HUB RESEARCH PAPER

Economics & Management

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HUB RESEARCH PAPER 2010/30
OKTOBER 2010

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Abstract

By means of a cost benefit analysis, we compare public and private incentives to invest in extensive green roofs in urban areas. From the comparison of these public and private incentives we find that subsidies for green roofs are socially desirable and that subsidies are actually needed to convince potential private investors to construct green roofs. Specifically, we estimate the costs and benefits associated with an investment project in Groot-Bijgaarden (Belgium) where a real estate investor considers the construction of an extensive green roof on an office building.

Keywords: Cost benefit analysis; Green roofs; Subsidy

1. Introduction

Due to an ever increasing degree of urbanization, pressures on the natural environment are rising. A promising route to create more green in urban areas involves the greening of buildings, for example, by constructing green roofs. In this contribution, we compare public and private incentives to invest in green roofs by means of a cost benefit analysis. The comparison of public and private incentives allows us to comment on whether subsidies for green roofs are socially desirable and whether these subsidies are actually needed to convince potential private investors to construct green roofs. Specifically, we estimate the costs and benefits associated with an investment project in Groot-Bijgaarden (Flanders, Belgium) where a real estate investor wants to install an extensive green roof on an office building.

Extensive¹ green roofs typically consist of several layers: vegetation, a substrate layer, a drainage layer and several protection layers. The vegetation asks little or no maintenance since it is usually limited to sedum species, mosses, succulents and herbaceous perennials. Moreover, as a rule no spontaneous vegetation growth is to be expected, and the roofs are laid out by sowing or planting particular plant species, or by using precultivated vegetation blankets (WTCB, 2006b). Since extensive green roofs have a relatively thin substrate layer, their total weight is also relatively low (30 to 100 kg/m²) and this often allows their installation on existing roof tops without the need to adapt the roof construction (Mentens et al., 2002). Once constructed, extensive green roofs are in general only accessible for maintenance and are not used as roof gardens.

Green roofs are increasingly popular due to a number of marked advantages such as water retention, improved insulation, noise muffling, the provision of new habitats for fauna and flora as well as a distinct visual impact (Mentens et al., 2002; Hermy et al., 2005). While several studies focus on one or more of these advantages², only a few attempt to compare and quantify the costs and benefits associated with green roofs. These exceptions include Porsche & Köhler (2003), Wong et al. (2003b), Banting et al. (2005), Carter & Keeler (2007), Oberndorfer et al.

¹ Green roofs can roughly be divided into two categories: 1) intensive green roofs that are accessible and can be compared to a roof garden, and 2) extensive green roofs that have a more shallow depth and are mostly not accessible.

² In the remainder of the text several of these studies are discussed.

(2007), and Arcadis (2008). Of these, only the Dutch study by Arcadis (2008) compares private with public incentives to install a green roof on different types of representative buildings for Rotterdam (The Netherlands). The study investigates the general effects of converting a large part of all roof surface in Rotterdam into green roofs (ranging from 25% for small private buildings to 100% for publicly owned buildings). In our study, we investigate explicitly the desirability of financial support for green roof construction for one specific case study in Groot-Bijgaarden (Belgium).

In section 2 we describe the case study on which we base the cost benefit analysis. In section 3 we discuss the method we use and the main assumptions needed to perform a cost benefit analysis. Also we describe, and if possible quantify, the different costs and benefits associated with green roof construction. In section 4 we present the results of the public and private cost benefit analysis, which we discuss in section 5. Section 6 concludes.

2. Background to the case study

We study a green roof investment project in Flanders, which is one of the three regions in Belgium. The number of green roofs in Flanders is steadily growing due to increased media coverage and the implementation of several policy measures. These measures include the provision of information (e.g. information brochure '*Extensive Green Roofs*' for Flanders, Mentens et al. 2002) and a subsidy program. However, policy efforts are rather fragmented and small-scale: for instance, municipalities can decide individually whether they want to provide subsidies for extensive green roofs and how to allocate these subsidies. As a consequence not every municipality is offering subsidies³ and subsidy requirements vary across municipalities. The subsidy amount⁴ offered is 31 euro per m² of green roof and requirements can include a minimum size of the green roof or a ceiling on the total subsidy amount paid.

Moreover, the information available on the number of green roofs in Flanders is scarce and incomplete since no single administration is responsible to build a systematic inventory. In 2002 Mentens (2003) has contacted firms active in the construction of green roofs in Flanders and

³ Only municipalities that signed the partnership program 'Nature as a step towards sustainable development' can offer the subsidies. In total 145 of the 308 Flemish municipalities participated in the program (www.natuurenbos.be).

⁴ The partnership program specifies that participants have to provide a subsidy of minimally 31 euro/m². Most municipalities have chosen for that minimum subsidy amount, except Eeklo where the subsidy equals 50 euro/m².

Brussels and he was able to create an estimate of the number of green roofs based on the firms' past projects. According to these data, almost no green roofs were constructed in the early nineties: overall some 20 green roofs, less than 10000 m² in total, were in place in 1995. However, a strong growth in the number of green roofs installed could be observed towards the end of the nineties, going from only 15 new roofs in 1996 to 97 in 2001. Mentens (2003) reported the presence of 509 green roofs (198 extensive, 285 intensive and 26 combinations of both) in total in Flanders in 2002 covering approximately 140000 m². In order to obtain more recent numbers we contacted the Flemish administration for nature and forest (Heirbaut, 2010) and we observe a steady increase in the annual number of green roofs installed within the subsidy program. Table 1 presents the total surface area (in m²) of extensive green roofs that were constructed and subsidized since 2003.

Table 1: Annual surface area of extensive green roofs (m²) subsidized by the partnership program 'Nature as a step towards sustainable development' in Flanders (source: Heirbaut, 2010)

	2003	2004	2005	2006	2007	2008	2009
Extensive green roofs on third party properties (m ²)	380	1 000	6 100	8 400	13 350	13 850	22 700
Extensive green roofs on municipal properties (m ²)	-	-	-	2 200	6 700	6 200	3 800

The project⁵ we study in more detail involves the construction of an extensive green roof on an existing office building in Groot-Bijgaarden (Dilbeek). The current roof terrace has a slight slope of 1° and the extensive green roof will consist of a root barrier, a drainage layer (1-2 cm) and a limited substrate layer (3-4 cm) since the construction was insufficiently stable to support more weight. The rooms below the green roof are heated using natural gas and the water drainage from the roof and the office is separated. The actual roof consists of two parts: on part A the construction of a green roof of 305 m² is planned and on part B two strips of green roof of 86 m² each are planned. In total the surface area of green roof amounts to 477 m². The construction was planned for January 2010 in order to allow the sowing of sedums in April/May. However, due to a change in the subsidy policy of the municipality Dilbeek the construction of the green roof is currently postponed (see also section 3.2.2).

⁵ The project developer PYLOS (Trappeniers, 2010) assigned the project to the architectural firm Bofa (Pierard, 2010), who then contacted to subcontractor IBIC bvba (Adriaenssens, 2010) for the green roof construction.

3. Method

In order to compare the costs and benefits associated with green roofs we use a cost benefit analysis (CBA). Using a private CBA, we compare the private costs and benefits associated with the construction of a green roof for an investor. Thus we can analyze the private incentives to invest in green roofs. Also, it is possible to see whether - and to what extent - private parties need subsidies to stimulate the construction of green roofs. Next we use a social CBA to compare all – private and external – costs and benefits associated with green roofs. This will allow us to assess whether green roofs are desirable for society's point of view and consequently whether subsidization of private investors is desirable.

In order to execute the cost benefit analysis, it is necessary to describe the benchmark with which the investment in a green roof is compared. Our benchmark involves the placement of standard flat roof covering. The construction and material cost of the recently⁶ installed flat roof on the office building in Groot-Bijgaarden amounted to 109.9 euro per m² (Vansweevelt, 2010) and the annual maintenance costs are approximately 1 euro per m² (ARCADIS, 2008). A typically flat roof lasts some 25 years after which the roof covering needs to be replaced (Mann, 2002).

After identifying and valuing the relevant costs C_t and benefits B_t associated with a green roof covering for each time period t , we can calculate the net present value (NPV) of these value flows over the project's time horizon T using a discount rate of r :

$$NPV = \sum_{t=0}^T \frac{B_t - C_t}{(1 + r)^t}$$

The useful life of green roof is approximately 50 year (Mann, 2002). Thus we compare all costs and benefits of installing a green roof with the benchmark scenario, i.e. with a standard flat roof, for the next 50 years (from 2010 till 2060). We assume that the investment takes place in year 0. The CBA also takes into account that monetary values are time dependent and costs and benefits are discounted to reflect this. In line with the Flemish government, we use a private discount rate of 9% and a social discount rate of 4% (LNE, 2008).

⁶ A new flat roof covering was placed on the office building in 2008.

In case of the private CBA, we can conclude that the investment is (not) profitable for the investor if the NPV of private costs and benefits is positive (negative). Thus we can also assess whether subsidies are needed to convince private investors to construct green roofs. In case of the social CBA, we find that the construction of green roofs is (not) socially desirable if the NPV of all costs and benefits is positive (negative). So we can assess whether subsidies for extensive green roofs improve social welfare.

3.1 Description of costs and benefits

We now identify and describe the relevant cost and benefit categories associated with extensive green roofs (see table 2). The costs can be divided in two categories: direct and indirect costs. The direct costs include the investment costs, i.e. purchasing costs, and the operational costs, i.e. installation and maintenance costs. The indirect costs involve adaptation costs such as additional training of personnel and regulatory costs such as the costs of using public funds⁷ to pay out subsidies.

Table 2: Overview of costs and benefits

Direct costs		Indirect costs	
<i>Investment costs</i>		<i>Adaptation costs</i>	
<i>Operational costs</i>		<i>Regulatory costs</i>	
Economic benefits	Ecological benefits	Social benefits	
<i>Life span of roof covering</i>	<i>Air quality</i>	<i>Esthetics</i>	
<i>Energy use</i>	<i>Urban temperature</i>	<i>Noise muffling</i>	
<i>Fire protection</i>	<i>Precipitation</i>		
<i>Subsidy</i>	<i>- purification costs</i>		
	<i>- flood risk</i>		
	<i>Water quality</i>		
	<i>Biodiversity</i>		

The benefits associated with extensive green roofs can be divided into three categories: economic, ecological and social benefits. Under economic benefits we find the increase in the life span of the roof covering, the reduction in energy used for heating and cooling of the building,

⁷ The marginal cost of public funds (*MCPF*) measures the distortions caused by the collection of tax revenues. Each euro of collected taxes leads to a direct cost for the taxpayers (that one euro) as well as an indirect cost due to the less efficient functioning of the economy. After all, the transfer of resources from taxpayers to government alters the consumption and labor decisions of these taxpayers and influences market behavior.

the fire resistant qualities of green roofs and the potential subsidies. The ecological benefits include the ‘urban heat island’ effect (i.e. changes in air quality, urban temperature and water management), the change in the quality of runoff water and increased biodiversity. Finally, the social benefits involve the esthetical aspects of green roofing and noise muffling.

3.2 *Estimation of costs and benefits*

After the identification of relevant costs and benefits, we turn to their monetary valuation. First we discuss the costs associated with green roof construction. Next we focus on the different benefits that might be obtained and discuss the economic, ecological and social benefits separately.

3.2.1 *Costs*

The additional construction and material costs to install a green roof covering on top of the existing (new) flat roof are approximately 32 euro per m² (Adriaenssens, 2010), while the additional maintenance costs are estimated to be 1 euro per m² (ARCADIS, 2008). The adaptation costs consisting of the training of the builders are assumed to be negligible. Next, we look at the regulatory cost of granting subsidies. Since subsidies need to be financed from the (labor) tax revenues collected by the government, the cost of collecting 1 euro to pay out subsidies can be estimated at 1.2 euro (Proost & Rousseau, 2007). These regulatory costs include a direct part, i.e. that 1 euro paid by tax payers, and an indirect part consisting of administrative costs and distortions on the labor market.

3.2.2 *Economic benefits*

Next we aim to estimate the value of the different categories economic benefits in monetary terms. However, due to a lack of reliable data, some categories will only be discussed in qualitative terms and will not be included in the private and public CBA. These qualitative benefits include the ozone and carbon dioxide intake of sedums on green roofs, the fire resistant qualities of green roofs, the impact on biodiversity and the esthetical value. Thus the monetary valuation of the benefits included in the CBA form a lower bound of the true value of the benefits associated with extensive green roofs.

Life span of the roof covering

Due to absorption of UV and IR radiation by the vegetation cover, the supporting construction underneath green roofs lasts significantly longer than standard roof covering (Hermy et al., 2005; Oberndorfer et al., 2007; Siaz et al., 2006; Getter et al. 2009). Depending on the type and thickness of the different layers, the green roof also offers protection against extreme weather circumstances such as frost, hail storms and temperature fluctuations (Teemusk & Mander, 2009a, 2009b; Ekaterini & Dimitris, 1998). Thus the expected renovation costs of the roof decrease as long as it offers sufficient resistance against root perforation. According to Mann (2002), a standard roof covering has a life span of some 25 years, while a green roof can expected to lasts twice as long. The expected savings of roof renovation can be approximated by the standard roof construction costs we calculated previously for the benchmark scenario: 109.9 euro per m² corrected for an average inflation rate of 2% gives an expected savings of 180.3 euro per m² in the 25th year.

Decreasing energy costs

A green roof covering also has an insulating function (Hermy et al., 2005; Oberndorfer et al., 2007; Wong et al., 2003a, 2003b; Niachou et al., 2001; Kumar & Kaushik, 2005; Carter & Keeler, 2007; Teemusk & Mander, 2009b), which results in a decrease of the energy demand and/or an increase of thermal comfort in the building since less cooling in summer and less heating in winter will be needed (WTCB, 2006b). In a recent Chinese study, Feng et al. (2010) found that on average only 1.2% of heat (100%) was stored by plants and soil, or transferred into the room beneath reaches the room below a green roof. The energy savings associated with increased insulation obviously depends on the size of the building, the climate zone and the type of green roof. For moderate climate zones studies are scarce: Niachou et al. (2001) found an energy reduction of 2% in Athens (Greece), while Siaz et al. (2006) calculated a reduction of 1.2% in Madrid. In tropic climate zones estimated energies savings are higher: Wong et al. (2003a) found an 8% reduction in Singapore and Carter & Keeler (2007) found a 3.3% in Athens (USA). For the Flemish case study, we estimate the energy savings at 1.5 % based on the European studies.

Assuming that the rooms under the fully covered green roof (part A) in Groot-Bijgaarden will be used as an office building for financial institutions and that the relevant fuel source is natural gas, we estimate an annual average energy consumption of 1.14 GJ per m² or equivalently 316.92 kWh per m² (Aernouts & Jespers, 2005). The rooms below the roof surface of 305 m² will then have an estimated annual energy consumption of 96661 kWh or 2706.5 euro⁸. Thus the expected energy reduction of 1.5% by constructing a green roof on the building in Groot-Bijgaarden will lead to an annual saving of 40.6 euro in total or 0.133 euro per m² green roof surface⁹.

Fire protection

To our knowledge, the specific fire protection characteristics of green roofs have not yet been studied and quantified. On the one hand, sedums are water retaining plants which might decrease the risk of fire spreading (Wolf & Lundholm, 2008). On the other hand, dry plants might stir up fires. As a case in point, the Flemish association of architects and builders recommends to use compartment zones of 50 to 100 cm when constructing green roofs (WTCB, 2006b). Since the risk of fire in one particular building is extremely small, we feel that this particular effect of green roofs is likely to be negligible and do not include it in our CBA.

Subsidy

As mentioned before, the Flemish government stimulates municipalities to grant subsidies to promote the construction of green roofs since 2002. Municipalities are free to participate in the program and to determine the subsidy requirements, but the subsidy has to be set at minimally 31 euro per m² (Agentschap voor Natuur en Bos). In practice, all participating municipalities (except Eeklo) offer this minimum subsidy amount. Thus the subsidy for the project in Groot-Bijgaarden was expected to be 31 euro per m². However, in 2010 the subsidy was revoked by the municipality (De Vits, 2009) and the 2009 budget was insufficient to award the subsidy to the project (Trappeniers, 2010).

⁸ The industrial natural gas price in 2008 was 7.83 euro per GJ or 0.028 per kWh (FOD Economy).

⁹ Note that this figure underestimates the energy savings since the green roof strips on part B are not included in the calculation.

3.2.3 *Ecological benefits*

The Urban Heat Island (UHI) effect stands for the observation that cities tend to have higher temperatures, higher concentrations in particulate matter and more pollution problems than in the surrounding countryside (Green roofs for health cities, 2009; Takebayashi & Moriyama, 2007). However, it has been shown that green roofs can reduce urban temperatures (Alexandri & Jones, 2008) as well as filter polluting substances (Yang et al., 2008). Banting et al. (2005) describe a simulation for Toronto in 2002 where a temperature decrease of 2°C could be calculated when 50% of roofs would be green roofs. The UHI-effect also includes precipitation effects since a large part of the rainfall on green roofs are released into the air through evaporation or transpiration (Hermy et al., 2005; Kasmin et al., 2009). Thus, lower volumes of water will be discharged in the sewer system or discharge will be delayed, which has a positive effect on water management.

Next we discuss the three elements included in the UHI effect: air quality, urban temperature and precipitation.

Air quality

The environmental and health damage caused by air pollution, in particular particulate matter (PM), is an important problem that increasingly targeted by policy makers. Studies for Flanders (VMM 2009) show estimates of the external health effects such as bronchitis and other respiratory problems associated with the long term effects of particulate matter between 483 and 546 euro per inhabitant per year. Green roofs can reduce the concentrations of nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon dioxide (CO₂), ozone (O₃) and PM.

Li et al. (2010) investigate the effect of green roofs on the surrounding CO₂ concentration in Hong Kong. They find that a green roof may lower the CO₂ concentration in the nearby region as much as 2% on a sunny day. Moreover, they also found that the CO₂ absorption rate of a plant in the daytime on a typical sunny summer day in Hong Kong is much greater than the CO₂ emission rate at night. The extent of the green roof effect on CO₂ concentrations obviously depends on the condition of the plants, the position of the green roof, weather and ambient airflow conditions.

Also, Yang et al. (2008) found that green roofs in Chicago mainly absorbed O_3 and NO_2 . They note that in general the higher the ozone levels, the more ozone a green roof will absorb. A modeling study (Casey Trees Endowment Fund and Limno-Tech, Inc., 2005) for Washington examined the potential air quality benefits of installing green roofs on 20 percent of total roof surface for buildings with roofs greater than 10000 square feet (930 m^2). Under this scenario, green roofs would cover about 20 million square feet (almost 2 million m^2) and remove annually, about 6 tons of O_3 and almost 6 tons of PM_{10} . Also Green roofs for healthy cities (2009) states that 1 m^2 of grass roof can remove approximately 0.2 kg of airborne particles from the air per year.

Unfortunately, the available information with respect to carbon dioxide, ozone and particulate matter absorption of green roofs is insufficient to allow us to quantify and monetize this effect. However, we are able to estimate and quantify the NO_x absorption effect for the project in Groot-Bijgaarden. To this end, we calculate three different estimates based on the literature: the first uses data from Detroit and Chicago (Clark, 2005), while the other two use data for NO_x concentrations in Flanders (Clark et al., 2006).

Case 1: Clark (2005) studied NO_x absorption from green roofs in Detroit and Chicago. He found that sedum species absorb 0.01 pound NO_x per ft^2 and he values NO_x reduction at 3375 USD per m^2 in 2004. This implies a annual reduction of $4.21 \cdot 10^{-4}$ kg NO_x per m^2 or 0.0014 USD per m^2 . Thus we can estimate¹⁰ the value of NO_x absorption by green roofs at 1.03 euro per m^2 per year.

Case 2: Clark et al. (2006) state that approximately 5 to 10% of surrounding NO_x and SO_2 concentration is absorbed by green roofs. The average NO_2 concentration (1995-2010) in Sint-Agatha-Berchem (municipality next to Groot-Bijgaarden) equals 31.56 μg per m^3 (IRCEL-CELINE). This is an instantaneous measure, which can be recalculated as a yearly average of 0.995 kg NO_2 per m^2 per year¹¹. Assuming that the 5% to 10% of the NO_2 present in the nearest air layers above the green roof is absorbed, gives a reduction 0.05 – 0.10 kg NO_2 per m^2 per year. Marien et al. (2001) calculated that the total benefit of a reduction of 68 kiloton NO_x equaled 334 million euro; or 1 kg NO_x reduced is worth 4912 euro. Thus we can estimate the value of NO_2 absorption by green roofs as lying between 0.246 to 0.491 euro per m^2 per year.

¹⁰ The exchange rate on 11 April 2010 allows us to convert 1 USD to 0.734806 EUR.

¹¹ $31.56 \mu g/m^3 \times 60 \text{ seconds} \times 60 \text{ minutes} \times 24 \text{ hours} \times 365 \text{ days} = 995 \times 10^6 \mu g/m^2/\text{year} = 0.995 \text{ kg}/m^2/\text{year}$.

Case 3: Clark et al. (2006) estimated the intake of NO₂ by plants on green roofs at 0.27 kg NO₂ per m² per year. For the green roof project in Groot-Bijgaarden this amounts to 128.78 kg NO₂ reduced per year or 1.33 euro per m² per year.

Since case 2 seems to be most realistic and is calculated based on local NO₂ concentration estimates, we use an average reduction estimate of 0.369 NO₂ per m² per year in the CBA.

Urban temperature

The municipality Groot-Bijgaarden is located in the Brussels' suburbs. So the green roof project can be considered as located in an urban area. However, we can exclude the possibility that within our study period, i.e. within the next 50 years, green roofs will reach a share of 50%. Thus, a temperature decrease of 2°C as calculated by Banting et al. (2005) is very unlikely. We therefore assume that the green roof studied here does not influence urban temperature.

Precipitation

Evaporation or evapotranspiration is influenced by the total leaf surface present on the green roof and takes place in general when the green roof is sufficiently humid (Lazzarin et al., 2005). On a warm summer day, Hermy et al. (2005) have calculated that approximately 0.5 liter water evaporates per m² for a green roof with a 3 cm substrate layer. The evapotranspiration of sedum species varies seasonally and depends on the amount of precipitation. Up to now, this parameter proves difficult to quantify. However, a study in Sheffield (UK) by Kasmin et al. (2009) shows that the evapotranspiration is largest during the summer months.

Besides evapotranspiration, part of the precipitation is retained by the green roof (water retention) and part permeates the substrate layer (runoff). The amount of runoff water can be predicted based on the thickness of the substrate layer and annual precipitation amounts (Hermy et al., 2005; Van Woert et al. 2005). Mentens et al. (2004) found that water retention by a 4 cm substrate layer is 1.9% lower than that of a 6 cm layer for a pilot project in Leuven (Belgium) and that runoff is substantially higher in winter than in summer months. Mentens et al. (2006) studied runoff for extensive green roofs in Brussels using the following formula:

$$\text{Annual runoff} = 693 - 1.15 \text{ prec} + 0.01 \text{ prec}^2 - 0.8 \text{ sub}$$

with *prec* representing the precipitation volume (in mm per year) and *sub* the thickness of the substrate layer (in cm). The green roof in Groot-Bijgaarden was designed to have a substrate layer of maximum 5 cm. The average annual precipitation in lower and middle Belgium is 800 mm (KMI, 2010). Thus the annual runoff can be calculated to amount to 409 mm, implying that only 50% of the rain will permeate the green roof.

Water retention and runoff by green roofs influence the municipal water purification costs as well as the risk of flooding. Since less water will end up in the sewer system, water purification costs will decrease. For the project in Groot-Bijgaarden, we estimated the runoff at approximately 0.4 m³ which amounts to 190.8 m³ for the total roof surface of 477 m². Since the purification costs of waste water in Flanders are estimated by 0.7580 euro per m³ (SERV, 2007), we can estimate the savings caused by a decrease in rainwater that needs to be purified at approximately 0.303 euro per m². Green roofs also help with urban water management by decreasing the risk of flooding since less precipitation reaches the sewer system. A pilot project by WTCB (2006a) in Limette (Belgium) shows that the peak volume of downpours is postponed by eight minutes and is decreased with 52% when an extensive green roof with a 4 cm substrate layer is compared to a classic roof cover. Thus, there is not only less water that reaches the sewer system, but it is also spread more evenly over time. According to VMM (2005), the risk of flooding in Groot-Bijgaarden is negligible. However, we can quantify the decreasing load of rain water on the sewer system. A cost benefit analysis for Rotterdam (The Netherlands) estimates the transportation costs of rainwater through sewers at an average of 0.10 euro per m² roof cover (Arcadis, 2008).

Water quality

Besides reducing the amount of runoff water as described above, green roofs might also influence the quality of the remaining runoff water. Precipitation is then filtered by the different layers rather than by a water purification station. Up to now there is no consensus on the effect of green roofs on water quality. The overview made by Berndtsson (2010) shows that contradictory results are obtained in part because studies are executed on different locations, for short measuring periods, with a variety in green roof layers and with different fertilization regimes. In general, it can be said that green roofs retain heavy metals such as zinc, copper, cadmium and lead. The

amount and type of fertilization determine to a large extent the share of organic substances (COD and BOD) in runoff water (Berndtsson, 2010; Berndtsson et al., 2006; WTCB, 2006a).

The WTCB (2006a) analyzed in 2003 runoff samples of several green roofs in Limelette (Belgium). The only positive effect on water quality was the neutralizing effect of green roofs on acid rain (pH, acidity). Green roofs seem to enrich rather than purify rainwater: the conductivity of the water increases as well as the concentration of organic substances. By adding fertilizers, the volume of oxidizable chemicals increased. In short the WTCB concluded that runoff water of green roofs cannot be used for domestic use, but requires additional treatment.

In the project in Groot-Bijgaarden the runoff water is discharged in surface water. Thus, the runoff can be considered as non-polluted rainwater. However, according to recent Flemish regulation (VLAREM art. 4.2.8.1.1, §1, 3°) domestic waste water in areas without connection to a waste water purification station cannot exceed a BOD level of 25 mg per liter. According to WTCB (2006a) rainwater contain on average 6.6 mg per liter in Belgium and runoff water from green roofs 19.3 mg per liter. Thus, it seems prudent for the firm that uses the office building in Groot-Bijgaarden to take a runoff water sample each year. Taking and analyzing the sample costs approximately 30 euro (ILVO). If the BOD level exceeds 25 mg per liter, an individual treatment installation for waste water will have to be installed.

Biodiversity

Green roofs provide a habitat for fauna and flora. The specific plant and animal species that are attracted to green roofs depend on the type of green roof, plant species richness, the presence of fauna and flora in the surroundings and the humidity of the green roof (Mentens et al., 2002; Hermy et al., 2005; Oberndorfer et al., 2007; WTCB, 2006b). In general, green roofs are shown to host a variety of invertebrate and avian communities (Coffman & Davis, 2005; Brenneisen 2006; Kadas, 2006; Schrader & Böning, 2006; Köhler & Poll, 2010). They are commonly inhabited by insects such as beetles, ants, bugs, flies, bees, spiders, and leafhoppers (Coffman & Davis, 2005), but they have also been used by nesting birds and native avian communities (Baumann, 2006). Rare plants and lichens often establish spontaneously on older roofs as well (Brenneisen, 2006). Furthermore, green roofs may be part of a larger system of wildlife corridors in urban and suburban areas, including park areas, gardens and graveyards, offering an

environment for plants, birds and invertebrates. Thus, the greening of roof tops is likely to have a positive effect on biodiversity, but for the specific project this benefit could not be quantified due to a lack of data.

3.2.4 Sociale benefits

Finally, social benefits of green roofs include their esthetic value and their noise muffling characteristics.

Esthetic impact

When walking around town green areas have a positive effect on people's state of mind since green elements influence mental (stress reduction), physical and social well-being (Berghage et al., 2007; Abraham et al. 2010; Gidlöf-Gunnarsson & Öhrström, 2007). However, passers-by cannot see the green roofs in Groot-Bijgaarden, only employees can see approximately 25% of the green roof. The productivity and state of mind might be positively influence by the construction of the green roof, but this effect is difficult to quantify.

Noise muffling

Green roofs have a positive effect on the acoustic quality of a building. Van Renterghem and Botteldooren (2009), for instance, show that traffic noise is muffled by green roof coverings in a Flemish study. The building in Groot-Bijgaarden is located near the intersection of the E40 highway and the ring road around Brussels; so most noise is caused by car traffic. According to VMM (2006), noise levels in that neighborhood range from 76 to 80 Lden¹², where levels of over 65 dB(A) by day and 60 dB(A) by night are already considered to be irritating.

The mass of the construction plays an important role in noise muffling. The substrate and drainage layer as well as the sedum plants make the roof construction heavier, which leads to noise muffling. The flat roof in Groot-Bijgaarden weighs approximately 50 kg per m² (Vansweevelt, 2010). The combined weight of the green roof in saturated condition and the flat roof lies between 110 (Adriaenssens, 2010) and 140 kg per m² (Temmerman, 2010). In

¹² Lden - *Level day-evening-night* measures the average noise level of ambient noise in dB(A). Additional decibels are added for evening (5dB(A)) and night (10dB(A)).

unsaturated condition the weight will obviously be lower. According to WTCB (2006b), a green roof will provide acoustic insulation of approximately 38 to 40 dB. This noise reduction is, however, only valid for the roof covering, the other sides of the building will not be affected. To make a cautious estimate, we assume an inside noise level of 50 to 60 dB(A).

The reduction in noise levels inside the office building will positively affect the property value. On average the estimated market value of a property decreases with 0.6% when the ambient noise level increases with 1 dB (A) (Proost & Rousseau, 2007). With outside noise levels of 76 to 80 dB(A) and estimated inside levels of 50 to 60 dB(A), the studied green roof will decrease noise levels with some 23 dB(A). Assuming that the building and the green roof have a life span of 50 years, the value of the office building would increase with 13.8%. However, the green roof only covers 15.8% of the plot. Moreover, the decrease in noise levels will only influence the highest of three floors. Also, the estimated current market value of the office is 1.5 million or 312.3 per m² of the plot (Trappeniers, 2010). Thus, the benefit of the decrease in noise levels associated with the green roof can be approximated by 14.4 euro per m² over the whole life span, or 0.287 euro per m² per year.

Not only the mass of the roof influences the noise insulation properties, but also the linkage between the green roof layers and the supporting structure. To optimize the acoustic insulation all ventilation holes need to be reduced to a minimum by, for instance, filling them with mineral wool (WTCB, 2006b).

4. Results

After the description and valuation of the different costs and benefits associated with green roofs, we can now compare the private and public incentives to invest in green roof projects. As summarized in table 3, private investors weigh investment, maintenance and water sampling costs against the subsidy received, the decrease in energy use, the increase in acoustic quality and the avoided costs of roof renewal when deciding to invest in green roofs. Specifically for the project in Groot-Bijgaarden, we find that the net present value of the investment equals 10 euro per m² green roof constructed. However, when no subsidies are granted, the net present value of the investment drops to -18 euro per m².

Next, we look at the social incentives to invest in green roofs by comparing social costs and benefits (see table 4). Therefore, we compare investment, maintenance, water sampling costs and the social cost of using public funds for subsidies with the increased energy efficiency, the increase in noise muffling, the avoided costs of roof renewal, the improvement in air quality (NO_x absorption) and the decrease in water purification and transportation costs. This comparison leads to a net present value of 38 euro per m² green roof constructed.

Table 3: Comparison of private costs and benefits per year (in euro per m²)

Private CBA	Year 0	Year 1	Year 2-24	Year 25	Year 26-50
<i>Private costs</i>					
- Investment and maintenance costs	32	1	1	1	1
- Water sampling	-	0,063	0,063	0,063	0,063
<i>Private benefits</i>					
- Subsidy	-	31	-	-	-
- Energy use	-	0,133	0,133	0,133	0,133
- Noise muffling	-	0,287	0,287	0,287	0,287
- Avoided roof renewal	-	-	-	180,30	-
<i>Net benefit</i>	-32	30,357	-0,643	179,657	-0,643

Table 4: Comparison of social costs and benefits per year (in euro per m²)

Social CBA	Year 0	Year 1	Year 2-24	Year 25	Year 26-50
<i>Social costs</i>					
- Investment and maintenance costs	32	1	1	1	1
- Water sampling	-	0,063	0,063	0,063	0,063
- Cost of public funds	-	0,620	-	-	-
<i>Social benefits</i>					
- Energy use	-	0,133	0,133	0,133	0,133
- Noise muffling	-	0,287	0,287	0,287	0,287
- Avoided roof renewal	-	-	-	180,30	-
- Air quality	-	0,369	0,369	0,369	0,369
- Water purification costs	-	0,303	0,303	0,303	0,303
- Water transportation costs	-	0,10	0,10	0,10	0,10
<i>Net benefit</i>	-32	-0,491	0,129	180,429	0,129

5. Discussion and sensitivity analysis

Based on the social CBA (table 4), we find that the construction of an extensive green roof in Flanders is socially desirable since the net present value of the investment is positive. However, without subsidies, the private costs of constructing an extensive green roof exceed the private benefits for the investor since the net present value of the private CBA is negative. Private incentives are therefore insufficient to convince private parties to invest in green roof construction even though social benefits exceed social costs. In such instances, government might decide to grant subsidies to private investors. These subsidies should be at least as high as the difference between private costs and benefits. Thus, we can conclude that the subsidy policy of the Flemish municipalities is likely to lead to social benefits and can be positively evaluated. However, the implementation of the subsidy policy in Flanders can be improved since not all municipalities offer subsidies, subsidy amounts and requirements differ, the available budgets are quite limited and also the information provision can be improved. The subsidy policy would therefore be more effective if it was standardized across Flanders and if clearer information was provided. Policy centralization would also facilitate the creation of a central inventory of the construction of green roofs in the region.

Looking at the estimated monetary value of the benefits associated with extensive green roof, we should note that this value presents a lower bound of the actual benefits, since several of the benefit categories could not be expressed in monetary terms due to a lack of data. Thus, the benefits of increased fire protection, decrease of urban temperatures, increased biodiversity and aesthetics could not be estimated.

The magnitude of the results obtained for the private CBA is comparable to the results for green roof construction in Rotterdam (ARCADIS, 2008). Depending on the degree of urbanization, the net present values for the private CBA in Rotterdam range from -10 to -28 euro per m² for the five hypothetical scenarios studied. However, the results for the social CBA are considerably different. The net present values for the social CBA in Rotterdam range from -44 to 8 euro per m². So our results show higher social returns on investments in green roof construction.

Further, in order to test the robustness of our results, we perform a sensitivity analysis by looking at a worst case and a best case scenario. In the worst case scenario we use minimal values for the

benefit categories and maximal values for the cost categories, while in the best case scenario we use maximal values for benefits and minimum values for costs. These minimal and maximal estimates for the relevant values¹³ are presented in table 5. For the different cost categories as well as the benefits associated with rain water transportation and noise muffling minima are 5 % lower and maxima are 5% higher than the current estimate. Minimal purification cost savings are calculated using a runoff of 35%. The air quality values are based on the calculations made in case 1 and case 2 in section 3.2.3. The minimum value of the decrease in energy use is based on a 1% estimated energy savings and the maximum on a 2% estimate.

Table 5: Sensitivity analysis

	Estimate (euro/m²)	Minimum (euro/m²)	Maximum (euro/m²)
<u><i>Costs</i></u>			
- <i>Investment costs classic roof covering</i>	109.9	104.40	115.40
- <i>Investment costs green roof</i>	32	30.4	33.6
- <i>Water sampling</i>	0.063	0.060	0.066
<u><i>Social benefits</i></u>			
- <i>Noise muffling</i>	0.287	0.273	0.301
<u><i>Ecological benefits</i></u>			
- <i>Air quality</i>	0.246 – 0.491	0.246	1.33
- <i>Water management</i>			
- <i>purification</i>	0.303	0.288	0.318
- <i>transport</i>	0.10	0.095	0.105
<u><i>Economic benefit</i></u>			
- <i>Energy use</i>	1.33	0.88	1.78
- <i>Life span roof covering</i>	50 year	30 year	50 year

The social CBA in the worst case scenario shows a negative net present value of -22 euro per m² (see table 6). Thus, investments in green roofs are no longer socially desirable and subsidies should not be granted to private investors. However, this scenario is unlikely to be realistic since several benefit categories are excluded from the analysis.

¹³ Since the uncertainty regarding the subsidy amount, MCPF and maintenance is assumed to be negligible, their values are retained in the sensitivity analysis.

Table 6: Net present value in worst and best case scenario

	Private CBA (incl. subsidy)	Private CBA (excl. subsidy)	Social CBA
<i>Base scenario</i>	10.30	-18.14	37.81
<i>Worst case scenario</i>	7.84	-20.60	-21.77
<i>Best case scenario</i>	27.99	-0.45	96.42

The social CBA in the best case scenario shows a positive net present value of 96 euro per m² (see table 6), implying that green roof investments are socially desirable. Moreover, the private CBA shows an almost positive net present value of -0.45 when subsidies are excluded. Thus, there is only a very minimal subsidy amount needed to convince private investors of the desirability of construction an extensive green roof on an existing building.

The results from the sensitivity analysis show that the assumption on the increased life span of the roof covering under a green roof is decisive. A high quality foundation of the estimated life span is thus very important. Both Porsche and Köhler (2003) and Hermy et al. (2005) assume that the life span of the roof covering doubles when a green roof is constructed. Mann (2002) and Siaz et al. (2006) estimate the life span of green roofs to be between 30 and 50 year. Oberndorfer et al. (2007) assume that the roof covering last an additional 20 years under a green roof. The Belgian building association WTCB (2006b) is more careful and does not formulate exact predictions. However, they do mention that the life span of the roof covering can greatly increase as long as the covering resists roof perforation and micro organisms. The building and architectural firms associated with project in Groot-Bijgaarden used a substrate layer that should have a life span of 50 to 60 years (Adriaenssens, 2010).

In general, we should note that green roof Construction techniques originated some 40 years ago. Thus, it is not yet possible to exactly determine the average life span of extensive green roofs (Porsche & Köhler, 2003). Moreover, the Belgian climate is such that we can exclude frequent extreme weather events and extreme high UV or IR radiation, which implies that the green roof covering and the roof construction will experience only limited damage.

6. Conclusion

Green roofs become increasingly popular and are often stimulated by subsidies. Nevertheless, information on costs and benefits of green roof construction is often fragmented, based on ad hoc assumptions or derived from limited pilot studies. This study made an attempt to order the available information more transparently. Moreover, we compared private and public incentives to invest in green roofs and showed that green roofs are socially desirable. Since private incentives to invest are insufficient, a subsidy policy is advisable. The subsidy granted should bridge the gap between the private costs and the private benefits associated with extensive green roofs.

More specifically, the costs and benefits were estimated for a green roof project in Groot-Bijgaarden and based in large part on existing studies. The negative results for the water purification impact of green roofs should be especially noted. Rainwater falling on green roofs becomes more contaminated with organic particles and is no longer usable for domestic use (WTCB, 2006a). On the long term green roofs appear to be preferable to classic roof coverings. The decisive parameter in this analysis is the prolonged life span of the roof covering: the life span of green roofs is approximately twice that of classic roof coverings.

Looking at trends for the future, we can expect that environmental benefits from greening will increase due to climate change. Energy savings associated with green roofs will become more important. Green roofs can also mitigate the impact of some of the predicted consequences of climate change such as more intense precipitation and extreme weather events. Thus, the social benefits from green roofs are likely to increase in the future. At the cost side two counteracting effects can be distinguished: resource costs are likely to rise due to increasing scarcity, but due to learning effects installation costs can be expected to decrease.

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