Green roofs and climate resilience in The Hague

Master Thesis Research Project

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Green roofs and climate resilience in The Hague

Spatial, financial & stakeholder analyses

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Glossary

GI	Green infrastructure
UHI	Urban heat island effect
SWF	Stormwater flooding
VVE	Vereniging van eigenaren; association of house owners
ES	Ecosystem services
EC	European commission
GWR	Geographically weighted regression analysis
SAC	Spatial auto correction
WLC	Weighted linear combination method
GIS	Geoinformation systems

Summary

Due to climate change, cities are expected to become subject to increasingly intense heat waves and precipitation. This calls for them to become more resilient towards such fluctuations. Green infrastructure is increasingly acknowledged as a means to enhance climate resilience, but cities – especially city centres – often lack the necessary space for realising such infrastructure. That is why green, vegetated roofs are frequently promoted as a potential solution for this spatial problem. This is also the case in the city of The Hague. In this municipality, green roof development has been stimulated for years with subsidies to increase the resilience towards the urban heat island effect (UHI) and stormwater flooding (SWF).

But while there is consensus within the municipality that more green roofs should be realised, no clear, quantifiable targets are set to achieve specific resilience goals. In part, this is because the potential benefits of green roofs have not been quantified at the city scale. And while most local benefits of green roofs are well known, downsides, costs and the barriers to implementation are not well understood.

The goal of this study is to examine the extent to which green roofs can increase climate change resilience in The Hague. In order to view this matter from complementing perspectives, three methods are used to answer five sub-questions. These methods are spatial analysis, financial cost-benefit analysis and stakeholder interviews. The sub-questions and their corresponding answers are as follows:

(1) Which areas of the city hold the biggest potential for green roof development? Based on roof suitability data and local climate nuisance, these are the city centre and adjacent South neighbourhoods.

(2) How much would green roofs decrease the UHI and SWF nuisance in the city, if they were realised? This calculation is based on the most simple and cheap type of green roof available. When extrapolated at the city level, green roofs could have a significant effect on mitigating UHI and SWF nuisance. Still, additional resilience measures would likely be necessary to meet the total local demand.

(3) What are trends in the city's green roof subsidies, since the start of subsidising? About 0,5% of flat roofs have been made green thus far. These roofs are generally not realised in the neighbourhoods that hold significant potential for green roof development. There appears to be a mismatch between the places where green roofs are most needed and where subsidies help to realise them

(4) How can green roofs be financially viable, given their costs and benefits? When comparing a standard bitumen roof to a green roof and a combined green-photovoltaic roof over 60 years, green roofs outperform traditional roofs financially. The critical factor that allows this is the increase in property value. This result heavily contrasts the general public perception of green roof costs, as generally, green roofs are considered to be more of a financial burden than a sound investment.

(5) How do relevant stakeholders perceive green roofs in contrast to academic literature? Interviews with relevant stakeholders revealed new perceived barriers to the implementation of green roofs. A novel finding compared to literature was the

uncertainty on how worthwhile green roof investment is and the lack of evidence to achieve the claimed lifespan of 60 years. Several citizens were also interviewed and asked for their willingness to pay for green roofs. They expressed no evident desire for green roof development or a desire for UHI and SWF mitigation.

In conclusion, large scale realisation of extensive green roofs is likely to have a positive effect on climate resilience in The Hague. These effects are significant at the city scale if green roofs are realised in large quantities, but they will likely not lead to easily noticeable results for the average citizen on the street. Substantial economic, political, legal and social barriers need to be overcome to implement green roofs at city scale for public environmental benefits. Several areas in the city do however hold notable potential to use its roof space for increased climate resilience.

Nederlandse samenvatting

Door klimaatverandering worden steden steeds vaker onderworpen aan alsmaar heviger wordende hittegolven en extreme regenval. Dit vraagt steden om hun weerbaarheid (resilience) hiertegen te vergroten. Groene infrastructuur wordt steeds vaker genoemd als een middel om de weerbaarheid ten aanzien van het klimaat in steden te verbeteren. Maar, deze gebieden - in het bijzonder stadskernen - hebben vaak niet genoeg ruimte om zulke infrastructuur te realiseren. Daarom worden groene, met vegetatie bedekte daken steeds vaker gepromoot als een mogelijke oplossing voor dit ruimtelijke probleem. Dit is ook het geval in Den Haag. In deze gemeente worden groene daken al jaren gesubsidieerd om de stad beter te wapenen tegen het stedelijk hitte-eiland effect (UHI) en overstromingen als gevolg van extreme regenval (SWF).

Maar ondanks dat er binnen de gemeente een consensus is dat er meer groene daken zouden moeten worden gerealiseerd, worden er geen duidelijke, kwantificeerbare doelen gesteld binnen de resilience visie. Dit komt deels doordat de potentiële voordelen van groene daken nog niet gekwantificeerd zijn op stedelijke schaal. En hoewel lokale voordelen van groene daken welbekend zijn, worden de nadelen, kosten en barrières tot de implementatie van groene daken nog niet goed begrepen.

Het doel van deze scriptie is om te onderzoeken in welke mate groene daken de klimaat-weerbaarheid van Den Haag kunnen vergroten. Om deze kwestie vanuit complementaire invalshoeken te bekijken, worden drie methoden gebruikt om vijf deelvragen te beantwoorden. Deze methoden zijn: ruimtelijke analyse, financiële kosten-batenanalyse en interviews met relevante stakeholders. De deelvragen en de bijbehorende antwoorden zijn als volgt:

(1) Welke delen van de stad hebben de grootste potentie voor groendakontwikkeling? Op basis van data over de geschiktheid van daken en data over de lokale klimaatoverlast zijn dit de binnenstad en aangrenzende wijken in het Zuiden.

(2) Hoeveel zouden groene daken de UHI- en SWF-overlast in de stad verminderen als ze gerealiseerd zouden worden? Bij deze berekening is uitgegaan van het meest eenvoudige, extensieve en goedkope type groendak dat er is. Geëxtrapoleerd op stadsniveau kunnen groendaken een significant effect hebben op het verminderen van UHI- en SWF-overlast. Toch zijn waarschijnlijk aanvullende veerkrachtmaatregelen nodig om aan de totale lokale vraag te voldoen.

(3) Wat zijn trends in de subsidies voor groene daken van de stad sinds de start van de subsidiëring? Tot dusver is ongeveer 0,5% van de platte daken vergroend. Deze daken worden doorgaans niet gerealiseerd in de wijken met de grootste potentie voor groendakontwikkeling. Er blijkt een mismatch te zijn tussen de plaatsen waar groene daken het meest nodig zijn en waar subsidies op dit moment helpen om deze te realiseren.

(4) Hoe kunnen groene daken financieel levensvatbaar zijn, gezien hun kosten en baten? Wanneer een standaard bitumen dak wordt vergeleken met een groendak en een gecombineerd groen-fotovoltaïsch dak gedurende 60 jaar, dan presteren groendaken financieel beter dan traditionele daken. De kritische factor die dit mogelijk maakt, is de

stijging van de vastgoedwaarde. Dit resultaat staat in schril contrast met de algemene publieke perceptie van de kosten van groene daken, aangezien groene daken in het algemeen meer als een financiële last dan als een gezonde investering worden beschouwd.

(5) Hoe zien relevante belanghebbenden groene daken in tegenstelling tot academische literatuur? Uit interviews met relevante stakeholders kwamen nieuwe barrières naar voren ten aanzien van de implementatie van groene daken. Een nieuwe bevinding in vergelijking met de literatuur is de onzekerheid of de investering wel de moeite waard is en het gebrek aan bewijs om de geclaimde levensduur van 60 jaar te bereiken. Ook zijn diverse burgers geïnterviewd en gevraagd naar hun bereidheid om voor groene daken te betalen (willingness to pay). Daaruit kwam geen duidelijke wens voor meer groene daken naar voren. Ook was er geen duidelijke vraag naar het verminderen van UHI en SWF-overlast.

Als conclusie kan gesteld worden dat de grootschalige realisatie van extensieve groene daken heeft waarschijnlijk een positief effect op de klimaatbestendigheid in Den Haag. Deze effecten zijn significant op stadsschaal als groendaken in grote hoeveelheden worden gerealiseerd, maar zullen waarschijnlijk niet tot gemakkelijk merkbare resultaten leiden voor de gemiddelde burger op straat. Aanzienlijke economische, politieke, juridische en sociale barrières moeten worden overwonnen om groene daken op stadsschaal te implementeren. Verschillende gebieden in de stad hebben echter zeker de potentie om de aanwezige ruimte op de daken te gebruiken om de klimaat-weerbaarheid van de stad te vergroten

1 | Introduction

Due to climate change, cities are expected to become subject to increasingly intense heat waves and precipitation. This calls for them to become more resilient towards such events. The Rockefeller Foundation (2017) defines the concept of resilience as "the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience".

Chronic stresses are slow-moving disasters that weaken the fabric of a city. They include themes such as high unemployment, climate change, organised crime and overpopulation. Acute shocks are sudden, sharp events that threaten a city, such as terrorism attacks, floods, heatwaves or a pandemic.

The Hague is working to make its city more resilient through their The Hague Resilient Strategy. To cope with climate change related shocks and stresses, one of their policies is a green roof subsidy (Carrilho, 2015; Gemeente Den Haag, 2019). Privately owned rooftops occupy a significant amount of surface area within the city while providing few public benefits. The city wants to change this because public space is relatively crowded and limited, while roofs sit mostly "empty" (Carrilho, 2015; Triarii, 2019). The stimulation of green roof development is a global trend – both in academic literature as in newspapers – as a promoted solution for densely populated urban areas to ensure an adequate supply of regulating Ecosystem Services (ES) like stormwater management, thermal regulation, ecological habitat and also relaxation and social integration (Langemeyer et al., 2019).

Since the start of the subsidy in 2009, the share of all flat roofs that have a form of vegetation on them has risen to about 0,5%, consisting of 52.000 m2 out of 11,3 mln m2 available (Carrilho, 2015). Meanwhile, Rotterdam realised 360.000 m2 out of 14,5 mln m2 available (2,5%) over a similar period (Remmers, 2017). The vast majority of these roofs are privately owned.

The city of The Hague has concluded that developments in resilient roofing are not going fast enough (Triarii, 2019). It has expressed their intention to accelerate the growth of all possible resilient roof options, including green, white, blue and yellow roofs. These refer to vegetation, white paint to reflect sunlight, water retention and solar energy roofs respectively (Triarii, 2019).

While there is consensus within the municipality that more resilient roofs should be realized, no precise, quantifiable targets are set to achieve specific climate resilience goals for roofs (Gemeente Den Haag, 2019; Triarii, 2019). In part, this is because the potential benefits of green roofs have not been quantified at the city scale. And while most local benefits of green roofs are well known, downsides, costs and the barriers to implementation are not well understood (Personal Communication, M. L. Carrilho, R. van der Landen & N. Al, 2019). The reason why these two knowledge gaps exist is not clear. One of the causes could be that within government, more emphasis is put at the energy transition, rather than climate resilience.

1.1 The need for climate resilience

The municipality's push for resilient roofs, with an emphasis on green ones, is a direct political response to a critical chronic stress factor: anthropogenically enhanced climate change (Gemeente Den Haag, 2019). The consequences of climate change are characterized by interdependence and feedback loops that can amplify or chain extreme events. For example, higher temperatures lead to air being able to hold more water, which facilitates more intense storms and precipitation (Wirsenius, 2018). Many more feedback loops like this are found in climate change research (Hansen et al., 2016). Given that the earth's mean temperature is continuing to rise in the coming decades, this means that there is an increasingly urgent need for societies and cities to become more resilient towards climate change effects. For Dutch cities like The Hague, more frequent and prolonged heatwaves and droughts, as well as more intense and more frequent storms are the most relevant (Meerow, Newell, & Stults, 2016). This subset of resilience will be called 'climate resilience'.

While climate change affects all places on earth, it is clear that the effects will particularly impact cities, immediately affecting many people at once (IPCC, 2014). Currently, more than half of the world's population lives in cities, and these numbers are expected to grow. Not only because of possible climate refugees, but also because of existing global migration patterns due to economic opportunities and armed conflicts (Gago, Roldan, Pacheco-Torres, & Ordóñez, 2013).

Given their high population densities, geographical locations - often near seas - and their dependency on infrastructure and real estate, many cities are particularly vulnerable to heatwaves, storms, floods and sea-level rise (IPCC, 2014). Besides directly leading to deaths and property damages, these shocks also put a strain on emergency services, healthcare capacity, resources, critical infrastructure and indeed a prospect to live and work in a specific area. When multiple problems coincide, these problems are only further emphasised(Kalkstein & Greene, 1997; Rockefeller Foundation, 2017).

The city of The Hague has created a 'resilient strategy' to deal with the aforementioned climate-related issues. This strategy goes much further than only climate change. Many of the topics the strategy deals with already had policy programs underway before the resilience strategy was written. However, the concept of resilience is now used as a unifying framework to link seemingly divergent subjects and to push a multidisciplinary perspective to complex problems. This relevant because the municipality aims to realise synergies between solutions, such as the energy transition and green roofs, in the form of solar-green roofs (Gemeente Den Haag, 2019).

Already in 2012 The Hague established that its main climate resilience problems are rising sea levels, intense precipitation & flooding and higher temperatures & heatwaves (Gemeente Den Haag, 2012). Rising sea levels do not involve much complexity since it is part of the national government sea defence program (source). It primarily consists of increasing the height of dikes, dunes and other seawater barriers. Intense precipitation and heat waves, on the other hand, are more complex problems. In the next paragraphs, I will elaborate on why that is, and why green roofs may have a role in mitigating those problems.

In cities, problems with higher temperatures and heat waves are more pronounced than in the countryside due to the urban heat island effect (UHI). This is an area or region for which the temperature is higher than the adjacent areas, caused by materials with a high heat capacity that act as heat sinks (Hoeven & Wandl, 2018). Too much heat is unhealthy for humans and can cause heat strokes, skin disorders, heat cramp, heat exhaustion from dehydration, fainting and deaths (CBS, 2019; van Dalen, 2015). It also makes sleeping more difficult, which indirectly leads to health issues and lost productivity. Hence that UHIs are the first areas of a region or city to run into problems during a heatwave. Specifically, the elderly and weak need to be protected during those hot periods.

This simple principle of more heat retainment in urbanised, paved areas, gets more complicated when studied in detail. A difference has to be made between the atmospheric UHI, surface UHI and perceived UHI. Atmospheric UHI is most pronounced at night after sunset and weakest during the day because of the slow release of heat from structures in the built environment. The surface UHI is present both day and night but is often most pronounced by day when the sun is heating up the earth.

Surface UHI is the easiest to measure since remote sensing technology can map the surface temperature at regular intervals, but it is also the most indirect indicator. Ground stations can measure air temperature, but it cannot definitively state the level of perceived heat. Research has also shown that big differences can be found between air temperature indoors and outdoors (Vaissier, 2019).

Potential solutions for the UHI effect also do not always work the same throughout the day. For example, water bodies cool a city down during the daytime, because they act as heat sinks. But this means that during the night, water bodies actually give off heat and therefore contribute to night UHI. These two effects stem from the surface energy balance: the net solar radiation equals the sum of the energy exchanged through evapotranspiration (latent heat flux), the energy used for conversion from heat to surface air (sensible heat flux) and the energy absorbed by building, ground and surfaces (ground heat flux) (Hoeven & Wandl, 2018).

To ameliorate this heat problem, the city has to create shade, evaporate water to cool the city down and reduce its heat capacity through material choices with less heat capacity. Many options exist to accomplish this, but one that is increasing in popularity is to increase the amount of green infrastructure. When designed as parks, they usually fulfil all three requirements, while also providing a recreational and aesthetical benefit to the city. Green roofs might be the next best option when space for parks and trees is not available. Hoeven & Wandl (2018) have shown that the surface area of a green roof can be lower than a standard bitumen black roofs by as much as 40 °C. This lower temperature is due to three factors: evapotranspiration, an increased albedo factor (compared to bitumen) and the heat capacity of the soil itself.

Similar to UHI, intense precipitation and resulting stormwater flooding (SWF) are more complex than they may appear at first. Sewers are calibrated for standard rain profiles, which means that the drainage infrastructure is well equipped to deal with such rain events. But as climate change persists, it is highly likely that storms will become much more frequent that release orders of magnitude more water. These intense precipitation events do not only yield a lot of cubic meters of water, but they also happen very fast, resulting in a high peak load on the sewer system (Broks & van Luijtelaar, 2015). And when sewers and other basins cannot cope anymore, that means that parts of the city get flooded. While this mostly leads to property damage and inconvenience in the Netherlands, casualties have fallen in the past and become more likely as weather worsens.

The most dominant strategy regarding SWF is to store water and delay its discharge (Broks & van Luijtelaar, 2015). Green roofs are known to be able to soak up water like sponges, similar to other green infrastructure. However, in the same way, the effectiveness of green infrastructure is in part tied to the quality and soil category it sits on (van Oorschot, 2019), not all green roofs are created equal. Semadeni-Davies et al. (2008) have shown that while the water capacity of a green roof can easily be calculated, the actual rain that will be captured by the roof can vary tremendously. The more intense the precipitation, the more likely that the water will not be captured and instead will runoff. The exact numbers are not well known yet, but green-blue roofs with a pinched drain pipe do exist that are more efficient at storing the precipitation than standard extensive green roofs (Broks & van Luijtelaar, 2015).

1.3 Definitions and theoretical framework

In order access the impact of green roofs for the city of The Hague and their ability to mitigate UHI and SWF, four concepts need to be defined: ecosystem services, green infrastructure, nature based solutions and green roofs themselves. Their interrelation is pictured in Figure 4. Green roofs are a subset of nature based solutions, which in turn are a subset of green infrastructure. These three have the capability of providing (ecosystem) services to society for the benefit of human well-being and climate resilience.

Green roofs have existed for millennia, going as far back as the Babylonians and prehistoric primitive shelters. Modern green roofs are often categorized in extensive and intensive. Extensive roofs are low in maintenance, have a weight up to 60–150 kg/m2, are moderately easy to construct and have a thickness of soil up to 200 mm, resulting in a low diversity of plants (mosses, herbs and grasses).

Intensive roofs resemble gardens. They require maintenance like a garden, may weigh 300 km/m2 or more (and thus may require structural support if they are retrofitted), are technically more complex to construct than extensive roofs and have a soil thickness of 200 mm or more, resulting in more diverse plants such as lawns, perennials and shrubs.

The most well known benefits of green roofs are storm water buffering and improved water quality (Broks & van Luijtelaar, 2015), reduce urban heat island effect (Oberndorfer et al., 2007), increased habitat promoting biodiversity, roof longevity

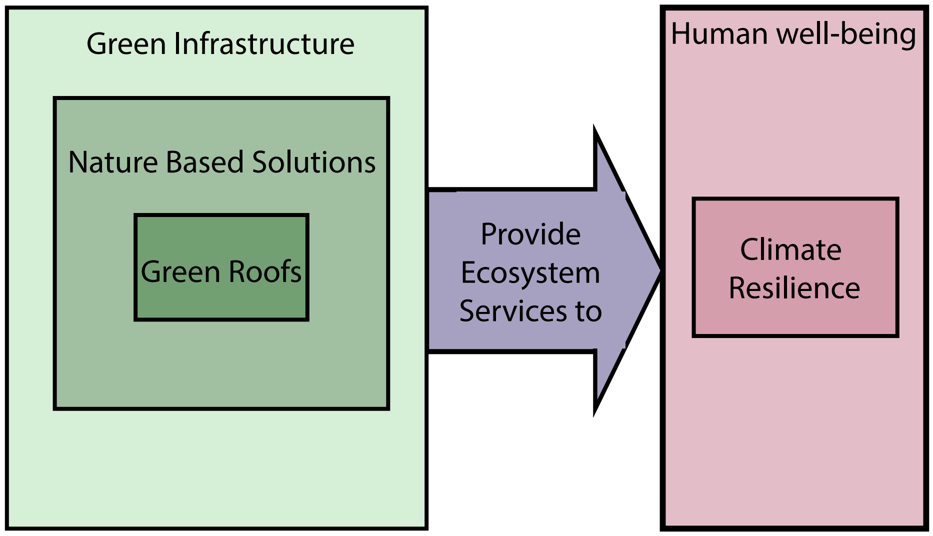

Figure 1: The relation between green infrastructure, nature based solutions, green roofs and ecosystem services. Note that many other concepts fit in these categories; this is only to illustrate the definitions relevant to this thesis.

(General Services Administration, 2017), energy consumption reduction, sound insulation and noise reduction, and air pollution mitigation (Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014). And going deeper, there are social and economic benefits, such as lower energy costs, job opportunities and health benefits for people living in more green districts (Shafique, Kim, & Rafiq, 2018).

The most well known challenges of green roofs include maintenance costs, leakage problems, high capital costs, root penetration, safety, building structural requirements and technical difficulties (General Services Administration, 2011; Shafique et al., 2018).
The 'benefits' of networks of planned and unplanned green spaces provide are typically described by and quantified as ecosystem services (ES) (Berghöfer et al., 2011). While several definitions of ES exist and are heavily debated (van Oudenhoven, 2015, p. 3), I will use the definition by TEEB (2010): "the direct and indirect contributions of ecosystems to human wellbeing".

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Two works in ES literature that are frequently cited are TEEB and the Millennium Ecosystem Assessment (2005). Both recognize four categories of ES: (1) provisioning services are goods such as food production, fresh water and plant-derived medicines; (2) regulating services refer to services such as clean air, carbon storage and protection from disasters; (3) cultural services refer to non-material benefits for people, such as recreation, spiritual & aesthetic values; and (4) supporting services facilitate the other three categories, such as soil formation, photosynthesis and nutrient cycling. The focus of this work is on regulating ecosystem services, as these are related to climate adaptation and resilience. ES cannot be measured directly. They always need to be made tangible through the use of indicators.

In a lot of literature regarding green roofs, spatial analysis is used in order to located areas that are useful for green roof development (Langemeyer et al., 2019; Zwaanenburg, 2019) or the theoretical existing ES capacity is calculated, usually this concerns all green infrastructure, and not just green roofs (Meerow & Newell, 2017; van Oorschot, 2019). Other times, theoretical models are constructed the calculate theoretical ES flows, such as the water buffer capacity for various rain events (Broks & van Luijtelaar, 2015) or heat reduction in urban canyons (Alexandri & Jones, 2008; Damen & Brouwers, 2012). But seldomly are the actual ES flows calculated for a city wide case study. This is one of the research gaps this thesis will address.

Green roofs are a form of nature based solution (NBS). In recent years the European Commission (EC) has and defined this concept as "living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social and environmental benefits". This in turn, is a subset of green infrastructure. The EC has recognized the necessity of passing from building "grey" infrastructure to building "green" infrastructure, to restore ecological balance within the urban landscape for the dual purpose of developing resilient ecosystems and healthier societies. This thinking is based on the fundamental role that nature plays through the provision of ecosystem services in supporting the economy as well as the livelihood of citizens (Lafortezza, Chen, van den Bosch, & Randrup, 2018). Norton and colleagues define urban green infrastructure (GI) as "the network of planned and unplanned green spaces, spanning both the public and private realms, and managed as an integrated system to provide a range of benefits." GI can include native vegetation, parks, private gardens, golf courses, street trees, green roofs, green facades, biofilters and raingardens (Norton et al., 2015).

1.4 The economical challenge

As mentioned in the beginning, the Hague wants to increase the amount of green roofs in its city, but it is facing a fundamental economic challenge in trying to realize that: it trying to enhance GI within its borders in areas where there is not much public space and a lot of private ownership. This reveals an old challenge between the division between public and private costs and benefits. One of the oldest examples of this tension is the Fable of the Bees from 1714 by Bernard Mandeville regarding "Private Vices and Publick Benefits". Goods can be excludable or non-excludable and they can be rival or non-rival. Excludable goods, such as green roofs and cable television, can be governed well by market forces. This stimulates innovation and through competition prices remain relatively fair. But non-excludable goods and especially are also non-rival, are known as public goods and cannot be governed by market forces (Figure 5).

The municipality wants to increase its resilience, which results in a city that is not overrun with water and that is not too hot, but the main way to get there, is through private goods (green roofs). This means real estate owners who invest in green roofs, do not yield the positive externalities privately, it is the public that yields the most benefits, while the consumer has all the costs. Of course, if enough private benefits are present, one may still be pursuaded to invest in a green roof. But these private benefits are not obvious to many. Green roofs are therefore seen as long term investment with little short term returns (Blackhurst, Hendrickson, & Matthews, 2010; Engström, Howells, Mörtberg, & Destouni, 2018).

To deal with this issue non-market goods need regulation and collective management. Two institutions have done so in the case of The Hague: the municipality and the water board “Hoogheemraadschap Delfland”. They stimulate the investment in green roofs in the form of subsidies, offsetting their costs to be more competitive with standard roof types. The successfulness of this strategy depends on perspective. On the one hand the subsidies are well used, yet on the other hand, cost-effective policies to accelerate sustainable roof development beyond the 0,5% of vegetated roofs right now, for large scale urban benefits are yet to be found (Personal Communication, M. L. Carrilho, R. van der Landen & N. Al, 2019).

Studies on the profitability and costs versus benefits of green roofs also yield mixed results. Some argue that green roofs are currently too expensive in relation to their benefits (Blackhurst et al., 2010). Others argue that climate change is slowly increasing the value of those benefits, and calculate a return of investment between 6.2 years to 15 years (General Services Administration, 2017).

Also there seems to be a debate on where subsidies work best. As a yearly pay-out for the provision of an ecosystem service, as a subsidy to pay maintenance, or a more traditional one-time gift. How green roofs can financially be viable for the bigger public remains to be seen (Clark, Adriaens, & Talbot, 2008).

Figure 2: Two by two matrix of the four types of goods. Excludable goods adhere to market economics, non-excludable goods require government or community intervention.

1.5 Knowledge gap and research questions

Three knowledge gaps have been identified in this chapter: (1) several ES of green infrastructure have been quantified in The Hague, but the effect of green roofs has not (van Oorschot, 2019). (2) While green roofs have been subsidized for a decade, The Hague seems to lag behind other cities, without clear explanation; local barriers to entry are not well known. And (3) seldomly are the actual ES flows calculated for a city wide case study to model its expected effects.

To address these knowledge gaps, the research questions are as follows:

To what extent can green roofs increase the city of The Hague's resilience towards its urban heat island effect (UHI) and stormwater flooding (SWF)?

1. *Which areas of the city hold the biggest potential for green roof development?*
2. *How much would green roofs decrease the UHI and SWF nuisance in the city, if they were realised?*
3. *What are trends in the city's green roof subsidies, since the start of subsidising?*
4. *How can green roofs be financially viable, given their costs and benefits?*
5. *How do relevant stakeholders perceive green roofs in contrast to academic literature?*

The purpose of the five sub questions is to view the main research question from serveral perspectives and triangulate observations. Do the quantitative results from RQ1-3 match the experience of real people, addressed in RQ5?

RQ1 has the purpose to assess the current green roof situation and identify in what areas of the city more can be realised. RQ2 investigates that if all those roofs were to become green, what effect that would have. RQ3 then directly addresses the 2nd knowledge gap: where do subsidies end up and how does that relate to the results from RQ1? The purpose of RQ4 is to not only view the topic from the environmental (RQ1-3) or social (RQ5) side, but also from an economical point of view. And this can nicely be compared with RQ5, which loos at all pros and cons stakeholders perceive. Especially in terms of investment and costs: is the perception of stakeholders correct?

2 | Methodology

To assess to what extent green roofs can increase The Hague's resilience towards its UHI and SWF nuisance, three methods were used: spatial analysis (RQ1 - 3), financial cost-benefit analysis (RQ4) and qualitative stakeholder interviews (RQ3 & 5). While the aim of the research questions was to investigate the subject holistically from multiple perspectives, it was the aim of the methodology to balance quantitative and qualitative tools. Also, to view the problem from multiple angles. describe the specific steps that were taken to answer each research question respectively.

2.1 Spatial analysis

In this thesis, spatial analysis was chosen to answer research question one to three specifically. This was done because the use of open data and remote sensing made it possible to plot city wide analyses with minimal resources and field work necessary.
Today, spatial analysis is often used to improve the resilience and sustainability of cities. An increasing number of academics have been calling for the use of spatial analysis in order to stimulate better decision-making (Ahern, 2007). This is particularly true of green infrastructure projects aimed at enhancing ecosystem services (Ahern, 2007; Meerow & Newell, 2017).

Three software programs were used to conduct the spatial analysis: QGIS, ArcGIS and Google Earth Engine. The reason for this diversity was not planned, but the result of technical limitations and the fact that some datasets malfunctioned in certain software, making it necessary to switch for a particular analysis. All final maps were generated in QGIS. Table 1 shows the list of all datasets that were used.

To bridge the gap between the abstract concept of ecosystem services and measurable, real world phenomena, indicators are necessary. Indices translate the concept of an ecosystem service flow into a measurable unit. In literature it has increasingly become clear that choosing appropriate indices is vital to facilitate reliable, practical and useful results. I have therefore used the credibility, salience, legitimacy and feasibility framework to select my indicators (van Oudenhoven et al., 2018). All indicators were aggregated to the neighbourhood level of the city, to make fair comparisons between all areas of the city.

2.1.1 Locating current green infrastructure

In order to answer RQ1, the location of existing green infrastructure had to be mapped. Several indicators exist to computate green infrastructure using remote sensing data. The Normalized Difference Vegetation Index (NDVI) is the most widely used (source). The index is based on the principle that healthy vegetation will not reflect much red light because of photosynthesis, while near infrared light remains untouched. NDVI is useful because only two spectral bands from a satellite with light sensor are needed.

Table 1: Overview of all data sources used.

Dataset name	Use	Category	Data type	Source
Sentinel-2 Jul-2019	NDVI	Green infrastructure	Raster data (10x10m)	Sentinel
Administrative boundaries	Municipal, district and neighbourhood boundaries	Land cover data	Polygon	Den Haag Dataplatform
Landsat 8 Jun-Jul-Aug-2019	Land surface temperature	Urban heat island effect	Raster data (30x30m)	USGS & Google Earth Engine
Wateroverlast	Stormwater flooding	Stormwater Retention	Raster data (0.25x0.25m)	Klimaatatlas 2008
Zonneïnstraling	Roof slope	Suitability	Polygon - buildings	Den Haag Dataplatform
Zonneïnstraling	Roof area	Suitability	Polygon - buildings	Den Haag Dataplatform
Huisnummers	VvEs	Ownership	Points - plots	Kadaster
Points of interest; land use	Relevant flooding selection	Land cover data	Polygon	Open street maps
BGT-Roads	Relevant flooding selection	Land cover data	Polygon	Basisregistratie Grootschalige Topografie
Green roof subsidy '16-'19	Subsidy distribution	Subsidy policy	Excel	The Hague internal communication
Green roof subsidy '09-'15	Subsidy distribution	Subsidy policy	Pdf report	The Hague internal communication
Woningcorporaties	Housing corporations distribution	Ownership	Polygon - buildings	Den Haag Dataplatform
Ruimtelijke kengetallen	Ownership percentages per neighbourhood	Ownership	Polygon	Den Haag Dataplatform

The most important downside is the sensitivity for noise: clouds, atmospheric effects, soil effects and other sources can diffuse output of NDVI.

Other indicators were concidered, but rejected. The Leaf Area Index (LAI) and Shade from trees are two commonly used indicators for UHI too. LAI is a dimensionless quantity that characterizes plant canopies. It is useful for assessing GI such as trees, but is less suitable for grassy plains. This is the same for shade as an indicator, since shade from green roofs is not possible. Therefore NDVI was chosen.

NDVI is calculated using the following formula:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

In which NIR means the Near Infra Red band and Red means the red band. These bands are the result of a sensor on a satellite. Both NASA and ESA have current missions monitoring Earth with sensors that support these bands. For this study I choose to use ESA's Sentinel-2 satellite, because it allowed me to calculate in a higher resolution (10x10m) than NASA's Landsat-8 mission (30x30m). This yielded a very precise NDVI map that could be related to land ownership, to generate a map that shows private GI and one that shows public GI.

2.1.2 Geographically weighted regression analyis

In order to further analyse the GI data, geographically weighted regression (GWR) analyis was used. This relates mainly to RQ1 and RQ3. Several civil servants have mentioned that subsidies do not end up in the right parts of the city. In order to statistically test this I have used Geographical Regression Analysis (GWR) in ArcGIS. Using this method I could for example test if vegetation (or lack thereof) was linked with subsidy distribution. GWR is a very common way to statistically analyse local spatial patterns, while the Ordinary Least Square (OLS) method is commonly used to analyse global patterns. GWR can be thought of as a test if the dependent variable can be predicted by the explanatory value. For example if the subsidy distribution can be explained by temperature: do subsidies occur more often in areas with high temperatures? GWR is calculated using the following formula:

$$\gamma = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon$$

Where γ is the dependent variable and x the explanatory variable. β is a the coefficient that is used to express the strength of the relationship and ε is the 'residuals'. This represents the model's under and over predictions and are therefore the parts where the dependent variable is not explained by x.

ArcGIS then yields the adjusted R-squared value, which is the correlation coefficient. When values are between 0,5 and 1 it can be concluded that x indeed successfully predicts γ. In order for a GWR to be valid however, a spatial autocorrection must be ran on the residuals ε, to see if clustering appears. If clustering does appear it is an indication that the model is missing key explanatory variables and should therefore be considered unreliable. The spatial autocorrection calculates Moran's index and the z-score. Moran's index should not be higher than 0,4, while the z-score should not be on standard deviation away from the mean. In this study GWR has been used to correlate NDVI with LST and SWF and subsidy distribution with NDVI, LST and SWF.

2.1.2 Locating the areas that hold the biggest green roof potential

As mentioned at the start of the previous section, the following paragraphs deal the the method used for identifying which neighbourhoods in the city hold the most potential for green roof development. This was done by using the weighted linear combination method. Both the suitability of roofs to house vegetation and the severity of the nuisance they can potentially solve were combined to answer this question

The Weighted Linear Combination method (WLC) is an analytical method that is frequently applied in GIS studies for generating composite maps, because of the ease of applying it. It is based on the concept of the weighted average. The weights of relative importance are assigned by the decision maker to each layer. Every single alternative's score is acquired by multiplying the importance weight assigned to each attribute to the alternative and then summing the products over all attributes. At the base indicator level the scores are calculated by normalizing the best value as 1 (either the minimum or maximum of the set) and then scaling all other values accordingly. Figure 3 shows the WLC that has been applied in this thesis to calculate the problem, suitability and opportunity indices. After considering the assigned weights carefully I choose to leave them in equal, default position. This was because no substantial reasons could be found to alter them.

The resulting indices maps were scaled to 'low', 'medium' and 'high' problems, suitability and potential respectively. This makes the maps easy to communicate to stakeholders and civil servants.

Before this WLC method, an Analytical Hierarchy Process was considered, because it is a more sophisticated application of the WLC method and aims to make determining the weights more objective. However, this is only works when the number of alternatives or indices per hierarchy level is bigger than two. Otherwise the pairwise weight matrix always yields the same result, no matter what the inputs. Therefore this method was not chosen, though it is recommended for future research when more indicators are used.

For the problem index I needed an indicator for the UHI effect and SWF, because The Hague had identified those as the most pressing climate resilience issues.

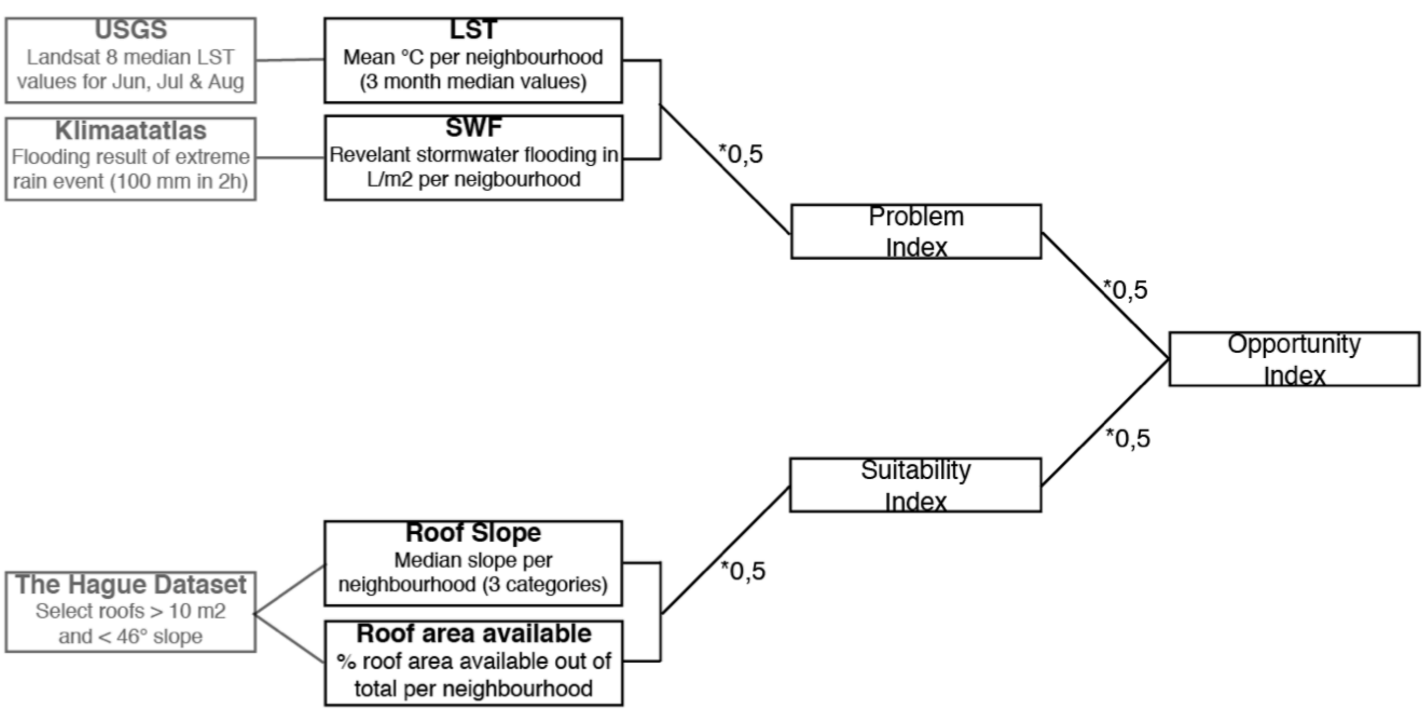


Figure 3: Weighted Linear Combination Scheme to calculate the three indices.

For the UHI many indicators do exist, such as the Land Surface Temperature (LST), Outdoor Thermal Comfort (PET), Heat stress, Air temperature and more. In 2019 a MSc thesis study was done about UHI in The Hague, using PET (Vaissier, 2019). PET is the most understandable indicator for civilians, since it reflects the temperature and thermal comfort they actually experience, while LST is only an indirect indicator. But to calculate PET, a lot of variables are needed, including data from fieldwork. This was feasible for my study, and therefore I choose to use LST. Using Landsat-8 and Google Earth Engine it is relatively easy to compute this indicator. I choose to take the median temperature over the entire Summer, such that hotspots would clearly show up. I then used the resulting raster layer (30x30m) to calculate the mean C° per neighbourhood. Because of technical issues I was not able to use the Sentinel-2 satellite for a higher resolution

SWF can be challenging to calculate, because it is highly dependent on the type of rainfall. Furthermore the existence of sewer systems and water bodies makes it difficult to reliably model water flooding without using advanced software (Slager, Asselman, & Blom, 2018). However, through klimaatatlas I was able to obtain the resulting flood levels layer after one particular rain event event. This meant that infiltration, sewers, land height and water bodies were already taken into account with this layer as a result. I then used two other datasets from BGT and OSM to select flooded parts of the city that were 'relevant'. Relevant would be any pixels (0.25x0.25m) that intersected with roads, urban areas like gardens and plots, and points of interests, such as sports pitches. This resulted in a spatial layer with relevant water flooding nuisance, which was aggregated to neighbourhood level resulting in Liters/m2 nuisance per neighbourhood. The rain event selected is a theoretical very intense storm of 100 mm in 2 hours. The Dutch governmental weather bureau expects this type of extreme rain events to become substantially more frequent (KNMI et al., 2014).

In order to make a suitability index, the most relevant parameters that influence green roof renovation had to be found. The most frequent mentioned aspects in subsidy policies and literature is the available roof area and the slope of a roof. Literature has shown that green roofs on slopes more than 45° are unfeasible, while subsidy policies often demand a minimal amount of square meters. For this reason, roofs in The Hague were selected that had a slope smaller than °46 and an area larger than 10 m2.
To be able to compare all roofs equally, the indicator for Roof Surface Area (RSA) was calculated as follows per neighbourhood:

$$RSA = \frac{available\ roof\ area\ [m2]}{total\ neighbourhood\ area\ [m2]} \cdot 100\%$$

For roof slope this was done differently. Because quantity is important, the median of all roof slopes within a neighbourhood was calculated and put into one of 3 categories: 0 – 5°, 5° – 15° and 15° – 45°. This is because previous work has shown that prices for green roofs commonly jump in these increments, non-linearly (Zwaanenburg, 2019).

Due to the imperfect nature of the weights being used in the analysis, a sensitivity analysis was undertaken to test how robust the model was to changing weights. The balance of the weights where systematically changed in by plus or minus 10%. The output of the model was categorized in “low”, “medium” and “high”, and as the weights were tweaked, the number of category changes in the model were tracked. A high number of changes would indicate a high sensitivity.

2.1.4 Quantifying ecosystem service flows

To answer research question 2: “How much would green roofs decrease the UHI and SWF nuisance in the city, if they were realised?” it was needed to quantify the resulting ecosystem service flows of installing green roofs in the city. I based the numbers on an actual green roof sold by sedumdak.nl. It is an extensive, low weight, moss & sedum roof. This roof was chosen because this type has the highest chance to fit on existing without much structural modification. The most important characteristics of the vegetation that influence heat transfer of a green roof are plant height, leaf area index (LAI), fractional coverage, albedo, and stomatal resistance (Berardi et al., 2014).

Based on literature I assumed that GRs can reduce the LST cell that they occupy with a conservative 1 °C, given that a roof will never completely cover a cell (Berardi et al., 2014; Di Giuseppe & D’Orazio, 2015).

For SWF, I assumed that roofs 0° - 5° could buffer 25 L/m2, 5° - 15° could buffer 15 L/m2 and 15° - 45° could buffer 5 L/m2 during the extreme event of 100 mm rain in 2 hours (Getter, Rowe, & Andresen, 2007). Both ES capacities were aggregated to neighbourhood level for comparison with the base situation.

2.1.5 Analysing The Hague’s green roof subsidy policy

To answer research question 3 regarding trends in the city’s green roof subsidies two datasets were made available by the municipality. One was a report on subsidy spending from 2009 - 2015 and the other was all data from subsidies from 2016 – June 2019. These datasets were made anonymous and were scaled to neighbourhood level to ensure privacy. In the case of the first dataset the were even scaled to district level.

Because not that many subsidies had been handed out over the years, two indicators were chosen to investigate two perspectives. The goal was to fairly evaluate if certain neighbourhoods are receiving disproportionally more than others. This is slightly complicated because neither the amount of money subsidized nor the sum of m2 roofs realized are shy of skewing the perception, slightly. The best example of this is one massive green roof that has been built in the South part of the city at 1100 m2, bigger than all other green roofs by a long shot. It was however the only green roof to be realized in that part of the city for the entirety of ’16-’19. But in the East the reverse happened, as a large number of very small green roofs was realized.
The mitigate skewing as much as possible the first indicator was:

$$\text{Subsidy indicator} = \frac{subsidized\ green\ roofs\ per\ neighbourhood\ [m2]}{total\ available\ roofs\ per\ neighbourhood\ [m2]} \cdot 100\%$$

The second indicator was determined to be the number of realised green roofs per neighbourhood. This way one indicator was based on m2 and one on the amount of roofs. Together then could form a fair picture.

The stakeholder interviews, which will be explained in section 2.3, yielded that ownership associations (VVEs) and housing corporations were the most important real estate owners in the city. It was therefore relevant to compare these two groups with the subsidy distribution to see if these relatively powerful groups are making use of the subsidy from common money, or if this is not the case at all.

To do this, I used the address numbers from the Kadaster dataset. Any address with a suffix (such as 5a, 5b, etcetera) means by definition that these homeowners have a VVE together (personal communication, Hans-Jurgen Kramer, 14 November 2019). By dividing VVE address by the total amount of addresses we find the percentage of VvE addresses per neighbourhood. In a similar manner housing corporation addresses were calculated to find their percentage per neighbourhood.

2.2 Financial cost-benefit analysis

To answer research question four, a financial cost-benefit analysis was conducted. Several cost-benefits analyses have been done over the years to evaluate the business case of green roofs. For example a study in the USA yielded an NPV of $2.5/ft2 at an IRR of 5.0% (General Services Administration, 2017). But these studies often take into account less measurable benefits, such as positive externalities that has been converted in monetary values.

Therefore, the purpose of the financial cost-benefit analysis (FCBA) is to make a straight forward comparison between a standard, traditional bitumen roof, an extensive green roof and a green + photovoltaic roof over their life time to see how they compare. Only straightforward, measurable parameters that were relatively easy to quantify were considered, in order to understand the real financial consideration that consumers, and also corporations face, when deciding to install a green roof or not.

In an FCBA the net present value is calculated by using the following formula:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+r)^t}$$

In which
R_t= net benefit in year t
r = discount rate
t = number of time periods

The parameters that were considered where:

- Discount rate [%]
- Instalment costs [€ /m2]
- Subsidy The Hague [€ /m2]
- Subsidy Water Board [€ /m2]
- Maintenance [€ / m2 / year]
- Energy savings [€ / m2 / year]
- Project lifetime [years]
- Inflation of maintenance in accordance with Dutch minimal labour salary trendline [%]
- Deflation of energy prices due to renewable energy boom this century invers logarithmic S-curve
- Property value increase [€/m2]

The s-curve used for the energy price gradient was calculated using the following formula:

$$F(x) = \frac{L}{1 + e^{-g(x-x_0)}}$$

In which
L = maximum value
g = growth rate
x_0 = half of lifetime

It was assumed that no repairs would be necessary during the lifetime of the roof, only regular maintenance. The green roof would suffice 60 years, bitumen 30 years and PV+green 20 years, after which new PV panels would be installed, twice. A base discount rate of 10% was assumed, because the interviews with stakeholders had yielded that consumers did not have much patience for their investments to return: "An investment of more than 5 years is for most VVE members too far into the future".

Due to the fact that discount rates and inflation rates had to be selected, a sensitivity analysis was conducted. In sequence, all parameters got the same percentage added and subtracted from their value and the effect on the NPV was tracked. This way parameters for which the model was particularly sensitive could be identified. These results are in the appendix.

The property value increase was based on reserach by Bianchini et al. (2012). They found that extensive green roofs could increase the properties value by between 2% and 5%. Assuming an average base property value in The Hague of about €5000/m2 leads to a €100/m2 increase. Then I take 75% to be more conservative, ending up at €75/m2 property value increase.

2.3 Stakeholder interviews

To assess the social perspective on green roofs and thereby answer research question 3 and 5, qualitative interviews were arranged with relevant stakeholders (SH). According to Reed (2008), there are two categories of projects in which stakeholders can play a role: organization focussed and issue-focused. Because green roof development falls into the latter category I chose the following definition for a Stakeholder: "Those who can affect or are affected by (the solution of) an issue".

A distinction between "office" and "street" interviews was made.

The interviewees in the first category, office, were selected based on the result the Bryson (2005) framework. I questioned them about the pros and cons they saw towards green roofs and what experiences they had had. This led to qualitative insights that helped to choose meaningful topics for spatial analysis for RQ3.

The second category of SHs were locals that I literally approached on the street, or whom I was able to contact through local community centres. I polled to what extent they were experiencing the problems that green roofs may help solve and asked for their willingness to pay to solve these problems. Their answers gave insight into the social factors of green roofs and their financial willingness to invest.

Research question 5 comprises the perception of green roofs by relevant stakeholders. Hence these stakeholders needed to be identified and interviewed. A qualitative approach was chosen, due to the available resources for the research. Some results also fed into answering research question 3 regarding the trends in subsidies.

2.3.1 Stakeholder mapping

When determining which stakeholders are relevant it must then be evaluated who has a claim, what value is at stake and how legitimate those claims are, regarding harms or benefits and voluntary and involuntary risks.

In the case of green roofs, when I determined which stakeholders to consider, I informally asked civil servants from the municipality for their opinion. Eventually I settled on nine interviews: four of which were with housing corporations (including the three biggest ones), one with the water board "Hoogheemraadschap Delfland", one with the municipal VVE service desk, one with a VVE manager, one with a housing corporation public space manager, and one representative from a tenants' association. These were deemed both influential to the process of green roof development in The Hague and it was logistically feasible to arrange meetings with them.

Next to these "top-down" interviews, I also set out to interview local residents to verify "bottom-up" to what extent the ideas and perceptions matched and to test their interest in green roofs. I managed to interview seven local residents.

The stakeholder framework by Eden & Ackermann (1998) was chosen to map all relevant SHs. This is a well known framework to map SHs onto a 2D plane, to determine the most influential ones (Ackermann & Eden, 2011). I first filled in the framework myself and then compared it with the interpretation of the interviewees. This lead to a list of all SHs perceived relevant by the SHs themselves in the investment of green roofs in the city of The Hague.

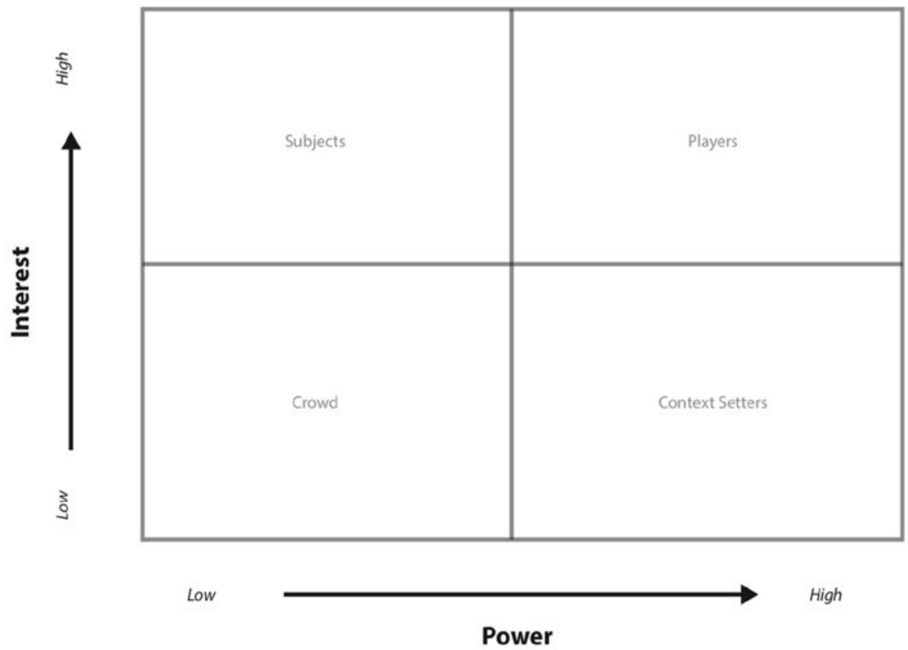


Figure 4: Qualitative framework for stakeholder mapping by (Eden & Ackermann, 1998, p. 122).

Within the Eden & Ackermann framework the concepts of power and urgency are used. Power is defined as “the ability to bring about desired outcomes & the ability to control the behaviour of others to achieve one’s own interests (rather than the interest of others)”. Interest is defined as “the degree to which stakeholder claims call for immediate attention” (Mitchell, Agle, & Wood, 1997). During the interviews this was sometimes simplified into power: “the ability to influence decisions” and urgency: “how much one cares about the issue at hand”. I did this when the interviewee struggled to comprehend the framework, since for most it was the first time they saw it.

2.3.2 Interviews

The TU Delft ethics committee was asked permission for the doing the interviews (appendix). The overall health and privacy risk was considered very low, since the data was made anonymous. The interviews did however include the recording of the respondents for easy transcription later. After the study, these recordings have been permanently deleted. When quotes from participants were used, the participant in question was consulted by email to give them the opportunity for rectifications.

When devising the protocols for the interviews I used two sample interview protocols as example and inspiration (CSED, n.d.; Sheppard et al., 2010). I based my interviewing technique on the books “Interviewing” and “The good interview” which were recommended. The most important aspects were to really give interviewees the space to answer freely, ensure a pleasant and good atmosphere to facilitate honest and realistic answers and to be careful not to take over the conversation as if it were a friendly discussion (Holstein & Gubrium, 1995; Stewart & Cash, 2008).

The interviews with stakeholders (office interviews) were structured semi-flexible. This meant that a interview protocol was made, but that is was permitted to divert from the order and exact wording of the questions, if the interview gave reason to do so. The goal of the interviews was to: (1) capture their perception on the pros and cons of green roofs, (2) ask about their perception on sustainability and resilience in general, and (3) retrieve their perception on the two problems green roofs can potentially solve: UHI and SWF. The interview was "sandwiched" between easy start and end questions, with a more in depth middle part.
Early on, emphasis was put on housing corporations, given that they own a lot of real estate (32%) in the city and are thus a cluster of actors with potential decision power and potentially high impact for the city if they were to implement green roof implementation policies. The aim was to question people for opinions until exhaustion. Meaning that no new opinions were being found despite the increase in participants.

The interviews with residents (street interviews) were shorter and structured differently, yet also semi-flexible. The concept of hedonic pricing was used to test their perceived value of green roofs and UHI & SWF mitigation. This was done by asking them their willingness to pay (WTP) to receive theoretical benefits that green roofs can indirectly provide. These benefits were exaggerated in order to provoke response. For example "cooling" of the street was compared with the temperature inside a supermarket during Summer. The strategy was to make participants think about the summer of 2019 which had two heat waves and to them have them imagine personal areas that were cool and pleasant. Such that I could ask them how much they would be willing to pay to have that same comfort in their house (private) or street (public). And I specifically asked for a one time payment versus a monthly pay.

Only in the last phase of the interview were participants asked directly for their perception of the pros and cons of green roofs, to prevent bias. Before doing the real interviews, I first tested twice on friends to see if the interview protocol worked and I adjusted accordingly. The local interviews were also recorded. Also in this case the goal was to "ask until exhaustion", until no new or exceptional answers were coming up.

The analysis of the interviews afterwards was done using an interview coding method by Löfgren (2013). The complete method is found in the appendix. The interviews were first loosely transcribed in a simplified way, by only writing down quotes and not every word spoken. This reduced the workload and improved the process speed of the analysis.
The method then consisted of 5 steps: (1) reading the transcripts carefully for familiarization with the data, (2) labelling relevant pieces (called coding), (3) bringing codes together into categories and (4) labelling the categories and finding connections between them and (5) writing down results; summarizing insights into hierarchies or figures if possible.

3 | Results

In this chapter, each section treats one research question respectively. Firstly, green roof potential is assessed by locating current green infrastructure and by combining roof suitability and climate nuisance. Secondly, ecosystem service flows are calculated in the scenario that all suitable roofs would be made green. Thirdly, subsidy trends are analysed and compared with real estate ownership and several qualitative insights from interviews. Fourthly, the financial viability of green roofs is explored. And lastly, stakeholder perception of green roofs is evaluated, as a result from the conducted interviews.

3.1 The Hague's green roof potential

As introduced in chapter 2, the first research question consists (1) identifying where green infrastructure is currently located, (2) the GWR analysis and (3) locating what areas hold the most potential to realise green roofs.

3.1.1 Green infrastructure spatial distribution

The presence and lack of GI, may be a first indication of where green roofs might be useful. Green infrastructure, as represented by the mean NDVI per neighbourhood, seems to be most absent in the city centre and adjacent South-West neighbourhoods (Figure 5). These are districts such as: Laak & Spoorwijk, Binckhorst, Schilderswijk, Centrum, Stationsbuurt, Valkenboskwartier, Regentessekwartier, Groente- en Fruitmarkt and Transvaal. A notable exception is Scheveningen in the North, which, due to its harbour and built environment has the lowest mean NDVI of the municipality. Predictably districs such as Haagse Bos and Zuiderpark score high NDVI, since these are a forest and a park.

When compared to density, the NDVI is strongely correlated. Where NDVI is high, density is low. This would be expected, that indeed GI is low in areas with high density. Duindorp, in the North-East is an exception, scoring low NDVI and low density respectively. High density could also be an indication that such areas have many roofs.

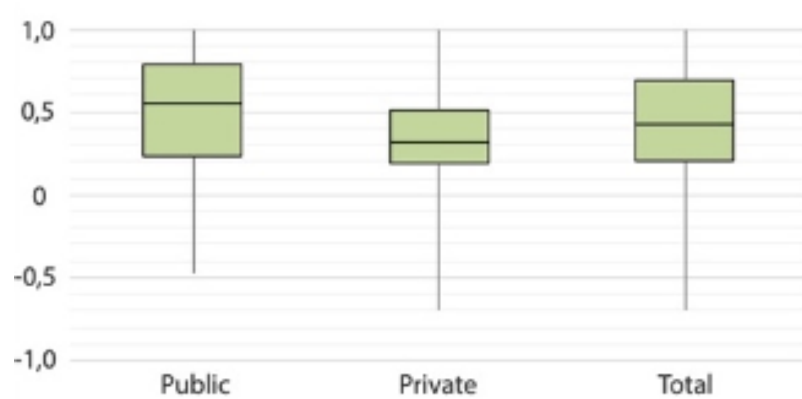


Figure 5: Boxplot of public, private and total NDVI values. Q1 and Q2 (the average) differ each 0.3 points. Public NDVI values are generally higher.

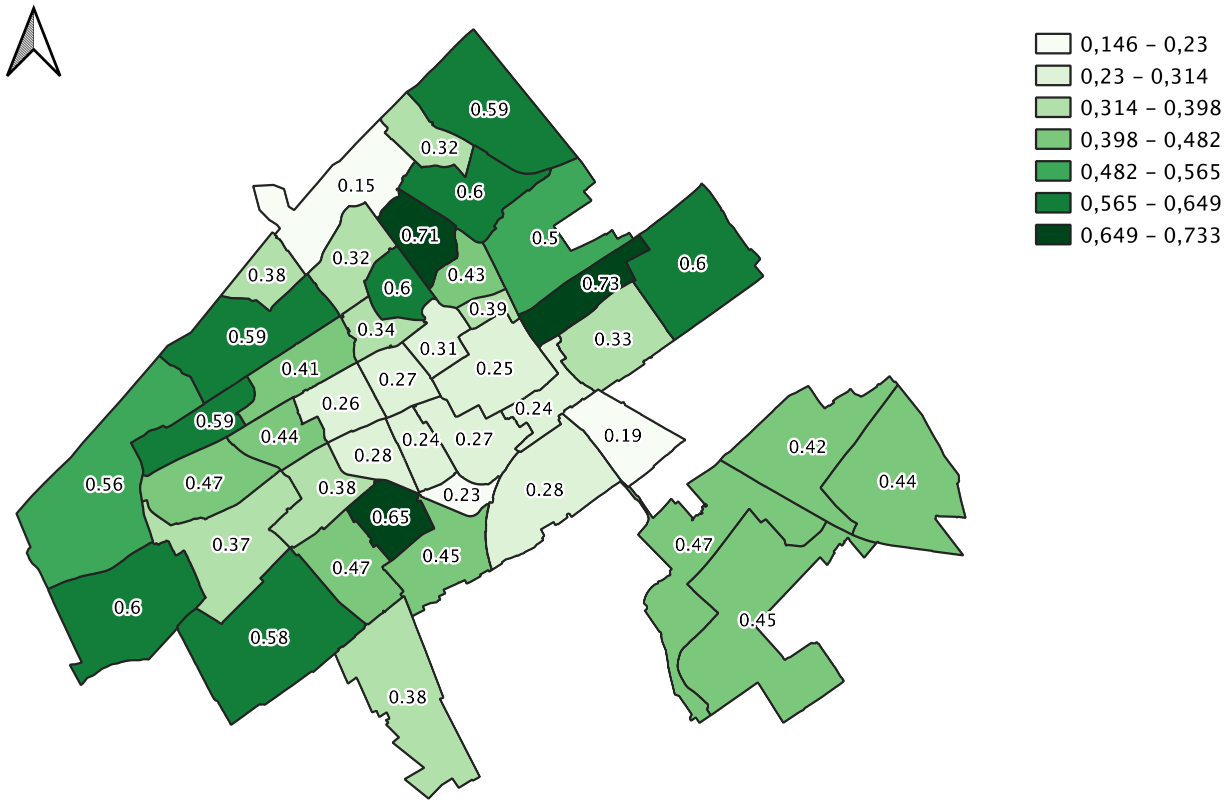


Figure 6: Mean NDVI values per neighbourhood. Central area and adjacent neighborhoods score lowest values. Low NDVI values correlate with high density values.

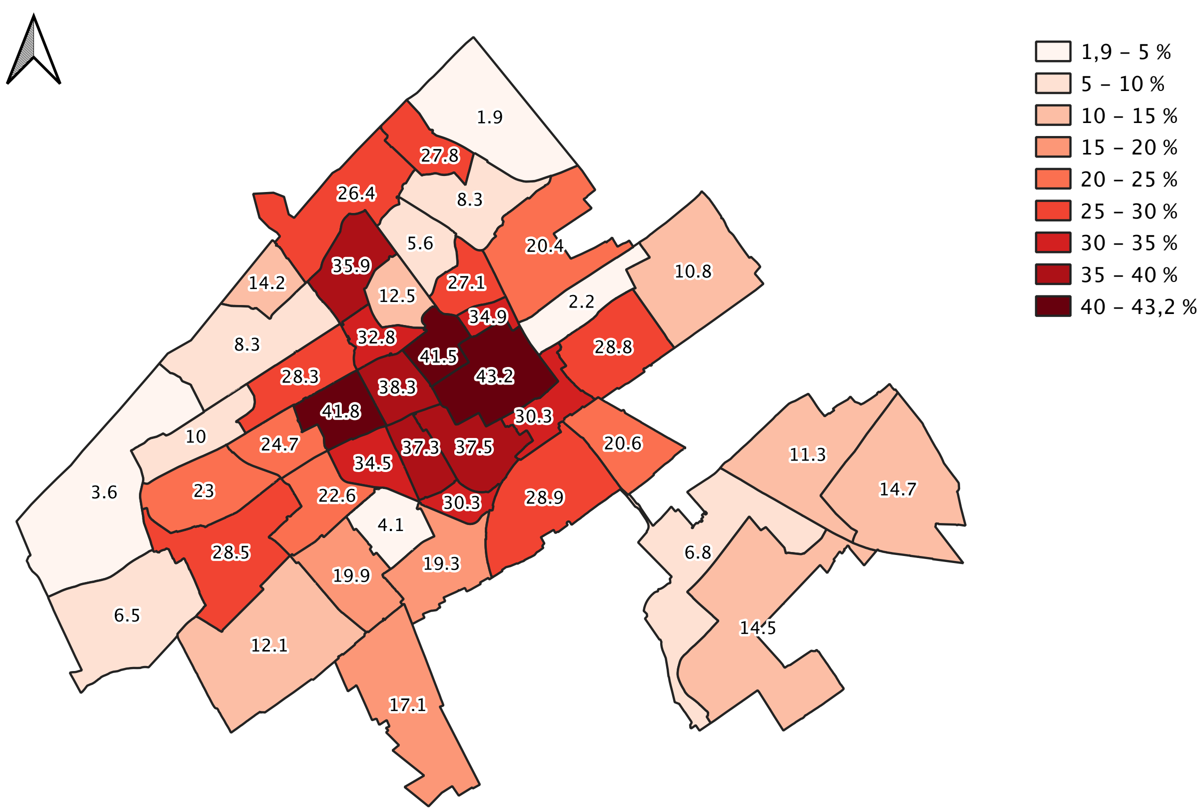


Figure 7: Percentage of built envrionment per neighbourhood; urban density. High density values correlate with low NDVI values.

Roofs that are located in areas with low NDVI, and therefore potentially a need for increased vegetation.

This is further strengthened when NDVI values are split into public and private property (as discussed in chapter 2). Private property yields much lower much values than public space. There is a difference of about 0.3 points on average, as well as the quantile 1 values (Figure 5). Public space is generally greener than private space.

3.1.2 GWR analysis

As mentioned previously in chapter 2, civil servants told me that green roof subsidies did not end up on the areas of the city where they were needed most; the areas with most UHI and SWF problems. A geographically weighted regression analysis was carried out in ArcGIS to test this statement.

NDVI was tested as dependent variable in relation to LST, SWF and subsidy distribution and LST and SWF where also tested as dependent variable in relation to subsidy distribution (Table 4).

Only in the case of NDVI with LST was R2 greater than 0,5, meaning there is a statistical relationship between temperature and vegetation. No such relationship was found between SWF and vegetation, meaning GI cannot be used to help predict SWF, whereas a higher temperature is confirmed to be correlated with lower NDVI values.

No relationships where found between subsidy and NDVI, LST and SWF. This means that the civil servant's statement is likely correct: the distribution of subsidies over the municipality does not coincide with the areas with high LST, SWF or NDVI values.

Table 2: Results of the GWR analysis. Only NDVI + LST yields R2 greater than 0,5 confirming a correlation.

Dependent variable	Explanatory variable	R2 Adjusted	Moran's index
NDVI	LST	0,647	0,129
NDVI	SWF	0,194	0,066
NDVI	Subsidy distribution	0,174	0,150
LST	Subsidy distribution	0,002	0,24
SWF	Subsidy distribution	-0,022	0,01

3.1.3 The areas that hold the most green roof potential

The last part of RQ1 is about locating the areas with the biggest potential for green roofs. These were calculated by combining SWF & UHI nuisance (problem index) with roof slope and available roof surface (suitability index). All intermediate steps can be found in the appendix. The end result is shown in Figure 8.

Many of the neighbourhoods that score the highest in terms of potential are the same ones as the ones with low NDVI values: Laak & Spoorwijk, Schilderswijk, Centrum, Stationsbuurt, Valkenboskwartier, Regentessekwartier, Groente- en Fruitmarkt and Transvaal. Neighbourhoods at the edge of the city score low potential values, given their low densities and high NDVI values. The average potential is medium (0,66). This could be because of the high number of flat roofs in The Hague (Gemeente Den Haag, 2012)

The highlighted areas in the box in Figure 8 will receive extra attention and money in the coming years for sustainability and resilience efforts. This is captured in the so called "raamovereenkomst" between the housing corporations and municipality, a binding agreement. Two out of six priority neighbourhoods are classed as high penitential, while the majority is not.

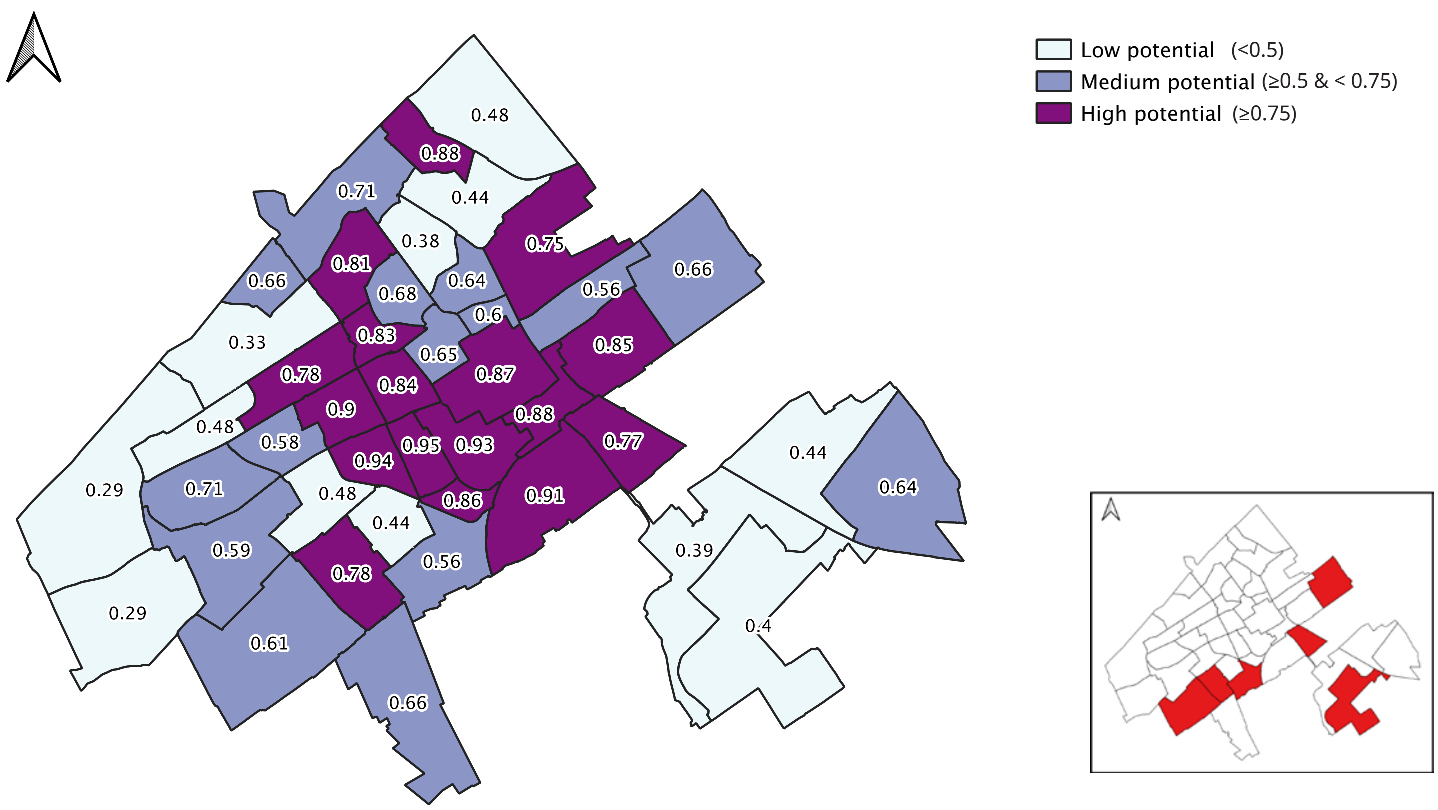


Figure 8: The potential of green roof development in The Hague. Combination of problem index and suitability index, aggregated with equal weights.
In the box: Priority areas for urban and sustainable development as determined in the 'raamovereenkomst' (binding agreement) between housing corporations and the municipality.

3.2 Ecosystem service flows

To answer research question two, ecosystem service flows were calculated to assess the ability of extensive green roofs to mitigate SWF and UHI. It was assumed that all roofs would become green. The areas with high potential sometimes differ from the actual ES flow that can be provided. The total water buffering by green roofs at best was able to mitigate 5% of the needed capacity. The highest temperature difference was 0.9 °C for an average temperature of 33,3 °C instead of the 34,2 °C it would otherwise have been. The mean temperature in The Hague meanwhile was 30,9 °C wiht an average decrease of -0,73 °C.

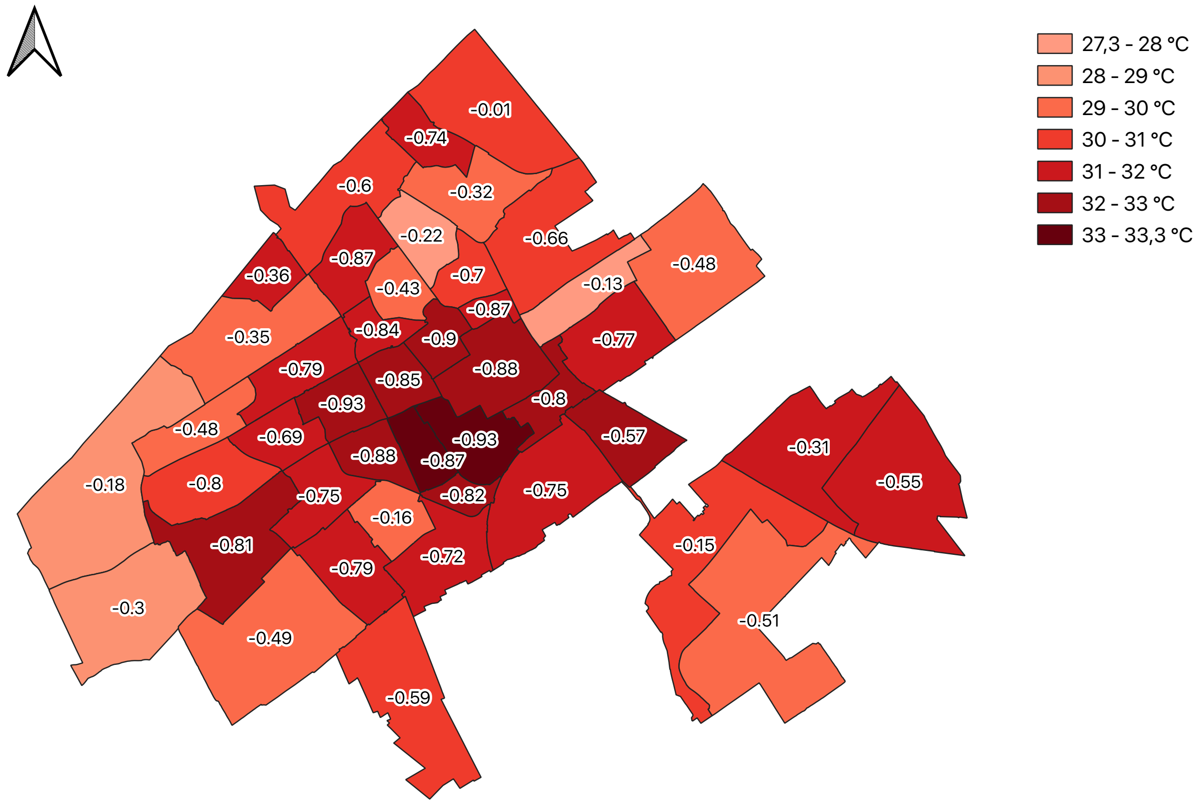


Figure 9: The predicted decrease in temperature per neighbourhood when all available roofs contribute to a lower mean LST per neighbourhood.

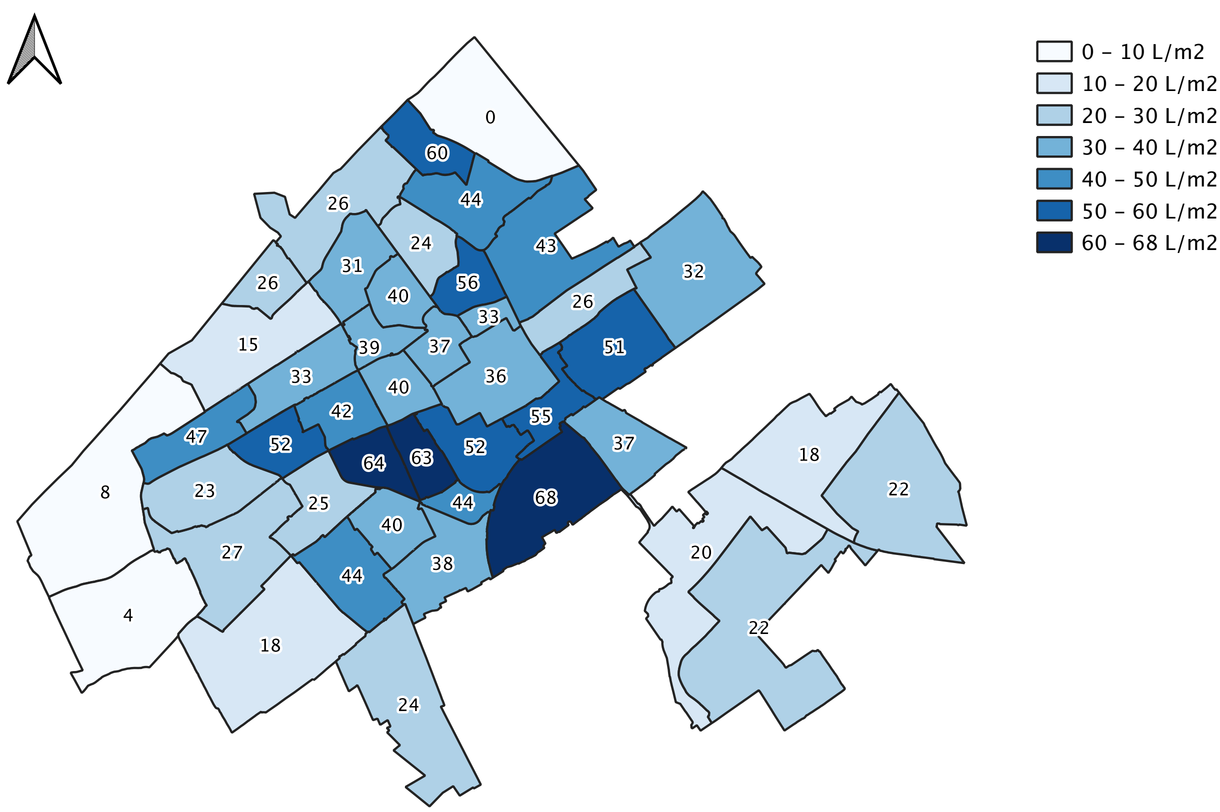


Figure 10: The predicted increase in storm water buffer capacity per neighbourhood for the specific rain event of 100 mm in 2 hours

3.3 Subsidy trends

In this section, research question three is examined: can trends in the city's green roof subsidies be found? Two neighbourhoods clearly stand out: Scheveningen and Mariahoeve (Figure 11). They score the highest for the two subsidy indicators that were used. Both of these have a "medium" score in terms of potential. Although Scheveningen is very close to getting a score high enough for "high potential" (0.71, where 0.75 is needed). This is a significant difference with the other neighbourhoods of The Hague, which average at a score of 0,15.

The average green roof is between 30 – 40 m2 and on average costs are €77/m2 (median €69/m2). There is a big variance in costs ranging from €19/m2 to €493/m2.
In the period of 2016 – June 2019 there were 175 people who received subsidy, out of 314 requests. In the period of 2009 – 2015 about 6.336,83 m2 green roof was realised per years. In the period of 2016 – 2019 that was 5.717,80 m2 per year. So there is a small decline in subsidy rates. Despite the policy changing every few years, this has not had a big effect on the distribution (Carrilho, 2015).

When compared to roof ownership several patterns arise (Figure 12). Subsidy spending is very low in neighbourhoods with a high percentage of housing corporation ownership. Also in about half of the cases of high potential, housing corporation ownership is also high. This could mean that they could get an important role if green roofs are to be realised at scale.

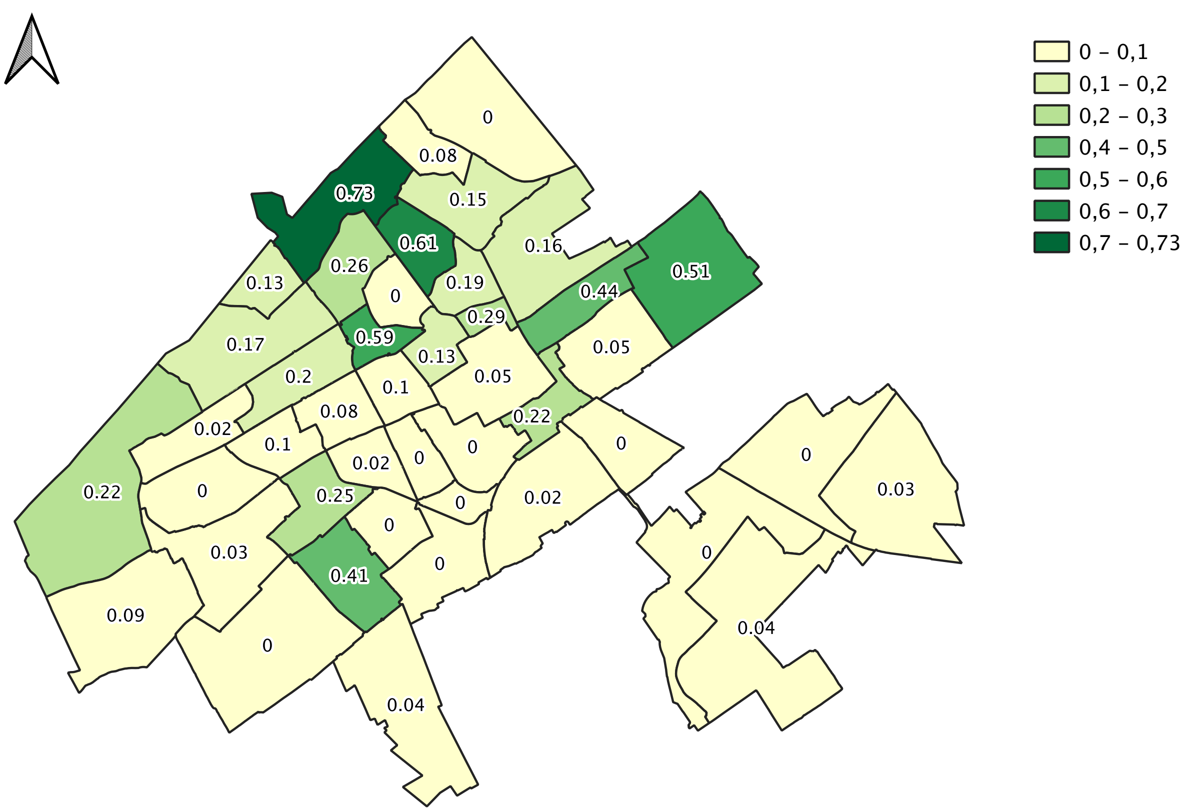


Figure 11: Distribution of subsidized m2 as a percentage of all available m2 roofs per neighbourhood (2016 – June 2019).

When compared with VVE distribution patterns are harder to identify. VVEs appear to be everywhere in the city and no clear correlation with potential for green roofs, housing corporations or subsidy distribution can be made.
None of the housing corporations spoke about subsidies. Green roofs are almost always paid by corporations themselves and usually only if there is budget left over. Subsidies seem to not reach these corporations.

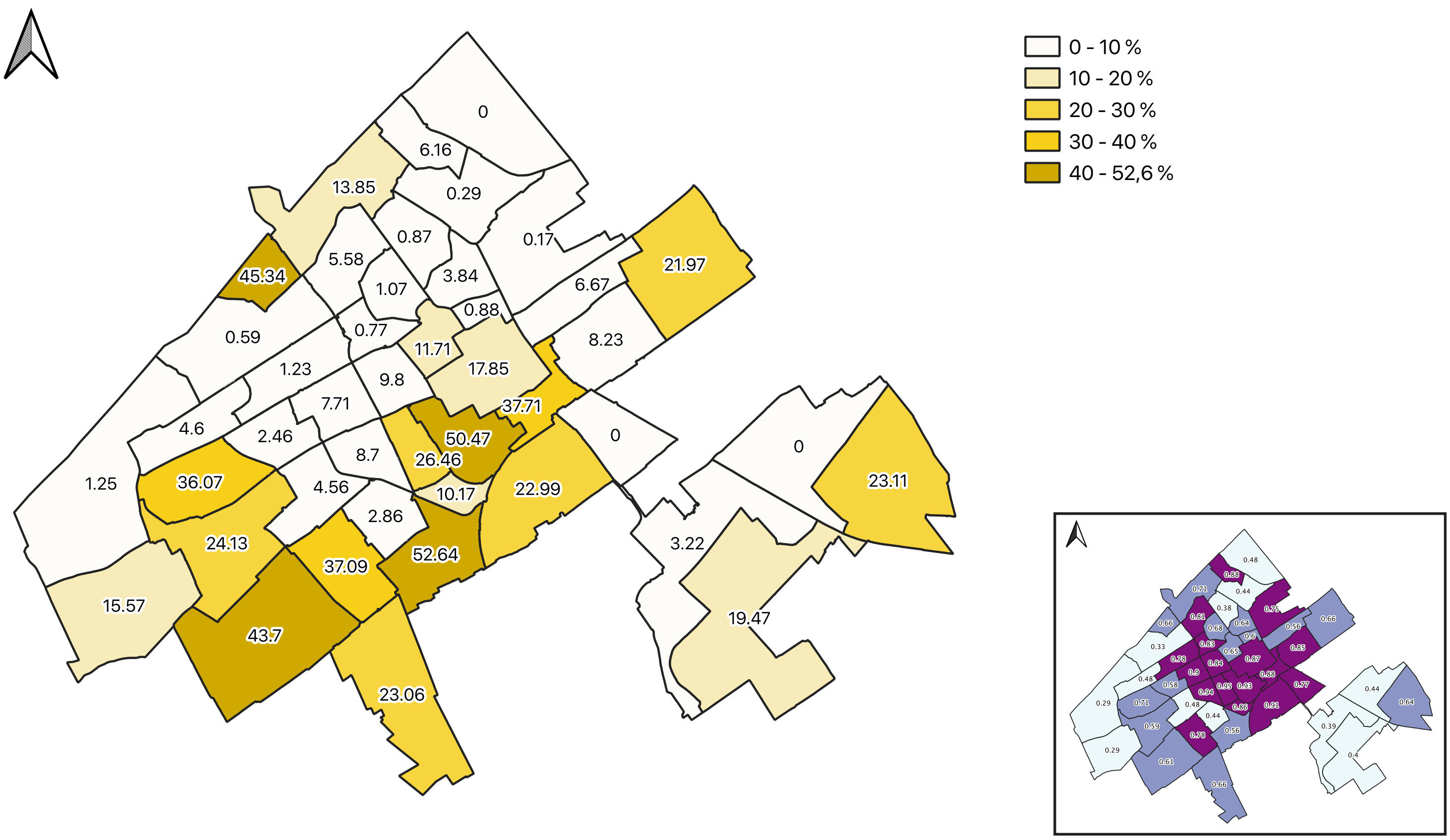


Figure 12: Percentage of housing corporation ownership per neighbourhood.
In the box: the potential for green roof development for easy comparison (Figure 11).

3.4 The financial viability of green roofs

Green roofs seem to be financially viable under the current subsidy conditions. in The Hague. A standard bitumen roof yields an NPV of -€30, assuming a life span of 30 years and a project of 60 years. A standard green roof yields an NPV of €-29,51. This difference in NPV means that the green roof performs slightly better than the business as usual. However, all numbers are estimated conservatively, specifically the discount rate of 10% and the property value increase of €75/m2 (Bianchini & Hewage, 2012). This means that with higher discount rates the difference can me more stark. The green roof + PV option yields an NPV of €119,48 with an IIR of 56%. This suggests that this would be a very worthwhile investment. In fact, this is without the increased efficiency that green + PV roofs are claimed to have. A sensitivity analysis was also done, as mentioned in chapter 2. Most parameters proved to be sensitive for change. Maintenance costs and property value increase (see appendix). A few corrections to the NPV calculation are found in appenxdix 7.9

Table 3: Bitumen

Inputs		Outputs	
Discount rate	10%	IRR	-
Installation costs/m2	- € 15,00	NPV	€ -30,00
Subsidy Hague/m2	€ -	Payback in year	-
Subsidy Water board/m2	€ -		
Maintenance/m2/yr	€ -		
Energy saving/yr	€ -		
Project Lifetime [years]	60		

Table 4: Green roof

Inputs		Outputs	
Discount rate	10%	IRR	12,95%
Installation costs/m2	- € 62,00	NPV	€ -29,51
Subsidy Hague/m2	€ 25,00	Payback in year	0
Subsidy Water board/m2	€ 15,50		
Maintenance/m2/yr	- € 5,00		
Energy saving/yr	€ 2,00		
Project Lifetime [years]	60		
Inflation maintenence	5%		
Energy inflation	2%		
Property value increase	€ 75,00		

Table 5: Green roof + photovoltaic

Inputs		Outputs	
Discount rate	10%	IRR	56,09%
Installation GR [€/m2]	- € 62,00	NPV	€ 119,48
Installation PV [€/m2]	- € 120,00	Payback in year	2
Subsidy Hague [€/m2]	€ 25,00		
Subsidy Water [€/m2]	€ 15,50		
Maintenance [€/m2/yr]	- € 5,00		
Energy savings [€/yr]	€ 2,00		
Energy/yr/m2 [kWh]	125		
Energy price [year 0]	€ 0,22		
Energy price deflation	s-curve		
Project Lifetime [years]	60		
Inflation maintenence [%]	5%		
Property value increase [€/m2]	€ 75,00		

3.5 The stakeholder perception of green roofs

In this section, the results are presented of the stakeholder mapping and the interviews. I conducted 9 office interviews and 7 street interviews. In total I approached 10 people for the latter category. Probably thanks to my position as an intern at the municipality of The Hague, non of the people I approached for an office interview declined.

3.5.1 Stakeholder mapping

All housing corporations filled in the Eden & Ackermann framework to identify key players, subjects, context setters and crowd. Four categories had notable exceptions, these are highlighted with a square in Figure 16.

Housing corporations where generally placed as a key player, but one corporation placed himself in the crowd category. This was a very small corporation in The Hague, and he had therefore a different perception than the other interviewees.

VVEs are generally regarded as key players, but one interviewee places them in crowd. The majority of VVEs in The Hague (±90%) are small, with less than 10 participants. These do not have much power, is the reasoning. Other corporations think VVEs have much more power, because they legally have rights and can halt progress or block initiatives when corporations share a VVE with house owners.

One participant places suppliers as a key player, because they can make or break the product, especially if they also do maintenance. Most other corporations see suppliers as dependent on them as a customer, so much less power.

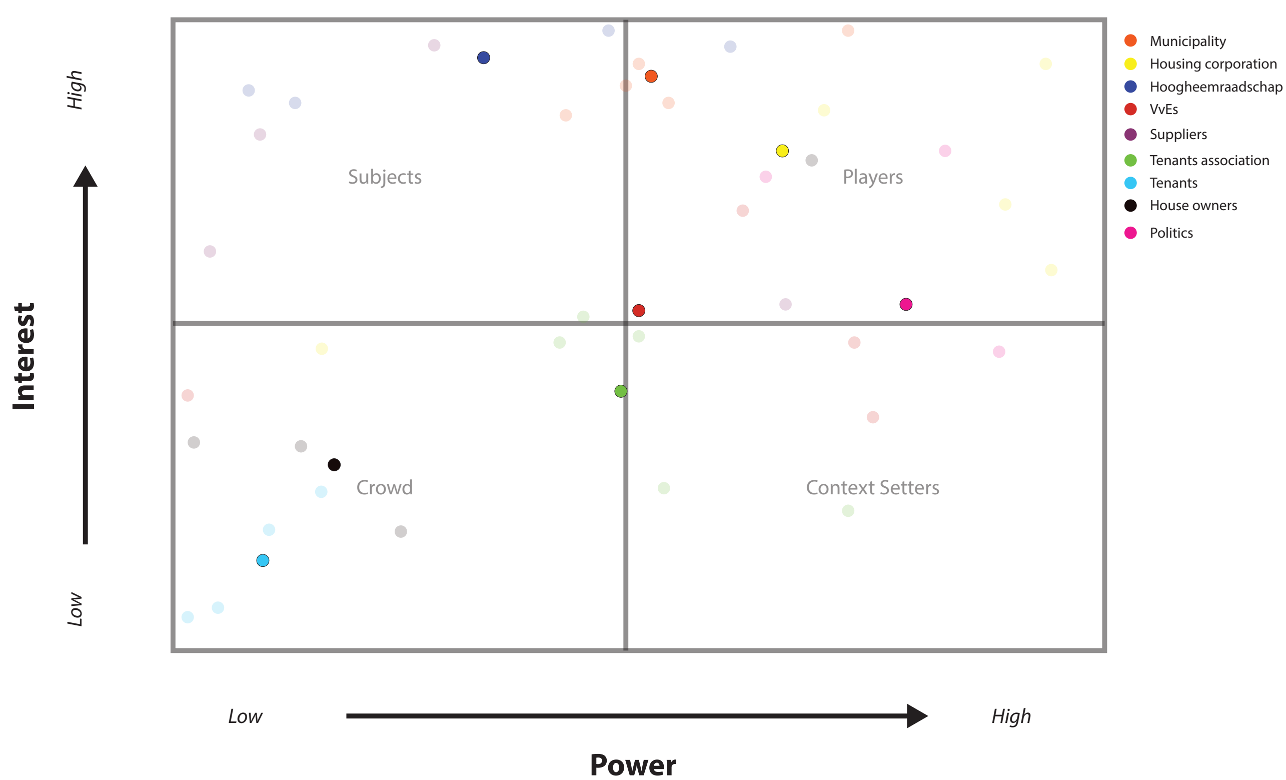


Figure 13: Stakeholder map with average location highlighted.

The last exception is house owners. One interviewee viewed this as a key player, because they are independent and can do with their property what they want. While others think their diffusion makes them not very powerful in decision making processes. Other than these exceptions the clusters of dots seem to agree with my hypotheses. Key players are therefore: housing corporations, the municipality, politics, and VVEs. Tenants and house owners are crowd, what not much influence or interest in urban green roof development.

3.5.2 Office interviews

The purpose of the office interviews was to find all perceived pros and cons of green roofs. The most important pros are aesthetics and water buffer capacity; seven out of nine interviewees mention this straight away. Maintenance / costs and the uncertainty if it is a worthwhile investment are the most important cons, with seven and six respondents respectively.

Generally speaking, stakeholders are positive, but they are unsure about the investment. There is still much unknown and even though they want or like it, it is hard to sell because it does not seem to yield many private benefits. Housing corporations and VVEs both do not have a lot of many available, so every euro needs to be spend well. It is not obvious to them that green roofs fit into that picture.

Tenants are also important, since they too do not have much money. "No matter what sustainable investment you make, at the end of the day it is going to increase the value of that apartment, which will result in high rent".

All perceived pros are known in academic literature and have been studied extensively. The heat management remains a point of discussion (Berardi et al., 2014). In terms of cons, some new points are raised: uncertainty about the investment and about the lifespan is not reflected in literature, but at least half of the interviewees were concerned about that.

Another new barrier is the complexity of VVEs and right of consent. Housing corporations are more or less obliged to agree with the other members of a VVE, they cannot force sustainability renovations. Members are legally protected against such behaviour. But also in housing with only tenants from the corporation there are rules. For big investments, which inevitable will result in higher rent, 70% of tenants need to agree with the plans. This makes housing corporations rather cautious in their ambitions, according to their own statements.

VVEs are seen as a substantial barrier to sustainability efforts in general. They are relucted to invest and are legally not obligated to improve, only to maintain their current house. "I'm involved with guiding VVEs for renovations and I always try to sell the idea of green roofs, which I barely succeed in at all." This is because the legal obligation of a VVE to maintain, means that even during reparations, buildings can be kept to 1900s standards. "These are the main pain points: (1) they never see their personal stake; they see limited benefits, but large costs, (2) it takes too long for them to earn their investment, more than 5 years is too long, (3) legal issues, objection procedures, and (4) no financial means and little willingness to borrow money from the bank."

A very specific issue that the Water Board is facing, is the "legal safeguarding that a water buffer continues to perform over the years". They see the necessity to invest

Table 6: Pros and cons from office interviews, and how often items were mentioned.

Pro	Frequency	Con or barrier	Frequency
Aesthetics / embellish city	High	Maintenance / costs	High
Water buffer	High	Uncertain if worthwhile investment	High
Extended lifespan of roof	High	Costs / more expensive than traditional	High
Heat island effect reduction	Medium	Uncertain if lifespan can be achieved	High
Insulation	Medium	Leakage and how to repair leakages	High
Profitable (green roof + PV)	Low	Weight / construction	Medium
Beneficial for corporate image	Low	Complexity because of VVEs	Medium
Ecological value	Low	Hard to get 70% majority to approve	Low
Purify air	Low	Knowledge gap	Low
		Competition from bitumen (lifespan)	Low
		Organisation / transition to green roofs	Low
		Safety during inspection / maintenance	Low
		Fear for the unknown	Low
		Fragmentation of ownership	Low
		Business partners	Low
		Legal safeguarding that water buffer continues to perform over the years	Low
		Training own personnel to be able to monitor outsourced work	Low
		Plants sometimes don't flourish	Low

Table 7: Pros and cons in academic literature that was not mentiond by anyone in the interviews

Pro	Source	Con	Source
Sound insulation and noise reduction	(Berardi et al., 2014; General Services Administration, 2011)	Management issues	(Shafique et al., 2018)
Recreational opportunities	(Langemeyer et al., 2019)	Not actually green	(Vijayaraghavan, 2016)
Urban agriculture	(Shafique et al., 2018)	Runoff quality	(Vijayaraghavan, 2016)
Job generation and economic development	(General Services Administration, 2011)	Polluting polymer materials and ultimate disposal	(Shafique et al., 2018; Vijayaraghavan, 2016)
Increase the property values	(Bianchini & Hewage, 2012; Shafique et al., 2018)	Structural damage	(Vijayaraghavan, 2016)
Public health	(Shafique et al., 2018)	Insects / pests	Shafique et al., 2018)
Helps against seaguls	(Barker, 2020)		

Table 8: Pros and cons from street interviews, and how often items were mentioned.

Pro	Frequency	Con	Frequency
No idea; hard for me to imagine	High	No idea; hard for me to imagine	High
Aesthetics	Medium	Mould (?)	Low
Insulation	Low	Dirt and filth across the windows when it rains (?)	Low
Ecological value	Low	Birds and therefore bird poop	Low
Purifying air	Low	Weight / construction	Low
Environmentally friendly	Low		

in bottom-up, small scale resilience measure, because “large scale water management infrastructure is reaching its limits in terms of physical space and affordability”. But they do not know how to ensure that the water buffer capacity will remain stable over the decades, while house owners can move.

There are also multiple housing corporations with bad experiences with green roofs. Leakages, or plants that don’t flourish, “just a lot of hassle, if you build a bitumen roof you don’t have to visit it for the next 18 years instead of once every 6 months”.

In terms of business case, a PV + green roof option is also difficult, because a housing corporation is not allowed to be an energy producer. So legally they cannot realize the best possible scenario. That makes it difficult. And “In the end: green roofs may improve the climate on the street, but people see “de street” as a given, they just except whatever temperature or weather is out there and just deal with it”.

Table 6 has an overview of all perceived pros and cons. When compared to the academic literature there is not much emphasis on corporations and VVEs; stakeholders in general. A lot of research is about the environmental and macro economic effects. Table 7 shows the which pros and cons were not mentioned by the stakeholders. From the responses that were given quite often (7), three I could not find in literature. These were: uncertain if worthwhile investment, uncertain if lifespan can be achieved and complexity because of VVEs.

3.5.3 Street interviews

The purpose of the street interviews was to find perceived pros and cons of green roofs and to test willingness to pay for green roofs, by asking if they experience nuisance from the UHI and SWF, which green roofs can help solve.

Most respondents had no idea about green roofs. Six out of seven could not think of much pros and five out of seven could not think of any cons. Half of the respondents did say they would enjoy the aesthetics.

Regarding water nuisance WTP was zero, because nobody experienced any hindrance of SWF. There is a high level of acceptability when it comes to flooding, as long as it does not flood their own homes. But even then people see that as impotence and not as incompetence of the municipality.

Four out of seven respondents said they did experience significant hindering of heat during the heat waves in their home, while three did not care and just dealt with it. Especially sleep was difficult, which is in line with the literature. Most did know what their roof looked like, but trying to imaging that green was difficult. Many did like the idea of an intensive roof garden, unless they already had a garden.

Three overarching patterns were found: (1) a common lower trust in the municipality, housing corporation, presented information and other institutions, (2) sustainability, environmental impact, climate change, recycling, green: all these concepts were one and the same, and (3) respondents made several comments about having little money to spare.

4 | Discussion

The result of RQ1 was a high potential for green roof development in and around the central city area. This clustering seems to be a global trend. Other cities and metropolitan regions show similar patterns towards urban cores, when green roofs or green infrastructure demand is examined (Langemeyer et al., 2019; Meerow & Newell, 2017). A study by the European Commission found that wind speed and density can predict UHI (RAMSES, 2018), which is, of course, one of the climate resilience issues green roofs aim to solve. So, one could wonder how precisely it is possible to predict climate resilience demand in cities. Such that this can be used to improve cities with policy.

RQ1 also confirmed a correlation that had been found by van Oorschot (2019) regarding NDVI and LST correlation. My R2 came out lower, despite us using similar spatial data. And she found a correlation between SWF and NDVI, while I did not. The data may have been the same, though; it was different. Specifically, my method for calculating SWF (based on an existing model from klimaatatlas) was entirely different from her method with soil types. In the area where we should find similar R2 values, we did. Since both of us used NDVI and LST values, but we used different periods. My LST was a median over summer, while hers was a single day.

The GWR analysis in RQ1 also confirmed the suspicions from civil servants about the subsidy spread. And this was later confirmed from a different angle as well in RQ3: subsidies are spread unequally over the city and do not end up in neighbourhoods where they are most needed. Most needed being neighbourhoods with high potential and low income. The latter was not explicitly part of my study, but, e.g. the liveability index almost totally correlates with the "raamovereenkomst" map (figure 8) and the spread of housing corporations (figure 12). These are areas where residents are likely not able to afford green roofs themselves, and they often have high scores for green roof potential. The priority map from van Oorschot (2019) also shows stark similarities with the green roof potential map. Van Oorshot's work did also use the liveability index.

Research question 2 showed a novel way to calculate an ES flow for a city while not being overly unrealistic. It would not have been reasonably possible to calculate better, more accurate UHI indicators than LST, given the available data. (Alexandri & Jones, 2008) have demonstrated how complex the many variables are that influence temperature in cities. My model should therefore also not be taken too literal, because it ignores any feedback loops in the microclimate of cities.

However, I think it does give an idea of what a possible effect of green roofs might be, rather than only pointing to the spot where they would probably be beneficial.

In recent years, we have already begun to experience more frequent heatwaves, and consequently, the research on it has also gone up. Huynen et al. (2001) has shown that deaths from heat grow exponential as temperatures become tropical (around 30 °C). In the 2005 heatwave, deaths increased by about 12,1%, which corresponds to about 40 deaths per day. And it was confirmed that these were not only people already vulnerable (so-called 'early harvesting'); in part, the increase in deaths also come from more healthy people.

So, given the exponential relationship between mortality and temperature, a
1°C drop in ambient temperature, could save lives. Again, the ES flow I calculated was not the ambient temperature; it was surface temperature. But those two are also linked of course (Hoeven & Wandl, 2018)

The water buffer capacity of green roofs is often most well known and most celebrated in public discourse, but academic literature and the Water Board I interviewed are more reserved. A big problem is increased runoff as rain intensity increases (Bengtsson, Grahn, & Olsson, 2005; Semadeni-Davies, Hernebring, Svensson, & Gustafsson, 2008), which is coincidentally precisely when one wants more water buffer capacity. That is why I used conservative numbers in my ES flow calculation, and that is also why the Water Board and Amsterdam rainproof advocate additional water buffering measures. At the time of writing, the Water Board of The Hague (Hoogheemraadschap Delfland) is conducting their own research to measure the exact, real water buffer capacity of green roofs under various forms of precipitation. Future studies could improve on my model by using their calculations.

Research question 4 concludes something novel, which even advocates of green roofs usually do not mention. Because when the property value is considered, green roofs are a good, or at the very least equally good alternative to a standard roof (from a financial point of view). This was found despite the fact that the costs of green roofs are always listed as one of their main downsides (Blackhurst et al., 2010; Zhang, Shen, Tam, & Lee, 2012). The increase in property value might be a game-changer. Rather than a break-even point of 6 – 15 years, thanks to marginal (and debatable) energy savings (General Services Administration, 2017), homeowners could practically instantly break even. But, not in the form of a direct cash flow of course.

So in practice, the business case would probably still be up for debate. Likely, the investment would change for the worse if repairs are needed during its lifetime, or leaks occur. But for landlords and housing corporations this may make a difference for their willingness to invest.

The financial perspective also draws parallels to solar energy literature. Green roofs are a new technology, where PV panels were new on the market 20-30 years ago. In terms of the product life cycle, solar energy is in the phase of rapid exponential growth and increasing product quality. Whereas it was only speculated how PV could be a valuable addition to the energy mix and “Today, the cost of PV electricity is too high for bulk power production.” (Pietruszko, 2004). PV prices have actually fallen by 90% since 2009 (Bloomberg new energy finance, 2016).

The interviews (RQ5) lead to a broader discussion: that of aligning incentives between renters and homeowners, as well as privately owned buildings versus the city-wide benefits of green roofs. This is again the fundamental, old economic issue addressed in the introduction: private costs and public benefits. There is, in principle, a collective action problem: everyone would benefit from having more green roofs, but no one wants to be first. In principle, people may want to pay for mitigating heat and water nuisance, but it is also not obvious.

No obvious answers to this problem have come forward through my research. Barriers to the implementation of green roofs are very diverse (legal, social, financial) and many stakeholders play a role, while no stakeholder holds leveraging power. This scattering of power and responsibility, came forward in most interviews: “in the end we don’t have much to say, we follow”. So it is a bit of a collective action problem. If every homeowner and VVE invested, everyone would receive similar benefits for similar costs. But right now there is not much social momentum yet.

In principle, the more inherently private goods or events can be caught in conjunction with green roofs, the more lucrative a green roof becomes. Roof gardens and intensive green roofs with thick soil layers yield more considerable (private) benefits, such as recreation and insulation. But the number of rooftops suitable for intensive green roofs is limited due to technical and financial limitations.

Another possibility is to subsidise maintenance, taking away one of the most significant barriers to entry. This could be branded as getting paid for the ecosystem service that one’s roof is providing for the city. This would require a shift in mentality from both homeowners as well as the municipality.

A business could also help innovate. By leasing roofs to private companies, the incentive to make long-lasting roofs that indeed reach the 60 year lifetime become possible. One housing corporation is experimenting with a similar concept. They are outsourcing their roofs to a roofing company, who have freedom on how they want to manage their portfolio. As long as they are in good shape. That also shifts incentives.
In the end, there is still much to be researched and learnt about how to increase green roofs in cities for resilience.

4.1 Methodological reflections

When reflecting on the methods, I used the number of respondents is the first thing that pops out: seven street interviews. Even though I consciously choose to do qualitative interviews, I could, of course, have interviewed more people to validate my claims further. I did ask until the point of exhaustion - when no more new answers are found, no matter how much more people you interview -, and I just happen to reach this point sooner than later. Another reason why the number is low, was because it was difficult to arrange meetings with residents and finding them. I got my interviews through community centres, which were very helpful, but also many did not respond to my emails. In the end, I am confident that the number of respondents was sufficient; clear patterns were found, but to be extra sure it would have been useful to interview more people.

I could also have chosen a comprehensive cost-benefit analysis, focussing more on positive and negative externalities. That would likely have given a different perspective and a complete view on all the pros and cons. However, I am more interested in the business case, since many of the residents of The Hague do not have a warm heart for resilience. So if an investment just makes financial sense, then that lowers the barrier to entry significantly.

If I had had a suitable background, I could have made a more comprehensive model with more variables. Not only LST and SWF, but also recreation and biodiversity for example, similar to the work of Langemeyer and Meerow. But this allowed me to also focus on the qualitative part of my research and triangulate results.

4.2 Future research

Several possibilities for future research have been found.
Firstly, a more comprehensive approach to resilient roofs could be studied. Since the municipality has committed to making their roofs more resilient in the coming years, the city wide ES flows could be calculated for different roofing options in relation to their costs to investigate their cost-effectiveness.

Secondly, in terms of suitability it would be relevant to consider proximity as an indicator. Green roofs are most needed in areas where there are high amounts of problems, low amounts of green infrastructure and where there is very little space to increase that infrastructure. Currently, the proximity of a roof to other roofs is not considered in the calculations. In higher urban densities or high proximity adapting the roof increasingly becomes the only option that is left, if streets and parks are already full of GI.

Thirdly, as more roofs are turned green it would be useful to use drones or computer vision and the high resolution photography dataset of the Netherlands to monitor the development of green and other resilience roofs and estimate their effect on mitigating UHI and SWF, to verify this thesis' findings.

Fourthly, there is demand for a hands-on tool for both the municipality and stakeholders, to determine which resilient roofs are needed in which parts of the city. A roadmap or flowchart, together with a stress map. This was specifically mentioned by a stakeholder during one of the office interviews. In line with the work of Meerow (2017), also other ES such as biodiversity, nitrogen sequestration, air and water purification could be considered in the light of the multifunctionality of green infrastructure and green roofs.

Fifthly, it is not certain that the effects of green roofs scale linearly to the city level. Alexandri (2008) has modelled feedback loops and aggregated effects of the urban heat island effect and green roofs. But this has never been modelled for an entire city, like The Hague. One of the biggest barriers for stakeholders is the uncertainty if green roofs are a worthwhile investment. The more evidence that can be provided to demonstrate the effectiveness of green roofs, or lack thereof, the more likely stakeholders are to be willing to invest. Especially housing corporations show a concern about the impact of their real estate on the city, but they want to invest only if the effects of their investment are measurable and significant.

4.3 Policy recommendations

Today, the discussion on green roofs is becoming more and more relevant, also politically. In the light of a more resilient city but and a subsidy policy that has not delivered all that much yet, recently an initiative was done in the council (Barker, 2020). It calls for better communication, refurbishing municipal real estate and lowering the barrier to receiving a subsidy. To complement this increasing momentum in the municipality, I have the following suggestions.

The first insight for the municipality is that with the green roof potential map, it can now be more confidently asserted that the distribution of subsidies is not optimal when looked at the areas that hold the biggest potential. The green roof subsidy is the same in the entire city. This 'equality principle' is deemed very important by civil servants. However, the fear that residents from across the street would be annoyed for being treated differently if that subsidy would be distributed more strategically does not seem grounded. There are already clusters of subsidised roofs within neighbourhoods, not so much between them. I would recommend re-evaluating strategic subsidy distribution related to the neighbourhoods that show the highest green roof development potential.

It is also strongly advised to research ways to simplify how homeowners, but especially VVEs can quickly get insight into sustainable renovation options (through the sustainability information booth of the municipality). Several interviewees confirmed that many people are put off by the process of making a shared building more sustainable. Such a process can easily take up to half a year, while all they want to know: how much more do I need to pay per month, to receive which benefits? VVEs are everywhere in the city, and their legal mandate (preserve, do not improve) makes them a difficult barrier to be overcome. A barrier that can be overcome however, because some projects have been very successful.

Several housing corporations were also asking the municipality to take a more leading role in sustainable roofing. Together with the knowledge of where green roofs are likely most effective, it may be possible to make better deals with housing corporations to realise more green roofs. There is a need for realistic and quantifiable resilience targets and for example, a decision tree to quickly decide in which areas of the city which resilience measures should be taken when periodic maintenance is being conducted. Because many housing corporations, who need to think about every coin they spend, will not invest unless they have to or clearly see the benefits of an investment that is in principal higher than business as usual.

Heatwaves and floods are also the right moments to make citizens more aware of green roofs and resilience measures in general. I would advise not to shy away from low-income neighbourhoods to increase this awareness. Housing corporations have several success stories about public parks, maintained by tenants. Enthusiasm and awareness go a long way and this could also been done for green roofs (especially ones that also facilitate recreation).

5 | Conclusion

The goal of this study was to examine to what extent green roofs can increase the city of The Hague's resilience towards its urban heat island effect (UHI) and stormwater flooding (SWF). This was done using spatial analyses, a financial cost-benefit analysis and two sets of stakeholder interviews.

It can be concluded that large scale realisation of extensive green roofs are likely to have a positive effect on climate resilience in The Hague. These effects are significant at city scale if green roofs are realised in large quantities, but they will likely not lead to easily noticeable effects for the average citizen on the street. Areas with high potential for effective green roof development have been identified and these areas do not overlap with the spread of subsidies so far. They disproportionately end up in the North and East of the city, where they are needed, but not needed most urgently. The "raamovereenkomst" housing corporation priority areas also do not overlap much with these high potential areas. Several areas in the city do hold a big potential to use its roof space for increased climate resilience, specifically the city centre and adjacent neighbourhoods to the South-West.

From a purely financial perspective, green roofs appear to be a viable investment in their current, subsidized form, despite their maintenance. This contradicts the general consensus about green roofs, which states that green roofs are too expensive for too little benefits. This positive net present value is largely caused by the increase in property value.

Substantial economical, political, legal and social barriers will need to be overcome to implement green roofs at city scale for public environmental benefits. New found barriers, that are often absent in literature include: the uncertainty if the increased lifespan can actually be achieved, fragmentation of roof ownership, the difficulty of housing corporations to get 70% of tenants to approve expensive renovations, safety during maintenance and the opportunity cost of training own personnel to be able to monitor maintenance work that has been outsourced. Amongst local residents, no obvious desire for green roof development or a desire for UHI and SWF mitigation was found.

The perception of the cost-effectiveness of green roofs remains open for debate and is largely stakeholder dependent. Green roofs can contribute significantly to the resilience level of cities, but how well they stack up against other alternatives, remains to be seen.

6 | Literature

Ackermann, F., & Eden, C. (2011). Strategic Management of Stakeholders: Theory and Practice. *Long Range Planning*, *44*(3), 179–196. https://doi.org/10.1016/j.lrp.2010.08.001

Ahern, J. (2007). Green infrastructure for cities: The spatial dimension. In V. Novotny & P. Brown (Eds.), *Cities of the Future: Towards Integrated Sustainable Water and Landscape Management* (pp. 267–283). London: IWA Publishing.

Alexandri, E., & Jones, P. (2008). Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. *Building and Environment*, *43*(4), 480–493. https://doi.org/10.1016/j.buildenv.2006.10.055

Barker, R. (2020). *Haagse Daken Kleuren Groen: Initiatiefvoorstel*. Den Haag.

Bengtsson, L., Grahn, L., & Olsson, J. (2005). Hydrological function of a thin extensive green roof in southern Sweden. *Nordic Hydrology*, *36*(3), 259–268. https://doi.org/10.2166/nh.2005.0019

Berardi, U., GhaffarianHoseini, A. H., & GhaffarianHoseini, A. (2014). State-of-the-art analysis of the environmental benefits of green roofs. *Applied Energy*, *115*, 411–428. https://doi.org/10.1016/j.apenergy.2013.10.047

Berghöfer, A., Mader, A., Patrickson, S., Calcaterra, E., Smit, J., Blignaut, J., & van Zyl, H. (2011). TEEB Manual for cities: Ecosystem services in urban management. In *The Economics of Ecosystems and Biodiversity*. Suiza.

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

Blackhurst, M., Hendrickson, C., & Matthews, H. S. (2010). Cost-effectiveness of green roofs. *Journal of Architectural Engineering*, *16*(4), 136–143. https://doi.org/10.1061/(ASCE)AE.1943-5568.0000022

Broks, K., & van Luijtelaar, H. (2015). Groene daken nader beschouwd: Over de effecten van begroeide daken in breed perspectief met de nadruk op de stedelijke waterhuishouding. In *Stowa&Rioned*. Bennekom: Modern.

Carrilho, M. (2015). *Evaluatie en Vooruitblik: Groene daken subsidieregeling Den Haag 2009 - 2015*. Den Haag.

Clark, C., Adriaens, P., & Talbot, F. B. (2008). Green roof valuation: A probabilistic economic analysis of environmental benefits. *Environmental Science and Technology*, *42*(6), 2155–2161. https://doi.org/10.1021/es0706652

CSED. (n.d.). Interview Protocol. In *Dictionary of Statistics & Methodology*. https://doi.org/10.4135/9781412983907.n981

Damen, N. A. G. ., & Brouwers, H. J. H. (2012). *Technische eigenschappen van groene daken en gevels*. (november), 1–37.

Di Giuseppe, E., & D'Orazio, M. (2015). Assessment of the effectiveness of cool and green roofs for the mitigation of the Heat Island effect and for the improvement of thermal comfort in Nearly Zero Energy Building. *Architectural Science Review*, *58*(2), 134–143. https://doi.org/10.1080/00038628.2014.966050

Eden, C., & Ackermann, F. (1998). *Making strategy: The journey of strategic management*. London: SAGE Publications.

Engström, R., Howells, M., Mörtberg, U., & Destouni, G. (2018). Multi-functionality of nature-based and other urban sustainability solutions: New York City study. *Land Degradation and Development*, *29*(10), 3653–3662. https://doi.org/10.1002/ldr.3113

Gemeente Den Haag. (2019). *The Hague Resilience Strategy*. Den Haag.

General Services Administration. (2011). *The Benefits and Challenges of Green Roofs on Public and Commercial Buildings: A Report of the United States General Services Administration*. Washington DC.

General Services Administration. (2017). Green Roof Benefits and Challenges. *U.S. General Services Administration*, 1–65.

Getter, K. L., Rowe, D. B., & Andresen, J. A. (2007). Quantifying the effect of slope on

extensive green roof stormwater retention. *Ecological Engineering*, *31*(4), 225–231. https://doi.org/10.1016/j.ecoleng.2007.06.004
Hoeven, F. van der, & Wandl, A. (2018). *Haagse Hitte: Het Haagse warmte-eiland in kaart gebracht*. Delft, Netherlands: TU Delft.
Holstein, J. A., & Gubrium, J. F. (1995). *The active interview* (37th ed.). Thousand Oaks, CA: SAGE Publications.
KNMI, Van den Hurk, B., Siegmund, P., Klein, A., Eds, T., Attema, J., … De Vries, H. (2014). KNMI ' 14 : Climate Change scenarios for the 21st Century. *Scientific Report WR2014-01, KNMI, De Bilt, The Netherlands. Www.Climatescenarios.Nl*, (May), 98pp. https://doi.org/10.1007/s00382-009-0721-6
Lafortezza, R., Chen, J., van den Bosch, C. K., & Randrup, T. B. (2018). Nature-based solutions for resilient landscapes and cities. *Environmental Research*, *165*(December 2017), 431–441. https://doi.org/10.1016/j.envres.2017.11.038
Langemeyer, J., Wedgwood, D., McPhearson, T., Baró, F., Madsen, A. L., & Barton, D. (2019). Creating urban green infrastructure where it is needed – A spatial ecosystem service-based decision analysis of green roofs in Barcelona. *Science of the Total Environment*, (xxxx), 135487. https://doi.org/10.1016/j.scitotenv.2019.135487
Löfgren, K. (2013, May 19). Qualitative analysis of interview data: A step-by-step guide for coding/indexing. Retrieved November 6, 2019, from https://www.youtube.com/watch?v=DRL4PF2u9XA
Meerow, S., & Newell, J. P. (2017). Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. *Landscape and Urban Planning*, *159*, 62–75. https://doi.org/10.1016/j.landurbplan.2016.10.005
Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: Synthesis*. https://doi.org/10.5822/978-1-61091-484-0_1
Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a Theory of Stakeholder Identification and Salience : Defining the Principle of Who and What Really Counts. *Academy of Management Review*, *22*(4), 853–886.
Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning*, *134*, 127–138. https://doi.org/10.1016/j.landurbplan.2014.10.018
Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., & Rowe, B. (2007). Green Roofs as Urban Ecosystems : Ecological Structures , Functions , and Services. *BioScience*, *57*(10), 823–833.
Pietruszko, S. M. (2004). Photovoltaics in the world. *Opto-Electronics Review*, *12*(1), 7–12. https://doi.org/10.1007/1-4020-3562-4_15
RAMSES. (2018). Scientific publications RAMSES. Retrieved August 14, 2020, from https://ramses-cities.eu/science/
Reed, M. S. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation*, *141*(10), 2417–2431. https://doi.org/10.1016/j.biocon.2008.07.014
Remmers, M. (2017, November 1). Het platte dak wordt steeds groener in Rotterdam. Retrieved August 13, 2020, from https://nos.nl/artikel/2200732-het-platte-dak-wordt-steeds-groener-in-rotterdam.html#:~:text=Maar liefst 14%2C5 miljoen,die M op het dak.
Rockefeller Foundation. (2017). *100 Resilient Cities: The EU Resilience Prospectus*. New York City.
Semadeni-Davies, A., Hernebring, C., Svensson, G., & Gustafsson, L. G. (2008). The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: Combined sewer system. *Journal of Hydrology*, *350*(1–2), 100–113. https://doi.org/10.1016/j.jhydrol.2007.05.028

Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities and challenges – A review. *Renewable and Sustainable Energy Reviews*, *90*(April), 757–773. https://doi.org/10.1016/j.rser.2018.04.006

Sheppard, S., Atman, C., Fleming, L., Miller, R., Smith, K., Stevens, R., … Lund, D. (2010). *An Overview of the Academic Pathways Study: Research Processes and Procedures: Technical Report #CAEE-TR-09-03*. Washington DC.

Slager, K., Asselman, N., & Blom, G. (2018). *Overstromingsrisico's door intense neerslag*.

Stewart, C. J., & Cash, W. B. (2008). *Interviewing: Principles and practices.* Boston, MA: McGraw-Hill.

TEEB. (2010). *The Economics of Ecosystems & Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.*

Triarii. (2019). *Actieplan Versnelling Verduurzaming Haagse Daken*. Den Haag.

Vaissier, N. (2019). *Modelling the risks of urban heat islands for the ageing society Case study: The Hague*. TU Delft.

van Oorschot, J. (2019). *Spatial planning of green infrastructure for fostering urban resilience in The Hague*. Leiden University & Delft University of Technology.

van Oudenhoven, A. P. E. (2015). *Quantifying the Effects of Management on Ecosystem Services*. Wageningen University.

van Oudenhoven, A. P. E., Schröter, M., Drakou, E. G., Geijzendorffer, I. R., Jacobs, S., van Bodegom, P. M., … Albert, C. (2018). Key criteria for developing ecosystem service indicators to inform decision making. *Ecological Indicators*, *95*, 417–426. https://doi.org/doi.org/10.1016/j.ecolind.2018.06.020

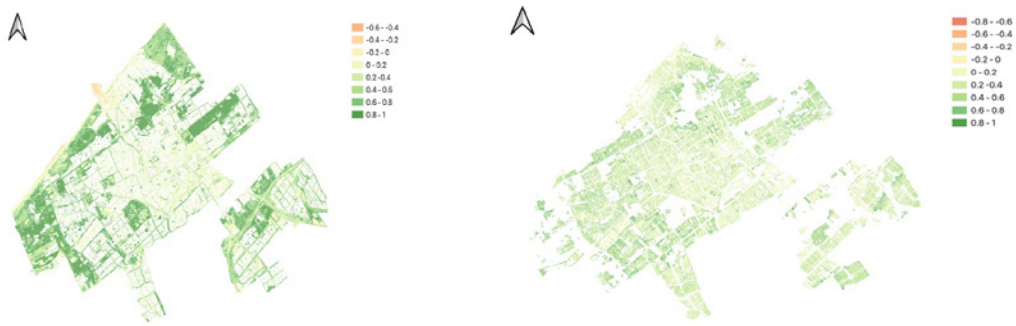
Vijayaraghavan, K. (2016). Green roofs: A critical review on the role of components, benefits, limitations and trends. *Renewable and Sustainable Energy Reviews*, *57*, 740–752. https://doi.org/10.1016/j.rser.2015.12.119

Zhang, X., Shen, L., Tam, V. W. Y., & Lee, W. W. Y. (2012). Barriers to implement extensive green roof systems: A Hong Kong study. *Renewable and Sustainable Energy Reviews*, *16*(1), 314–319. https://doi.org/10.1016/j.rser.2011.07.157

Zwaanenburg, L. (2019). *Spatial Analysis for Green Roof Multifunctionality Maximization Opportunities in Rotterdam*. Leiden University & Delft University of Technology.

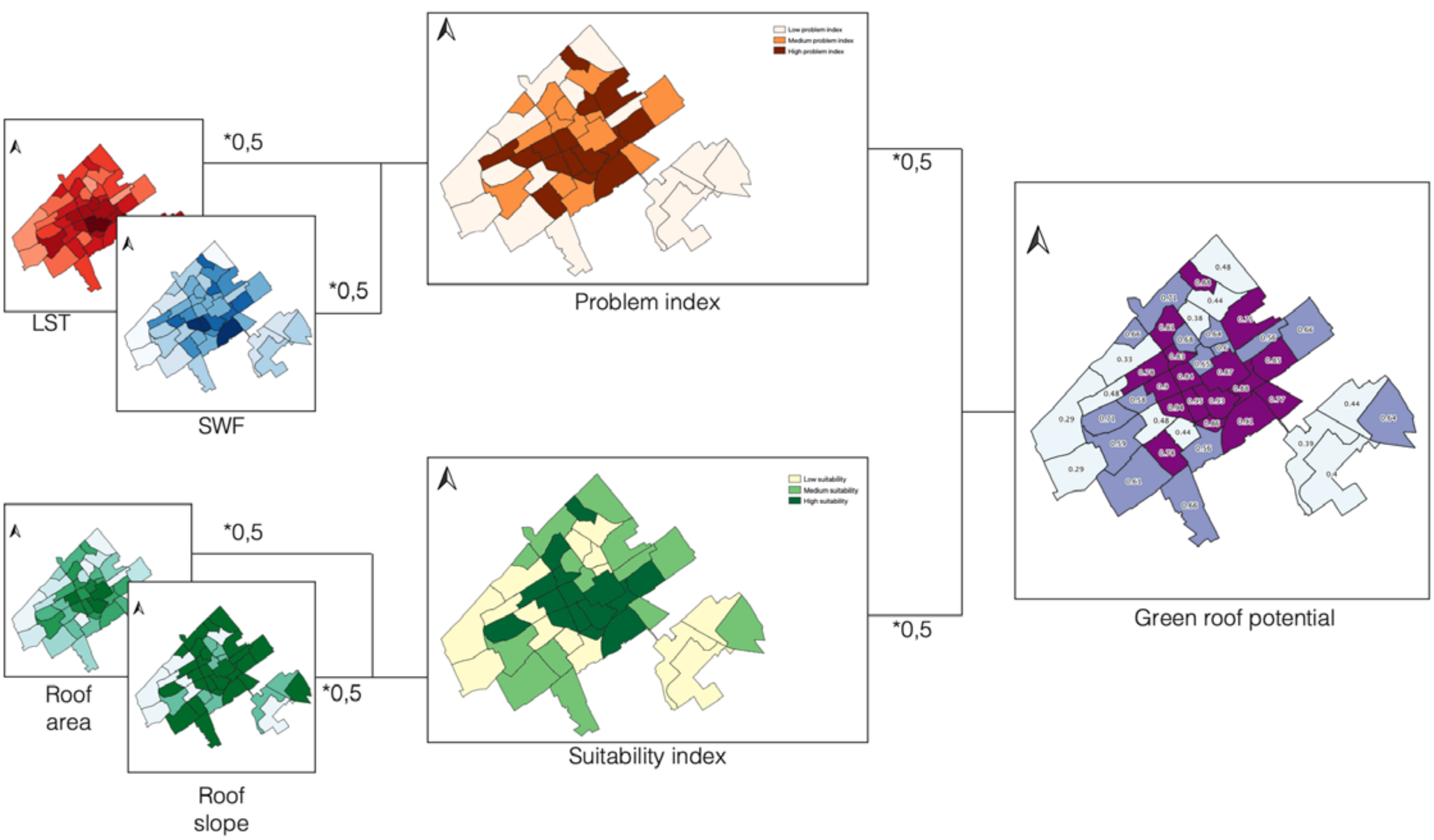
7 | Appendix

7.1 NDVI raster maps

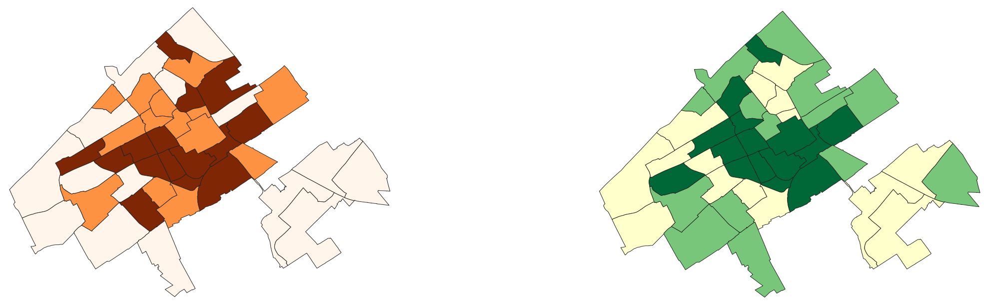


Original NDVI maps, split in public- and privately associated raster cells based on spatial lot data.

7.2 Intermediate steps to calculate green roof potential

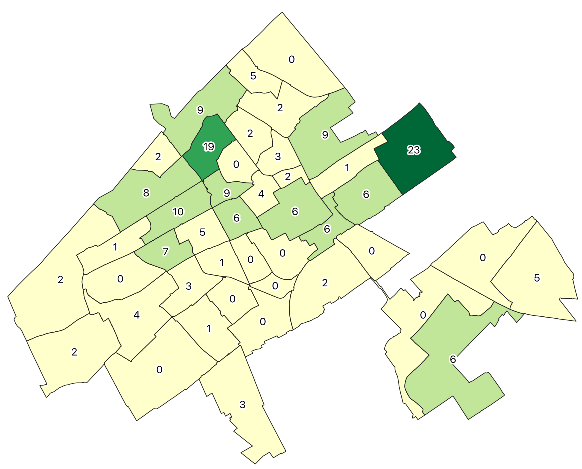


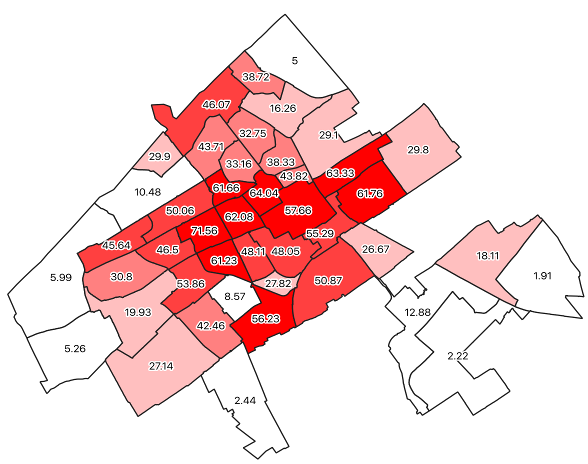
7.3 Problem and suitability index



Problem index with quantile distribution of problem scores. Combination of relevant SWF and mean LST per neighbourhood, aggregated with equal weights. And Suitability index with quantile distribution of suitability scores. Combination of median roof slope and the percentage of available roof space per square meter of neighbourhood, aggregated with equal weights.

7.4 Subsidy distribution (2nd method) and VVE distribution





7.5 Sensitivity analysis green roof potential

P = problem

S = suitability

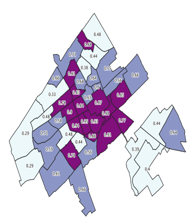
H = roof slope

A = roof area

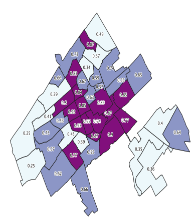
W = water flooding

T = land surface temperature

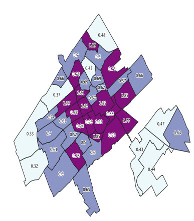
Base scenario



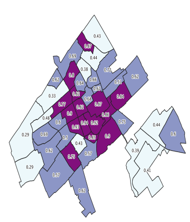
P=0,4 S =0,6
0 changes



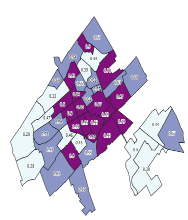
P=0,6 S=0,4
5 changes



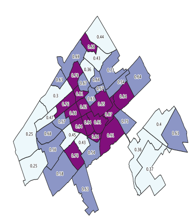
H=0,4 A=0,6
0 changes



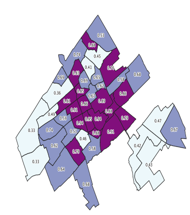
H=0,6 A=0,4
2 changes



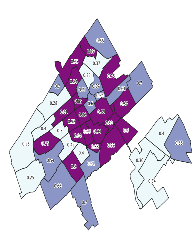
T=0,4 W=0,6
0 changes



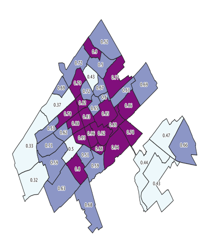
T=0,6 W=0,4
3 changes



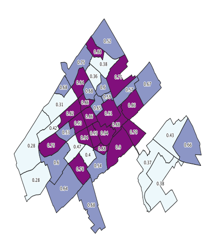
P=**0,4** S=**0,6**
H=0,6 A=0,4
5 changes



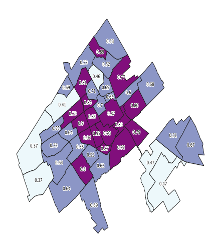
P=**0,6** S=**0,4**
H=0,6 A=0,4
5 changes



P=**0,4** S=**0,6**
T=0,6 W=0,4
3 changes



P=**0,6** S=**0,4**
T=0,6 W=0,4
7 changes



Benoordenhout & Waldeck do switch sometimes.

7.6 Sensitivity analysis NPV

Green roof

	Value	NPV	% change
Energy saving	2	€ -29,51	0%
	1	€ -39,63	-34%
	4	€ -9,26	+69%
Property value	75	€ -29,51	0%
	50	€ -54,51	-85%
	100	€ -4,51	+85%
Maintenance	5	€ -29,51	0%
	10	€ -132,76	-350%
	2,50	€ 22,12	+175%

Green roof + photovoltaic

	Value	NPV	% change
Energy saving	2	€ 119,48	0%
	1	€ 109,44	-8%
	4	€ 139,55	+17%
Property value	75	€ 119,48	0%
	50	€ 94,48	-21%
	100	€ 144,48	+21%
Maintenance	5	€ 119,48	0%
	10	€ -8,87	-107%
	2,50	€ 146,01	+22%
Energy Price	0,22	€ 119,48	0%
	0,20 (-10%)	€ 94,38	-21%
	0,24 (+10%)	€ 144,57	+21%

7.7 Coding method

Method by Löfgren (2013).

STEP 1, reading the transcripts
1.1. Browse through all transcripts, as a whole.
1.2. Make notes about your impressions.
1.3. Read the transcripts again, one by one.
1.4. Read very carefully, line by line.

STEP 2, labeling relevant pieces
2.1. Label relevant words, phrases, sentences, or sections.
2.2. Labels can be about actions, activities, concepts, differences, opinions, processes, or whatever you think is relevant.
2.3. You might decide that something is relevant to code because:

- it is repeated in several places;
- the interviewee explicitly states that it is important;
- you have read about something similar in reports, e.g. scientific articles;
- it reminds you of a theory or a concept;
- or for some other reason that you think is relevant.

You can use preconceived theories and concepts, be open-minded, aim for a description of things that are superficial, or aim for a conceptualization of underlying patterns. It is all up to you. It is your study and your choice of methodology. You are the interpreter and these phenomena are highlighted because you consider them important. Just make sure that you tell your reader about your methodology, under the heading Method. Be unbiased, stay close to the data, i.e. the transcripts, and do not hesitate to code plenty of phenomena. You can have lots of codes, even hundreds.

STEP 3, decide which codes are the most important, and create categories by bringing several codes together
3.1. Go through all the codes created in the previous step. Read them, with a pen in your hand.

3.2. You can create new codes by combining two or more codes.
3.3. You do not have to use all the codes that you created in the previous step.
3.4. In fact, many of these initial codes can now be dropped.
3.5. Keep the codes that you think are important and group them together in the way you want.
3.6. Create categories. (You can call them themes if you want.)
3.7. The categories do not have to be of the same type. They can be about objects, processes, differences, or whatever.
3.8. Be unbiased, creative and open-minded.
3.9. Your work now, compared to the previous steps, is on a more general, abstract level. You are conceptualizing your data.

STEP 4, label categories and decide which are the most relevant and how they are connected to each other

4.1. Label the categories. Here are some examples: Adaptation (Category) Updating rulebook (sub-category) Changing schedule (sub-category) New routines (sub-category) Seeking information (Category) Talking to colleagues (sub-category) Reading journals (subcategory) Attending meetings (sub-category) Problem solving (Category) Locate and fix problems fast (sub-category) Quick alarm systems (sub-category)
4.2. Describe the connections between them.
4.3. The categories and the connections are the main result of your study. It is new knowledge about the world, from the perspective of the participants in your study.

STEP 5, some options
5.1. Decide if there is a hierarchy among the categories.
5.2. Decide if one category is more important than the other.

5.3. Draw a figure to summarize your results.

STEP 6, write up your results
6.1. Under the heading Results, describe the categories and how they are connected. Use a neutral voice, and do not interpret your results.
6.2. Under the heading Discussion, write out your interpretations and discuss your results. Interpret the results in light of, for example:

- results from similar, previous studies published in relevant scientific journals;
- theories or concepts from your field;
- other relevant aspects

7.8 Ethics committee approval

Date 26-07-2019
Contact person Ir. J.B.J. Groot Kormelink, secretary HREC
Telephone +31 152783260
E-mail j.b.j.grootkormelink@ tudelft.nl

Human Research Ethics Committee
TU Delft
(http://hrec.tudelft.nl/)
Visiting address
Jaffalaan 5 (building 31)
2628 BX Delft
Postal address
P.O. Box 5015 2600 GA Delft
The Netherlands

Ethics Approval Application: MSc Thesis: Policy strategies to efficiently increase green infrastructures on private property in The Hague, to enhance the city's resilience towards climate change
Applicant: Gameren, Lennart van

Dear Lennart van Gameren,

It is a pleasure to inform you that your application mentioned above has been approved.

Good luck with your research!

Sincerely,

Prof. Dr. Sabine Roeser
Chair Human Research Ethics Committee TU Delft

Prof.dr. Sabine Roeser
TU Delft
Head of the Ethics and Philosophy of Technology Section
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7.9 Correction on NPV calculation

After the final hand-in and presentation a few small errors were spotted in the NPV calculation.

- The bitumen roof should have an NPV of -€15,86. The second investment was not discounted in the original calculation.
- In order for green roofs to successfully compete with a standard roof, one needs to accept a slightly higher discount rate of 11,11%. Otherwise the green roof is a worse investement, from the NPV perspective.
- The higher efficiency of green + PV roofs was not taken into account in the original calculation. So its NPV is even higher than the calculated €119,49

Bitumen roof corrected

Inputs		**Outputs**	
Discount rate	10%	IRR	-
Installation costs/m2	- € 15,00	NPV	- € 15,86
Subsidy Hague/m2	€ -	Payback in year	-
Subsidy Water board/m2	€ -		
Maintenance/m2/yr	€ -		
Energy saving/yr	€ -		
Project Lifetime [years]	60		

Green roof corrected

Inputs		**Outputs**	
Discount rate	11,11%	IRR	12,95%
Installation costs/m2	- € 62,00	NPV	€ -15,65
Subsidy Hague/m2	€ 25,00	Payback in year	0
Subsidy Water board/m2	€ 15,50		
Maintenance/m2/yr	- € 5,00		
Energy saving/yr	€ 2,00		
Project Lifetime [years]	60		
Inflation maintenence	5%		
Energy inflation	2%		
Property value increase	€ 75,00		