infrastructure scenario and 2% for the 10% infrastructure scenario (26 M€ and 5 M€). With these assumptions, the total value for a 50% green roof scenario would be between 31-57 million euros and for 10 % infrastructure scenario between 5-11 million euros for the expected time span of 40 years.

The range of the green roof benefit for the storm-water management is then 1.9- 3.4 €/m². This result is only valid in case of a wide implementation of green roofs. Note that this is the range of the average benefits per installed green roof square meter in the Helsinki city area. The benefits are thus likely to be much higher in the downtown area and much lower in scarcely built areas.

4.3 Scenic and health benefits

Most intangible ecosystem services, such as aesthetics, are usually left out of the cost-benefit analyses simply because those are so hard to valuate in monetary terms. Practical assessment studies are scarce and uncertainty on the valid methods still exists. Contingent valuation (starting from Randall et al. 1974 for landscape degradation) and hedonic pricing method have been applied regularly (e.g. in Finland Tyrväinen, 1997; Tyrväinen and Miettinen, 2000) to landscape values.

In the case of green roof aesthetics people seek higher aesthetic quality compared to a normal roof or simply a more beautiful view. However, as Price (2008) pointed out, the concept of good aesthetic quality has changed over time and varies between different cultures (and among a culture), though some normality of good aesthetic taste exists between different cultures. Another problem in the valuation is the interaction between constituents of value: a particular landscape cannot be assessed independently of other landscapes surrounding it (Price, 2008). Also if people have a choice, they tend to live in areas of which characteristics they most prefer. This and a phenomenon called *familiarity effect* results in a situation where people tend to overvaluate the characteristics of their own surroundings relative to other people.

In addition to visual benefits, a set of epidemiological studies have provided evidence on the positive relationship between well-being, health and green space (Tzoulas et al., 2007). Positive relationships with green space have been found between senior citizens' longevity (Takano et al. 2002), self-reported health de Vries et al. (2003) and Payne et al. (1998) with general perceived health, higher levels of acitivity and the ability to relax faster. Health benefits may be in part explained by aesthetic benefits.

We tackled the problem of valuation of the aesthetic value of green spaces with hedonic pricing theory. Hedonic pricing theory (e.g. Griliches, 1971; Rosen, 1974; Sheppard, 1999), as applied to the housing market, views housing as a bundle of goods. Housing consumption is in fact the

concurrent consumption of several attributes coming with the property, such as attributes of the structure itself, proximity to services, transportation, amenities and labor, as well as more abstract attributes such as the neighborhood's socio-economic profile, culture, prestige associated with certain locations, and overall environmental quality. While the housing consumer would prefer a combination of the "best" attributes, in reality scarce resources in the city, budget constraints, and by variations in the bid-rent functions of consumer groups, establish a need for prioritizing and compromising among attributes and locations. Hedonic price theory views this process as an indicator for the partial utilities that consumers attach to the various housing attributes. By estimating the joint distribution of the observed market price and attributes, hedonic models are able to estimate the marginal value of each attribute. In the context of ecosystem functions or services valuation, this framework enables the estimation of marginal values that are typically part of housing, such as urban green, urban blue and environmental quality (see e.g. de Groot et al. 2002 for a review of what functions can be valued via the hedonic method).

Votsis (2012) and Votsis et al. (2013) used spatial hedonic models for estimating the marginal value of different types of urban green an urban blue in Espoo, Helsinki, and Pori. The effects of distances and densities on price were used as indicators of marginal value. The values exhibit high sensitivity to the context within the urban system, as well as the choice of spatial scale.

While urban parks are equally distributed across Helsinki, their marginal effect on housing value is the highest in the central business districts (CBD), and declines noticeably when moving towards the suburbs, where other forms of urban green (e.g. forests or large recreation areas) substitute urban parks in the hierarchy of utilities. The coastline was found to be a strong positive determinant of housing prices in all three cities (sea for Espoo and Helsinki; river and sea for Pori), even when controlling for interfering factors such as distance to the CBD and urbanization history. As with urban parks, the magnitude of the effects of the coastline in Helsinki decreases by distance to CBD, as other ecosystem types substitute the utility provided by living near the sea.

Varying the spatial scale indicates that the marginal value of urban green and blue remains positive, but the results refer to different planning solutions depending on the scale: the immediate vicinity of dwellings (architecture and site planning) versus the general ecological profile of the neighborhood (urban design and planning). The gradient of the positive spillover effects seems to vary as well, depending both on location and the choice of the spatial scale. In other words, the extent of the positive influence of urban ecosystems as well as the rate of change of the influence vary depending

on the location within the city and on whether the analysis looks at neighborhoods or individual dwellings. (Votsis, 2012).

These findings can be interpreted as the composite effect of a given ecosystem type minus the effects that are controlled for in the model. Thus the estimated positive value of urban parks or the coastline reflects their scenic/aesthetic, psychological, health, noise abatement, exercise benefits and many more. Other factors reflected in the estimated benefits may be the type of urban form usually found in the vicinity of parks as well as micro-climate characteristics established by parks, which are factors difficult to disentangle from each other.

4.4 Energy savings

The impact of green roofs on energy savings is a difficult parameter to estimate because it is not the same for any two buildings, climates or green roof systems. The energy demand is dependent on building characteristics such as number of floors, location of the building and the purpose of use of the building. However, for a specific building with specific properties, the demand for energy can be calculated in the present climate and predicted in the future climate. Jylhä et al. (2012) presented an example of these kinds of simulations in the Finnish climate and building codes applied to the building specifics. By modifying the properties of the roof of these simulations, we can estimate the energy savings that can be achieved with green roof technology. Another approach is to study the insulating and cooling properties of the vegetated roofs and compare them with those of the non-vegetated roofs (Seppänen, 2001). This is the approach we take on estimating the savings on energy demand for heating. For cooling demand, we rely on the existing simulations and literature review.

Energy demand for heating

The impact of a green roof on the energy consumption of a building can be calculated by comparing the heat loss of different types of roofs, in other words by calculating how much a green roof reduces heat loss compared to non-vegetated roofs. In this way, we do not have to study the properties of the entire building. For these purposes we need data on the hourly temperatures from that region where the green roofs are supposed to be built at. For this purpose, we use observations from Kaisaniemi (in Helsinki). We selected years 2008 and 2010 of which year 2008 was unusually warm and 2010 in contrast unusually cold.

The hourly heat loss q of the roof can be calculated with the following formula (Seppänen, 2001):

$q = U_1 \times A \times (T_s - T_u)$, where

U = Coefficient of thermal transmittance, the smaller the coefficient, the better the insulation; unit $W/(K \times m^2)$

A = Roof area, unit m^2

T_s = Target temperature inside the building, unit K (or C)

T_u = Hourly average temperature outside, unit K (or C)

For a new building, the coefficient of thermal transmittance U is approximately 0.09 (defined in the Finnish building regulations) which could be reduced by some estimates to 0.08 with a vegetated roof (confirmed by Jokisalo, 2012). For older buildings, the difference in insulation is larger, for example the coefficient U of the roof of a typical building constructed in 2005 was 0.15. However, more research on the isolative properties of green roofs is needed to give more reliable estimates.

By summing up the hourly heat losses of the roof and taking the average of the colder year and the warmer year, we get an estimate for the annual heat loss for each roof.

$$Q_1 = \sum_{1.1.xx\ 00.00}^{31.12.xx\ 24.00} q_1 \text{, for the conventional roof}$$

$$Q_2 = \sum_{1.1.xx\ 00.00}^{31.12.xx\ 24.00} q_2 \text{, for the green roof}$$

By a subtraction $Q_1 - Q_2$ we get 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 with the combined efficiency of the heat supply system and heat distribution system, e.g. 95% for a building with a radiator (95%) and electric heating system (100%) (Finland's Environmental Administration, 2012). After that, we get the annual saving on the energy use (kWh) which we can convert into monetary savings by multiplication with the price of electricity (0.1 €/ kwh including the transfer price). Annual savings need to be discounted for the next 40 years, the time green roof is estimated to yield benefits.

For a new building (U=0.09) we get with the aforementioned settings total benefit of 3.33 €/m² (of which 14 cents for the first year, real discount factor of 3%).

For an older building (built before 2005, U=0.15, which is already an optimistic value for an older building) the total benefit would translate into 22.86 €/m². This is to showcase the fact, that in new buildings the insulation has been taken care so well, that green roofs can only have a small impact on the energy usage. But in older buildings adding a green roof could result in much higher level of benefits.

Energy demand for cooling

In Finland, for climatic reasons, much more energy is used to heat buildings than to cool them. Simulations show (Jylhä et al., 2012) that an example building (residential, one-storied, living area 133 m²) in southern Finland consumes 3 kWh/m² per year for cooling in the current climate with a small expected increase in the future to at most 3.5 kWh/m² in 2030. Using the estimate of Saiz et al. (2006), the energy demand for cooling is reduced by 25% for a one-floor building by thin, lightweight green roofs with succulent drought resistant plants. With the discount rate of 3%, this benefit translates to 1.9 €/floor m² which in a building with one floor is roughly the same for the roof area (for a relatively flat roof).

An example office building (five-storied, net room area 6245 m²) in the same report (Jylhä et al., 2012) showed that an office building uses relatively more energy for cooling than a residential building. The energy demand for cooling in southern Finland was estimated to be 7 kWh/m² per year now and 7.5 kWh/m²per year in 2030. For such a building, the reduction in the energy demand for cooling is roughly 10% (Saiz et al. 2006). The benefit is then 1.7 €/floor m². For a building with five floors, this roughly equates to 8.5 €/ roof m².

4.5 Increased urban biodiversity

Biodiversity is a rather complicated concept with several hierarchical levels or dimensions. The vital flow of ecosystem services is based on some minimum amount of different kinds of organisms (and thus biodiversity), and the value of biodiversity as such is infinite. While the value of

biodiversity as a whole cannot be estimated, the value of the change from one state to another can be evaluated. These kinds of changes in biodiversity could, for example, be the extinction of a certain species or a certain group of species. An example of such a research is a study (Nunes et al., 2001) that gathered results from existing literature and concluded that people give different values for different species of animals and plants. In the literature review (Chapter 2) of the biodiversity benefits of green roofs it was found that green roofs can support at least a wide variety of insects, spiders, other small organisms and birds.

4.6 Noise insulation

Green roofs reduce sound reflection and improve the soundproofing of a roof, thus resulting to a transmission loss of about 10 dB. These sound insulation benefits are particularly useful for buildings which lie under flight paths or which contain very strong sources of noise such as night clubs or highways. We did not find value estimates for the value of sound insulation benefit from the literature except for an estimate by Rosenzweig et al. (2006) for an average New York City building. They did not however reveal the valuation method and sound insulation benefits are likely to be very different in New York than in Helsinki.

On the air traffic zones, the improvement of soundproofing can be proved to be valuable. One example and a widely used technique to improve the noise insulation is to use plasterboards as an additional ceiling element (Helimäki, 2013). Based on the literature review (e.g. Connelly and Hodgson, 2008) the noise insulation benefits of green roofs are comparable (or better) to an additional (though unspecified) ceiling element. Thus, we use the cost of adding a plasterboard layer on a roof as an estimate for the benefit of green roof.

The price of a plasterboard is approximately 4 €/m^2. The installation costs are based on a workload estimate from a building contractor. The building contractor estimated that in an hour approximately 3 m^2 of plasterboard can be installed by a person. The hourly costs of hiring a contractor in Finland are approximately 50 €. Thus, the material costs and the installation costs are approximately 20 €/m^2. This is the high estimate for the noise insulation benefit of green roofs applicable only in air noise zones.

4.7 Emission regulation

One way of reducing air pollutants from the urban environment is the use of vegetation. Vegetation reduces air pollutants by passively filtering and directing airflows, and actively absorbing many pollutants. However, the choice of plant material essentially affects this air quality ecosystem service, as some trees for example release harmful volatile organic compounds (Steinbrecher et al., 2009). To quantify the air quality benefits, we need data on the gas exchange and filtering capacity of green roofs. The availability of such data is very limited. Only a couple of studies have modeled the removal of air pollutants by green roofs and none of these has been done in Finland. Thus, again, we need to rely on literature estimates.

Tan and Sia (2005) found in a field study that the levels of particles and SO_2 in the air above the roof were reduced by 6% and by 37% after a green roof was installed. This field measurement proved that green roofs could potentially improve the air quality in urban areas. Currie and Bass (2005) estimated that 109 ha of green roofs in Toronto could remove about 8 metric tons of unspecified air pollutants per year. Peck (2003) estimated that current roof greening in Toronto (covers over 6.5 million square meters) results in a 5-10% reduction in NO_2 and SO_2 concentrations in the air, and in reduction of 30 tons of particulate matter.

Yang et al. (2008) studied the performance of green roofs in Chicago. The result showed that a total of 1675 kg of air pollutants was removed by 19.8 ha of green roofs in one year with O_3 accounting for 52% of the total uptake, NO_2 (27%), PM_{10} (14%), and SO_2 (7%). The annual total removal per hectare of green roof was 85 kg ha−1 yr−1, of which 44kg was O_3, 23kg NO_2, 12kg PM_{10} and 6kg was of SO_2. They pointed out that air pollutant removal by green roofs in Chicago was affected by air pollutant concentrations, weather conditions and the growth of plants. The highest uptake occurred in May and lowest in February. Yang et al. (2008) compared their estimates to other studies and found out that their estimate was 18% higher compared than an estimate from Toronto (Currie and Bass, 2005). For our purposes, we utilize the proportions of gas reductions from Yang et al. (2008), use their estimate of 85 kg $ha^{-1}yr^{-1}$ as our high estimate and the estimate from Toronto (Currie and Bass 2005) of 69 kg $ha^{-1}yr^{-1}$ as our low estimate for green roof gas uptake potential.

The average costs of different emissions were studied in a report by Finnish Road Managements (Tervonen and Ristikartano, 2011). 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 separately estimated for both urban environment and for sparsely populated areas. The costs were significantly higher in urban areas since they have an effect on a higher number of people. The costs in urban areas are shown in Table 4.7

Type of emission	The average cost in a population center (€/1000kg)	The average cost in a sparsely populated area (€/1000kg)
SO_2	15 475	2 229
NO_x	1 281	501
PM_x	232 761	7 273
CO	28	1
hydrocarbons	77	77
CO_2	37	37

Table 4.7. The costs of different gases and particles (originally for car emission calculations) (Tervonen and Ristikartano, 2011

As we are concerned on green roofs in urban areas, we use the estimates from the second column. Unfortunately, no cost estimate for O_3 was found. However, it is again evident, that more populated the location the higher the benefits of green roofs. In Table 4.7.2, we have calculated the benefits based on empirical evidence on the uptake potential and calculated the total benefit for the life cycle of a green roof. The total air quality benefits still lack estimates for some gases, but the range for the quantifiable benefits vary from 4.8 €/m^2 to 6.9 €/m^2. The results are shown in Table 4.7.2.

Type of emission	Uptake kg $ha^{-1}yr^{-1}$	Benefit € $ha^{-1}yr^{-1}$	Benefit €/m^2
O_3	30-44 kg	not quantified	not quantified
NO_x	16-23 kg	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**

Table 4.7.2. Green roof air quality benefits

5 COSTS OF GREEN ROOFS

5.1 Cost estimates from Finland, industry survey

Suppliers of green roofs in Finland gave a cost estimate for an installation of a lightweight, inaccessible (new) green roof on a low-slope roof with an area of 500 m^2 or more. Obviously the size and complexity of a green roof system have a significant impact on both the labor and material costs, thus more complex systems are much more expensive. 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 with sufficient loading capacity. The roofing membrane consists of a manufactured sheet of bitumen. Some additional costs will incur if an existing roof layer needs to be removed.

- The standard bitumen roof costs are around 35 €/m^2 (+VAT 24%, = 43 €/m^2). This includes rubber bitumen layers, waterproofing and installation costs. 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 (around 53% of the additional costs), the additional installation costs (around 24% of the additional costs) and additional taxes (23%).

The least expensive green roof installation method is the by installing a drainage layer, filter fabric soil, and plants from cuttings and seed. These green roofs allow for more plant diversity due to the soil depth, 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 50 €/m^2 including VAT.

As mentioned, these estimates do not include any structural modifications that some buildings may require to accommodate a green roof. Some studies suggest that a new industrial building could require up to 45% increase in building structural costs in order to accommodate a green roof with a design load of 125 kg/m^2. Green roofs with lower load levels are being designed and implemented

at least in Germany (Zinco, 2012), in Japan (moss panels) and in Switzerland (China reed as the lower light-weight water retention layer).

5.2 Economies of scale and increased competition

Cost estimates from Finland are very high in comparison with estimates in particular in those countries with established green roof industries. Estimates for (additional) average green roof costs in Germany range from 13 €/m^2 to 41 €/m^2 (in 2007, estimates from Toronto and Region conservation 2007). The low price level in Germany is a result of more than twenty years of development and the availability of thin green roofs. In Switzerland, developed low-cost solutions cost approximately only 20 €/m^2. (Professor Stephan Breinneisen, pers. comm., May 2013). In newer markets (such as Finland) competition is scarce (only three major suppliers in Finland), no economies of scale exist, labor is more expensive since installers lack experience and there is a tendency to use custom-design systems. Obviously, one option that would support the proliferation of green roofs would be to adopt low-cost techniques. The additional costs of a green roof have gone usually down by 33%-50% (Toronto and Region Conservation, 2007) since the industry has established itself. In our scenarios we assume that the same would happen in Finland if 50% of roof top area in Helsinki was to be greened and the cost level would be closer to those of Germany and Switzerland.

The total amount of roof area in Helsinki is about 1743.7 ha which is estimated by calculating the sum of building polygons footprints (MML Maastotietokanta, 2010). If 50% of the rooftops were replaced with a green roof whenever a non-vegetated roof is worn out, the total additional costs are estimated to be in the range of 600 million euros to 900 million euros of which 120-170 million euros would go back to the government as collected tax revenue.

6 GREEN ROOF COST-BENEFIT ASSESSMENTS

6.1 A single roof-top-installation

Table 6.1 lists the costs and benefits surrounding a single green roof installation decision in Helsinki. Benefits are dependent on a number of different factors, including building specific factors such as number of floors and type of use, system specific factors such as location in the city (e.g. surrounding noise levels) and preference specific factors (e.g. how much the building owner appreciates the gain in green space). In Table 6.1 we list the cost and benefits on the low scenario (high costs, low benefits) and in a high scenario (low costs, high benefits). In addition, we list the most relevant factors that determine the scope of the benefit. The analysis shows that for the green roof investment to be justified for a private decision maker, the personal preference to own a building with a green roof must be high. The current level of costs is usually too high compared as the level of private benefits.

	Low scenario	High scenario	Relevant factors
Additional costs of installation	60 €/m²	50 €/m²	lower costs possible for buildings with strong structural capacity
Private benefits			
Energy demand for heating	3.3 €/m²	3.3 €/m²	Isolative properties of the alternative (roof)
Energy demand for cooling	1.9 €/m²	8.5 €/m²	Savings lower for a residential building, higher with (multilevel) office building

Membrane Longevity	23.6 €/m²	23.6 €/m²	Service life 40 years (20 service life for a conventional roof)
Sound insulation	0 €/m²	20 €/m²	Potential benefits in air traffic noise zones
Aesthetic value of the roof (personal preferences of the owner)	0 $€/m^2$	++	More research needed to quantify benefits
B/C -ratio	**0.5**	**1.1 (+ aesthetic value)**	B/C –ratio between 0.5 and 1.1

Table 6.1. Private costs and benefits, organized to produce two different scenarios: low (=high costs, low benefits) and high (=low costs, high benefits)

6.2 50% implementation infrastructure scenario

In Table 6.2 we list the costs and benefits of a (hypothetical) 50% green roof–infrastructure-scenario in Helsinki. High level of implementation would bring the (additional) costs of the green roofs down. In our low scenario, we assume the reduction to be 33% and in our high scenario we assume the reduction to be 50%. Next to the benefits of a single (isolated) green roof, some public benefits are expected to emerge with a higher implementation rate. These public benefits include storm-water management and air quality improvements. Intangible benefits such as the increased urban biodiversity and scenic value of the green roof can be proved to have a positive value (e.g. Votsis, 2013) but more research is needed to put a value-range on these benefits. The inclusion of (quantified) public benefits and lower costs results in B/C coefficients between 0.9 and 2.2 even without biodiversity and scenic value benefits.

	Low scenario	High scenario	Relevant factors
Additional costs of installation	40 €/m²	30 €/m²	Market structure, taxation

Energy demand for heating	3.3 €/m²	3.3 €/m²	Isolative properties of the alternative (roof)
Energy demand for cooling	1.9 €/m²	8.5 €/m²	Savings lower for a residential building, higher with (multilevel) office building
Membrane Longevity	23.8 €/m^2	23.8 €/m²	Service life 40 years (20 service life for a conventional roof)
Sound insulation	0 €/m²	20 €/m²	Potential benefits in air traffic noise zones
Aesthetic value of the roof (personal preferences of the owner)	0 €/m²	++	More research needed to quantify benefits
Private B/C -ratio	**0.7**	**1.8 (+ aesthetic value)**	Private B/C –ratio between 0.5 and 1.1
Public Benefits			
Storm-water-management	1.9 €/m²	3.4 €/m²	The proportion of Sewage infrastructure costs reduced
Air quality regulation	4.8 €/m²	6.9 €/m²	The green roof performance in the climate conditions of southern Finland still unclear
Increased urban biodiversity	+	++	Evidence shows that people assign

			(usually) positive values to increased biodiversity, more research needed to determine scope of the benefit
Scenic value	+	++	Evidence shows that urban green increases real estate prices in the close neighborhood
Total BC -ratio	**0.9 (+ increased urban biodiversity and scenic value)**	**2.2 (+ urban biodiversity + aesthetic value)**	The inclusion of biodiversity and scenic benefits can have a dramatically increasing effect on the B/C -ratio

Table 6.2. 50% infrastructure scenario, private and public benefits, for low scenario (high costs, low benefits) and high scenario (low costs, high benefits)

7 CONCLUSIONS

The main conclusions are:

1) The private benefits are not high enough to cover the current level of the (private) costs of the most commonly available green roof installation based on pre-grown vegetation mats.

2) Higher implementation rate would drive down the cost level and public benefits would emerge.

3) When adding up private and public benefits, the benefits would surpass costs and make green roofs good investments for the society.

4) Benefits are positively correlated with the amount and intensity of precipitation, outside temperature, and proximity to city centre.

5) If no incentives or regulation is developed, the level of green roof installation is expected to remain low. In order to promote green roofs, at least three options are available, and can be used simultaneously:

   a. Supportive policies for private decision-makers

   b. Investment in R&D to allow for lower cost green roof installation techniques and demonstration programs

   c. All the ecosystem services that are provided by the green roofs, should be made explicit, and both public and private decision makers should be aware of the services.

The aim of this study was to discuss the economic benefits and costs of thin, lightweight green roofs with minimal maintenance requirements. The type of green roof determines the diversity and volume of ecosystem services available; similarly the type of green roof also affects the installation costs. Additionally, the benefits and costs were estimated only in the city Helsinki. Nevertheless, the valuation methods used in this study can be applied just as well for other types of green roofs and for other urban systems. Green roofs provide many ecosystem services from which urbanites can benefit. Many of these benefits do not have a market price, thus ecosystem valuation methods need to be applied. The estimates reported in this study are of a preliminary nature, but results can be updated when more research results on the performance of green roofs in the Finnish climate and urban environment are available.

The costs of green roof installation were gathered by means of supplier interviews. The least expensive green roof installation method includes the installation of a drainage layer, filter fabric soil and plants from cuttings and seed. However, this installation method requires more structural capacity from the building than a lightweight, sedum-mat based solution. The additional costs of a green roof are around 50-60 €/m². Thus green roofs are over two times more expensive to install than a bitumen roof, which we used as a reference roof. Cost estimates were high, in particular compared to those countries with established green roof industries. The additional costs of green roofs have gone down significantly in Switzerland and Germany since the establishment of the industry in those economies. We assumed that a higher implementation rate would drive down the additional costs by 33-50% in the 50%-infrastructure-scenario for Helsinki (over 1700 ha of roof-tops greened). The total additional costs are estimated amount from 600 million euros to 900 million euros in this hypothetical scenario.

We were able to find value estimates for most of the ecosystem services that green roofs can provide over their expected life span of 40 years. The future benefits have been discounted in to the present values with the discount rate of 3%.

1)   Membrane longevity 24 €/m²

2)   Sound insulation 0-20 €/m²

3)   Energy savings:

      a.   cooling 1.9 €/m^2-8.5 €/m²

      b.   heating 3.3 €/m²-24 €/m²

4)   Air-quality benefits (average benefits in Helsinki) 4.8 €/m²-6.9 €/m²

5)   Storm-water management (average benefits in Helsinki) 1.9 €/m²-3.4 €/m²

Benefits were positively correlated with the outside temperature, as green roofs have a more significant effect on the energy demand for cooling than for heating, thus cooling savings increase faster than heating demand savings decrease. Benefits were also correlated with the level of precipitation and frequency of extreme downpours, and proximity to the city center. Thus, in the future, as climate change progresses and Helsinki attracts ever more habitants, the benefits are expected to increase. In addition to the estimated values, explanative quantitative analysis indicates that it is plausible that green roofs have a positive effect on the aesthetic quality of a city and increase urban biodiversity and thereby contribute to real estate value formation and has spillovers

effects on a whole neighborhood. Both of these aspects need to be included in the decision-making process in addition to the already quantified benefits.

Only a share of these benefits accrues to the owner of the property. These benefits are called private benefits which in the case of green roofs are membrane longevity, sound insulation and energy savings. The estimated B/C –ratio for a private building owner was between 0.5-1.1 (and in air traffic zones between 0.8 and 1.5). Consequently, in most cases the private benefits are not high enough to fully offset the additional costs of installation.

We also estimated the sum of private and public benefits in a hypothetical 50% green roof-infrastructure-scenario, in which half of total roof area in Helsinki is fitted with green roofs. High level of implementation would bring down the costs of green roofs and some benefits are expected to emerge only with a higher implementation rate. With such bold assumptions, the private B/C –ratio for green roof installation was 0.7-1.8 and the total B/C –ratio (private benefits + public benefits) was between 0.9 and 2.2 plus scenic value and biodiversity benefits.

The cost-benefit calculations hint that with a higher rate of implementation and realization of public benefits, the green roofs would be a good investment. However, because the private benefits are not high enough to justify a green roof installation for a private decision maker, the rate of implementation can be expected to stay low without corrective policy instruments. Policy instruments could include supportive policies that add incentives for private decision makers to install green roofs, such as storm-water fee reductions (already a reality in Vaasa) or real estate tax abatements. Essential is to introduce policies that transfer a part of the public benefits back to the green roof owner such that private benefits equal or surpass private costs. In addition a demonstrative program could help to drive down the costs. Another less recommended approach is to make green roofs mandatory for specific building types or for specific areas. In Copenhagen for example, green roofs are mandatory in most of the new local plans for houses with a roof slope of less than 30 degrees and as a result more than 200,000 m^2 of green roofs are expected to be installed in the next years based on local plans approved in 2010 and 2011.

ACKNOWLEGMENTS

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