Valuing the Benefits of Green Roofs for the “Green Deal – Green Roofs” Municipalities

Course: Value of Ecosystem Services
Environment and Resource Management 2015/2016

Supervised by Pieter van Beukering & Majelle Verbraak

Students
Martina Bubalo *(2579662)*
Kasper de Bruijn *(2653285)*
Lindsey Chubb *(2574196)*
Linda Mederake *(2577323)*

Client
Annemarie Bor *(AMBOR creatie)*

Date
15 October 2015

Word count
6283

Abstract

With expansion of urban areas and growing population density worldwide, the abundance of vegetation and green land in urban areas are increasingly under pressure. A potential solution for this problem can be seen in green roofs. Green roofs offer opportunities to recover green space and strengthen ecosystems in the urban environment while providing many ecological and economic benefits to the general public and private actors including residents and estate owners. The aim of this paper is to identify major ecosystem services (ESS) of green roofs for Dutch municipalities involved in the "Green Deal – Green Roofs" project and to economically valuate the benefits of those ESS. To link green roofs as an ecosystem, the services provided, and the resulting benefits for human well-being the paper draws on the service cascade framework of Haines-Young and Potchin (2011). The paper considers six ESS deemed important by the "Green Deal – Green Roofs" municipalities of which four have been economically valuated (*stormwater retention, air quality, building temperature regulation, and roof membrane longevity*). The research shows that these ESS, excluding air quality, have a high potential to provide tangible monetary benefits.

Table of Contents

1. Introduction

As urbanization increases worldwide and population and building density expands, the abundance of vegetation and green land in urban areas are increasingly under pressure (Hop & Hiemstra, 2013). Urbanization reduces the area available for natural flood management while increasing the number of homes and businesses located in flood-prone areas (EEA, 2012; Getter & Rowe, 2006). Land prices are high and space within cities is limited. Yet, green spaces in urban areas could prove to be very beneficial to residents within these communities.

Green roofs provide opportunities to recover green space and strengthen ecosystems in the urban environment (Getter & Rowe, 2006), while providing many ecological and economic benefits to the general public and private actors including residents and estate owners (Bianchini & Hewage, 2012; Oberndorfer et al., 2007). These benefits include, but are not limited to, stormwater management, cost savings due to building temperature regulation and increased waterproof membrane longevity, as well as aesthetic improvement for the area (Getter & Rowe, 2006; Oberndorfer et al., 2007). These benefits also provide new business opportunities and allow potential business model development (Bor, 2015b).

Green roofs are also an example of a "nature-based solution" to adapt to climate change which will increase the number of extreme weather events including heatwaves, floods, and droughts in many part of Europe (European Commission, 2015). Moreover, climate change is not only interconnected with urbanization but also demographic change. For example, an elderly population will be more at risk during a heatwave (EEA, 2012). Together, climate change and socio-economic changes increase the vulnerability of people, property, and ecosystems as long as no adaptation measures are taken (EEA, 2012).

Despite the benefits and business opportunities provided by green roofs, the willingness to invest in this type of infrastructure is still limited in the Netherlands (OndernemendGroen, 2014). This is due to several reasons. First, benefits of green roofs are not widely known by homeowners and potential investors. Additionally, the calculation of the economic benefit of green roofs is not yet very advanced and each particular green roof is very specific. It depends, for instance, on the type of green roof, construction methods, population and building density, soil quality, and climate which benefits people can derive from green roofs, who the main beneficiaries are and what the actual (economic) value of these benefits is (Bianchini &Hewage, 2012).

Against this background, the following research question arises: What are the most important benefits of ecosystem services provided by green roofs and how can they be valuated in monetary terms?

Our objective is to identify major ecosystem services (ESS) of green roofs for Dutch municipalities and to point out valuation techniques used to calculate a monetary value for those services. To do so, existing monetary values calculated by other researchers will be analysed and we provide some indications of benefit-cost ratios (BCR) for green roofs. Ultimately, this report hopefully contributes to increased knowledge and awareness of the value of green roofs, supporting the efforts to promote green roofs in the "Green Deal – Green Roofs" municipalities.

The report is structured as follows: Section two provides background information on the development of green roofs and the project "Green Deal – Green Roofs", as well as concise information regarding the methodological framework. The third section explains different types of green roofs and the costs of construction and maintenance. Fourthly, the paper considers six ESS, their benefits and how they can be valued. The fifth section focuses on green roofs in Rotterdam, as it is the only city of the "Green Deal – Green Roofs" municipalities where data on green roofs was available. Finally, the report will draw on the results of the previous analysis to summarise the findings, answer the research question, discuss the results, and indicate needs for further research.

2. Background and Methodological Framework

The widespread and intentional use of green roofs has quite a long history in Europe, especially in Germany where a substantial number of green roofs was already constructed in the 1970s and 1980s (Köhler and Keeley, 2005; Oberndorfer et al., 2007). In the Netherlands, the instalment of green roofs also started in the 1980s, but has only taken off in the last 10 to 15 years (Kerssen, 2015). Bade et al. (2011) report that 280 km^2 of flat roofs are still available in the Netherlands and according to Hop and Hiemstra (2013), there are approximately 380 km^2 of roofs suitable for greening in the entire country with 44 km^2 in Amsterdam alone. Yet, in Amsterdam only about 100,000 m^2 are covered by green roofs (Hop & Hiemstra, 2013). As approximately 20 million m^2 of roof area are renovated or newly constructed in the Netherlands each year, there is immense potential for green roofs (Bade et al., 2011).

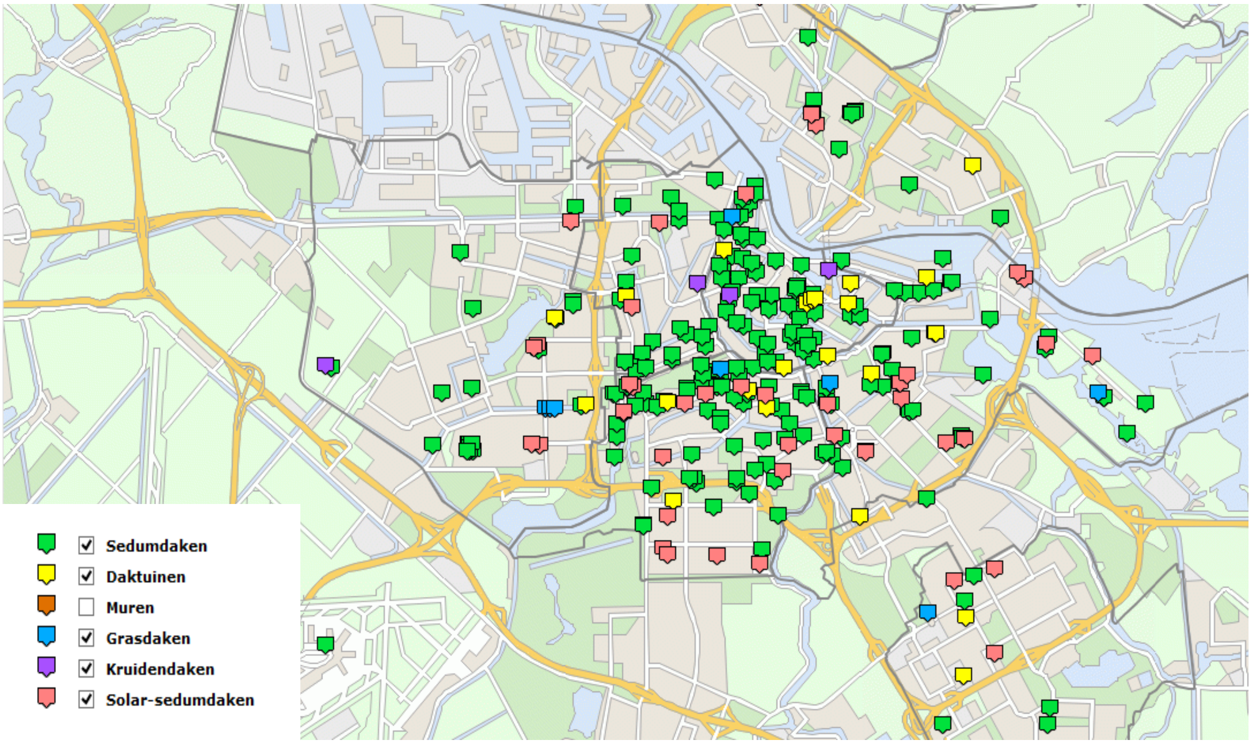

Figure 1. Map of green roofs in Amsterdam (City of Amsterdam, 2015).

The project "Green Deal – Green Roofs" was launched to further promote green roofs in the Netherlands. It brings together actors from four municipalities (Almere, Amsterdam, Rotterdam, Enschede) in a multi-stakeholder process with around 40 companies, authorities, NGOs, researchers and financial businesses to capitalize on the opportunities that green roofs provide. The project aims to remove barriers for the installation of green roofs and to work on a new societal business model beneficial for public and private actors. Together, parties develop pilot projects to make the benefits of green roofs visible to sceptics and the public in general. Best practices are shared and parties discuss possibilities to make green roof benefits tangible (AMBOR creatie, 2015; Bor, 2015a; OndernemendGroen, 2014).

To visualize the link between green roofs as an ecosystem, the services provided, the resulting benefits for human well-being and the value of those benefits, this report draws on the service cascade framework of Haines-Young and Potchin (2011) (Fig. 2).

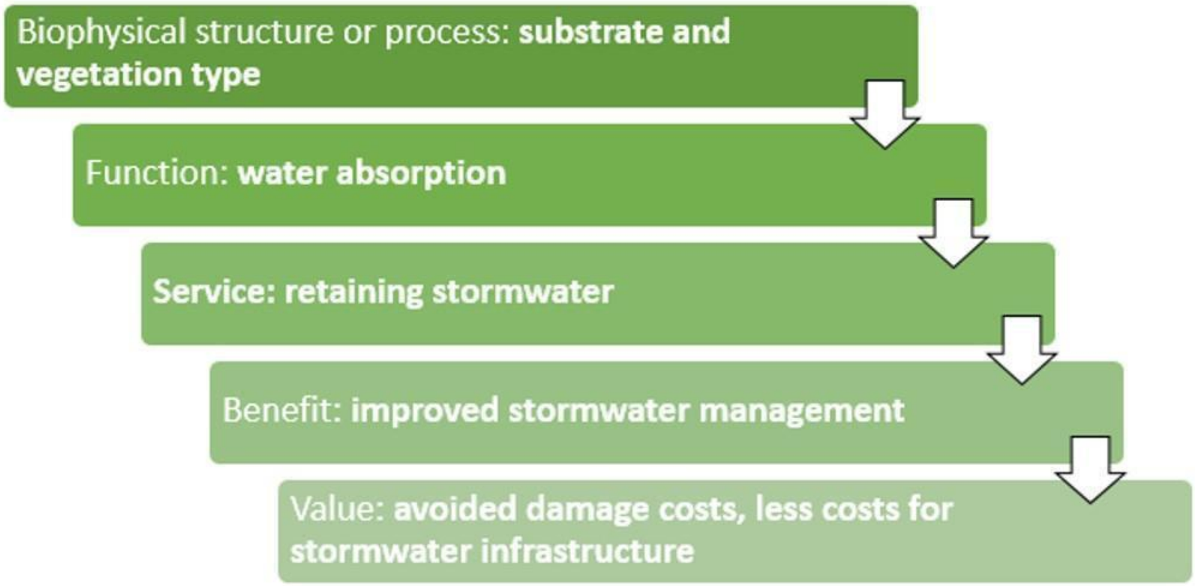

Figure 2. The ecosystem service cascade model applied to the ESS stormwater retention (based on Haines-Young and Potschin, 2011).

Function indicates capacity or capability of the ecosystem to do something potentially useful for people. In our example a potentially useful function is water absorption, which is determined by the depth of the substrate, vegetation type used, and roof membrane (Nurmi et al., 2013). On the other hand, *service* is only a service if a human can benefit from it. It is important to distinguish between 'final services' that contribute to people's well-being and the 'intermediate ecosystem structures and functions' that give rise to them (Haines-Young and Potschin, 2011). The example presented in Figure 2 shows that retaining stormwater on a roof is a final service from which people living in urban areas benefit. The main benefit is the ability for stormwater retention of green roofs which helps improving stormwater management in cities, thus decreasing the pressure on sewage systems during heavy rains. *Benefits* are separated from *values*, because it is argued that different groups may value welfare gains generated by ecosystems in different ways, at different times, and in different places (Haines-Young and Potschin, 2011). For example, the benefit of energy savings provided by green roof insulation will have much higher value for residents or real estate owners, than for the general population (Ascione et al., 2013). On the other hand, intensified air purification in urban areas is beneficial for all the people living in the city and therefore has a high societal value (Li et al., 2010), while real estate owners can hardly monetize the benefits.

Figure 3 depicts the conceptual framework used to structure this paper. It shows the underlying driving factors for the promotion of green roofs, the ESS this report focuses on and the overall aim to provide insights into the BCR of green roofs.

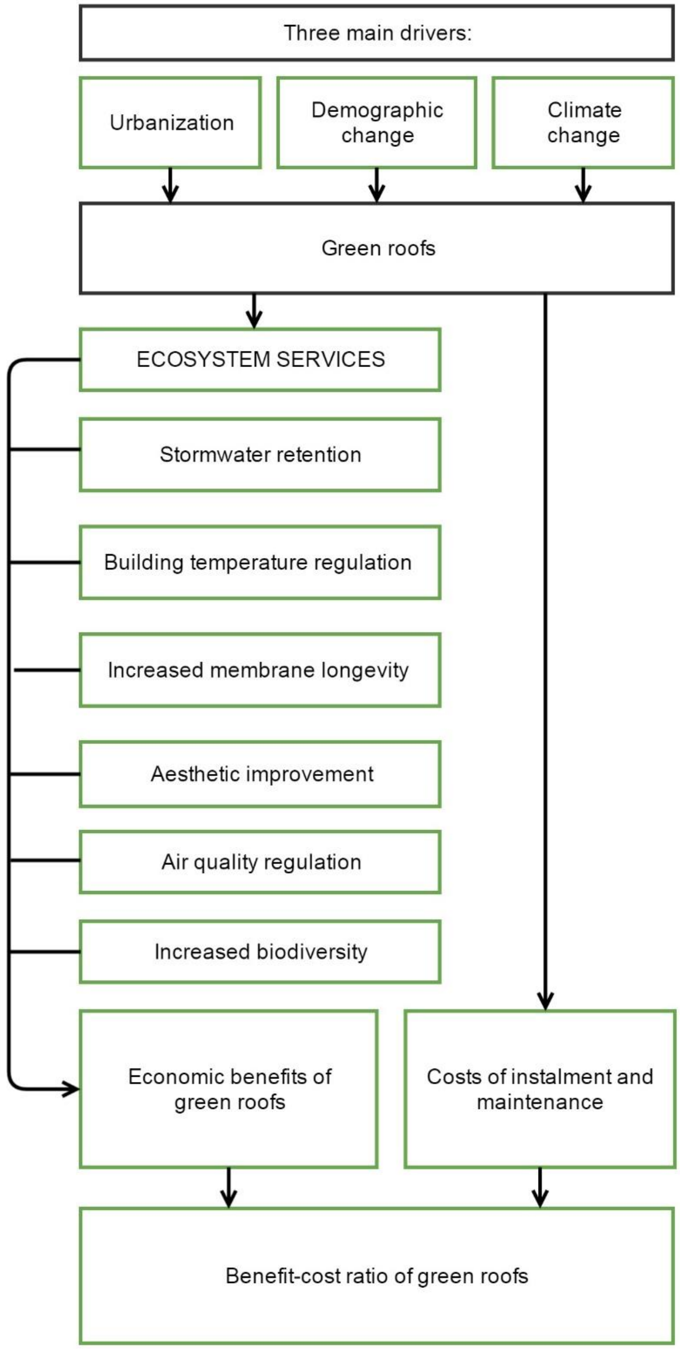

Figure 3. The conceptual framework used to structure this paper.

The report is mainly based on existing academic literature on ESS and green roofs, but also draws on reports directed at policy-makers or potential investors. Finally, some information was personally provided by Anne-Marie Bor, process manager of the project "Green Deal – Green Roofs".

3. About green roofs

3.1. Types of green roofs

Depending on the depth of growing medium and maintenance requirement, we can categorize green roofs into two main types, intensive and extensive green roofs.

Intensive green roofs (Fig. 4), have the appearance of conventional ground-level gardens, and can provide living and recreation green space in densely populated urban areas. They also add to the aesthetic value of the building. Intensive green roofs typically require substantial investments in plant care and maintenance. Furthermore, the space can be actively used for recreation or to grow vegetables (Oberndorfer et al., 2007). Generally, intensive green roofs have 150 to 1200 mm of growing medium, which is enough to support larger plant life, including larger bushes and even trees. Intensive green roofs can withstand foot traffic. However, this places larger weight load on the roof of the building that requires additional structural support (Kosareo & Ries, 2007).


a


b

Figure 4. Examples of (a) intensive green roofs (deeper substrate, elaborate vegetation, and higher maintenance requirements) and (b) extensive green roofs (shallow substrate; hardy, drought-tolerant vegetation; and low maintenance requirements). Locations: Amsterdam. (De Dakdoktors, 2015).

Extensive green roofs can be seen as a modern modification of the roof-garden concept (Oberndorfer et al., 2007). The main characteristics of extensive green roofs are shallower substrates, less maintenance requirements than intensive roof gardens, and only functional purpose. Foot traffic is usually not allowed on extensive green roofs because of the shallow and fragile root system of the vegetation (Kosareo & Ries, 2007). The simplest design of an extensive green roof includes an insulation layer, a waterproofing membrane, a layer of growing medium, and a vegetation layer (Oberndorfer et al., 2007). This type of green roof has between 50 and 150 mm of growing medium which limits the size of plants that can be used. Plant species include herbs, grasses, mosses, and drought-tolerant succulents such as Sedum (Getter & Rowe, 2006). Sedum plants are widely used for extensive green roofs, mainly for their ability to endure full sun exposure as they originate in open habitats such as cliffs, dunes, and heathlands (Lundholm, 2006; Oberndorfer et al., 2007).

Table 1 shows the differences between the two types of green roofs. The purpose for which the green roof is being made will determine what type is used.

Characteristic	Extensive roof	Intensive roof
Purpose	Functional; storm-water management, thermal insulation, fireproofing	Functional and aesthetic; increased living space
Structural requirements	Typically within standard roof weight-bearing parameters; additional 70 to 170 kg per m^2 (Dunnett and Kingsbury 2004)	Planning required in design phase or structural improvements necessary; additional 290 to 970 kg per m^2
Substrate type	Lightweight; high porosity, low organic matter	Lightweight to heavy; high porosity, low organic matter
Average substrate depth	2 to 20 cm	20 or more cm
Plant communities	Low-growing communities of plants and mosses selected for stress-tolerance qualities (e.g., *Sedum* spp., *Sempervivum* spp.)	No restrictions other than those imposed by substrate depth, climate, building height and exposure, and irrigation facilities
Irrigation	Most require little or no irrigation	Often require irrigation
Maintenance	Little or no maintenance required; some weeding or mowing as necessary	Same maintenance requirements as similar garden at ground level
Cost (above waterproofing membrane)	\$10 to \$30 per ft^2 (\$100 to \$300 per m^2)	\$20 or more per ft^2 (\$200 per m^2)
Accessibility	Generally functional rather than accessible; will need basic accessibility for maintenance	Typically accessible; bylaw considerations

Table 1. A comparison of extensive and intensive green roofs (Oberndorfer et al., 2007).

The layers of material (Fig. 5) are generally the same for both extensive and intensive green roofs. A typical green roof cross-section includes: corrugated steel deck, insulation, fiberboard, roof membrane, drainage and filter layers, and growing medium.

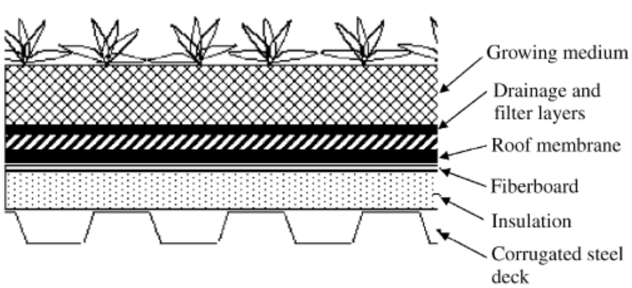

Figure 5. Cross-section through a green roof (Kosareo & Ries, 2007).

Although the materials used for green roofs implementation are similar for both types, construction requirements vary. As mentioned earlier, intensive green roofs require more structural support and can only be implemented on flat surfaces. On the other hand, extensive green roofs can be retro-fitted to buildings, without augmenting or replacing existing roof's structural support (Kosareo & Ries, 2007). Due to the less demanding construction requirements, extensive green roofs can also be implemented on sloped surfaces (Getter & Rowe, 2006). There are three different types of green-roofing technology. Complete systems technology is the first type in which each component, including the roof membrane is installed as an integral part of the roof. The second type, called modular systems, include installation of vegetation trays cultivated *ex situ* above the existing roof system. The last type are pre-cultivated vegetation blankets (Fig. 6) where growing medium, plants, drainage mats and root barriers are rolled onto the existing roofing (Oberndorfer et al., 2007), providing 100% coverage. There are also some sustainable and less expensive methods such as spontaneous colonization. This method of green-roofing includes sole installation of a growing substrate, and waiting for the plants to colonize the roof (Getter & Rowe 2006).

Figure 6. Example of pre-cultivated vegetation blankets. (Sempergreen, 2015).

3.2. Costs of green roofs

The total costs for a green roof include the initial construction costs and maintenance costs (Bianchini & Hewage, 2012). The installation price depends on a number of factors such as labour and equipment costs, the type of green roof, roof slope, and the fact whether a roof is new constructed or retrofitted (Bianchini & Hewage, 2012; City of Portland, 2008).

Experience from Germany has shown, that construction costs could be reduced up to 50% for larger installations after the industry had been established for over 30 years. This was due to economies of scale in materials purchasing, innovations in construction techniques, and experience gained by local contractors (Carter & Keeler, 2008).

Table 2 shows the costs (€/m²) for different types of green roofs in the Netherlands. The costs are averages of the prices of several Dutch companies who offer green roofs. The difference between the highest and lowest estimates from these companies was about 50 % (Gemeente Rotterdam, 2009).

Roof Surface	**Extensive Roof with a 0-4 degree slope**	**Extensive Roof with a 5-25 degree slope**	**Extensive roof with a 26-40 degree slope**	**Intensive roof, no slope**
≥ 501 m²	€52.75	€59.25	€92.75	€87.25
51 *to* 500 m²	€66.50	€73.00	€109.00	€101.25
≤ 50 m²	€81.47	€87.13	€123.03	€117.28

Table 2. Construction costs in Euro per m² for four types of green roofs (Gemeente Rotterdam, 2009).

The maintenance of a green roof typically includes visual inspections (once or twice a year for extensive roofs, more often for intensive roofs), repair, removing weeds, and plant maintenance (City of Portland, 2008). For extensive green roofs, annual costs are estimated to be about €0.58-€1/m² for the Netherlands (Bade et al., 2011; Claus & Rousseau, 2012; Gemeente Rotterdam, 2009). For an intensive green roof estimates are less reliant, but their maintenance costs are similar to those of gardens. Just to give an example, the report of the Municipality of Rotterdam estimates the annual maintenance costs to be around €5.6/m² (Gemeente Rotterdam, 2009).

4. Valuing benefits derived from ESS provided by green roofs

Green roofs can provide a wide range of different ESS in the urban areas including fire resistance or retardation (Oberndorfer et al., 2007), improved sound insulation (Dunnett & Kingsbury, 2004), pollination (Colla et al., 2009) and reduction the heat urban island effect (Getter & Rowe, 2006). However, there are a few services that are most significant regarding economic benefits. According to Carter and Keeler (2008), these are extended roof life, avoidance of stormwater management costs, and energy savings. Moreover, there are benefits that are especially important for stakeholders participating in the “Green Deal – Green Roofs” project. These include water management, increased biodiversity (highlighted by Rotterdam and Almere, but also Amsterdam), mitigating air pollution (mainly in Rotterdam), as well as aesthetic improvement and well-being (used to enhance public acceptability, e.g. if a new commercial centre is constructed) (Bor, 2015b).

With regard to biodiversity, studies show that green roofs are a suitable place for colonization not only by plants but also for spiders, birds, and insects (Brenneisen, 2003; Kadas, 2006; Coffman and Waite, 2011; Tonietto et al., 2011). So far, however, no studies have been conducted on the value of green roof biodiversity. Yet, some studies show evidence that a more diverse roof improves the value of *other* services provided. One study found that a green roof with grassy or broader leaf plant species increases its value for stormwater management (Dunnett et al., 2008). Lundholm et al. (2010) argue that certain mixtures of tall forbs (buttercups, clovers for example), grasses, and sedum increase green roof functionality for the following ESS: surface temperature, reflected sunlight radiation, and water storage and retention capacity. Therefore, it might be possible to economically value biodiversity through a 'detour', by studying the effect on facilitating green roof functionality for other, more tangible ESS. Yet, for now, the main driving force behind green roof biodiversity is architects, who like to mix native species in the standard mosses and sedums covering green roofs (Butler et al., 2012).

Figure 7. Roof Garden in Amsterdam (De Dakdokters, 2015).

Similar valuation problems exist for the aesthetic value of green roofs (Getter & Rowe, 2006). While people enjoy being in nature, and a building with a natural view could make it a more valuable real estate investment, most studies do not have a specific representation of real estate value increase as a result of green roof incorporation. At present, estimate of this monetary value have only been made by surveying potential real estate buyers about their willingness to pay more to live in an area in close proximity to a scenic park (Tomalty & Komorowski, 2010, Nurmi et al., 2013). Therefore, while we believe aesthetics do have the potential to influence an investment in green roofs, there is not enough information about the monetary value of this ecosystem service at present.

Based on the findings above, it was decided that this report would focus further on (1) storm water retention, (2) building temperature regulation, (3) membrane longevity, and (4) air quality.

4.1. Stormwater retention

Unlike forests and heavily vegetated areas, where plants absorb 95% of rainfall, urban areas are faced with problems of excessive runoff since surfaces absorb only 25% of rainfall (Scholz-Barth, 2001). In periods of high rainfall, the lack of rainwater absorption in cities can result in excessive runoff and flooding, possibly leading to sewage overflow, property damage, and human injury (Getter & Rowe, 2006). Green roofs are a suggested method for reducing and slowing stormwater runoff.

By introducing vegetation to urban roof settings, residents and building owners are taking advantage of a naturally occurring process in plants. Vegetated rooftops can retain large amounts of rainfall (approximately 10-15cm of water for every 4-20cm of growing medium in a grass roof), slowly releasing water as it drains through each layer. Precipitation is either retained in the media, or used by plants and evapotranspirated back into the atmosphere (Green Roofs for Healthy Cities, 2014). Green roofs can retain 70-90% of rainfall during summer months and approximately 25-40% of rainfall during winter months (Green Roofs for Healthy Cities, 2014). Water that does not evaporate or transpire back into the atmosphere, is delayed, inevitably running off once it passes through the substrate to drain. This is illustrated in Figure 8.

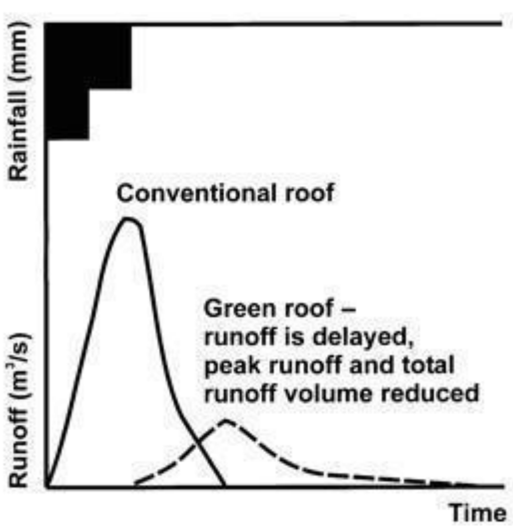

Figure 8. Rainfall runoff response in conventional vs. green roof (Stovin, 2010).

Delaying and reducing runoff could help prevent overflowing stormwater drains, lowering the risk of urban floods (Bengtsson et al, 2005). Additionally, new storm water systems could potentially have a smaller capacity for water flow, while old storm water systems could support water flow for longer. Based on stormwater management cost data from the city of Portland, Bianchini and Hewage (2012) calculate the annually avoided infrastructure improvement costs fluctuate between $8/m^2 and $26/m^2. Lower peak flows could also reduce spending in erosion control procedures for streams and rivers in the area (Tomalty & Komorowski, 2010).

Stormwater management provided by a green roof can be more beneficial in some areas than others, particularly in cities with high levels of precipitation and high concentrations of impermeable surfaces. This can be valued by calculating avoided costs of expanding stormwater treatment facilities and erosion control measures. Tomalty and Komorowski (2010) propose the following general equation to calculate the benefit of stormwater management in monetary terms:

$$b = (R+E)\, C \bullet a$$

b = benefit ($)
R = stormwater retention cost ($/m^3 water)
E = erosion mitigation cost ($/m^3 water)
C = average green roof capacity (m^3 water/m^2 roof)
a = green roof area (m^2 roof)

Factors affecting runoff dynamics are "**green roof characteristics** (number of layers and type of materials, soil thickness, soil type, vegetation cover, type of vegetation, slope in structure, roof position and age) and **weather conditions** (length of proceeding dry period, season/climate (air temperature, wind conditions, humidity) characteristics of rain event (intensity and duration))" (Berndtsson, 2010). When combined with other runoff water management measures, green roofs can help solve urban runoff problems.

4.2. Building temperature regulation

Many factors can affect a green roof's thermal performance, such as soil thickness and moisture content. Vegetation absorption of solar radiation is influenced by canopy density, plant height, leaf stomatal resistance, and the fractional vegetation coverage (Jaffal et al, 2012). In summer, green roofs keep the roofing membrane cool by direct shading and evaporation. They also provide insulation, and the growing medium can reduce thermal fluctuations going through the roofing system (Liu & Baskaran, 2003).

Research shows that green roofs can significantly lower energy demand. For instance, Liu and Baskaran (2003) found that an extensive green roof in Canada could reduce daily energy demand for air conditioning in the summer by over 75%. Climate is an important factor in whether energy savings are related to reduced cooling or heating demand (Jaffal et al., 2012; Ascione et al., 2013). Old buildings with poor existing insulation will benefit most from a green roof, while current building regulations in Europe require such high levels of insulation that green roofs have only minor effects on annual building energy consumption (Castleton et al., 2010; Nurmi et al., 2013).

Nurmi et al. (2013) emphasize that, in general, “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” (Nurmi et al., 2013, p. 33). Yet, for a specific building, it is possible to calculate the energy demand by measuring temperature differences or incoming and reflected radiation and feed the data into models (table 3).

Reference	Location	Type of Green Roof	Monetary Value (annually)
City of Portland, 2008 (see also Bianchini & Hewage, 2012)	Portland	extensive	\$0.22/m² for heating; between \$0.18/m2 to \$0.68/m² for cooling
Carter & Keeler, 2008	Athens, GA	extensive	\$0.37/m²
Claus & Rousseau, 2012	Dilbeek, Flanders	extensive	€0.133/m²
Nurmi et al., 2013	Helsinki	extensive	for heating: between €0.08 (new building) to €0.57/m² (old building) for cooling: 0.21/m² (five story office building)
Mann, 2002	Germany	extensive	€0,25/m²

Table 3. Monetary Value of Building Temperature Regulation.

Carter and Keeler (2008) measured the micrometeorological parameters of their study case such as humidity, air temperature, wind speed, radiation, and soil temperature and combined those with a laboratory analysis of the engineered growing medium in order to calculate their cost-benefit analysis (CBA). This data was then fed into a building energy model with different numbers of stories and a combined heat and moisture simulation. Modelled cost savings from the additional insulation provided as well as the reductions in the heating and cooling loads were then calculated using current electricity prices. In their sensitivity analysis, Carter and Keeler assume that energy prices will rise.

Claus and Rousseau (2012) base their assumption of an energy reduction of 1.5% on existing research for Athens and Madrid (Niachou et al., 2001; Saiz et al., 2006) and then use average energy consumption data for Flanders as well as current natural gas prices to calculate the monetary value per m^2. Nurmi et al. (2013) use existing temperature data to compare the energy consumption of a green roof in Helsinki to a non-vegetated roof. Subsequently, they divide the reduction in the heat loss with the combined efficiency of the heat supply system and heat distribution system based on data of Finland's Environmental Administration. The result are the annual savings on the energy use which are then converted into monetary savings by multiplication with the electricity price.

4.3. Increased roofing membrane longevity

Exposure to ultraviolet (UV) light causes damage to waterproofing membranes rather quickly on conventional dark roofs. Liu and Baskaran (2003) explain that UV radiation can change the chemical composition of bituminous materials and degrade its mechanical properties. These damaging effects are worsened with drastic temperature fluctuations which make the waterproofing membranes susceptible to "micro-tearing" (Liu & Baskaran, 2003). Green roofs are able to increase waterproof membrane longevity by shielding the membrane from UV light and stabilizing the fluctuations in roof temperature (Oberndorfer et. al, 2007).

The monetary benefit of increased roofing membrane longevity is calculated through the avoided re-roofing cost of a conventional roof which depends on contextual conditions such as the type of roof, material costs, wages etc. The typical lifespan for a conventional roof is approximately 20 years. Empirical evidence shows that green roofs will at least double this life span. Table 4 provides an overview of the monetary value of membrane longevity calculated by different researchers.

Reference	Location	Life Span Conventional Roof	Life Span Green Roof	Monetary Value
Bianchini & Hewage, 2012	USA	20 years	40-55 years	\$320/m² (2 times renewed)
City of Portland, 2008	Portland	20 years	40 years	\$161,5/m² (once renewed)
Carter& Keeler, 2008	Athens, GA	20 years	40 years	\$83.78/m² (once renewed)
Claus & Rousseau, 2012	Dilbeek, Flanders	25 years	50 years	€180.3/m² (once renewed, 2% inflation)
Nurmi et al., 2013	Helsinki	20 years	40 years	€23.6/m² (once renewed, 3% discount rate)
Mann, 2002	Germany	ca. 25 years	ca. 50 years	€25-50/m²

Table 4. Monetary value of extended roof longevity.

4.4. Air quality

Air quality effects of green roofs can be split into three parts: reduction of CO_2, effects on air pollutants and reduction of atmospheric particulate matter.

Plants make use of CO_2 during photosynthesis, and plant biomass has a direct correlation with the amount of CO_2 absorbed. CO_2 sequestration is an ESS that provides more on the global level and is not particularly relevant locally (Bolund and Hunhammar, 1999). In order to valuate air quality as an ESS, it makes sense to focus more on air pollution and public health. The detrimental effects of ozone and smog on human health are quite large (Mileu en Natuur Planbureau, 2005). On a yearly basis, 2,300-2,500 people die due to peak concentrations and 12,000-24,000 people die due to lifelong exposure to atmospheric particulate matter (APM) in the Netherlands alone (Bade et al., 2007). Green plants facilitate air quality by absorbing gaseous pollutants and capturing APM (Mudd & Kozlowski, 1975). Covering all suitable roof surfaces with extensive green roofs can lead to a reduction of about 20-25% of NOx and SO_2 levels (Currie and Bass, 2008). Currie and Bass (2008) calculations also show an intensive green roof is twice as effective as an extensive one. Bianchini and Hewage (2012) as well as Claus and Rousseau (2013) calculated the value of air pollution removal based on the market value of NOx emission credits in the US in 2005. According to Bianchini and Hewage (2012), the annual benefits range between \$0.025/m² and \$0.03/m². Claus and Rousseau (2013) calculate €0.0124/m².

Key factors that influence the green roof's ability to reduce air pollution include green roof area and vegetation type, because some plants are more efficient at capturing pollutants than others (Tomalty & Komorowski, 2010). Tomalty and Komorowski (2010) assess the economic value by calculating avoided costs of health care. They determined the annual value to be US\$0.0394/m². Three studies (Köhler, 2010; Wesseling et al., 2008; CROW, 2012) found the maximum effect of green roofs on reducing APM's to be in the lower single digit percentiles. The effect of green roofs on APM's seems to differ between studies, but the overall trend seems to be that the benefits are small. Similar to air pollutants, trees are more effective in reducing APM's than the plants usually associated with green roofs, and again, extensive green roofs are less effective than intensive green roofs (Tonneijck et al., 2008).

Valuation of air quality in monetary terms is considerably low. Therefore, the air quality benefits from green roofs should only be accounted for when assessing an entire community of green roofs (Tomalty & Komorowski, 2010).

4.5. Cost-benefit-analyses on green roofs

Most CBAs examining private and societal benefits separately, come to the conclusion that the BCR for private home owners is negative and thus not high enough to fully offset the higher investment costs for a green roof (Bes et al., 2008; Claus & Rousseau, 2012; Nurmi et al., 2013). The City of Portland (2008) report concludes that the private BCR will not be positive before

20 years have passed and conventional roofs would need to be replaced. Bianchini and Hewage (2012) are more optimistic about the private benefits, but still note that the net present value is higher when social costs and benefits are included in the analysis. In general, most authors conclude that green roofs are only beneficial from a societal point of view. For instance, Nurmi et al. (2013) conclude: “When adding up private and public benefits, the benefits would surpass costs and make green roofs good investments for the society” (Nurmi et al., 2013, p. 45).

Based on our findings of available literature presented above we determined the potential and, when available, the monetary value of the most important ESS for the stakeholders involved in “Green Deal – Green Roofs” project (table 5).

Ecosystem Services (as ranked by Dutch municipalities)	Potential	Monetary Value (annually)
1. Stormwater retention	high (public monetary benefits)	€0.18/m² to €0.57/m²
2. Biodiversity	important, potential to strengthen other services	so far not quantified (at all)
3. Aesthetic Improvement	important for promoting green roofs and public acceptance	so far not quantified (for green roofs)
4. Air quality	low (and intangible)	€0.02/m² to €0.04/m²
5. Building temperature regulation	high (private monetary benefits)	€0.13/m² to €0.78/m²
6. Roof membrane longevity	high (private monetary benefits)	€0.6/m² to €3.6/m²

Table 5. Overview of the most important ESS of green roofs, their potential and their monetary value (values were converted to € based on the current exchange rate).

Subsequently, we conducted some back-of-the-envelope calculations regarding the costs and benefits of extensive green roofs with a lifespan of 40 years. The benefits range from €0.93/m² to €4.99/m² (annually) and from €37.2/m² to €199.6/m² (lifespan). The lifespan costs range from €89.7/m² to € 106.5/m² calculated on the basis of €66.5/m² construction costs (see Table 3) and maintenance costs between €0.58 and €1. This leads to a benefit-cost ratio between 0.35 (worst case scenario) and 2.23 (best case scenario).

5. Benefits of green roofs for Rotterdam

Regarding green roofs, Rotterdam is considered to be of the most progressive cities in the Netherlands, having started a subsidy programme in 2008. Today, the city has around 200,000m² of green roof (Rotterdam Climate Initiative, 2015a, b) and aims to have a total of 800,000 m² by the year 2030 (Kerssen, 2015).

For the city of Rotterdam, green roofs are especially interesting because of their stormwater retention capacity, possibilities to increase air quality and biodiversity in the city (Bor, 2015b). In 2009, an analysis was carried out to identify the potential for green roofs in Rotterdam, mainly on the basis of whether roofs were flat or not. They found that a surprising amount of the roofs were flat: 70% of the residential buildings owned by housing corporations and 90% of the non-residential buildings (Killing, 2010). Overall, 4.6 km² of roof area were identified as being potentially suitable for green roofs (Gemeente Rotterdam, 2009). So, less than 5% of the total potential of green roofs is being used at the moment.

A extended CBA from 2008 calculated the societal yield of green roofs for different boroughs in Rotterdam. The study found that the societal yield is positive for the city centre and dense urban areas. The private yield, however, is negative as the costs for green roofs are carried only by private actors. From the city's point of view the construction of green roofs is a good investment in all areas of Rotterdam, as the public yield is positive.

borough	Roof surface (m²)	Private yield (€/m²)	Public yield (€/m²)	Societal yield (private and public) (€/m²)
Centre	122,658 (9%)	-14.68	+21.20	+2.45
Dense urban	894,891 (62%)	-9.95	+16.65	+7.93
Urban	286,487 (20%)	-24.08	+13.26	-32.46
Rural	40,425 (15%)	-24.74	+12.37	-39.58
Industrial area's	219,440 (15%)	-27.80	+13.22	-43.75
Total of Rotterdam	1,441,243 (100%)	-15.89	+15.33	-9.30

Table 6. Yield per m² green roof in Rotterdam (Bes et al., 2008).

The findings of Bes et al. (2008) are in line with the results of our back-of-the-envelope calculation, which shows that the BCR can be below or above one depending on the scenario.

6. Discussion and Conclusion

This report set out to answer the following research question: What are the most important benefits of ecosystem services provided by green roofs and how can they be valuated in monetary terms?

We aimed to answer this question by identifying major ESS of green roofs for Dutch municipalities and by pointing out valuation techniques used to calculate a monetary value for those services. We looked at six ESS deemed important by the “Green Deal – Green Roofs” municipalities. Our research shows that we could only put a monetary value on four of them. Valuation techniques included almost exclusively avoided costs.

Similar to the findings of Nurmi et al. (2013), our research emphasised that “how beneficial a certain service is depends not only on the service but also on the system where it is located” (Nurmi et al., 2013, p. 10). For example, stormwater retention can be highly beneficial in Dutch municipalities as they face high levels of precipitation and the country is densely populated. As table 6 with the Rotterdam CBA shows, benefits vary within cities depending on the proportion of impermeable surfaces and population density.

Costs and benefits of green roofs also vary depending on green roof type. Intensive roofs usually provide more benefits, but they are also much more expensive and there are more requirements that need to be fulfilled to be able to construct such a green roof. The Rotterdam CBA indicated high public benefits of green roofs, however, all of the costs for the construction and maintenance of green roofs are private costs which makes green roofs often not economically viable. Moreover, it is not feasible for the owner of a building with a green roof to charge neighbours a fee for improved air quality or a more pleasant view. As the “Green Deal – Green Roof” stakeholders want to promote the construction of green roofs in their municipalities, our findings suggest that they should therefore focus on three issues.

1. Reassess the ranking of ESS in terms of their actual value instead of their perceived value (if policy-makers want to base their decisions on an ESS approach).
2. In communication to the public, focus more on the private benefits, i.e. roof membrane longevity and energy savings, instead of public benefits such as biodiversity and air quality.
3. Create policy instruments which allow a transfer of public benefits such as reduced stormwater management costs to private actors.

Anyhow, green roofs will become more beneficial in the Netherlands due to climate change as temperature will rise and extreme weather events will increase (EEA, 2012). Stormwater retention and building temperature regulation will therefore become more valuable.

Our analysis further showed that existing research contains considerable knowledge gaps which hinder precise valuation of ESS benefits and add lots of uncertainty to existing calculations. On one hand, there are benefits such as increased biodiversity and improved aesthetics which are intangible and hard to valuate. Therefore, they are usually not included in current CBAs. Future research could try to value biodiversity by looking at other services that are strengthened through increased biodiversity. Additionally, research on aesthetics needs hedonic pricing valuation specifically for green roofs. On the other hand, existing CBAs all refer to data from just a few sources. For some ESS such as stormwater retention, it was difficult to find data on the value at all. Moreover, the existing data is not directly comparable to the cases of Dutch cities. Therefore, up to date field work is needed to provide a robust basis for decision-makers in Rotterdam and elsewhere. Only case-specific data will allow the “Green Deal – Green Roofs” municipalities to identify the ESS that provide the most valuable benefits for their area and to convincingly promote green roofs to the general public.

References

AMBOR creatie. (2015). *Green Deal Groene Daken*. Retrieved from http://www.amborcreatie.nl/opdrachten/green-deal-groene-daken/

Ascione, F., Bianco, N., de' Rossi, F., Turni, G., & Vanoli, G. P. (2013). Green roofs in European climates. Are effective solutions for the energy savings in air-conditioning? *Applied Energy*, *104*, 845–859. doi:10.1016/j.apenergy.2012.11.068

Bade, T., Smid, G., & Tonneijck, F. (2011). *Groen loont! Over maatschappelijke en economische baten van stedelijk groen.* Retrieved from De groene Stad website: http://www.nisb.nl/weten/bibliotheek/publicaties.html?item=8735&view=1017935

Bade, T., Tonneijck, F., & Middendorp, B. v. (2007). *Groen boven alles; over dak- en gevelgroen als fundament onder de groene stad.*

Bengtsson, L., Grahn, L., & Olsson, J. (2005). Hydrological function of a thin extensive green roof in southern Sweden. *Nordic Hydrology*, *36*(3), 259–268.

Berndtsson, J. C. (2010). Green roof performance towards management of runoff water quantity and quality: A review. *Ecological Engineering*, *36*(4), 351–360. doi:10.1016/j.ecoleng.2009.12.014

Bes, E., Goedbloed, D., Klooster, J., & van Moppes, D. (2008). *Het rendement van groene daken in Rotterdam* (H2O No. 24). Retrieved from http://edepot.wur.nl/183002

Bianchini, F., & Hewage, K. (2012). Probabilistic social cost-benefit analysis for green roofs: A lifecycle approach. *Building and Environment*, *58*, 152–162. doi:10.1016/j.buildenv.2012.07.005

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics*, *29*(2), 293–301. doi:10.1016/S0921-8009(99)00013-0

Bor, A.-M. (2015a). *Green Deal Groene Daken Green Deal Groen Daken: RVO Inspiratiesessie Nieuwe Business Modellen, 16 juni 2015.*

Bor, A.-M. (2015b). Green Deal - Green Roofs (personal communication).

Brenneisen, S. (2003). *The benefits of biodiversity from green roofs: Key design consequences: 1st North American Green Roof Conference: Greening rooftops for sustainable communities*. Chicago, Il.

Butler, C., Butler, E., & Orians, C. M. (2012). Native plant enthusiasm reaches new heights: Perceptions, evidence, and the future of green roofs. *Urban Forestry & Urban Greening*, *11*(1), 1–10. doi:10.1016/j.ufug.2011.11.002

Carter, T., & Keeler, A. (2008). Life-cycle cost-benefit analysis of extensive vegetated roof systems. *Journal of environmental management*, *87*(3), 350–363. doi:10.1016/j.jenvman.2007.01.024

Castleton, H. F., Stovin, V., Beck, S., & Davison, J. B. (2010). Green roofs; building energy savings and the potential for retrofit. *Energy and Buildings*, *42*(10), 1582–1591. doi:10.1016/j.enbuild.2010.05.004

City of Amsterdam. (2015). *Green Roofs*. Retrieved from http://maps.amsterdam.nl/groene_daken/

City of Portland. (2008). *Cost Benefit Evaluation of Ecoroofs*. Portland. Retrieved from https://www.portlandoregon.gov/bes/article/261053

Claus, K., & Rousseau, S. (2012). Public versus private incentives to invest in green roofs: A cost benefit analysis for Flanders. *Urban Forestry & Urban Greening*, *11*(4), 417–425. doi:10.1016/j.ufug.2012.07.003

Coffman, R.., & Waite, T. (2011). Vegetated roofs as reconciled habitats: Rapid assays beyond mere species counts. *Urban Habitats*, *6*.

Colla, S., Willis, E., & Packer, L. (2009). Can green roofs provide habitat for urban bees (Hymenoptera: Apidae)? *Cities and the Environment (CATE)*, *2*(1). Retrieved from http://digitalcommons.lmu.edu/cate/vol2/iss1/4

CROW. (2012). *Beplanting en luchtkwaliteit, in: CROW (Ed.), Luchtkwaliteit en verkeer. CROW, Ede, p. 72.*

Currie, B. A., & Bass, B. (2008). Estimates of air pollution mitigation with green plants and green roofs using the UFORE model. *Urban Ecosystems*, *11*(4), 409–422. doi:10.1007/s11252-008-0054-y

De Dakdokters. (2015). *Portfolio*. Retrieved from http://dakdokters.nl/portfolio/

Dunnett, N., & Kingsbury, N. (2004). *Planting green roofs and living walls*. Portland, Or: Timber Press.

Dunnett, N., Nagase, A., Booth, R., & Grime, P. (2008). Influence of vegetation composition on runoff in two simulated green roof experiments: Urban Ecosystems. *Urban Ecosyst*, *11*(4), 385–398. doi:10.1007/s11252-008-0064-9

European Commission. (2015). *Towards an EU research and innovation policy agenda for nature-based solutions & re-naturing cities: Final report of the Horizon 2020 expert group on 'Nature-based solutions and re-naturing cities' : (full version)*. *EDC collection*. Luxembourg: Publications Office of the European Union.

European Environment Agency. (2012). *Urban adaptation to climate change in Europe: Challenges and opportunities for cities together with supportive national and European policies*. *EEA report: Vol. 2012,2*. Copenhagen: European Environment Agency.

Gemeente Rotterdam. (2009). *Rotterdam Groen van Boven: Toepassing van groene daken in Rotterdam*. Rotterdam. Retrieved from http://www.rotterdam.nl/GW/Document/Groene%20Stad/Groen_van_boven_I.pdf

Getter, K. L., & Rowe, D. B. (2006). The Role of Extensive Green Roofs in Sustainable Development. *HortScience*, *41*(5), 1276–1285. Retrieved from http://hortsci.ashspublications.org/content/41/5/1276.full.pdf

Green Roofs for Healthy Cities. (2014). *How Your Community Will Benefit From Adopting Green Roof Policy*. Retrieved from http://www.greenroofs.org/resources/PolicyBrochure-HowYourCommunityWillBenefitFromGreenRoofPolicy.pdf

Haines-Young, R. H., & Potschin, M. B. (2011). Ecosystem services: Exploring a geographical perspective. *Progress in Physical Geography*, *35*(5), 575–594. doi:10.1177/0309133311423172

Hop, Margareth, & Hiemstra, J. A. (2013). *Ecosysteemdiensten van groene daken en gevels: Een literatuurstudie naar diensten op het niveau van wijk en stad*. Retrieved from Praktijkonderzoek Plant & Omgeving, onderdeel van Wageningen UR, Business Unit Bloembollen, Boomkwekerij en Fruit website: http://edepot.wur.nl/286734

Jaffal, I., Ouldboukhitine, S.-E., & Belarbi, R. (2012). A comprehensive study of the impact of green roofs on building energy performance. *Renewable Energy*, *43*, 157–164. doi:10.1016/j.renene.2011.12.004

Kadas, G. (2006). Rare invertebrates colonising green roofs in London. *Urban Habitats*, *4*.

Kerssen, A. J. (2015). *Green Roofs in the Netherlands*. Retrieved from http://livingroofs.org/green-roofs-netherlands

Killing, A. (2010). *Green Roofs in Rotterdam: Studies, Plans, Outreach, and Reducing Flood Risks*. Retrieved from http://www.worldchanging.com/archives/011610.html

Köhler, M. (2010). *Historie und positive Wirkungen von Fassadenbegrünungen | Biotope City*. Retrieved from http://www.biotope-city.net/article/historie-und-positive-wirkungen-von-fassadenbegr-nungen

Köhler, M., & Keeley, M. (2005). The Green Roof Tradition in Germany: the Example of Berlin. In *A Schiffer design book. Green roofs. Ecological design and construction.* Atglen, PA: Schiffer.

Kosareo, L., & Ries, R. (2007). Comparative environmental life cycle assessment of green roofs. *Building and Environment*, *42*(7), 2606–2613. doi:10.1016/j.buildenv.2006.06.019

Li, J.-f., Wai, O. W., Li, Y. S., Zhan, J.-m., Ho, Y. A., Li, J., & Lam, E. (2010). Effect of green roof on ambient CO2 concentration. *Building and Environment*, *45*(12), 2644–2651. doi:10.1016/j.buildenv.2010.05.025

Liu K., & Baskaran, B. (2003). *Thermal Performance of Green roofs through Field Evaluation - Ottawa*. Ottawa (Canada).

Lundholm, J. T. (2006). Green roofs and facades: a habitat template approach. *Urban Habitats*, *4*(1), 87–101.

Lundholm, J., Macivor, J. S., Macdougall, Z., & Ranalli, M. (2010). Plant species and functional group combinations affect green roof ecosystem functions. *PloS one*, *5*(3), e9677. doi:10.1371/journal.pone.0009677

Mann, G. (2002). *Ansätze zu objektbezogenen Kosten-Nutzen-Analysen*. Retrieved from http://www.gruendaecher.de/downloads/6553/6559/6775/PR_Kosten_Nutzen.PDF

Milieu en Natuur Planbureau. (2005). *Milieubalans 2005: Het Nederlandse milieu verklaard*. Bilthoven: RIVM.

Mudd, J. B., & Kozlowski, T. T. (Eds.). (1975). *Physiological ecology*. *Responses of plants to air pollution*. New York: Academic Press.

Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A., & Mihalakakou, G. (2001). Analysis of the green roof thermal properties and investigation of its energy performance. *Energy and Buildings*, *33*(7), 719–729. doi:10.1016/S0378-7788(01)00062-7

Nurmi, V., Votsis, A., Perrels, A., & Lehvävirta, S. (2013). *Cost-benefit analysis of green roofs in urban areas: case study in Helsinki*. Helsinki: Ilmatieteen Laitos Meteorologiska Inst.

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N.,. . . Rowe, B. (2007). Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience*, *57*(10), 823–833.

OndernemendGroen. (2014). *Green Deal Groene Daken - Nieuws Ondernemend Groen*. Retrieved from http://www.ondernemendgroen.nl/greendeals/Pages/Green_Deal_Groene_Daken_442.aspx?source=%2Fgreendeals%2FPages%2Fdefault.aspx#.VGz9dEtK6Tc

Rotterdam Climate Initiative. (2015a). *200.000 m2 groene daken in Rotterdam*. Retrieved from http://www.rotterdamclimateinitiative.nl/nl/nieuws/nieuwsberichten/200-000-m2-groene-daken-in-rotterdam?news_id=2158

Rotterdam Climate Initiative. (2015b). *Green Roofs Programme*. Retrieved from http://www.rotterdamclimateinitiative.nl/en/100procent-climate-proof/projecten/green-roofs-programme?portfolio_id=57

Saiz, S., Kennedy, C., Bass, B., & Pressnail, K. (2006). Comparative life cycle assessment of standard and green roofs. *Environmental science & technology*, *40*(13), 4312–4316.

Scholz-Barth, K. (2001). *Green Roofs: Stormwater Management From the Top Down*. Retrieved from http://www.greenroofs.com/pdfs/archives-katrin.pdf

Sempergreen (2015). *Vegetation blanket for green roof*. Retrieved from https://www.sempergreen.com/us/products/vegetation-blanket

Stovin, V. (2010). The potential of green roofs to manage Urban Stormwater. *Water and Environment Journal*, *24*(3), 192–199. doi:10.1111/j.1747-6593.2009.00174.x

Tomalty, R., Komorowski, B. (2010). The Monetary Value of the Soft Benefits of Green Roofs. *Canada Mortgage and Housing Corporation (CMHC)*, *1*(1), 27–45.

Tonietto, R., Fant, J., Ascher, J., Ellis, K., & Larkin, D. (2011). A comparison of bee communities of Chicago green roofs, parks and prairies. *Landscape and Urban Planning*, *103*(1), 102–108. doi:10.1016/j.landurbplan.2011.07.004

Tonneijck, F., Vries, B.d., Kuypers, V., DRO, 2008. Leidraad luchtzuiverend groen. Triple E, Alterra, Amsterdam.

Wesseling, J., Beijk R., & van Kuijeren, N. *Effecten van groen op de luchtkwaliteit. Status 2008: RIVM rapport 680705012*. Bilthoven.