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Cost-Benefit Analysis of Rain Gardens and their Grey Alternative in Thessaloniki, Greece

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Master in Economics

Supervisor:
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Associate Professor, Iscte-Iul

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Dedicated to my dear friend Alon Greenshpon

Acknowledgment

A large, intensive project like the master's thesis always has certain ups and downs. There are two people in particular who have supported me throughout the entire period and whom I would like to thank for helping me with my Master's thesis:

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Resumo

Os múltiplos desafios sociais, ambientais e económicos, particularmente nas cidades, são o resultado da emergência climática e dos efeitos dos recentes processos de urbanização global. As jardins de chuva urbanas são infraestruturas verdes que, por meio dos serviços ecossistémicos que oferecem, ajudam a mitigar algumas dessas questões. São reconhecidas como uma Solução Baseada na Natureza e passam frequentemente despercebidas pela sociedade como um todo, uma vez que é difícil estimar o seu valor monetário. Esta tese de mestrado centra-se num estudo de caso específico de um jardim de chuva em Salónica, Grécia, e determina os custos e benefícios do jardim de chuva com especial enfoque nos bens não mercantis. Posteriormente, os resultados da análise custo-benefício com uma análise custo-benefício de uma abordagem cinzenta e tradicional para mitigar as mesmas questões. Os dados foram recolhidos por meio do projeto do jardim pluvial e por meio de comunicação direta com o professor supervisor e a empresa do jardim pluvial. Os dados da alternativa cinzenta foram recolhidos por meio de pesquisa na literatura para alternativas ao jardim pluvial e da procura de projetos com as mesmas intenções de mitigação, mas com uma solução não baseada na natureza. Para a avaliação monetária dos bens não-mercantis, este trabalho utiliza o "Green Infrastructure Valuation Toolkit".

A estimativa do valor de projetos a longo prazo depende muito da taxa de juro. Assim, neste trabalho foram usadas três taxas de juro alternativas para calcular os valores dos projetos a longo prazo. Com uma taxa de juro de 3 por cento, tanto o jardim pluvial como a alternativa cinzenta têm um valor actual líquido positivo para o período calculado de 70 anos e são ambos (considerados individualmente) uma solução para o problema existente em Salónica. Com uma taxa de juro de 5 por cento, o Rain Garden deve ser construído e o túnel de armazenamento (alternativa cinzenta) já não tem interesse económico. Independentemente da taxa de juro em todos os cenários, o Rain Garden é a opção mais barata e melhor. A diferença significativa entre o jardim pluvial e a alternativa cinzenta sugere que este projeto não é um caso isolado, mas que em outros projetos o jardim pluvial é também a melhor opção. Deve então refletir-se sobre a razão pela qual os Rain Gardens não são o padrão atual em muitas cidades. Este trabalho apresenta possíveis explicações.

Palavras-chave: Alterações climáticas, Soluções baseadas na natureza, Jardins pluviais, Infraestruturas verdes, Ecossistema, Valor económico

Abstract

Multiple social, environmental, and economic challenges, particularly in cities, are the result of the climate emergency and the effects of recent global urbanization processes. Urban Rain Gardens are green infrastructures that, through the ecosystem services they offer, help to mitigate some of these issues. They are acknowledged as a Nature-Based Solution and frequently go unnoticed by society as a whole since it is difficult to estimate their monetary value. This master's thesis focuses on one specific case study of a Rain Garden in Thessaloniki, Greece, and determines the costs and benefits of the Rain Garden with a special focus on non-market goods. Results of the cost-benefit analysis are compared to a cost-benefit analysis of a grey, traditional approach to mitigate the same issues. Data was collected through the Rain Garden project and through direct communication with the supervising professor and company of the rain garden. The grey alternative's data was collected by screening the literature for Rain Garden alternatives and finding projects with the same intentions for mitigation but with a non-nature-based solution. For the monetary valuation of the non-market goods, this work uses the "Green Infrastructure Valuation Toolkit".

Estimating the value of long-term projects depends highly on the interest rate. This thesis used three alternative interest rates to calculate the long-term project values. At a three percent interest rate both the Rain Garden and the grey alternative have a positive present net value for the calculated period of 70 years. So, from an economic point of view, it makes sense to build one of the two alternatives to fix the existing problems in Thessaloniki. However, the Rain Gardens have great advantages over the grey alternative. At a five percent interest rate level the Rain Garden should be built and the storage tunnel (grey alternative) is not valuable anymore in an economic sense. Regardless of the interest rate in all scenarios, the Rain Garden is the cheaper and better option. The significant difference between the Rain Garden and the grey alternative suggests that this project is not an isolated case, but that in other projects the Rain Garden is also the better option. That leads to the question of why the Rain Gardens are not the current standard in many cities. This work presents possible explanations.

Keywords: Climate change, Nature-based solutions, Rain Gardens, Green Infrastructure, Ecosystem, Economic value

Contents

CHAPTER 1

Introduction

According to the 2021 Intergovernmental Panel on Climate Change report, the climate crisis has worsened [**Masson-Delmotte and Zhou, 2021**, p.121-124]. The current national ambitions for slashing greenhouse gas emissions are nowhere near the goal of 1.5 degrees Celsius. That combined with the global urbanization and densification causes irreversible harm to humans, animals, the environment and the whole biosphere [**Dumitru and Wendling, 2021**, p. 6]. Climate Change is not some event in the future we can prevent one day if the workload allows it. We can already observe different effects of climate change, not only in the world but also in Europe today [**Schroter et al., 2005**]. These changes can be seen in a wide variety of areas: Among others, increasing temperatures, heat waves, extreme rainfall events, flooding and droughts, and rising sea level. It threatens the society and economy we have today. Furthermore, it will get worse in the upcoming years - especially in cities [**Masson-Delmotte and Zhou, 2021**, p. 20] [**Kabisch et al., 2016**, p. 2]. Impacts of climate change on cities include extreme precipitation events that put the traditional urban water management systems to the test. The unique features of cities, like the impermeable surfaces and dense populations, result in stormwater, increase the amount of wastewater that needs to be treated, and lead to combined sewer overflows. Those overflows lead untreated wastewater into the environment and may endanger urban infrastructure [**Belčáková et al., 2019**, p. 552] [**Hobbie and Grimm, 2020**, p. 4][**Liu and Jensen, 2018**, p. 126-133]. One method to mitigate those risks and maybe even prevent some of them is a concept called "Nature-based solutions" (NbS), which established itself as an umbrella term for many ideas that address societal challenges with solutions based on nature. NbS can address a variety of challenges at the same time and seems to be the best answer to a growing climate crisis [**Dumitru and Wendling, 2021**, p.14].

The city of Thessaloniki, Greece, is proposing a Nature-based solution as a so-called "Rain Garden" for the current problem of overflowing sewers and flooding due to heavy rainfalls. Low-maintenance, self-watering gardens are created to catch rainwater from the surroundings (such as roofs, paved areas, and roads). They are covered with a bark mulch layer or other ground cover and planted with trees and bushes (typically native ones). Besides stormwater management benefits, Rain Gardens provide aesthetic, cultural, and biodiversity services to urban residents [**Beven and Germann, 1982**, p.1314]. The municipality has not yet decided to either build a new sewage system for the proposed area or, as an alternative, build Rain Gardens. Insights into the costs and benefits of the

Rain Garden and the grey/traditional alternative (tunnel storage system) will help decision makers to assess the effectiveness of different strategies and allocations of financial resources [**Vandermeulen et al., 2011**, p.198-206].

The core objective of the following master thesis is to analyze the quantitative and qualitative benefits and costs of NbS and their grey alternative on the example of a Rain Garden. The thesis will use the tool of a cost-benefit analysis and especially try to integrate non-market values, which are often omitted in existing literature or the calculations of policymakers.

CHAPTER 2

Literature Review

The following literature review covers the topic of "Nature-based Solutions (NbS) for Water Management in Urban Areas". After presenting the conditions and the challenges of the 21st century, this work will offer some theoretical tools to analyze the difficulties described and how to apply them to reality. In addition, other case studies and papers from the literature with similar approaches are also presented in Section 2.6 "Cost-Benefit Analysis".

1. Climate Change

The people's influence on the Earth's temperature, including atmospheric, ocean, and land components, is unequivocal[**Masson-Delmotte and Zhou, 2021**]. The industrial revolution was the significant starting point for a continuous increase in greenhouse gases emitted into the atmosphere. The industrial revolution also brought changes of a different kind. The use of land was completely rethought. For example, considerable population densification occurred during this period, and deforestation accelerated significantly. This in turn led to increased surface temperatures and other effects that we are still trying to understand in their complexity today [**Giorgi, 2006**, p. 33f][**Zittis et al., 2019**, p.2621f][**Cramer et al., 2018**, p.972f].

As indicated in the introduction, many of the current challenges nowadays are caused by the temperature increase. Therefore it is worth taking a look at the current numbers and figures.

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

FIGURE 1. Future Temperature

This table (Figure 1) from the IPCC in 2021 shows the different scenarios predicting the temperature in the near term, mid-term, and long-term. To do this, IPCC has calculated five different strategies of how we as a society deal with sustainability and linked that to the Representative Concentration Pathway (RCP). The shared socioeconomic Pathways (SSP) futures compromise: sustainable development (SSP1), middle-of-the-road development (SSP2), regional rivalry (SSP3), inequality (SSP4), and fossil-fuelled development (SSP5), where SSP5 is the highest greenhouse gas emitter, and SSP1 has the lowest greenhouse gas emission. As we can see in "Figure 1", an increase of two degrees would be reached under the high and very high GHG emissions scenarios in the 21st century (here: SSP3-7.0 and SSP5-8.5). In the intermediate scenario (SSP2-4.5), the two-degree increase would be exceeded "extremely likely." Finally, in the very low and low scenario (here: SSP1-1.9 and SSP1-2.6), it would be "extremely unlikely" to be exceeded [**Riahi et al., 2017**, p. 25].

Considering the Paris Agreement sets a goal of a temperature increase of under two degrees, preferably to 1.5, it is alarming to see a temperature increase up to 5.7 degrees in Figure 1. According to the IPCC, a 0.5-degree increase would significantly impact the world and imagining any scenario considering a 5.7 degree increase is unpredictable. For example, the world population exposed to heatwaves would more than double from 15 percent to 37 percent[**Masson-Delmotte and Zhou, 2021**]. Even though the experts do not put a likelihood on any single scenario within Figure 1, the sheer existence of temperature increases like 5.7 being included in the model is concerning since each scenario is considered realistic[**HAUSFATHER, 2018**].

One of the consequences of the expected sharp rise in temperature is extreme weather events. Many studies have been conducted on a European level to find out as much as possible about those weather extremes. Just to name a few: river floods [**Rojas et al., 2012**] [**Alfieri et al., 2018**], coastal floods [**Nicholls and Klein, 2005**][**Hinkel et al., 2010**], heat waves [**Fischer and Schär, 2010**][**Russo et al., 2015**][**Christidis et al., 2015**] , streamflow droughts [**Lehner et al., 2006**][**Forzieri et al., 2014**], windstorms [**Nikulin et al., 2011**][**Outten and Esau, 2013**] and wildfires [**Bedia et al., 2014**] [**Migliavacca et al., 2013**]. This work will focus on the water-related catastrophes described in the "Water Management" subsection. A holistic view of climate change will be presented by mentioning all the co-benefits from the NbS to other landscapes.

2. Urban Areas

As mentioned before, the climate crisis is provoked by humans. Hence, one should look at the regions with the highest human population density: cities.

Over the years, one could observe an urbanization effect, increased population density, and a lack of public investments in green initiatives [**Dupras et al., 2015**, p. 355-375][**Haaland and van Den Bosch, 2015**, p. 760-771]. Figure 2 shows that in 2007 urban population overtook the rural population, and since then, those two lines are shifting away from each other. One can also observe the overall population increase [**Ritchie and Roser, 2018**, p. 355-375].

Figure 3 below shows that approximately 74 percent of all Europeans live in urban areas. The European Commission estimates that by 2050 approximately 83,7 percent of

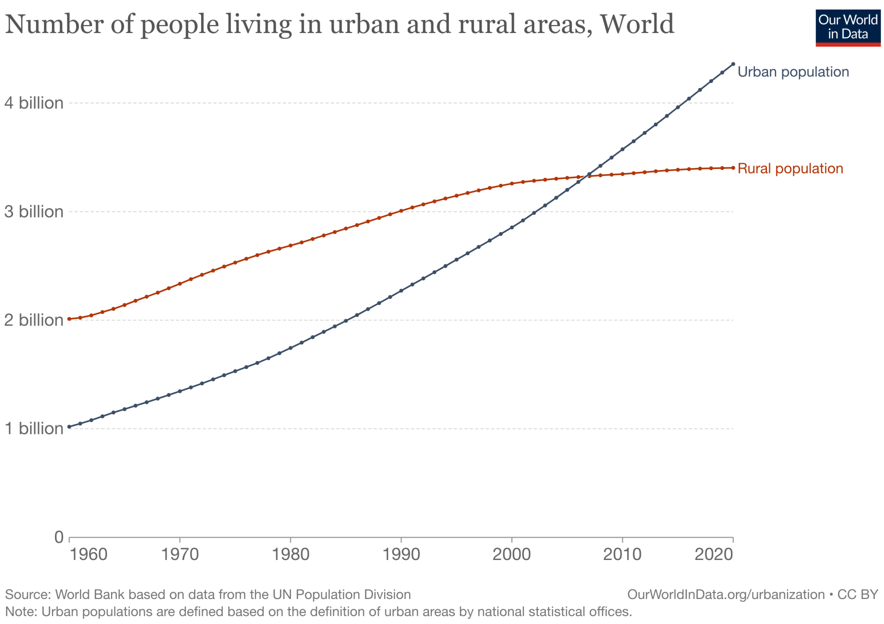

FIGURE 2. Population Percentage in Urban Areas

the population will live in urban areas [**on Foresight European Commission, 2022**]. Cities have a high demand for electricity, water, and other resources and are the most significant source of pollution ranging from greenhouse gases to water contamination. Looking at these problems from a different angle, one could also see the enormous potential for city infrastructural changes. One concept to address this potential strongly linked to NbS is the concept of green-blue infrastructure. It is an approach to landscape planning and urban design based on nature. Andreucci et al. (2019) define it as "a strategically planned network of natural and semi-natural areas, with other environmental features designed and managed to deliver a wide range of ecosystem services" [**Andreucci et al., 2019**]. It is often used for specific Water Management challenges in cities and is one of the many aspects of Nature-based solutions. Given that infrastructural change potential, cities must act now and set an example in climate change mitigation and adaptation actions[**Kabisch et al., 2017**, p. 8]. That is also the reason why this thesis will focus on urban areas.

The potential mentioned is not fully exploited for a variety of reasons. For example, Zhou et al.(2019) point out that the trivial reason for not reaching full potential is the lack of ecological knowledge in the urban planning and development sector [**Zhou et al., 2019**]. Another aspect is the poor surveying, monitoring, and assessing of present urban nature [**Haaland and van Den Bosch, 2015**, p. 760-771]. An additional reason for the stagnation of cities is the lack of ideas and creativity on financing long-term urban green or blue bottom-up measures [**Mattijssen et al., 2017**, p. 78-84]. This aspect of the thesis will be discussed in the chapter "Why aren't NbS more widely spread?"

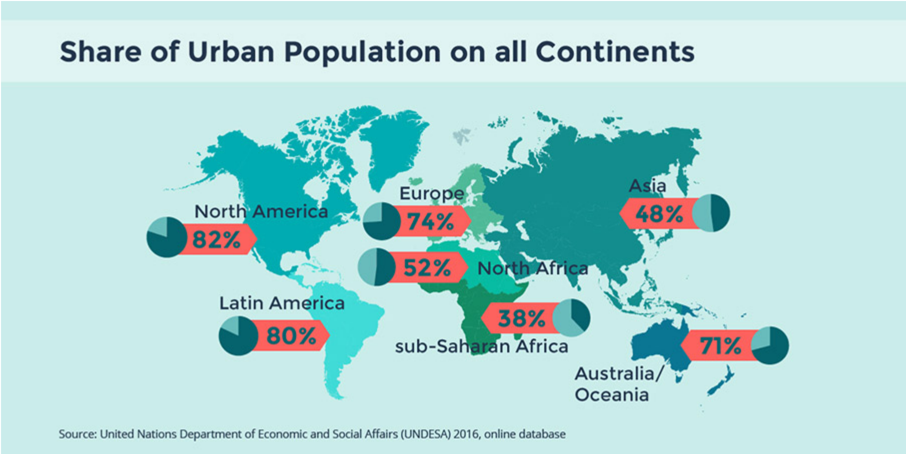

FIGURE 3. Population Percentage in Urban Areas

3. Nature-based solutions

Due to emerging policy discourse and the continuous increase of climate problems, the concept of NbS was introduced in the year 2000 by the International Union for Conservation of Nature (IUCN) and the World Bank portfolio "as a way to mitigate and adapt to climate change, secure water, food, and energy supplies, reduce poverty and drive economic growth" [**Pauleit et al., 2017**, pp. 29-49]. Nature-based solutions were introduced as a consistent term for green and blue infrastructure implementations. Since then, the concept of NbS has developed significantly, and 21 years later, the European Commission (EC) defines NbS in their most recent Handbook from 2021 as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions." [**Dumitru and Wendling, 2021**, p 6]. Exceeding the definition of the EC, NbS is being used as an umbrella term for all other "ecosystem-based" concepts that developed over the years[**Irfanullah, 2021**, p 6]. One can find different meanings of the NbS term in the literature [**Dumitru and Wendling, 2021**, p 20]. Dorst et al. (2019) describe Nature-based solutions as "interventions based on nature that is envisaged to address sustainability challenges such as resource shortages, flood, and heat risks and ecosystem degradation caused by processes of urbanization and climate change" [**Dorst et al., 2019**]. Kabisch et al. (2017) point out the holistic aspect and the co-benefits of the NbS: "the maintenance, enhancement, and restoration of biodiversity and ecosystems as a means to address multiple concerns simultaneously"[**Kabisch et al., 2016**]. Albert et al. describe NbS as "actions that alleviate a well-defined societal challenge (challenge-orientation), employ ecosystem processes of spatial, blue and green infrastructure networks (ecosystem processes utilization), and are embedded within viable governance or business models for implementation (practical viability)."[**Albert et al., 2019**, p 12]. On the other hand Frantzeskaki et al. (2017) see NbS more as an answer to a lot of questions the current environmental situation raises: "the concept it represents is of vital and urgent significance. As the grand challenges that face society continue to build, so does the need for multidisciplinary, evidence-based strategies to, for example, protect water supplies, address habitat loss, and mitigate and adapt to climate change"[**Raymond et al., 2017**]. For Short et al., NbS are "soft engineering approaches that are aimed at increasing the resilience of territories and societies affected by meteorological events and therefore reducing the economic, functional, cultural, and social damage disruption that such events cause."[**Short et al., 2019**, p 242].

In spit of all those slightly different yet similar definitions, the reader can build himself an idea of what the term Nature-based Solutions means. In 2015 Eggermont et al. pointed out that the unclear terminology also can lead to a misuse of the term NbS [**Eggermont et al., 2015**, p 242]. After raising more awareness of NbS in general and the EC defining NbS year after year, that risk should decrease over the years.

4. Infrastructure

In this thesis, we will split infrastructure into two different types: Nature-based solutions and Grey Infrastructure. While NbS is already defined, grey infrastructure still needs to be explained. However, first, a few words about infrastructure in general: There is a vast range of how much infrastructure is required to avoid weather related disasters. Some sources estimate costs of 150 Billion USD for the whole globe, and others estimate around 7.9 trillion USD. Considering the vast range of outcomes, it is sense to use the medians or averages of the extant literature. The "International Institute for Sustainable Development" has already done so, and the average annual cost of infrastructure investments worldwide is 4.29 trillion USD [**Bassi et al., 2021**, p 8]. Bassi (2021) states that the water and sanitation sector's average investment costs are about 448.43 billion USD annually. Those estimated costs include wastewater treatment, water retention, water supply, and drainage. According to Bassi (2021), 75 percent of that cannot be resolved by NbS and need to be traditional, grey infrastructure. Nature-based solutions could cover the remaining 25 percent of yearly gray investment costs in the future. Possibly more cost-effective and with many co-benefits. This estimation also considers limited space in urban areas [**Bassi et al., 2021**, p 9].

4.1. Grey Infrastructure

Unlike nature-based solutions, grey infrastructure has a more straightforward definition. Nevertheless, drawing a clear line between NbS and grey infrastructure is sometimes not evident.

Forster et al. (2011) describe grey infrastructure as reservoirs, detention ponds, and conveyances like pipes and canals, built mainly for managing drinking water, sewer, and stormwater. This infrastructure is primarily built out of concrete or metal [**Foster et al., 2011**, p 2]. Oppermann (2014) adds that grey infrastructure's purpose is to remove stormwater from sites as soon as possible to a close river or body of water through pipes or canals [**Opperman, 2014**].

In the existing literature, grey infrastructure is often compared to NbS, as we intend to do in this thesis. However, it is often the case that grey infrastructure already exists, and the question is which infrastructure to build on top of the existing one. Therefore, it is usually not a question of grey infrastructure or NbS, but what is the right mix of both [**Kapetas and Fenner, 2020**]. In addition to that, Forster (2011) also points out that buildings, roads, and bridges are also grey infrastructure, but not the ones linked to environmental goals [**Foster et al., 2011**, p 4]. So, when this work talks about grey infrastructure, it will talk about grey infrastructure in the context of environmental goals and not about grey infrastructure in general. Having defined both the NbS and the grey alternative, this Thesis will now take a closer look at the current state of the literature. To do so, we compare both topics based on the existing literature. First, the primary advantages of NbS compared to the grey alternative will be mentioned, followed by a particular focus on the cost advantages. The disadvantages of NbS will not be discussed further in this chapter for two reasons: 1) The advantages predominate in the literature. 2) The disadvantages and challenges of NbS are discussed in the chapter "Why aren't NbS more widely spread?".

4.2. Benefits of NbS over Grey Infrastructure

Biodiversity: One of the key concerns of the EC handbook (2021) is biodiversity loss. A functioning ecosystem needs diversity in which every little bacteria or big mammal plays its role. To regain the lost biodiversity the handbook is recommending the implementation of NbS [**Dumitru and Wendling, 2021**, p 146-160]. Some even call biodiversity "the heart of NbS" [**Eggermont et al., 2015**, p 244].

Simultaneity: Indeed, one of NbS's main advantages is its potential to simultaneously address several goals, as shown in Figure 4 below, which is also the Cover of the European Commission (EC) Handbook. For example, a green roof is suitable for cooling the surface, mitigating heavy rainfall effects, and simultaneously improving air quality and biodiversity. Moreover, green spaces positively affect people's stress and therefore contribute to their health. Often a grey infrastructure addresses only one challenge at a time.

Flood Risk: The urban development leaves little or none of the original vegetation after the cities are built. Roads, buildings, and other concrete surfaces eliminate the natural hydrology from before. In a way, the implementation of NbS is just regaining the natural environment piece by piece. Since roads and buildings do not have a permeable surface, heavy rainfall or river floods can be a challenge for urban areas [**Cameron et al., 2012**]. NbS, like wetlands or also green spaces, can handle floods and heavy rainfall more effectively than the grey alternatives [**Agency, 2010**][**Hartmann et al., 2019**][**Kalantari et al., 2018**].

FIGURE 4. Variety of NbS

Employment: Grey Infrastructure can create jobs, but most of the time, just for a project and its maintenance. NbS can, like grey infrastructure, create jobs directly through construction and maintenance. But they also indirectly offer the possibility of long term jobs e.g. by increasing tourism [**Lieuw-Kie-Song and Perez-Cirera, 2020**] [**Dunn, 2010**][**Council, 2015**][**Hansen and Pauleit, 2014**].

Physical activity and health: Air pollution alone accounts for around 600,000 deaths annually in the pan-European region [**Annerstedt van den Bosch et al., 2016**] and noise is a significant health problem, causally linked to, for instance, mental and cardiovascular disorders [**WHO, 2011**]. It is, therefore, surprising that in many studies, the health aspect is only listed as a co-benefit. But the topic is increasingly explored and it is likely be one of the essential factors soon. Almost every NbS contributes to improving the air quality [**Pugh et al., 2012**]. Trees in green areas, for example, do not only produce oxygen during photosynthesis, but they also absorb pollutants [**Dumitru and Wendling, 2021**, p 146].

Also, there is a significant correlation between access to NbS spaces and the level of physical health of the residents. Just because the opportunity of a park or a green area is there, people will tend to walk more, cycle more, and live a more active life [**Tzoulas et al., 2007**].

4.3. Benefits of NbS over Grey Infrastructure concerning the costs

Reduction of Grey Infrastructure: NbS can defer or even update high-priced grey infrastructure projects [**Foster et al., 2011**]. These installations, for example, big sewage expansions and deep tunnels, are high-priced to assemble and take years to complete, making them liable to growing prices of materials, labor, and financing. By comparison, the prices concerned with imposing NbS are less complicated to predict [**Emanuel, 2014**].

Reduced Water Treatment Costs: In the event of heavy rainfall on grey surfaces, the water takes away all the pollution with it. A wetland or a Rain Garden, for example, can filter out a lot of that pollution [**Lucas and Sample, 2015**] and prevent this pollution in the first place. That will lead to fewer chemicals in the water, water pumping, and energy. Therefore, water treatment costs are significantly lower [**Emanuel, 2014**][**Agency, 2010**].

Lower Maintenance Costs: When NbS meets its full potential, it often works self-sustainable or close to self-sustainable. For instance, natural rainwater harvesting systems and drought-resistant plants can reduce the costs of maintenance [**Agency, 2010**].

Property Values: Green areas in cities have always been popular, but their value seems to have increased recently. Properties gain a lot in value if they have a nearby NbS space [**Young, 2011**] [**Schilling and Logan, 2008**]. Green spaces are liked because of their possibility to go for a run there, their aesthetics, and just in general spending leisure time there. This can even spin the whole economic wheel and lead to economic growth and lower levels of crime [**Heritage, 2014**] [**Kondo et al., 2015**][**Infrastructure, 2015**].

Increased groundwater: With NbS, the groundwater will rise and therefore avoid increased pumping costs that are occurring with declining groundwater levels [**Wise, 2008**][**Agency, 2010**][**Foster et al., 2011**].

Water Imports: Many cities rely on water imports from great distances to meet their water demands. NbS can reduce that by saving water in the town and using, for example, the sponge technique [**Agency, 2010**]. A famous example would be Las Vegas, which imports around 90 percent of its water [**Pavelko et al., 1999**].

Reduced energy demand: Cities already suffer from heat islands in cities. Green roofs could provide insulation and shade and therefore reducing energy demand for heating and cooling [**Santamouris, 2014**][**Young, 2011**][**Heritage, 2014**] [**Salata and Yiannakou, 2016**].

After reading these benefits for the NbS, one might wonder why this thesis still wants to do a cost-benefit analysis of a Nature-based solution and a grey alternative and compare those. The literature is leaning toward the NbS: All the literature states there is a considerable advantage, but there are relatively few case studies and real-life examples where actual costs from different scenarios are compared. Another thing is that the popularity of NbS is still not fully developed. Therefore, there are still grey alternatives implemented every day, where probably a NbS could have been the better solution just because the policymakers do not know NbS and their advantages.

5. Water Management

Oral et al. (2020) enumerate several ways water can occur under the term "Water Management": "constructed wetlands," "Urban water in the field of food, water, and energy ecosystem," "Implementation of blue-green infrastructures," "Flood protection and risk management" and "Stormwater management" [**oral et al., 2020**, p 111-128]. In addition to that, Water Management in cities, or Urban Water Management (UWM), in general, refers to all water that is present in urban environments: natural surface water, groundwater, drinking water, sewage, stormwater, etc. [**oral et al., 2020**, p 118].

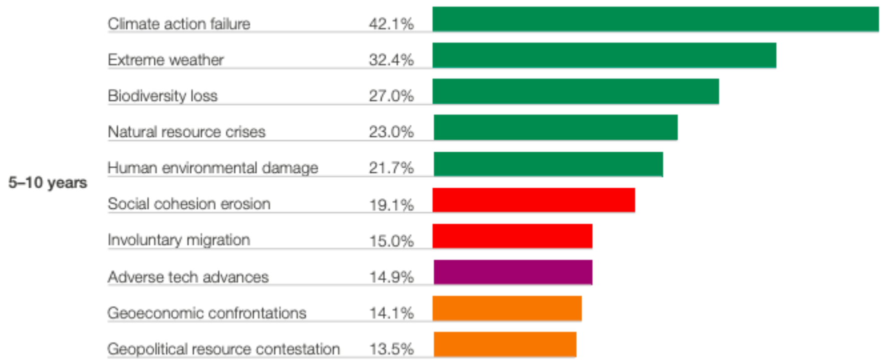

FIGURE 5. World Economic Forum Global Risks Report 2022

Figure 5 above shows the Top 10 risks to humanity in the next 5-10 years. 5 out of 10 are green which stands for "environmental," and all of the first 5 are environmental. Of all those, at least three are directly linked to Water Management. According to the World Economic Forum, "Extreme weather events" contain storms, rising sea levels, and floods. "Climate action failure" is directly linked to the measures the cities can take. For example, they are failing to prevent a flood in a city or not preparing for rising sea levels. "Human environmental damage" is the deterioration of the environment through the depletion of resources such as air, water, and soil. "Natural resource crises" and "Biodiversity loss" is also indirectly linked to Water Management [**RIS, 2022**]. The damages from flooding in Europe alone are expected to rise from about 6 billion annually to 108 billion in 2080. This calculation is made with the assumption of no further prevention or adaption[**Zingraff-Hamed et al., 2021**, p 1610].

After realizing that water management is one of the most critical elements of NbS now and in the future, this work decided to set a focus on that sector and explore all the potential [**Keesstra et al., 2016**, p 111-128] [**Kabisch et al., 2017**, p 118]. Wetlands, for instance, belong to the most productive ecosystems with often very high watershed systems, high biodiversity, and flood water retention. However, they also work like a sponge. Thus, especially for dense populations, they represent almost perfect NbS for risk mitigation and adaptation concerning both climate extremes: flood and drought. [**Kabisch et al., 2017**, p 117].

6. Rain Gardens

FIGURE 6. Rain Garden London

This thesis will analyze one particular Nature-based solution within Urban Water Management: Rain Gardens. In most cities, combined sewers deal with raw sewage and stormwater. They are most likely transported to a compact wastewater treatment plant together. In addition to that, current sewer systems are often not prepared for their treatment volume leading to frequent overflow. If the underground sewer system overflows in heavy rain, all the untreated, possibly contained water is dumped into nearby water bodies. The papers call that combined sewer overflow (CSO) [**USEPA, 2004**]. CSO events can have negative consequences on human health and ecology. The clean-up of those CSO events is difficult and, therefore, expensive. In 2000 already, the "Wet Weather Quality Act" estimated an annual clean-up cost of up to 654 Million US Dollars for the US and it is getting worse by year [**WWQ, 2022**]. One of the ways to mitigate those numbers is the concept of a "Rain Garden". It is listed under "Water Management" by the EC Handbook in the category "Infiltration, filtration, and biofiltration structures" [**Dumitru and Wendling, 2021**, p 125]. Rain Gardens look like common gardens, but they have some specific features. The primary purpose of Rain Gardens is to infiltrate and temporarily store stormwater and move it to deeper layers, all the way to pipes, drains, and eventually the groundwater or sea. But besides that, they also remove pollutants, slow down stormwater flows, filter the air, increase biodiversity, and have a good influence on people's health [**Council, 2018**][**Bray et al., 2012**]. To be named a Rain Garden, it has to contain different areas/layers:

Ponding Area: A ground depression where rainwater or running water can be collected. Surfaces with large slopes are therefore not suitable for Rain Garden construction. The ponding area is covered first by a gravel layer with a mulch layer on top and finally the topsoil. The different layers will infiltrate the water.

Inflow structure: Surrounding the Rain Garden, there needs to be a structure to deliver the water from impermeable areas like sidewalks or streets towards the garden.

Overflow area: Rain gardens are for heavy rains and below. If there is extreme weather, the Rain Garden ponds will overflow. That overflowing water needs a structure that allows water to exit. It will avoid erosion.

Plants: A garden needs plants. Besides their contribution to landscape aesthetics, they also help reduce pollutants, filter the air and retain water. Therefore, the selection of the plants is essential and varies from site to site. Rain Garden experts recommend a mixture of local, native plants that can tolerate high water levels and even inundation. In some areas, for example, Greece, that can be a challenge because local plants are more used to drought than to over flooding [**Katsifarakis et al., 2015b**][**Bray et al., 2012**].

Rain Gardens are helpful in significant rain events, but they are not suited ideally for heavy rainfall catastrophes. A wetland or other NbS might better mitigate that [**Holman-Dodds et al., 2003**]. Also, they need a lot of careful planning and implementation and often face legal barriers [**Morzaria-Luna et al., 2004**]. Financially Rain Gardens have been proven to be less costly than grey infrastructure alternatives. The cleaning process of the combined sewer overflow or different pipes - one for stormwater and one sewer - are both considered more expensive than the Rain Gardens [**Narayanan and Pitt, 2006**] [**District, 2012**].

In this work we narrow the focus from climate change to nature-based solutions to water management and finally to Rain Gardens in urban areas. The EC Handbook (2021) describes all essential aspects of NbS. Still, there are no quantified examples with costs and benefits to illustrate the success of case studies of NbS in the Handbook, even though they often mention the cost factor as a benefit over grey infrastructure. This also applies to the rest of the literature on that subject. Moreover, there are relatively few good calculations on the costs of NbS compared to either the cost of grey measures and alternatives or the long-term benefits of NbS.

7. Cost-Benefit Analysis

This work will compare the costs and benefits of different infrastructure solutions. To do that, we will choose the Cost-Benefit Analysis (CBA) as a tool to observe and quantify the data we got from case studies. Even though the origins of Cost-benefit analysis (CBA) can be traced back to somewhere around the nineteenth century, the modern CBA was established around 1940 [**Persky, 2001**, p 6]. Simply put, the CBA will systematically catalog all the benefits and costs of a project valued, typically in monetary units. After summing up both sides, one determines the net benefit by subtracting the summed costs from the calculated benefits. Instead of thinking of CBA as one rigid method, it is like a framework for rational decision-making. The simplest form of CBA can be demonstrated as a simple subtraction $NSB = B - C$, where NSB (Net-social benefit) equals the subtraction of Costs (C) from Benefits (B)[**Juvonen et al., 2020**, p 6].

A common mistake is to interpret the costs and benefits only as individual costs and benefits instead of considering all costs to society and even the "hidden" and alternative costs like opportunity costs or avoided costs. However, many sources do not consider that or point to another concept called "Social cost-benefit analysis" (SCBA). Social cost-benefit analysis is an extension of economic cost-benefit analysis, adjusted to consider the full spectrum of costs and benefits (including social and environmental effects). The challenge for those types of analysis is the monetary valuation of non-market goods like human health or air quality. After putting every cost and benefit - even the non-market goods into account, the SCBA works the same way a classical CBA works: To finalize a project, the sum of economic, social, and environmental benefits need to outweigh the sum of economic, social and ecological costs [**SOC, 2022**, p 2].

The purpose of CBA is to rationalize the decision-making process and assess projects on a quantitative basis. Typically, there are three types of CBA: ex-ante, in media res, and ex-posts [**Boardman et al., 2014**, p 1-12]. CBA is versatile in its application: It can be used for environmental, agricultural, transportation, land-use projects, and many more [**Mishan and Quah, 2020**, p 1-12]. This work will focus on SCBA for NbS.

According to Boardman et al. (2014), a CBA on a project has nine steps to follow:

(1) Specify the set of alternative projects.
(2) Decide whose benefits and cost count (standing).
(3) Identify the impact of categories, catalogue them, and select measurement indicators.
(4) Predict the impacts of quantitatively over the life of the project.
(5) Monetize (attach dollar values to) all impacts.
(6) Discount benefits and costs to obtain present values.
(7) Compute the net present value of each alternative.
(8) Perform sensitivity analysis.
(9) Make a recommendation.

The first four steps are undoubted in the literature. The fifth step, "monetize," on the other hand, is strongly disputed. According to Boardman et al. (2014), some "..are unwilling to attach a monetary value to life or some other impact. This forces them to use an alternative method..." [**Boardman et al., 2014**, p 12]. Additionally, there is a whole spectrum of literature dealing with this subject (e.g., Ackermann and Heinzerling (2004); Atkinson und Mourato (2008); Boadway (2006); Kelman (2002); Martens (2011); Sen 2000 and van Wee (2012)) much of it highlighting that moral is neglected in most CBA's. Some projects whose costs exceed the benefits are not selected but are morally right; contrarily, some decisions where the benefits seem more significant are ethically wrong. For instance, two critics of monetizing are Frank Ackerman and Lisa Heinzerling. They published the paper "Pricing the priceless: Cost-benefit analysis of environmental protection" in 2001 where they question the sense of monetizing environmental aspects and, therefore, the health of humans [**Ackerman and Heinzerling, 2001**, p 1553-1559]. Nevertheless, since 2001 some tools and ways have evolved to estimate the monetary value of health. A classical approach is a "Contingent Valuation" (CV) where surveys are used to directly ask potential users how much they would be ready to pay to use a specific environmental asset or how much they would be willing to accept to forego its benefit. The worth of the questioned environmental asset is then determined by applying statistical analysis to these numbers. The evaluation of projects' ecological effects also employs this method [**Carson and Hanemann, 2005**]. For instance, people might be questioned on their willingness to pay for an investment project to enhance a specific lake's water quality.

The tool has become more and more popular over the years. However, it should also be noted that the literature on environmental value identifies numerous issues with applying this strategy. After the Exxon Valdez oil spill in 1989, when the contingent valuation method was employed to estimate the harm to natural resources, discussions over the methodology intensified. The State of Alaska sued the responsible party, and the actions sought a sizable sum of compensation. As a result, both parties funded studies to determine the method's accuracy, which led to a scholarly discussion over contingent valuation. While critics questioned the validity and dependability of the contingent valuation method, advocates disseminated papers that supported it [**Bennett, 2011**]. During this time, contingent valuation has significantly changed, and other technique variations have appeared. Strategic behavior bias, hypothetical bias, and starting point bias are the current top three issues with applying the contingent valuation technique. When respondents bid an amount greater or lower than their willingness to pay, this is known as strategic behavior bias. The type of strategic behavior frequently depends on respondents' opinions on money matters, or more specifically, whether or not they will be expected to pay for the investment's cost. Respondents might be underbid, for instance, if they think their taxes will help pay for the investment. On the other hand, a person who believes that others will finance the acquisition may be motivated to maximize the likelihood that it will be provided and, as a result, may bid more than they are willing to spend.

An incomplete understanding of the interviewer's scenario by respondents may result in hypothetical bias. Because it may be challenging for individuals to understand what a change, for example, in the sulfur dioxide or dissolved oxygen implies in terms of air or water quality, Whittington et al. (1990) have stressed that such biases typically occur in evaluating the willingness to pay for environmental quality[**Whittington et al., 1990**, p 299]. Furthermore, respondents' dishonest responses also result in hypothetical mistakes. Individuals' willingness to pay is ascertained using the contingent valuation method in two different ways. For example, "What is the most you would pay to clean up the lake?" is a direct question that forces respondents to disclose their maximum willingness to spend. The open-ended format is what is used for this. Alternatively, the respondent may be asked to select his maximum willingness to pay (WTP) from a range of possible WTP values or to indicate if he is willing to pay at least a specified sum. With the so-called "bidding game," those who agree to pay a set sum may subsequently be offered larger amounts to determine the upper limits of their willingness to pay. In these formats, the starting point bias appears. Answers to the following questions are frequently highly correlated with the original amount because the respondent tends to be affected by the interviewer's initial figure. This is a significant flaw in the contingent valuation approach [**Mitchell and Carson, 2013**]. The method's high desire to accept values relative to its low willingness to pay due to psychological factors and the respondents' and interviewers' lack of survey-related knowledge and expertise are further serious difficulties.

An alternative approach to the CV is Rosen's so-called "hedonic pricing" (1974). The premise behind the hedonic pricing method is a correlation between environmental assets and the cost of associated commercial items. In the hedonic pricing method, the price of residential properties close to the ecological amenity is first collected. Their values are then contrasted with the costs of comparable properties far from the environmental good in question. This procedure is typically used to estimate the value of ecological assets. Presumably, the price discrepancy reflects the worth of the environmental investment. For instance, the higher property values of neighboring inhabitants who gain from the scenic beauty and recreational opportunities offered by the park affect the worth of the park [**Rosen, 1974**].

The last idea presented is also interesting for environmental NbS that you can later visit: The concept of "Travel cost." The Clawson and Knetsch (1996) travel cost method supposes that the expenses associated with making recreational excursions reflect the cost that individuals are prepared to pay for the environmental service. Therefore, the foundation of travel cost calculations is estimating the cost individuals pay to visit a recreational place (such as a public park or beach) and the number of visits they take. The survey of visitors to the destination is intended to gather data on the number of trips made in the previous year, travel costs (such as gasoline, tolls, entrance fees, etc.), respondents' incomes, the distance traveled, and the depreciation of their vehicles. Utilizing pay rates, the opportunity cost of travel time, or the cost of time that could have been spent doing anything else, such as working, is computed and factored into travel expenses. Finally, the total cost per user per year for accessing the recreational facility is used to calculate the asset's yearly worth. The presence of multiple reasons for the journey poses a unique challenge to implementing the travel cost technique [**Clawson and Knetsch, 2013**].

Although these two methods do not appear later in this paper, the estimation of non-market goods is exactly the main focus of this work and therefore it is relevant to also present alternatives to the classical approach.

Similar Cost-Benefit Analyses A survey about "how to make NbS more popular" shows that 13 out of 53 respondents state that the top priority for implementing more NbS should be improved guidance and more quantified case studies with costs and benefits to make it more popular [**Naylor et al., 2016**, p 844]. Even though there is a lack of literature, some case studies have been found as an example of SCBA in the environmental sector:

Tavakol et al. (2016) compared all the green infrastructure costs with the grey infrastructure costs of solutions to the challenge of sewer overflows in Toledo, Ohio. Besides other tools, Tavakol et al. also used a cost-benefit analysis. The results were unequivocal. The Green infrastructure had lower life cycle costs, implementation and operation phases, and also higher efficiency [**Tavakol-Davani et al., 2016**].

Liu et al. (2018) analyzed a site in the London Borough of Southwark area. The paper uses a "do nothing" baseline, which means they compare all the estimations to a case of not taking action. "A cost-benefit analysis is implemented to assess the performance of real options in flood risk reduction compared to the fixed adaptation approach and 'do nothing' baseline." [**Liu et al., 2018**, p 7]. Additionally, as they try to make a long-term comparison, Liu et al. (2018) discount the future, a common instrument for comparing long-term scenarios[**Liu et al., 2018**].

Talberth (2013) uses their modification of a CBA to analyze different infrastructures and possible scenarios on various sites in the US [**Talberth et al., 2013**].

Bassi (2021) made an extensive study with CBA's of 10 different case studies [**Bassi et al., 2021**]. His main question was how the infrastructure gap could be closed soon. According to his study, NbS costs 50.7 percent less than grey infrastructure alternatives and also, at the same time, creates 28 times more value than grey infrastructure alternatives. In simpler words: On average, NbS generates 10 dollars for every dollar invested, while grey infrastructure generates only 3.6 dollars per 1 dollar investment. Both options are still better than keeping the status quo [**Bassi et al., 2021**, p 12].

A particular focus on incorporating non-market values in the formal CBA in water management practices is done by few. One of them are Alcon et al. (2013). They are focusing on the Tajo river in Spain, and a close-by crop field, including non-market values of the river [**Alcon et al., 2013**]. Alcon et al. state that "...These kind of "intangible" benefits are often ignored, but only the combination of market and non-market costs and benefits can produce a balanced assessment of water management options and lead to an efficient and sustainable allocation of the resource" [**Alcon et al., 2013**, p 2].

Another example is based in Los Angeles, California, USA. Kalman (2000) uses the benefit transfer method to incorporate non-market values into their benefit-cost analysis of several stormwater quality management options. The authors find the benefit-cost ratios are all close to zero and argue that a quick benefit-cost study with benefit transfer values is helpful as it can identify projects that are either unambiguously feasible or not. However, for middle ground projects, further primary analysis is required [**Kalman et al., 2000**, p 2].

In their assessment of green roofs in Athens, Georgia, the United States, Carter, and Keeler (2008) take into account certain social benefits. However, the study mainly consults secondary sources to determine social benefits (benefit transfer). The study found that, in this instance, a reduction in construction costs and an extension of the construction warranty period are needed rather than the inclusion of non-market benefits to make green roofs more widely used than conventional methods [**Carter and Keeler, 2008**].

Polyakov, Fogarty, and others compare the costs and amenity advantages of a living stream project in Perth, Western Australia (2017). Depending on the expected discount rate and the size of the amenity benefit, which is calculated using the hedonic price approach, they report benefit-cost ratios (BCR) of between 1.6 and 4.2 [**Polyakov et al., 2017**].

In Grand Rapids, Michigan, USA, Nordman, Isely et al. (2018) calculate the net present values of various green infrastructure choices. The benefit transfer approach is used to include non-market values. They discover positive NPVs for porous asphalt, Rain Gardens, street trees, and preserving natural areas for the basic case scenario; however, they find negative NPVs for green roofs and infiltrating bio-retention [**Nordman et al., 2018**].

In 2001 Macmillan elaborated on the trade-offs of non-market goods that are often omitted in studies. For example, a train can help in reducing CO2 emissions and therefore improve air quality, which is considered a classical non-market value. Meanwhile, a train can cause externalities like noise close to residents. Still, the non-market benefits can overrule the non-market costs, but often by looking at one, the other is omitted [**Macmillan et al., 2001**].

A final relevant paper is one by Bateman et al. from 2006. They analyze the cost and benefits of agricultural land use near water bodies. For instance, the environmental costs of the entrance of pesticides used for agriculture into water bodies [**Bateman et al., 2006**].

CHAPTER 3

Methodology

1. Data

In this work, the SCBA will use data from 2015 to 2016 from the municipality of Thessaloniki and two sources. Basdeki (2016) and Katsifarakis (2015) describe the studied area in detail and provide most of the necessary data [**Katsifarakis et al., 2015b**]

[**Basdeki et al., 2016**]. The remaining unclear questions were answered in direct correspondence with Professor Katsifarakis from the Aristotle University of Thessaloniki, who led the project on the Rain Gardens in the studied area. Other data is assumed through similar projects like the life cycle cost analysis of Rain Gardens in Cincinnati [**Vineyard et al., 2015**] or other. A final way to gather data is a tool called "GI-Val". It is presented below.

Especially concerning the construction costs, a lot of local data in Thessaloniki was found through different portals and websites. After collecting all the data for the SCBA of the Rain Garden, this work will also do a SCBA for the grey alternative to compare the two results. The comparison can help in the decision-making process and contribute to the lack of case study examples that also include the non-market values of a project of that size. Most of Rain Garden advice is for the backyard of homeowners.

The Rain Garden project in Thessaloniki was chosen for many reasons: 1) Rain Gardens are a way to green up existing grey infrastructure. Nevertheless, in this case study, there is a clear distinction between green and grey alternatives. 2) It is in the segment of Water Management and is also very urban. Unlike wetlands, which tend to be in the suburbs or close to the city - Urban Gardens can be placed anywhere in the heart of cities. 3) The concept is simple to understand but can have significant effects. 4) After starting the decision process in 2016, the city of Thessaloniki is still in the progress of deciding whether the grey or green option is more suitable for the project. Financing the project was the main challenge in the past. Now due to Covid-19, the project has been undermined in other priorities.

GI-Val The Mersey Forest created the excel-based toolbox known as GI-VAL between 2008 and 2010 in association with 10 other organizations. The tool's current iteration is a prototype; therefore, not all Green Infrastructure development's benefits are fully realized. The tool, created for a UK environment, serves as a framework to identify and evaluate the advantages of investing in current or prospective GI interventions in urban settings. It covers a broad range of industries, offering a framework for understanding what an investment can involve and when stakeholder participation might be helpful [**Riedel, 2022**]. It is meant to build an investment case for various local stakeholders and to make it easier to compare various development possibilities (i.e., land managers, developers, local authorities, city region representatives, local enterprise partnerships, economic development agencies, and volunteering organizations). It is intended to provide a return-on-investment figure when used in conjunction with a proposed or planned development project. It can also be used to analyze the economic value of an existing location, which will help evaluate additional development ideas. This work will use the tool mostly to put an economic value on non-market goods. For example, the money value of air quality or the cooling effect of trees is expressed in monetary numbers.

2. Area of study

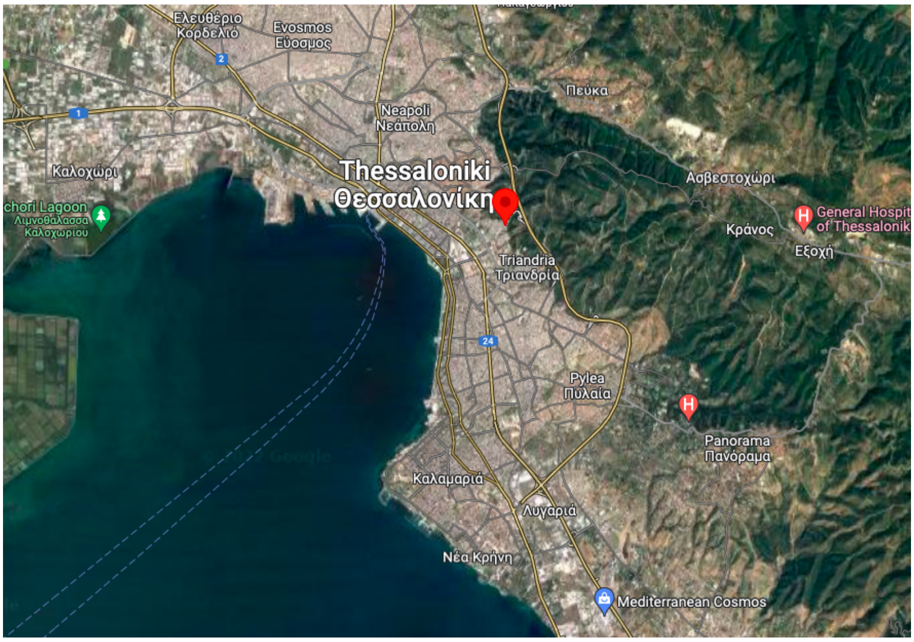

FIGURE 1. Saranta Ekklisies

The area studied in this master's thesis is located in Thessaloniki. Thessaloniki is the second largest city in Greece and had a population of 1,100,100 in 2019. This makes it one of the most densely populated cities in the world with 16.526.8 inhabitants per square kilometer. With its large port, its proximity to international highways, its universities, and its historical background, it is nowadays an important commercial and cultural center of Southeastern Europe. Its central part, continuously inhabited since 315 B.C., is densely built. The Rain Gardens studied in this work are located in the Saranta Ekklisies, a neighborhood in the heart of Thessaloniki. The big red marked position in Figure 7 represents the location of the analyzed project. The area is generally a little greener than the rest of the city center. Most of the neighborhood's surface is sloping. Thessaloniki is not prone to significant floods from the sea for the following reasons: The city is built across the Thermaikos Gulf, namely across the last recipient of rain runoff. Urban streams have relatively narrow hydrologic basins and are partially protected by an artificial ring channel. However, it is damaged by medium rain events, mainly where the ground slope changes suddenly, like in Saranta Ekklisies. Even though Greece is among the very few ancient civilizations where clean water management technologies were practiced as early as 400 BC, the wastewater management history of the country has followed similar development paths to other nations in Europe, namely France, Germany, and Britain. For centuries wastewater management was not given much, if any, attention [**Lofrano and Brown, 2010**]: There are numerous areas in the city where the sewage network is inadequate. That caused problems during significant rain events in the past. When the slope is flattened, much rain is concentrated on a small surface and can cause overflowing sewers. In addition to that, the inlets to the installed sewer system are inadequate to handle all the rainwater. The rain runoff mainly takes place on impermeable streets and sidewalk surfaces. Even lower rain intensity can and does cause problems. In 1992 a wastewater treatment plan was developed for the city. A plant has been built seven kilometers southwest of the city, currently supporting about 1 million residents of the greater Metropolitan area by treating 160,000 cubic meters of wastewater daily. Extension plans to future capacity up to around 300,000 m3/day. The treatment process includes screening, grit removal, primary sedimentation, conventional activated sludge treatment with nitrogen removal, and effluent disinfection using chlorine gas. The treated effluent is mainly discharged to the nearby Thermaikos gulf, which is characterized as a sensitive area. The city of Thessaloniki suffers from rain events that lead to flooding regularly. In May of 2018, the streets flooded and caused much damage. In September 2019, one of the most extensive downpours of recent years happened and left the roads flooded. It is expected to get worse by weather scientists. In a simulation by Tsaples et al., those events changed their likelihood from "very low" to "high" and now are expected to occur once a year [**Tsaples et al., 2021**, p 261]. The observed case study in this thesis tries to prepare for heavy rain events that only occur every two years [**Basdeki et al., 2016**, p 6]. The source is not expecting it to get worse, or at least Basdeki et al. (2016) did not prepare any further. The city has been in the process of the building since the year 2016. That is why we assume all the costs and benefits in 2016.

CHAPTER 4

Analysis

The analysis will be divided into two phases: Construction and Operation and Maintenance.

1. Rain Garden

1.1. Pre-Construction Costs

Before costs for construction appear, some costs might occur. For example, one significant cost factor in professional Rain Gardens is the selection of the sites. It will still count into the calculation of construction costs.

1.2. Planning Costs

Planning costs are not included in this work. We assume that the planning for the Rain Gardens and the grey alternative do not make a significant difference. For the Rain Gardens, contractors must be hired, and a construction plan must be made. However, this must also be done for the grey alternative. A Rain Garden may be a bit easier, but these minor cost variances do not make a difference with the otherwise relatively high costs. This thesis does not have confirmed information and numbers on the planning costs; an estimate here would be very vague. So, we assume any planning costs are included in the construction cost.

1.3. Site Selection Costs

In the analyzed case study, two Rain Garden experts from the Aristotle University of Thessaloniki, on behalf of the city of Thessaloniki, did first map inspection and then on field survey during different rain events to select the right areas for the Rain Gardens [**Basdeki et al., 2016**, p 4]. The location selection has to consider a few criteria: 1) The site has to be in an area where problems with drainage and heavy rainfall occur. In this case, it is where the slope of the region is flattening out, and the water is running down the hill. 2) The location needs to be owned by the city and not by some private owners. 3) The locations need to be close to buildings. One of the purposes is to prevent flooding for the buildings there (student dormitories). 4) Anticipated costs need to be taken into account. For example, if the site is hard to reach from the streets, the trucks and excavators cannot have easy access, which can influence the length of the project and, therefore, the price. There, various vacant sites were then checked for suitability for Rain Gardens. The experts inspected the areas, took soil samples on-site, and tested them for suitability. Parts of the later selected sites (for example, the site by the dormitories) were impermeable before building the Rain Gardens. From the paper, we know that one professor with a scientific employee worked on the site selections. The selection process took an estimated 20 days. Not at a stretch, because the heavy rainy days can not be planned, but observed occasionally. Consulting professors for the municipality includes a fee. Unfortunately, we do not have the price records, so we assume the usual professor's or scientific staff's hourly wages. We also believe 20 working days of 8 hours each. That results in 160 hours working hours. An average Greek professor earned about 20 Euros an hour in 2016. His assistant (most likely a working student) is paid minimum wage, which was 4,28 Euros an hour at that time [**Sal, 2022**]. We assume the labor costs are 20 percent on top of the before-tax salary. That makes the site selection process for all sites about 4.661,76 Euros.

The team of a professor and a working student will later be supervising the whole construction.

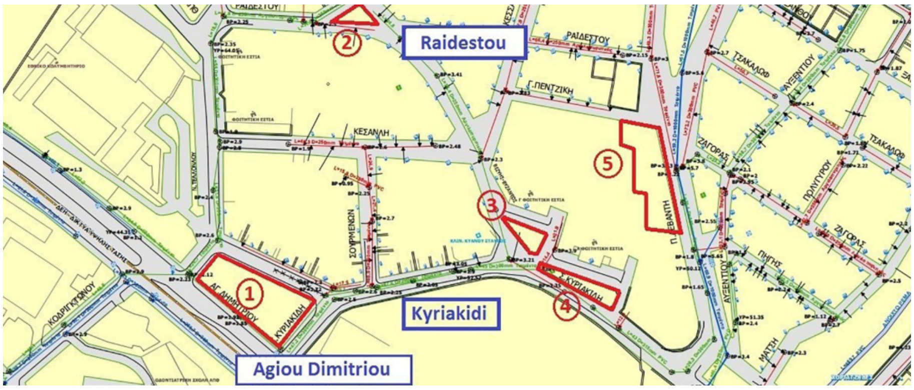

Figure 1. Locations of the sites

2. Construction Costs: Rain Garden

The city of Thessaloniki does not provide an accurate insight into the construction contracts and invoices. Still, the construction costs of Rain Gardens are relatively simple to estimate because the principle is always the same. Also, this work has all the exact construction plan data of square meters, the thickness of soil layers, and other data. It is therefore possible to precisely estimate material costs and work hours and compare them to other projects. We use two tools to have a broad idea of how much the costs will be. First of all, the city of Thessaloniki says in correspondence that one square meter of Rain Garden costs a little less than 50 Euros per square meter [**Basdeki et al., 2016**, p 3]. Second, a Rain Garden Calculator is provided by the "raingardenalliance", an Alliance of many non-profit organizations, corporations, educational institutions, and government agencies. It is located in Pennsylvania, US. The calculator is intended only as a small guide because it is designed more for small back gardens in private homes. It is more about material procurement than hourly wages, as the calculator also assumes that homeowners do the work themselves. In the case of our case study in Thessaloniki, this is not the case. Extra contractors and gardeners were hired. In addition, more professional tools were needed, such as an excavator. Given the size of the Rain Gardens, digging by hand is too tricky [**cal, 2022**]. Also, there is a significant difference between US and Greece costs, besides the currency change in 2016.

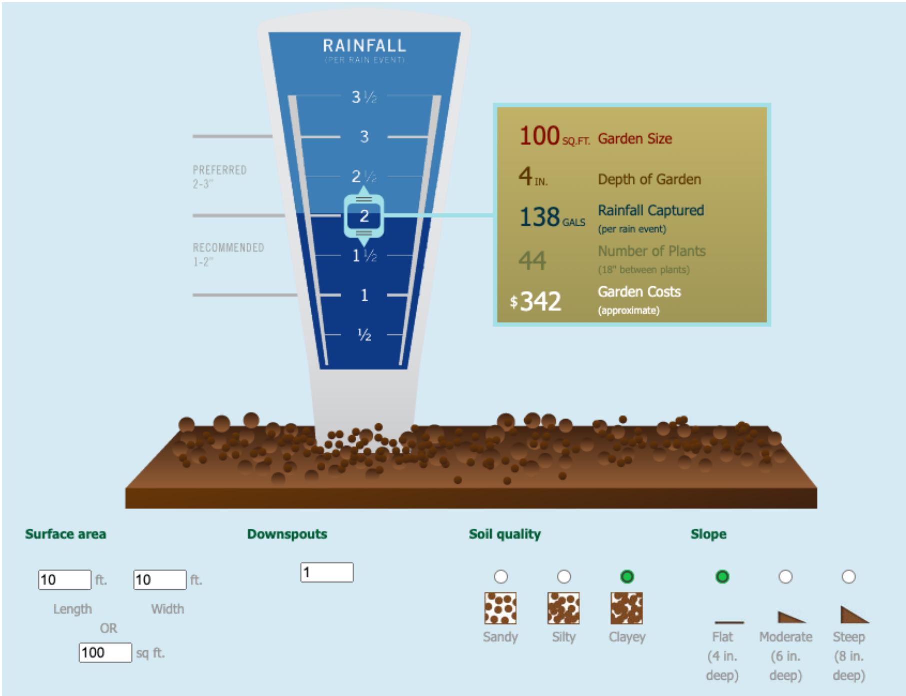

FIGURE 2. Rain Garden Alliance Calculator

To put all the necessary data in, we need to summarize the different sites we have in Thessaloniki. Location K1 (at Agiou Dimitriou Street; can be seen at Figure 9) has 2415 square meters and no slope. Location K2 (at the junction of Raidestou and Anaktoriou Streets) has a little slope and only 33 square meters. Locations K3, K4, and K5 are next to each other and, therefore, will be considered as one site in the calculations. Because all the materials have to be driven once and all the tools are already on site. That means the square meters of 273 for K3, 360 for K4, and 1543 for K5 can be summed up to 2176 square meters. All those three sites have no slope. All the sites are somewhat sandy or silty than clayey, as one can tell from the available pictures [**Katsifarakis et al., 2015a**, p 345] and the fact that most of the soil was not reused in the project. The project's main purpose for the city of Thessaloniki was to prepare for bigger rain events. Rain events that heavy that they occur only once every two years. That is why we put the rain regulator on the calculator at the highest possible level. So the results we get after using the calculator and putting everything in metric numbers and Euros are construction costs of 69.497,59 Euro for the site K1. For K2, the cost estimation from the calculator gives us 949,68 Euros. K3, K4, and K5 have summed up costs of 62.619,2994 Euros. If we want to compare that to the "less than 50 Euros" statement from the city of Thessaloniki, we have to take the average cost per square meter of all the used sites. Summed up, the square meters are 2415+33+2176= 4624 square meters. Summed up Costs: 69.497,59 + 949,68 + 62.619,2994 = 133.066,57. Divide costs by square meters: 133.066,57 /4624= 28,78 Euros per square meter Rain Garden. So, we got a broad direction of the construction costs. It will be between 50 and 28,78 Euros per square meter. Nevertheless, the price of a professional Rain Garden built by experts in Thessaloniki is expected to be slightly higher than the calculated 28,78 Euros. To find out the actual construction price, this master's thesis will put the data we have into monetary numbers. Besides the costs, the calculator also estimates a space for 2670 plants, and 48.679,532 liters of rainwater can be captured.

2.1. Digging costs

As we do not have the construction costs step by step from the contractor, we try to make estimations with a lot of average data and costs from portals that one can find for Thessaloniki. According to the paper of Thessaloniki, there are three layers planned. First, the pond's 0,15 meters (b1) is seen in the Figure below. Then the soil layer (b2) with 0,4 meters and 0,25 meters of gravel layer (b3). That requires digging of 0,8 meters (b1+b2+b3) times the summed up 4624 square meters. That results in 3.699,20 cubic meters. So the professional gardener will be digging 3.699,2 cubic meters.

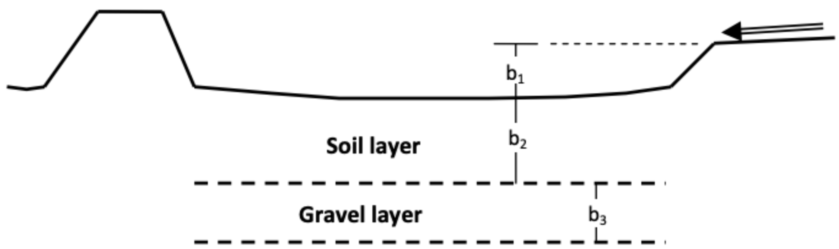

FIGURE 3. Layers Rain Garden Thessaloniki

To do that, he needs an excavator typical for garden work like that. Through various websites that collect wages of individual industries, this work knows that a gardener for this type of work in Greece makes an estimated 10 euros an hour [**Gar, 2022**][**Sal, 2022**]. The labor costs are at 14,5 Euros per hour[**Lab, 2022**]. Gardeners who mow the lawn or trim the hedges for other people make 7 Euros an hour in Greece but are not a good fit for the Rain Garden project. You need a landscaper with some experience in this kind of work. An excavator, commonly used for this type of work, has about 90 horsepower and thus manages an average of about 30 cubic meters per hour in digging [**Exc, 2022**]. The 3.699,2 cubic meters divided by the 30 are 123,31 hours of digging. That is approximately 15,41 days of digging if we assume an 8-hour day, excluding a one-hour break. 123,31 times 14,5 Euro average labor costs for gardeners results in 1.787,95 Euros of pure digging the holes for the Rain Gardens. Renting out an excavator in Thessaloniki costs 110 Euros per day for 15,41 days, according to a price comparison on a portal (https://en.nicelocal.gr/) that rents out machines like that. 110 times 15,41 would be 1.695.1 Euros. The gas for the excavator can be calculated, too. In everyday usage, the excavator needs almost 8 liters of diesel per hour [**Spr, 2022**]. In Greece, diesel was at 0,96 Euros per liter at that time

[**Die, 2016**]. All that calculated makes diesel costs of 947 Euros for the digging process. That makes a sum of 4430,41 Euros for digging alone. The exact fees and calculations can be found in the Appendix.

2.2. Old soil costs

The Rain Garden experts decided the sites were good due to the sandy soil, making the digging relatively easy. However, the earth is not ideal for the garden. It is too inconsistent, and the sandy soil mix is not what the professionals look for. So it is suggested to take the dirt away from the gardens and bring it to the closest waste management company, where they have a pit for soil waste. It is called "Filippidis Filippos" and is six kilometers from the site. Of course, the soil may be brought elsewhere. Maybe it can be used elsewhere at the university, or the gardener is happy to keep it. However, for the sake of the estimation, we assume it is brought to Filippidis Filippos, where it costs five Euros per cubic meter of soil waste. The site has 3.699,2 cubic meters of dug-up soil. The digging must be on to a truck to take the soil away. The truck that fits the site's needs costs 120 Euros a day and has a capacity of 17 cubic meters [**Ren, 2022**]. To match the speed of the excavator, our project needs two trucks and two drivers. So the rental costs of the truck would result in 3.699,2 Euros, and the workers' wages end up at 3.575,89 Euros. The gas is estimated with the number of trips and the distance from the sites and results in 401,08 Euros. So the estimated fee for the soil waste is 18.496 Euros. The summed up estimated "old soil costs" end up at 26.172,17 Euros.

2.3. New soil costs

We assume the soil on the sites was evaluated and considered not usable for the Rain Garden. We have neither the composition of the earth nor the costs for it available. According to the "raingardenalliance", which also provides the cost calculator, the perfect Rain Garden soil mix contains 30 percent sand, 40 percent loamy topsoil, and 30 percent organic material from yard waste composts [**cal, 2022**]. The sand that is the best fit for the project costs about 11 Euros per cubic meter [**san, 2022**]. Loamy topsoil costs about 15 Euros per cubic meter [**Loa, 2022**], and the organic material costs 29 Euros per cubic meter [**Org, 2022**]. As shown in Figure 10, the b2 layer is 0,4 meters of the 0,8 meters total. That means the soil needed is 50 percent of the total soil of 3699,2 cubic meters: 1849,60 cubic meters. After doing the math, the material cost of the new soil is 33.909,33 Euros. The truck rental costs + gas + Driver + the excavator rental + excavator gas + excavator driver ends up being 5.533,55 Euros. That makes the total estimated costs of the new soil 39.442,89 Euros.

2.4. Gravel costs

The needed gravel for the b3 layer with a depth of 0,25 meters is 1.156 cubic meters. The gravel price has a wide range, but in 2016 it is most likely between 12 Euros per cubic meter and 75 euros per cubic meter [**Gra, 2022**]. The most common gravel for this type of work is available for 52 Euros in the price list [**Kie, 2022**]. That results in costs of 60.112 Euros. Driving the gravel to the site and from the location that sells gravel and putting it in the pits with the excavator is calculated the same way it was in the new soil costs and ended up being 4.595,47 Euros. Together with the material costs of the gravel, it ends up being 64.707,47 Euros.

2.5. Plant costs

To estimate the cost of the plants, one needs to find out which plants are suitable for Rain Gardens in Thessaloniki. Literature always recommends a mix of local plants that do not mind being exposed to rain, but also can handle drought in such areas exposed to the sun. The combination of plants is relevant for biodiversity and also aesthetics. This thesis has not found any plant recommendations in literature for Greece, so it looked for a similar climate, where we have good recommendation of plants available: Washington State in the US. Thanks to "weatherspark," one can compare the environments of cities, and you can see that Olympia, Washington, and Thessaloniki have similar climates [**WeatherSpark, 2022**]. The "almanac" - a gardens magazine - provided a list of plants suitable for Rain Gardens in Washington. They even recommend the plant's location within the Rain Garden. In the center of the Rain Garden, plants with a high tolerance for water and deep roots are recommended. The outer edges need to be filled with plants that prefer a drier soil. According to the Rain Garden calculator, the sites have room for about 2670 plants. Other sources recommend a plant per square feet[**Gui, 2022**]. 4624 square meters are almost 50.000 square feet. In this work, we will stick with 2670 plants because those recommendations with that many plants are always for small gardens for homeowners. In more significant sites like the ones we look at, planting bigger plants and trees and, therefore, fewer plants might be wiser. Every type of plant has its purpose. Trees and large shrubs deflect rainfall, slowing it down before it reaches the ground, which allows it to soak better into the soil and not run off immediately. Tall grasses act as filters, sucking up water, trapping pollutants, and preventing silt from being carried into ponds or rivers. Shorter, well-established, deeply-rooted plants hold soil and direct water into the ground. The variety of the plants will provide a wildlife habitat for birds, butterflies, and insects [**Alm, 2022**]. The Bald Cypress (Taxodium distichum) is one typical tree in Greece and is also perfect for the center of any Rain Garden. It can grow higher than 18 meters and survive in very wet periods. It is also not sensible for droughts and is a good fit for Rain Gardens like the ones in Thessaloniki because of the size [**Allen et al., 1996**]. A small seedling costs around 10 Euros. A more grown Cypress can quickly cost 100 Euros. In smaller Rain Gardens, it is widespread to use just plants and plant just seeds. Rain Gardens should not be seeded as this takes too long to establish the desired root system, and the seed may be floated out with rain events. The professional approach can use some trees in the middle of the Rain Garden, and it is better to plant little seedlings of approximately one meter instead of putting seeds into the ground. At 4624 square meters, 10 of those trees would be reasonable, producing costs of 1000 Euros. Another recommended tree is the Goodding's Willow (Salix gooddingii). It is sacred in Greek mythology and grows up to 10 meters. It is native to Greece and provides food and shelter for many bird species. It is known for the adaptable level it has [**Stromberg, 1997**]. The seedlings are about 200 Euros each and are famous for how fast they grow. So, smaller trees should be fine. For the room in Thessaloniki, another quantity of 10 seems reasonable. That makes the cost 2000 Euros. The size of those 20 trees is taking away approximately 200 plants. Therefore we have room for estimated 2470 plants left. For those seedlings, we assume an average cost of 3 Euros. That makes the costs for the rest of the plants 2470 times three equal 7410 Euros. That makes the material cost 10.410 Euros. Planting those will take approximately 3 trips to the Plant shop (there are several options to buy those seedlings within a 4-kilometer radius). We assume it is a quick process of planting those seedlings. 15 seedlings an hour seem to be a reasonable planting average. Hiring enough people to do that in a day will cut down the truck rental cost, and the cost of planting will be 2.511,35 Euros. The total costs of planting trees, including the price for the seedlings and trees, are 12.921,35 Euros.

2.6. Supervision

Over the whole time, the Rain Garden project would have supervision by the professor and a working student. In correspondence and research, this work found that the professor used his Water Management network and worked with the "HYDROMANAGEMENT Consulting Engineers L.t.d.". The project can be co-supervised by consulting engineers with practical experience building Rain Gardens. For the professor, it can be his first bigger practical approach after following Nature-based Solutions for years. As this work would like to be exemplary for other NbS projects, we will monetize the free consulting of the engineers. In other projects, there may not be a professor with a good network. There you have to buy the consulting of the engineers conventionally. That means that we calculate both the laboratory costs of the professor and students, as well as the conferring of the engineers. The academic's hourly wage was calculated earlier and came up to 24 Euros an hour. The sequence of each layer determines the duration of the planned construction. First, the hole is dug (16 days), then the gravel is embedded in the spot (9 days), then the new soil is let in (14 days), and finally planting, seedlings (1 day). That makes 40 days, excluding the weekends, 8 weeks of work. Assuming the supervision is not needed every day but 10 hours a week, a total of 80 hours of management is required. That makes a total of 1920 Euros for the professor and 410,88 Euros for the student. Assuming that the professor does not need supervision from the engineers all the time, we consider some hours of half of the time for the consultancy of the engineers (40). An engineer in Thessaloniki in 2016 earns an average of 12 Euros an hour. Calculating this labor cost, we get a labor cost of 14,4 Euros an hour [**Sal, 2022**]. That gives us a total of 576 Euros for consultant costs. Therefore the estimated total supervision costs are 2906,88 Euros.

2.7. Total Construction Costs

The estimated construction costs come down to a total of 155.242,93 Euros. Converted, this would be 33,57 euros per square meter of space. So the result would be on the lower end of the range between 25 and 50. Most of the sources for "professional Rain Gardens" are located in the US, and expect construction costs for professional sites like the one in Thessaloniki of 430.4 Dollars per square meters [**Vineyard et al., 2015**, p 1349]. Another source estimates costs of 215,2 Dollars per square meter [**Rai, 2022**, p 1349].

There are two main explanations that the prices are much higher from most sources: 1) Salaries, materials, and rentals in the US and Greece are very different. 2) Between 2016 and 2022, the prices changed significantly due to Inflation, Currency exchange, and other factors. Therefore the price we estimated seems reasonable, especially with considering that the work itself estimated a price under 50 Euros per square meter.

This compilation of total costs certainly does not include all costs. For example, the delivery of the excavator or the CO2 emissions of the construction could still be monetized. Alternatively, other things that this work has not even thought of. Nevertheless, we assume that these things can be omitted. Either because they are vanishingly small or because they do not play a role later in comparison with the grey alternative, since the costs were not considered there either. For example, omitting the CO2 costs for both alternatives does not distort the comparison with each other later.

FIGURE 4. CONSTRUCTION COSTS DIAGRAM

3. Operation and Maintenance Costs

Asleson et al. (2009) monitored twelve Rain Gardens in Minnesota, USA. Four of them were determined "nonfunctional" for several reasons. All of those reasons were consequences of lack of maintenance. That is why Asleson et al. (2009) recommend periodically inspecting Rain Gardens for vegetation and infiltration [**Asleson et al., 2009**, p 1019–1031]. In private projects, maintenance prices are often assumed to be zero because the homeowners are expected to do the weeding, watering, and other maintenance tasks. Therefore, this case study also expects relatively low maintenance costs. The first year is more intense since the plants need more attention. However, periodic watering and weeding are easy and can be done by almost everyone after a short briefing or education.

After taking extra care for the first year, the gardens are almost self-sustainable. Only weeding and inspecting now and then is necessary. Besides that, the selection ensured that the plants were resistant to heavy rainfalls and extended dry periods.

In 2016, the City of Thessaloniki anticipated half a gardener position for the first year's maintenance. After that, this work assumes that a quarter position should be sufficient. Therefore, the calculated labor costs of 14,5 Euros per hour can be applied here too. Half a position is 20 hours a week, and a quarter is 10 hours a week. That makes costs 15.121,44 Euros for the first year of maintenance. After that, the gardener labor costs for maintenance will be 7.560,72 Euros per year.

Personnel transportation and tool transportation for maintenance is assumed to be 10 kilometers round trip and included in the labor costs for the worker. That includes the trips to each site. The vehicle is assumed to be a standard transport van capable of carrying passengers and towing light equipment. It is assumed to be included in the labor costs of the gardener.

4. Opportunity Costs

The planned Rain Gardens take up 4.624 square meters of surface space in the heart of a dense city like Thessaloniki. This is leading to significant opportunity costs. Buchanan (2017) defines opportunity costs as the following: "Opportunity costs are the evaluation placed on the most highly valued of the rejected alternatives or opportunities", which is to say, it is the value that is sacrificed in any choice in a decision-making situation [**Buchanan, 2017**, p 1-5]. This cost is usually the highest benefit that could have been produced by choice. However, the solid choice forwent that: opportunity cost equals the return on most profitable investment choice minus the return on investment chosen to pursue. Rain Gardens have value for society, but there are other ideas to use the given-up surface space to contribute to society. For example, building a hospital or a playground instead of a Rain Garden can have significant societal benefits, or building another resident area can create more living space. The opportunity cost of using urban space is almost exclusively represented in the literature with land or real estate prices. The thought behind this is the underlying idea that construction is always the next best profitable option. This work has several smaller sites. Only one of them would qualify for a residential area. K1 has 2415 square meters. The average square meter price in Saranta Ekklisies in Greece is 700 Euros per square meter, which results in 1.690.500 Euros. Now the opportunity costs are not calculated by the costs of the best alternative but by the benefits. The main benefit of building such a residential building could be a significant decrease in rent around that area. The housing market is very complex, and the concept of building new apartments to decrease rent has been questioned [**WEL, 2022**]. Therefore, this work will not consider a new apartment building in the area but a playground. Playgrounds have a significant influence on primary children but also on the adults that live close to the sites. It can help kids develop their physical activity skills and social skills. It can also be healthy for the community by providing a gathering space [**PLA, 2022**].

The monetary benefits are - once again - not easy to estimate. However, the increase of the value of the housing around the playground plus the social space for gathering and reducing stress is more explored in scientific papers. Therefore, we can use the GI-Val tool to estimate the monetary value of such a playground. After putting all the data in the tool, the playground is evaluated with 95.873 Euros which will be considered the Opportunity Costs of this work.

5. Benefits

Rain Gardens' main benefits are avoiding overflowing sewers and filtrating the stormwater before it goes into other water bodies or the groundwater. Therefore, the benefits need to be calculated for both aspects. All three main benefits are avoided costs: 1) Avoiding the wastewater treatment by putting the wastewater through "natural" filtration of the Rain Gardens instead of the sewers to the nearby plant. 2) Avoiding the cost of the overflowing nearby buildings and the area in general, and 3) Avoiding costs by not polluting nearby water bodies. The Gi Val Tool does contain one sector, "water," in the calculations, but it only considers the avoided wastewater and the energy for treating the water. Also, it does not consider all the specifications of the case study in Thessaloniki, namely the slope, the impervious surface, and the heavy rainfalls. Also, the calculation is done for green areas and not for Rain Gardens that are specifically designed to treat runoff water. This work will not consider the GI Val Toolkit for that area. Still, the table for the water treatment can be helpful for the calculations.

Treating a cubic meter of wastewater at the plant is relatively cheap, but it adds up with the high energy use and the CO2 emission. The costs can differ on the number of pollutants depending on the number of pollutants in the wastewater. The water diverted by the Rain Gardens from the sewers is estimated to be 135.470 liters yearly for the average rain plus the heavy rainfall events once a year and the even heavier rain events every two years that Basdeki (2016) describes [**Basdeki et al., 2016**]. That is summed up to 2597,47 cubic meters of rain annually diverted from the Rain Gardens' sewers. The costs for treating runoff wastewater depend on pollution, energy, and other factors like the distance from the plant to the sewage. We assume costs of 0,34 Euros per cubic meter for all those three costs combined after reviewing the paper from Wendland et al. (2005), where he describes all the operational costs of wastewater treatment plants [**Wendland and Ozoguz, 2005**]. Results in costs of 883,14 Euros per year.

Figure 10 shows the flattened-out area after a rain event that was reported as a "rain event" that occurred 10 times a year in 2016. Climate change is likely making those events more regularly. The student dormitories were regularly flooded on the first floor, and residents' gardens, basements, and first floors have been reported damaged. The Rain Gardens can prevent that in the future and significantly avoid some costs. Building damage only occurs when flood levels exceed 3 cm above ground level. That is estimated to happen about once a year, possibly more in the future. A similar study in Oslo estimated sewage overflow costs over 3cm in a residential area. It came down to costs of 686.490,57

Euros. Now Oslo - once again - has a different price level and the compared areas are very different compared to Thessaloniki. The study in Oslo is in a wealthy suburb, while Saranta Ekklisies is an area with less costly houses and buildings. After calculating the numbers of the Oslo studies with the data from Thessaloniki, the yearly avoided costs come down to 52.842 Euros for the overflow costs alone [**Wilbers et al., 2022**].

FIGURE 5. Sewage Overflow next to proposed site

The third component of the main avoided costs of Rain Gardens is the avoidance of pollution of other nearby water bodies. The nearest water bodies in question in the Rain Gardens are the lake of Limni Koronia and Limni Volvi, the groundwater, and the Aegean sea. Both lakes are located uphill and not in danger of getting polluted by the rain of water. We learned that cleaning water is not accessible, and cleaning groundwater is especially difficult. It is generally easier (and cheaper) to avoid polluting the groundwater than to clean it. There are several ways to clean it, for example, the pump and treat method, where the water gets pumped up and treated and then pumped back into the groundwater. This process is estimated with costs 42 Dollars per 1.000 gallons per year [**EPA, 2022**]. The rainwater overflow can be estimated with numbers from Basdeki (2016) and end up in costs of 9517,4 Euros per year [**Basdeki et al., 2016**]. We assumed all the water was going into the groundwater while, in reality, a part of it might go into the gulf and then into the Aegean sea.

Therefore the avoided cost for the treatment, overflow, and pollution is 63.242,14 Euros yearly.

6. Co-Benefits

The main benefit of the Rain Garden has been the cleaning of stormwater and flood prevention. As earlier described, the municipality of Thessaloniki searched for a solution to mitigate the floods on impermeable surfaces in the described area and, at the same time, find a way to clean up the water or separate the water into the "dirty stormwater" and the relatively clean water. These objectives were accomplished by creating Rain Gardens. Now we look at the side effects/co-benefits of building Rain Gardens. Please note that most of those effects are interdependent; therefore, some goals or advantages can be repeated. Also, the reader needs to remember that even with the given tools and calculators, a CBA can never catch all the influences of projects like that, even though this work will try to monetize as much as possible and avoid omitted variables in the calculations.

6.1. Physical and Mental Health

The Rain Gardens in this study are not large enough to do mainly physical activity like cycling or running. Nevertheless, one can run or walk through it or sit in the shadow of a tree and relax. That can have a significant influence on residents around the area. Figures 12 and 13 demonstrate the sites before planting a Rain Garden. One can imagine that a beautiful garden can make a difference in those areas. The Gi Val Tool has monetized the health factor by recognizing the walking and activity part of the rain gardens with 19751,81 Euros per year. The tool uses a mix of sources to value the life and costs of average treatments. In addition, Vujcic (2017) proved in an exciting study that the influence of NbS can be proved quickly in improving the mental health of the residents around those sites. The study participants significantly decreased stress, anxiety, and depression after only four weeks of being in NbS daily amount of time [**Vujcic et al., 2017**].

Unfortunately, all considerations and approximations for evaluating mental health are very vague. The tool has noted that "Health costs saving from the reduction in mental health disorders" and "Health costs savings from reduced in-patient stays" are significant and can be quantified. However, the trade-off for the costs for the medical system for the residents living longer is not yet done. Nevertheless, the tool has put the label "requires further work for developing a monetization" on it. Maybe the next version will contain such calculations.

6.2. Air Quality

Rain Gardens are not typically built with many trees. As stated earlier, the trees are meant to be in the center of the Rain Gardens, and for the available 4624, we assumed twenty trees are reasonable. The other plants are not paid attention to in terms of air quality because the significance is too low. The twenty trees are removing 35,81 Euros worth of pollution yearly.

6.3. Cooling effects

Green areas like a Rain Garden have a cooling effect on the heat islands of dense areas of cities. That is because trees can spend close shadow buildings and decrease their use of air conditioners. However, Rain Gardens have an insignificant amount of cooling effects. According to the GI Val tool, the peak surface temperature in the summer can decrease from 43 degrees to 18 degrees Celsius due to the surface change. That is a change of 25 degrees Celsius. Nevertheless, in monetary value, this will not make a significant difference.

6.4. Biodiversity

The plants and trees used in the Rain Gardens will contribute to biodiversity. The Rain Gardens mostly used native plants and plants that can handle floods and droughts. Because the Rain Gardens are relatively small, the biodiversity does not make a significant difference. The GI Val tool estimates seven Euros yearly as a monetary value for biodiversity. This time the tool does not estimate an average date but with the willingness to pay from residents nearby.

6.5. Property Value

The Gi-Val Calculator estimates a significant value increase of houses around the Rain Gardens just by the "greening" effect and the new aesthetics. As we can see in Figure 6 and Figure 7, the sites can significantly affect the surroundings. The somewhat sandy and concrete surfaces, in combination with the residential houses around, are in considerable contrast to the green gardens with trees and flowers and can have significant aesthetic effects. The tool estimates a one-time increase of 110.891,98 Euros for the NbS.

Figure 6. One of the proposed sites

FIGURE 7. Another of the proposed sites

7. Grey Alternative

The only costs that could occur before the construction cost for the grey alternative are the planning costs. The site selection is unnecessary because one of the two pipes covering these areas is already known to be the problem.

7.1. Planning Costs

As explained earlier, we assume no extra planning costs in this work. The planning costs are included in the construction price for the grey alternative.

7.2. Construction Costs: Grey Alternatives

The city intends to manage the problem of stormwater runoff and, therefore, the sewage over flooding. The worst rain event in the last two years is the benchmark for the measures taken. The mostly impermeable areas that are supposed to be drained by pipes A and B are equal to 19680 square meters and 52700 square meters. While Pipe A is declared sufficient according to the source's calculations, Pipe B is overburdened with such rain masses and is causing flooding [**Basdeki et al., 2016**, p 4]. The scientists from the university calculated that the proposed Rain Gardens are sufficient to handle that amount of rain. To make the grey alternative achieve the same goal, pipe B needs to be renewed. Renewed in this case can mean two things: Either one removes pipe B and puts in a new one with more capacity, or the city decides to put in another one to relieve pipe B. Vineyard et al. (2015) suggest in a similar study that a pipe renewal for the pipe would not be similar enough to the multi-functional Rain Garden functions. A new pipe with a bigger capacity would only solve the flooding problem, but not the pollution of the wastewater and their mix in the combined sewage with the water cycle. They suggest an underground storage tunnel that detains the wastewater and then moves it back to a local treatment plant before it is released into the urban water cycle [**Vineyard et al., 2015**, p 1347]. The case study from Vineyard et al. (2015) was on a much bigger scale. The storage tunnel was estimated to cost 250.000.000 Dollars for a storage capacity of 151.416 cubic meters of wastewater, including a pump station and wastewater plant upgrades to facilitate the treatment of its volume. The storage capacity of the rain gardens in Thessaloniki adds up to 1410,2 cubic meters. The price of the Ohio storage tunnel transformed into the needed size in Thessaloniki would result in 2.328.353,68 Dollars. Like the costs for the Rain Gardens, this price cannot just be taken as construction costs since it is the US price and is also not adjusted to inflation and currency exchange. The inflation is irrelevant since the Ohio project was at the end of 2015, and the Thessaloniki plans were made in April 2016. The price difference between the US and Greece is relevant. The project is particular, so an exact price difference is hard to estimate. Therefore, we assume that the price differences in the construction industry are comparable and reflected in the construction of water management elements. According to the construction price indices from the FRED, the US prices were more than double in 2016 compared to Greece, 2,15 to be precise. Therefore, the original construction cost for the tunnel transformed into Greece prices would be 1.082.955,2 Euros. After the currency exchange of May 2016 is applied, the price for the grey alternative is 1.029.273,11 Euros.

7.3. Maintenance Costs

Two sources of tunnel storage maintenance, like the one we use as a grey alternative, have been found. They both suggest one half-time job for the size of the tunnel used in our CBA and costs for significant pumping, fuel, equipment, and repair costs [**Murphy and Moore, 2007**][**Vineyard et al., 2015**]. The estimated lifetime of tunnels like that is 70 years. Vineyard (2015) states that even though the time is estimated at 70 years, reality has often shown the projects have a much longer lifetime and have to be maintained more intensely [**Vineyard et al., 2015**]. That is beyond our study. We will calculate the costs and benefits of the grey alternative with an estimated lifetime of 70 years. A half-time job cause costs 13.920 Euros yearly.

7.4. Opportunity Costs

This work will consider no opportunity costs for the pipe due to its location. There are no relevant alternatives to what to do with the space under the earth.

7.5. Benefits

The benefits of the storage tunnel are the same as the main benefits of the Rain Garden. The storage tunnel avoids sewage overflow and demolishes houses, basements, and gardens of the residential areas and the hospital. The storage tunnel also avoids the pollution of nearby water bodies. Special attention needs to be paid to the treatment of wastewater. The storage tunnel would collect all the wastewater from a heavy rain event and deliver it to the plant. That means the treatment costs still need to be paid. Simply the mixing with the "other" sewage water is not happening. That leads to no further pollution of the sewers, even in heavier rain events. Therefore, the benefit calculated for the Rain Garden can be used and subtracted by the treatment costs of the plant. That gives us a primary benefit of 62.359 Euros yearly.

No further co-benefits are found for the tunnel storage.

7.6. Rain Garden vs. Storage Tunnel

The first step is to calculate the final CBA for both alternatives. The first step is calculating the net present value of all the yearly inputs and combining all the data. The essential point is to specify the life of a storage tunnel and a Rain Garden. The tunnel has a lifetime of 70 years, as stated earlier. It is uncertain, however, how long the life span of Rain Gardens are. Life times of Rain Gardens have not yet been scientifically proven. Vineyard (2015) calculates it for 35 years but also states that the literature has not been further developed here, too [**Vineyard et al., 2015**]. Some calculate a lifetime of 20 years, and some say it will improve over time because a well-established colony of beneficial microbes and fungi also increases the capacity to break down pollutants [**EHS, 2022**]. This work will use a lifetime of 35 years for the Rain Gardens as seen in comparative literature, but not without noticing that both the tunnel and especially the Rain Garden are probably suitable for longer than their estimated lifetime. The sources that this thesis found seem overly pessimistic, but also are the only sources one can find to the life span of Rain Gardens. There are a few ways to deal with the comparison of different lifetimes too. We chose the assumption of rebuilding the Rain Gardens after 35 years with all the earlier calculated construction costs. We assume that rebuilding the garden with all the new digging and refilling the pit with the different layers is just as expensive as the original building was. The construction costs need to be discounted, too, because they will be built in the future, and money has more value today. The next step is to determine a discount rate for the upcoming years. Vineyard and other literature use 3 percent, 5 percent, and 7 percent. That is why this work chose those percentages as possible scenarios, too. Another reason for looking at different scenarios is the fact that we live in uncertain times and face significant hurdles due to climate crises, wars, and demography.

Another note: The absolute results will play a role here, but the main focus will be comparing the two results. That means discount rates and other factors will influence the results but should not significantly change the result for comparing both options.

7.7. Results

Three percent interest rate

At an interest rate of three percent, the Rain Garden has a Net-present value (NPV) of 1.431.392 Euros after 70 years of implementation. Therefore, the Rain Gardens already have a significant positive NPV three years after construction and are worthy of implementation in the proposed area.

Net-Present Value			
Year	2023	2024	2025
Investment	- 155.346,93	-	-
Payout	56.318	56.318	56.318
Sum	**- 99.029**	**56.318**	**56.318**
Interest rate	3%		
Year	0	1	2
Discount factor	100%	94%	92%
Discounted Sum	**- 99.029**	**53.085**	**51.539**
Net-Present Value	**5.596**		

FIGURE 8. Positive NPV after three years

There are two interesting observations in the 3 percent calculation: first, even at three percent, the reconstruction of the project after 35 years has become much less expensive and hardly matters. The construction of the project costs instead of the initial 155,346.93 euros construction costs now discounted to only 99,027.58 euros. The higher the interest rate the fewer future construction costs Rain Gardens will incur. The second is that even after 70 years of discounts, there is still a yearly payout of 7,117.41 Euros. This is a significant difference from the other two interest rates.

On the other hand, the storage tunnel has an NPV of 382.847 Euros after 70 years of observation. Therefore it is also positive, and the grey alternative is better than the "do-nothing" baseline. It is profitable 34 years after building it.

Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Investment	- 1.029.273,11	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	- 980.834,11	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**- 980.834,11**	**45.658,40**	**44.328,55**	**43.037,42**	**41.783,91**	**40.566,90**	**39.385,34**	**38.238,19**	**37.124,46**	**36.043,17**
Year	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**34.993,36**	**33.974,14**	**32.984,60**	**32.023,89**	**31.091,15**	**30.185,58**	**29.306,39**	**28.452,81**	**27.624,08**	**26.819,50**
Year	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**26.038,35**	**25.279,95**	**24.543,64**	**23.828,78**	**23.134,74**	**22.460,91**	**21.806,71**	**21.171,56**	**20.554,91**	**19.956,23**
Year	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**19.374,98**	**18.810,66**	**18.262,77**	**17.730,85**	**17.214,42**	**16.713,03**	**16.226,24**	**15.753,63**	**15.294,79**	**14.849,31**
Year	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**14.416,80**	**13.996,90**	**13.589,22**	**13.193,42**	**12.809,14**	**12.436,06**	**12.073,85**	**11.722,18**	**11.380,76**	**11.049,28**
Year	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**10.727,46**	**10.415,01**	**10.111,66**	**9.817,14**	**9.531,20**	**9.253,60**	**8.984,07**	**8.722,40**	**8.468,35**	**8.221,70**
Year	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**7.982,23**	**7.749,74**	**7.524,02**	**7.304,87**	**7.092,11**	**6.885,55**	**6.685,00**	**6.490,29**	**6.301,25**	**6.117,72**

FIGURE 9. Storage Tunnel at a 3 percent level

The direct comparison of the two alternatives is clearly in favor of Rain Gardens. They have lower costs and higher payouts, even without including all the Co-Benefits.

Five percent interest rate

With calculations of a five percent interest rate the Rain Gardens still have a lower but still positive NPV of 908.562,12 Euros and therefore should still be implemented.

The Storage Tunnel, on the other hand, no longer has a positive NPV. After 70 years, an NPV of -90,026.58 Euros can be observed. The investment costs of 1,029,273.11 Euros are too high at the beginning and the higher interest rate ensures yearly payouts of less than 2000 Euros from year 65.

interest rate	5%
Net-present value (NPV)	- 90.026,58 €

Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Investment	- 1.029.273,11	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	- 980.834,11	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**- 980.834,11**	**43.935,60**	**41.843,43**	**39.850,89**	**37.953,22**	**36.145,93**	**34.424,69**	**32.785,42**	**31.224,21**	**29.737,34**
Year	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**28.321,28**	**26.972,65**	**25.688,24**	**24.464,99**	**23.299,99**	**22.190,46**	**21.133,78**	**20.127,41**	**19.168,96**	**18.256,15**
Year	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**17.386,81**	**16.558,87**	**15.770,35**	**15.019,38**	**14.304,17**	**13.623,02**	**12.974,30**	**12.356,48**	**11.768,08**	**11.207,69**
Year	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**10.673,99**	**10.165,71**	**9.681,63**	**9.220,60**	**8.781,52**	**8.363,35**	**7.965,10**	**7.585,81**	**7.224,58**	**6.880,55**
Year	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**6.552,91**	**6.240,86**	**5.943,68**	**5.660,65**	**5.391,09**	**5.134,37**	**4.889,88**	**4.657,03**	**4.435,26**	**4.224,06**
Year	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**4.022,92**	**3.831,35**	**3.648,90**	**3.475,15**	**3.309,66**	**3.152,06**	**3.001,96**	**2.859,01**	**2.722,87**	**2.593,21**
Year	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092
Investment	-	-	-	-	-	-	-	-	-	-
Payout	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Sum	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00	48.439,00
Discounted sum	**2.469,72**	**2.352,12**	**2.240,11**	**2.133,44**	**2.031,85**	**1.935,09**	**1.842,94**	**1.755,18**	**1.671,60**	**1.592,00**

FIGURE 10. Storage Tunnel at a 5 percent level

As a result, a storage tunnel cannot solve the existing problem in Thessaloniki. At least not at an interest rate of five percent. At this interest rate level, there is no need to compare the two alternatives.

Seven percent interest rate

At the seven percent level, the NPV of the Rain Garden is still at 631.292 Euros. Decision makers would still highly consider this project to be built. In year 70 after building it, the yearly payout from the project would be at a very low level of 494,38 Euros. This gives rise to the question of whether a longer existence of the projects at the 7 percent level would make a significant difference. Annual payouts drop to such a low level that a longer lifetime won't make much of a difference. Just out of interest, we tested at what interest rate the NPV becomes negative at the Rain Garden. At a 40 percent interest rate, the Rain Garden is still positive and it is, therefore, worthwhile to build it. From 41 percent the Rain Garden goes into the negative range of the NPV.

The storage tunnels are at the seven percent interest level at an NPV of -340,189.10 Euros. From an economic point of view, it, therefore, makes no sense to implement the storage tunnel at a seven percent interest level.

CHAPTER 5

Why are NBS not used all the time?

Most of literature found on NbS has the same results as this case study - especially concerning water management. NbS are less costly, have a higher environmental impact, and have many Co-benefits that the science still tries to quantify. Even though many NbS are implemented, and the concept has risen, one might wonder: Why is NbS not used everywhere since every criterion seems to be better in that kind of infrastructure? There are many explanations, and the key elements will be presented in the following.

Stakeholders: One of the most significant advantages of NbS is the many challenges it can approach simultaneously. That has a downside. Before a Nature-based solution is implemented, many stakeholders often have to communicate with each other. Additionally to that, the responsibility of those projects is not distributed clearly. The given literature described the situation as "institutional fragmentation" or also "sectoral silos" [**Pauleit et al., 2017**]. The challenge is to make those sectors communicate with each other - even though they often speak a different language and have different interests and priorities [**Kabisch et al., 2017**][**Dale et al., 2019**, p 42-49]. Splitting up the responsibilities can also leave a responsibility hole behind, where no policy maker is sure how to operate and maintain the NbS in the long term [**Wamsler, 2015**]. That might not only cause conflicts but also lead to inaction. One agency might see the responsibility of the case in another agency's hands and therefore not act or even refuse to act. In financing the projects, this can be crucial [**Abdul-Razak and Kruse, 2017**, p 104-122]. In this work, the number of stakeholders was low; therefore, it was comparatively easy to define responsibilities and tasks. Also, the project was done entirely by the municipality of Thessaloniki, and all the stakeholders were under one roof. That can make things easier because the networking effect can be more considerable. Still, it took the city of Thessaloniki from 2016 to now to make a decision.

Fear of the unknown: Like every other paradigm shift, human nature is built to have skepticism toward new implementations. The answer to water management problems has been, historically speaking, always grey solutions. Humans build a wall or grey infrastructure to avoid disasters if a flood is expected. Most of the time, those solutions work and do not have a bad reputation because it is linked to the "urban growth" idea. Because of that, policymakers tend to the implementations that worked in the past, ignoring that the circumstances change

[**Kabisch et al., 2016**, p 21]. Davies (2019) calls that phenomenon "path dependency". Decision makers often actively decide based on their memory of past experiences, which often leads to hesitation towards change and new projects [**Davies and Lafortezza, 2019**]. Kabisch et al. (2016) call this phenomenon the "paradigm of growth" [**Kabisch et al., 2016**]. Changing that mindset in people will take some time and effort, but it gets easier every day since the pressure of breaking a lot of "path dependences" grows with the active climate change [**Santiago Fink, 2016**].

Land requirements: NbS solutions often require more land than traditional grey infrastructure to provide the same expected benefits [**Pontee et al., 2016**]. The urbanization effect leads to more and more limited space and, therefore, can be a barrier to implementing NbS [**Krauze and Wagner, 2019**].

Knowledge Gaps: The EC Handbook (2021) tries to spread awareness and knowledge of the topic of nature-based solutions for every reader, whether the reader is an expert or has never heard of the concept before [**Dumitru and Wendling, 2021**]. Despite the efforts, some authors describe the term Nature-based Solutions as still "vaguely defined" [**Pauleit et al., 2017**, p 3]. It is fair to say that grey infrastructure tends to be more straightforward - especially in the past. However, if one tries to answer the environmental challenge of our time in all their complexity, the answer cannot be straightforward. Kabisch (2017) highlights the importance of the diffusion of the know-how of NbS to the broader public. According to Kabisch, it is becoming more crucial to win over many people for the concept of NbS and fundamentally change the way of thinking about green infrastructure and designing cities in the future. The knowledge of NbS benefits will not help society without implementing it on a smaller scale (maybe some personal Rain Garden project) and also being aware of the importance of more extensive projects in cities [**Kabisch et al., 2017**].

In a different paper in 2016, Kabisch identifies four main knowledge gaps: 1) the effectiveness of NbS; 2) the relationship between NbS and society; 3) the design of NBS, and 4) legal implementation aspects [**Kabisch et al., 2016**, p 31]. People, who are not familiar with NbS have relatively little knowledge about the synergies of NbS and advantages over technology infrastructures. Another field that is not researched enough is the relationship between NbS and society. Especially the field of "Health" is not discussed enough and researched. It is not easy to quantify the synergies of NbS and human health. For example, how much healthier is a human living next to a park instead of a concrete skyscraper? One knows the park helps people a lot regarding mental health, air pollution, physical activity, and aesthetics, but how much is difficult to define. There are some instruments to find (monetary) numbers for that, but it is still a controversial topic for many. Many papers and articles have been published in the past years, but no wider agreement exists. Hartig et al. (2014) did a meta-study of many of those papers concerning health and environment in urban areas [**Hartig et al., 2014**, p 31]. Hartig et al. focused primarily on air quality, physical activity, social cohesion, and stress reduction as the main factors for human health improvements through green environments. The third point of Kabisch (2016) is the design of NbS. Often, policymakers know how NbS works but do not know how to implement it on their sites. Who can support them, and which architecture office or engineer will do this for me? How do I build green infrastructure on top of my existing grey infrastructure? Those are typical questions. The last knowledge gap point Kabisch et al. make is the legal implementation. Urban planners are pressured to implement NbS in areas where the population is dense and space is expensive. They often lack information on what type of NbS is best for circumstances and urban planning goals. A common problem is implementing a green space, and part of the land needed is owned by a private person. There is evidence and good examples needed for cases like that. Improved knowledge is needed not only on the NbS but also on the legal implementation and the strategies for mixing areas owned by the city with residential areas [**Kabisch et al., 2016**, p 31].

Short term politics: In democracies, most politicians have been elected to office. Usually, they are in office for 4-5 years before the next election. So that politicians are re-elected and try to achieve successes in a short time. The Rain Gardens we have analyzed in this paperwork from the beginning tend to reach their full potential only in 5-10 years. Therefore, it is conceivable that politicians like to think in short time frames and not look at the whole picture. This challenge has no accurate response or solution. People in favor of NbS can hope that NbS is more researched, and the benefits of it are so apparent that policymakers can not avoid using NbS over grey solutions.

Good Examples: This master's thesis was done because of the literature's lack of cost and benefit analysis. There are good examples like Naumann [**Naumann et al., 2014**], as mentioned earlier in this paper, but those are not enough. Further research is necessary to have a solid evidence base and highlight the efficiency of NbS. Even though most of the literature finds NbS to be more cost-effective, there is still a stigma that NbS are either much more expensive or harder to implement and often also impossible to implement [**Santoro et al., 2019**]. The difficulty of quantifying numerous benefits of NbS and their effectiveness strengthens this negative stigma even more [**Krauze and Wagner, 2019**]. Especially the co-benefits need to be included in the calculations to show the full effect of NbS. Learning from NbS would be desirable, but obtaining the information can be challenging. Kabisch (2016) especially demands a focus on the future literature on stormwater management examples, which complement existing grey infrastructure, for instance, Rain Gardens [**Kabisch et al., 2016**, p 32]. A similar recommendation comes from an expert group in the EC. They call for "... more comprehensive evidence based on the social, economic and environmental effectiveness of possible nature-based solutions..." [**Commission, 2015**, p 21]. This demand is not only made up by the academic circle. It is addressed to all possible professional groups that are in contact with NbS: Architects, NbS Gardeners, engineers, landscape designers, and everyone interested [**Kabisch et al., 2016**, p 32].

CHAPTER 6

Conclusion

Rain Gardens, as a Nature-based solutions, can play an essential role in urban environments in reducing the impacts of stormwater runoff. After reviewing both a Rain Garden and the traditional grey alternative (a storage tunnel), the present paper strongly recommends implementing the Rain Garden on this specific site. The results of the Rain Gardens of Thessaloniki seem realistic and are lining up with scientific estimations. A more accurate calculation would be possible with better knowledge of the life span of a Rain Garden. Three sources proposed 20-35 years as the typical life span. Without further knowledge and also as a non-landscaping expert, this work cannot calculate with other numbers, although 35 years seems pessimistic to the author. Lifespan has a big impact on calculations of the costs. A longer life span could see Rain Gardens even more at an advantage over other options. Therefore it is strongly recommended to improve research about the topic.

The second finding of this work was that the question of whether NbS are the better alternative has long been settled in scientific circles. It is now a question of ”how” to implement NbS in a wide range of applications. The last chapter tried to find reasons why the grey alternatives are still implemented nowadays. This work sees high importance in presenting more examples of costs and benefits in the literature, especially in developing tools and ways to integrate non-market valuations. Therefore, co-benefits could set new standards for marketing NbS to policymakers. But not only scientists and policymakers can make a difference. The idea of NbS can also be implemented on a private level. That is one of the reasons why Rain Gardens are interesting to look at: They can be implemented in every little space in the city and also in backyards and roofs.

In view of the major climate challenges of the coming years, much of this work also questions the current status quo and calls for a rethink. Nevertheless, an acknowledgement of the rapid rise of the concept of NbS should be allowed. With the European Commission as a decisive player and the currently visible climatic changes, a rethinking among large parts of the population is noticeable. This can bring some optimism to the negative future forecasts.

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CHAPTER 7

Appendix

You can find all calculations, graphs, and additional information at this link below.
https://drive.google.com/drive/folders/1q6p2KTamdevE3jq-0tTk3uM_-fNGbFeW?usp=share_link