Towards a successful development of smart cities

An exploratory research on factors influencing the financial feasibility

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Towards a successful development of smart cities:

An exploratory research on factors influencing the financial feasibility.

Master Thesis

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Preface

In front of you lies the master thesis "Towards a successful development of smart cities: An exploratory research on factors influencing the financial feasibility." This thesis has been written in the context of my graduation from the master Construction Management and Engineering at the Eindhoven University of Technology. The study was in collaboration with Park Strijp Beheer, the developer of the former factory site of Philips: Strijp-S. From February 2018 until August 2018 I have been engaged in the research and writing of the thesis.

The process of writing my thesis was not always easy. The project was long, and it has been difficult sometimes to keep a clear view on track. Therefore, I would like to thank my first supervisor: Bauke de Vries from the Eindhoven University of Technology who brought me into contact with the company Park Strijp Beheer and supervised me during the project. I also want to thank Qi Han and Elke den Ouden for keeping a clear and critical view on my research. Besides the graduation committee from the university, I would like to thank Park Strijp Beheer for giving me the opportunity to graduate at Strijp-S. Furthermore, thanks to Thijs van Dieren, Renzo Dingler and Wouter Beelen for helping me in understanding how Strijp-S as smart city is developed, providing information and structuring my graduation project. Besides the steep learning curve of my graduation, being part of a company attributed to my personal development as well. Therefore, a thanks to all the people I worked with during my graduation at Strijp-S.

Finally, I want to thank my parents for making it possible for me to study. Additionally, I want to thank my girlfriend, friends and housemates for their support and positive distraction during this period.

I hope you enjoy reading.

Johan Slob

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Summary

The ongoing process of urbanisation results in an expectation that 68 percent of the world's population will be living in urban areas by the year 2050. Additionally, the world's population is expected to grow with 2.5 billion in this same timeframe. Besides the increase of the world density and the mixed diversity of cultures, the second issue humanity is currently facing is the climate change due to the use of fossil fuels and the associate emissions of greenhouse gases. In the Paris Agreement of 2015 the participating countries agreed on keeping the global warming "to well below 2°C above pre-industrial levels", which requires that we, as the Earth's inhabitants, need to use our resources more efficiently and develop more sustainable products.

These are two important issues that influence our way of life in and how we design the urban environment. A concept that aims to deal with these issues is the "smart city". The notion "Smart City" is very broad and multiple definitions exists. Although there is no commonly accepted definition of what a smart city should look like, the benefits of transforming cities into smart cities are clear. A smart city is efficient with resources and can provide thorough analyses that help solve the problems related to these trends. Nevertheless, the fact that there is no working definition for smart cities, the notions of ICT, sensors and a digital infrastructure are recurring. The smart city includes an implementation of communication technology in order to give real time insight into how a city functions, is able to act on this and is able to interact with its residents to become more efficient with resources (in the broadest sense). This increases the sustainability of the city.

Because transforming an area or an entire city is complex, and the technologies involved in this process are new, so called "living labs" are developed. Living labs are user-oriented locations in the urban environment where innovative processes and/or technologies are tested allowing co-creation to develop solutions for urban issues. Besides smart city technologies, services and solutions to the urban issues, the financial picture is of importance. This study aims to give a clearer insight in the investment costs and potential revenues based on a literature and a case study. To support this aim, the following research question is formulated: *What factors of an area characterise a smart city and which of these factors influence the financial feasibility of implementing smart city technology and what is the relation between these factors?*

As there is no commonly agreed on definition for the notion of smart city, the first step in this study is conduct literature research on what makes a city smart. It can be concluded that creating connectivity in an area is necessary in order to develop a smart city. The connectivity creates a platform for IoT. The IoT makes it possible to influence six different aspects in the urban environment: waste; pollution; traffic; energy; parking; lighting. From taking a closer look at how the IoT influences these aspects, it can be concluded that data is the key factor. Depending on what kind of IoT is implemented, it is possible to offer numerous services.

Creating connectivity and offering smart city services has an effect on the urban environment and the people using this area. The quality of life may be increased, and the local economy can be improved. These results help in the increasing need for efficiency in urban environments/cities.

Technology and data are the aspects that in theory make a city smart: they make it possible to be more efficient with resources. Technology however is of course not the only factor of importance when developing a smart city. By comparing different frameworks, a distinction is made between smart city drivers and smart city outcomes. Technology is one of the drivers, together with "community" and "policy". These drivers are important to consider when searching for locations to develop as smart city.

The community can also be described as the potential market for smart city services. Therefore, the demographic composition is of importance for the selection of the types of services to be offered in a specific area. From the literature, function types are derived which can be used to classify neighbourhoods. As the smart city concept is still under development, it is not possible to assign specific services to these function types. The attributes selected per function type are called enablers (part of the IoT): platforms that make certain types of services possible. Implementing the enablers is inseparable from implementing services: it depends on which enablers are implemented, what services can be developed. The services influence certain fields of the urban environment: liveability and wellbeing (quality of life), sustainability and local economy (the outcome). The balance between implementing enablers (investment) and income from these enablers is important to create maximum value with the least costs. The demographic composition of the community determines the balance.

The literature gives more insight into why the smart city concept is interesting to implement in the urban environment, as well as insight into what drives the development and what are the outcomes. To understand how a smart city can be developed, Strijp-S, the former factory site of Philips in Eindhoven is used as case study. The technology at Strijp-S is implemented as a backbone (glass fibres, electricity and smart city hub) which enables the connectivity. Several enablers are connected to this backbone. The enablers implemented at Strijp-S match with the found enablers that should be implemented according to the literature. To summarize what can be learned from Strijp-S with regard to which factors influence the financial feasibility of implementing smart city technology, is how the infrastructure makes the connectivity possible.

Using a System Dynamics approach, all the found factors are brought together into a model that shows how these factors influence the financial feasibility of the implementation of smart city technology and how the outcome-factors are influenced by the implementation of the smart city enablers.

The results of using the stock and flow model are two-fold. First different scenarios pointed out that governmental interference can increase the speed at which the implementation of smart city technology can become financially feasible. If a government provides an economic incentive and focus on shortening the required procedures, the implementation can become more interesting regarding financial feasibility. This is related to the policy-driver of smart cities: if there is policy for smart cities, then governments are more likely to be willing to support the smart city project. Secondly, the result of running the model including different areas in the Netherlands points out which factors regarding community and technology are important: a high-density urban area with relatively high-income residents, an attractive physical environment and a significant amount of businesses in the catering and retail sector. In this study, this type of area is classified as "city-centre areas".

Samenvatting

De wereldwijde migratie van het platteland naar de stad resulteert in de verwachting dat in 2050, 68 procent van de wereldbevolking in een stad woont. Daarnaast wordt verwacht dat de wereldbevolking in dezelfde periode met 2,5 miljard personen zal groeien. Verder is een tweede kwestie waar de mensheid momenteel voor staat de klimaatverandering, als gevolg van het gebruik van fossiele brandstoffen, en de bijbehorende uitstoot van broeikasgassen. In de Klimaatakkoord van Parijs uit 2015 zijn de deelnemende landen overeengekomen om de opwarming van de aarde "ruim onder 2°C boven het pre-industriële niveau" te houden, wat vereist dat wij als de bewoners van de aarde onze bronnen efficiënter moeten gebruiken en duurzamere producten moeten ontwikkelen.

Dit zijn twee belangrijke zaken die onze manier van leven beïnvloeden en hoe we de stedelijke omgeving ontwerpen. Een concept dat bijdraagt aan de verbetering van deze problemen "Smart City". Hoewel er geen algemeen aanvaarde definitie is van hoe een smart city eruit moet zien, zijn de voordelen van het transformeren van steden in slimme steden duidelijk. Een smart city is efficiënt met middelen en kan analyses bieden die de problemen in verband met deze inefficiëntie helpen oplossen. Desalniettemin het feit dat er geen definitie bestaat voor smart cities, komen de begrippen "ICT", "sensoren" en een "digitale infrastructuur" regelmatig terug. De smart city omvat een implementatie van communicatietechnologie om actueel inzicht te geven in hoe een stad functioneert, is in staat om hiernaar te handelen en is in staat om met haar bewoners te communiceren om efficiënter te worden met middelen (in de breedste zin van het woord). Dit verhoogt de duurzaamheid van de stad.

Omdat het transformeren van een gebied naar een smart city complex is en de technologieën die bij dit proces betrokken zijn nieuw zijn, worden er zogenaamde "living labs" gebruikt. Living Labs zijn gebruikersgerichte locaties in de stedelijke omgeving waar innovatieve processen en/of technologieën worden getest. Door middel van co-creatie kunnen oplossingen voor stedelijke problemen ontwikkeld worden. Daarnaast is het financiële plaatje van belang. Deze studie beoogt een duidelijker inzicht te geven in de investeringskosten en de potentiële inkomsten van een smart city, dit op basis van literatuur- en een casestudie. Om dit doel te ondersteunen, wordt de volgende onderzoeksvraag geformuleerd: *Welke factoren van een gebied karakteriseren een slimme stad en welke van deze factoren beïnvloeden de financiële haalbaarheid van het implementeren van smart city technologie en wat is de relatie tussen deze factoren?*

Omdat er geen algemene geaccepteerde definitie bestaat voor het begrip smart city, is de eerste stap in dit onderzoek het uitvoeren van een literatuurstudie naar wat een stad slim maakt. Geconcludeerd kan worden dat het creëren van connectiviteit in een gebied noodzakelijk is om een smart city te ontwikkelen. De connectiviteit creëert een platform voor het "Internet der Dingen (Internet of Things (IoT))". De IoT maakt het mogelijk om zes verschillende aspecten in de stedelijke omgeving te beïnvloeden: afval; vervuiling; verkeer; energie; parkeren; verlichting. Van het verder onderzoeken naar hoe de IoT deze aspecten beïnvloedt, kan worden geconcludeerd dat data de sleutelfactor is. Afhankelijk van wat voor soort sensoren worden geïmplementeerd, is het mogelijk om tal van diensten aan te bieden.

Het resultaat van het creëren van connectiviteit en het aanbieden van smart city diensten is een verhoogde kwaliteit van leven en een verbeterende economie. Deze resultaten helpen bij de toenemende behoefte aan efficiëntie in stedelijke omgevingen.

Technologie en data zijn de aspecten die in theorie een stad slim maken: ze maken het mogelijk om efficiënter met middelen om te gaan. Technologie is echter niet de enige factor die van belang is bij het ontwikkelen van een smart city. Door verschillende kaders met elkaar te vergelijken, wordt een onderscheid gemaakt tussen “smart city drivers” en “smart city resultaten”. Technologie is een van de drijfveren, samen met de gemeenschap en beleid. Deze drijfveren zijn belangrijk om in acht te nemen bij het zoeken naar geschikte locaties die getransformeerd kunnen worden naar een smart city.

De drijfveer “gemeenschap” kan ook worden omschreven als de potentiële markt voor de smart city diensten. Deze samenstelling van de gemeenschap is dus van groot belang in de selectie van smart city diensten. Uit de literatuur zijn functietypen afgeleid die worden gebruikt om buurten te classificeren. Echter, omdat het concept smart cities nog in ontwikkeling is, is het niet mogelijk specifieke diensten toe te wijzen aan deze functietypen. Het is wel mogelijk bepaalde technologieën (enablers) aan de functie typen toe te kennen. Deze technologieën functioneren dan als platform voor diensten. Het implementeren van de enablers is onlosmakelijk verbonden met het aanbieden van diensten: het hangt af van welke enablers worden geïmplementeerd, welke diensten kunnen worden ontwikkeld. Het aanbieden van smart city diensten beïnvloed bepaalde factoren in de stedelijke omgeving: kwaliteit van leven, duurzaamheid en de lokale economie. De balans tussen het implementeren van enablers (investering) en inkomsten uit deze enablers is belangrijk, om maximale waarde te creëren tegen de minste kosten. De demografische samenstelling (gemeenschap) van een gebied bepaalt de balans.

Naast de literatuurstudie, wordt een case gebruikt om te begrijpen hoe een smart city kan worden ontwikkeld. Hiervoor wordt Strijp-S, de voormalige fabriekslocatie van Philips in Eindhoven, gebruikt. Op Strijp-S is smart city technologie geïmplementeerd in de vorm van een backbone (glasvezel, elektriciteit en een smart city server). Deze backbone faciliteert connectiviteit waarop enablers zijn verbonden. De enablers geïmplementeerd op Strijp-S komen overeen met de enablers die volgens de literatuur zouden moeten worden geïmplementeerd in een dergelijk gebied. Van Strijp-S kan vooral de ervaring hoe de connectiviteit kan worden gerealiseerd, dit in relatie met de financiële haalbaarheid: de investeringskosten.

Door middel van een System Dynamics-benadering worden alle gevonden factoren uit de literatuur en de casestudie samengebracht. Het model dat hieruit volgt laat zien hoe deze factoren de financiële haalbaarheid beïnvloeden. Daarnaast laat het zien hoe de gevolg-factoren worden beïnvloed door de implementatie van de smart city enablers.

De resultaten van het model zijn tweeledig. Ten eerste wijzen verschillende scenario's erop dat overheidsinmenging invloed heeft: als een overheid een economische stimulans geeft en zich richt op het verkorten van de vereiste procedures, kan de implementatie sneller het beoogde rendement halen. Dit is gerelateerd aan de beleids-driver van smart cities: bij het aanwezig zijn van smart city beleid, zijn overheden eerder geneigd om het smart city-project te ondersteunen. Ten tweede geeft het runnen van het model met verschillende gebieden aan welke factoren met betrekking tot de demografische samenstelling van belang zijn. De conclusie hieruit is dat geschikte gebieden stedelijk zijn, een hoge inwonersdichtheid hebben en dat de inwoners een relatief hoog inkomen hebben. Verder is een aantrekkelijke fysieke omgeving en een aanzienlijk aantal bedrijven in de horeca en detailhandel van belang. In dit onderzoek is dit type gebied geclassificeerd als "stadscentra".

Abstract

The development of smart cities is a complex process. There is no commonly agreed on definition, but the positive effects on the urban environment are clear: implementing smart city technology can increase the quality of life, improve the local economy and attribute to the sustainability of an area. This is especially of interest due to the ongoing urbanisation process and the climate change the world is facing. However, at this moment the concept "smart city" is mainly developed in living labs, supported by subsidies. This study aims to point out the factors which are important when making the smart city concept financially feasible.

In the developing of smart cities, there certain factors that can drive the development, these area: community, policy and technology. The community includes the demographic composition of the area. This includes among other things: residents, businesses, urban density and the current quality of life. The policy-driver describes whether a government supports the implementation of smart city technology or not. To understand the technology-driver, a case study is conducted to Strijp-S, the former factory site of Philips in Eindhoven. In this area, a backbone is constructed that facilitates connectivity. Connectivity offers the opportunity to implement the Internet of Things in an area. The Internet of Things enables the offering of smart city services.

A System Dynamics approach is used to bring all the found factors together into a model that shows how these factors influence the financial feasibility of the smart city concept and how the outcome-factors are influenced by the implementation of the smart city enablers. It appeared that the policy-driver mainly influences the transformation time of an area and so the speed with which the transformation to a smart city becomes profitable. Secondly, the community and technology drivers include variables that describe whether an area can be part of a profitable transformations. An area should be a high-density urban area with relatively high-income residents, an attractive physical environment and a significant amount of businesses in the catering and retail sector. In this study, this type of area is classified as "city-centre areas".

List of Abbreviations

- CBS — Central Bureau voor de Statistiek
- CLD — Causal Loop Diagram
- CPB — Centraal Plan Bureau
- Enablers — Devices that make it possible offer smart city services, part of the Internet of Things.
- IoT — Internet of Things
- QoL — Quality of Life
- ROI — Return on Investment
- SCD — Smart City Drivers
- SCO — Smart City Outcomes
- SFM — Stock and Flow model
- SPN — Smart Public Nodes

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1. Introduction

In the year 1950, only 30 percent of the world population lived in cities. Nowadays, in the year 2018, 55 percent of the world population resides in urban areas and this percentage is growing. The united nations (UNDESA, 2018) expect that by the year 2050, 68% of the world's population will be living in urban areas. Besides the fact that people migrate from rural areas to urban areas, the urbanization can also be explained by the growing world population (UNDESA, 2018). This movement to cities is a transition from the trend in the early 20th century to move out of cities to suburbs and so called garden-cities (Clapson, 2000). This urbanisation is an issue because an urban region needs resources to be able to for a population to grow. However, cities do not provide these resources, they only use them.

Besides the increase of the world density and the mixed diversity of cultures, the second is the fact that the world is facing a climate change due to the use of fossil fuels and the associate emissions of greenhouse gases. In the Paris Agreement (UNFCCC, 2015) the participating countries agreed on keeping the global warming "to well below 2°C above pre-industrial levels", which requires that we, as the Earth's inhabitants, need to use our resources more efficiently and develop more sustainable products.

These are two important issues that influence our way of life in and how we design the urban environment. A concept that aims to deal with these issues is the "smart city". The notion "Smart City" is very broad and multiple definitions exists (Albino, Berardi, & Dangelico, 2015). Although there is no commonly accepted definition of what a smart city should look like, the benefits of transforming cities into smart cities are clearer. A smart city is efficient with resources and can provide thorough analyses that help solve the problems related to these trends (Jessen, 2015). Although Albino et al. (2015) did not point out one working definition for smart cities, the notions of ICT, sensors and a digital infrastructure are recurring. The smart city includes an implementation of communication technology in order to give real time insight in how a city functions, is able to act on this and is able to interact with its residents to become more efficient with resources (in the broadest sense). This increases the sustainability of the city.

In January 2017, a Dutch newsfeed focussing on sustainable business headed "Nederlandse steden nemen het voortouw in Smart City Strategie" (Vergeggen, 2017) (Dutch cities are taking the lead in smart city strategies). It refers to the fact that the largest five cities in the Netherlands are taking the lead in learning how to develop a smart city. Because transforming an area or an entire city is complex, and the technologies involved in this process are new, so called "living labs" are developed. Living labs are user-oriented locations in the urban environment where innovative processes and/or technologies are tested (Bilgram, Brem, & Voigt, 2008) allowing co-creation to develop solutions for urban issues.

These living labs focus on developing new technologies, measuring the effect of the implementation and sharing their gained experience. An example of a living lab is Strijp-S in Eindhoven. This area is being redeveloped after Philips left the old factory location in 2001. In the past years, the redevelopment was combined with the implementation of smart city technology. The transformation into a smart city is achieved by developing a data infrastructure. This not only connects an area physically but also digitally. This is achieved by making investments in a glass fibre infrastructure that facilitates a high-quality connectivity in the entire area. To support this infrastructure, an urban data centre has been opened at

Strijp-S, which makes the area Strijp-S one of the first smart neighbourhoods in the world (VolkerWessels, 2017). The urban data centre at Strijp-S was developed as part of the creative urban living lab S-mart Strijp-S (Goulden, 2015). The infrastructure and the urban data centre are used to test different systems that define a smart city. Some examples of these implemented systems are: parking management, smart lighting and crowd management.

The living lab Strijp-S is part of the Triangulum project. The Triangulum project aims to demonstrate, disseminate and replicate solutions and frameworks for Europe’s future smart cities (Triangulum, n.d.). One aspect of this is the financial feasibility of the transformation into a smart city. The goal is to “look beyond subsidies and demonstrate functioning business models and social value models for smart cities.” The dissemination and replication of the experiences gained at Strijp-S are the ground for this study with a main focus on the financial feasibility.

1.1. Problem definition

The aim of a living lab is to gain experiences which can be used elsewhere. This includes smart city services, technologies, development, but also the financial feasibility. In the developing of smart cities in the Triangulum project is a significant part of the total budget funded by the European Commission (Triangulum, n.d.). The aim is to be able to develop in the future self-sustaining smart cities, so the next step after the living lab, is the “living reality”. The aim of a living lab is to gain experiences which can be used elsewhere. This includes smart city services, technologies, development and financial feasibility. during the development of smart cities in the Triangulum project, a significant part of the total budget is funded by the European Commission (Triangulum, n.d.). The goal is to be able to develop self-sustaining smart cities. The next step, after the living lab, is the ‘living reality’. Using the experience from Strijp-S the smart city technology can be implemented into other areas. To be able to create the “living reality”, research is required to find out which factors are important in the development of smart cities and how these influences the transition to a smart city. Furthermore, it is necessary to understand what kind of areas exist in the Netherlands and which are suitable for the implementation of smart city technology. Lastly, insight in investments, revenues and the how area characteristics influence financial feasibility is required to develop a business case for implementing smart city technology. Because Strijp-S is one of the first smart neighbourhoods in the world and all the investments are already done, a lot of experience has been gained in implementing smart city technologies. This makes Strijp-S an excellent case for this research.

1.2. Research questions

To summarize the problem and set the scope of this study, the following research question is formulated:

What factors of an area characterise a smart city and which of these factors influence the financial feasibility of implementing smart city technology and what is the relation between these factors?

To answer this question, six sub questions were drafted:

1. What makes a smart city?
2. What is the result of the implementation of smart city technology?
3. What factors make an area suitable for the implementation of smart city technology?
4. What types of areas are there in the Netherlands and what are differences between them regarding financial feasibility?
5. What can be learned from the implementation of smart city technology in practise?
6. In what way do these factors influence the financial feasibility?

1.3. Research design

The research consists of five different stages. The first stage consists of a literature review that considers the first four sub-questions. These questions together form the theoretical framework of this study. The second stage is used to analyse the Strijp-S case in comparison to the literature. In the third stage, a mathematical model will be designed where the components from the theoretical framework and the results of the second stage will be brought together. The fourth stage includes a research to different areas in the Netherlands, partly selected as potential smart city areas and partly based on demographic characteristics to understand better what areas are suitable for smart city technology. In the fifth and last stage the main question will be answered and the conclusions and recommendations for further research are written out. In figure 1 an overview of the research model is given.

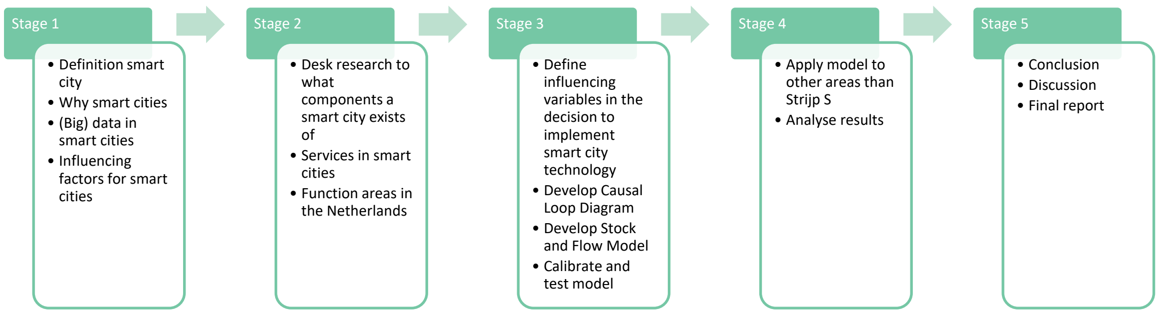

Figure 1 Research model

Regarding the design of the mathematical model, it is important to realise that the notion smart city has no set definition, which makes the research more complex. Especially because the paradigm concerns urban areas, which are complex as well due to the many different users of various areas. A system dynamics approach is desired for this because it supports *system thinking*: the ability to see the world as a complex system where "you can't do just one thing" and "everything is connected to each other" (Sterman, 2000). As these phrases are closely related to urban environments, the mathematical model will be developed with a system dynamics approach. The system dynamics approach exists of a few steps starting with the design of a causal loop diagram. The causal loop diagram gives understanding of what variables influence each other via feedback loops. The CLD gives insight in the causal relations between variables. Based on the CLD, a Stock and Flow Model (SFM) is designed. In contrast to a CLD, a SFM can capture the stocks and flows, along with feedback. This is essential in the system dynamics approach (Sterman, 2000). Once the model is finished, it will be tested and calibrated so the results from the model are correspondent with the real world.

1.4. Importance thesis

The importance of this thesis is derived from the necessity for the 'next step' in the development of smart cities. The gained experiences from the living labs need to be transformed into an understanding of what kind of areas are suitable for the implementation of smart city technology. Understanding the factors that determine the suitability emphasise both the practical importance as well as the social importance. The practical importance is about how the implementation of smart city technology can become self-sustaining and therefore financially feasible. it is necessary to conduct research to which factors lead to a successful (financially feasible) transformation from a "regular city" to a "smart city".

Besides the financial feasibility of smart cities, a closer look into what the social impact is of a smart city is important. How does the smart city technology affect the area where it is implemented? By understanding this, the benefits for the users or for the entire society become clear.

1.5. Reading guide

This study contains five chapters in total, of which this chapter is the first. The second chapter concerns the literature study. Chapter 3 includes the case study Strijp-S and the presentation of the results of this analysis. The fourth chapter presents a mathematical model in which the results from chapter 2 and chapter 3 are combined. Furthermore, this chapter includes an analysis of what factors are most important in developing a financially feasible smart city. Chapter 5 is used to formulate an answer to the main question.

2. Literature

This chapter includes the theoretical framework of the study. The theoretical framework gives answer to the first three sub questions of this study. The first section gives understanding to what smart cities are and what is needed to make a smart city. The second section relates to what the result(s) are when implementing smart city technology in an area. The last section of this chapter discusses what factors are of importance in the decision to implement smart city technology in an area. This includes a study to different types of areas and the financial feasibility of these types.

2.1. Smart city paradigm

Numerous researches already have been conducted to what smart cities are (Albino et al., 2015; Chourabi et al., 2012; Jessen, 2015). Albino et al. (2015) studied definitions and dimensions of smart cities stated in various studies. The article is split up in four different sections: definitions, dimensions, measuring and experiences. The first two are the most interesting sections, they include a summary of literature with definitions and dimensions of a smart city. The definitions and dimensions are used in this research to give an understanding of the paradigm of smart city. In this section, a small overview will be given of the research by Albino et al. (2015) to provide context for what a smart city is.

Before understanding what the notion smart city can mean, several other notions related to smart city must be understood (Albino et al., 2015):

- Digital city: a connected community that combines broadband communications infrastructure to meet the needs of governments, citizens, and business.
- Intelligent city: make conscious efforts to use information technology to transform life and work.
- Ubiquitous city: An extension of the digital city concept, making ubiquitous computing widely accessible and available to urban elements everywhere.
    - Virtual city: Hybrid concept that consists of a reality, with its physical entities and real inhabitants, and a parallel virtual city of counterparts, a cyberspace.

In the above-mentioned notions, the most important component is missing: people. Including people can make a city smart, this because people are those who interact with the city. Because people are inseparably connected to the notion of smart city, other terms are also related to the smart city paradigm: creativity, education and knowledge. This results in two domains: the first “hard” domain is about the implementation of ICT in energy grids, water management, natural resources, waste management, etcetera. The second, “soft”, domain is about people: education, policy, innovation, social inclusion. In this domain ICT is inessential. The notion knowledge-city is related to the soft domain: a knowledge city encourages the nurturing of knowledge (Albino et al., 2015).

Albino et al. (2015) also summarised dimensions of a smart city from eight different publications in four characteristics:

1. *A city’s networked infrastructure that enables political efficiency and social and cultural development.*
2. *An emphasis on business-led urban development and creative activities for the promotion of urban growth.*

3. *Social inclusion of various urban residents and social capital in urban development.*
4. *The natural environment as a strategic component for the future.*

It may be clear that the concept of a smart city functions between strategies, ICT and communities with the aim to be more sustainable by using ICT to achieve higher efficiency in the use of resources and improve the quality of life.

In a recent publication (Guerra, 2017), a description of what a smart city is, is given. It confirms the context of Albino et al (2015) that the goal of a smart city is to improve the quality of life for its citizens through ICT means and smart cities are based on intelligent sensors. Furthermore, the main characteristics and tools are represented in figure 2. These characteristics and tools can transform a city into a smart city. What stands out is that two of the five tools are related to digital technology: 'ICT' and 'Data driven'. The information technology and communications are essential in the smart city (Eremia, Toma, & Sanduleac, 2017).

The tools of a smart city (figure 2) are the attributes that make a smart city possible. The characteristics are the factors that are the result or are influenced by the implementation of the tools. The definition of the notion smart city lies in between. As for every city these tools and characteristics can differ, there is no set definition (Eremia et al., 2017).

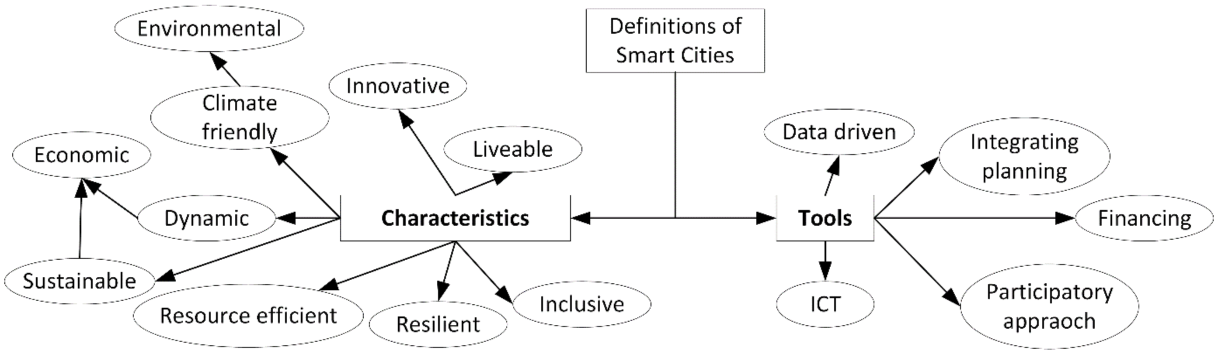

Figure 2 Characteristics and tools used to define a smart city (Eremia et al., 2017)

While there is no set definition yet to what smart cities exactly are, ICT, sensors and data are terms that arise often. This is however not a recent trend only connected to smart cities. Already in 1991, a first article was written about connecting everyday live articles via networks, so they could communicate with each other. Examples given in the article (Weiser, 1991) are sensors that communicate via infrared with small computers called tabs. These tabs could function as a personal badge, so the system registrates who is in which room, could open doors and can forward cell phones to the correct machine. Of course, this was a prediction of how the future could look like. Nowadays we use different communication technologies, but the framework in which the paradigm exists is the same. Nevertheless, only since 1999 the notion 'Internet of Things' is in use. The notion was coined by Kevin Ashton, who was a British technologist at MIT at that time (Jankowski, Covello, Bellini, Ritchie, & Costa, 2014).

2.1.1. Internet of Things

To better understand the Internet of Things (also referred to as IoT) a closer look is taken to the paradigm. It occurs that there are many visions on what the IoT is (Atzori, Iera, & Morabito, 2010). In general, three perspectives can be derived: the network-oriented perspective, the object-oriented perspective and the semantic-oriented perspective. Considering the name *Internet of Things*, it may be clear that the network-oriented perspective is about the *internet* and the object-oriented perspective is about the *things*. The third perspective describes the knowledge-part of IoT: unique addressing, representation and storage of exchanged information (Atzori et al., 2010). The Internet of Things can be seen as the convergence of the objects (things), the network (internet) and the semantic (knowledge) field. Besides defining what the Internet of Things includes, Atzori et al. (2010) defined five application domains for the IoT: Transportation and logistics; Healthcare; Smart environments; Personal and social; futuristic. Together with the major scenarios, this is visualised in figure 3.

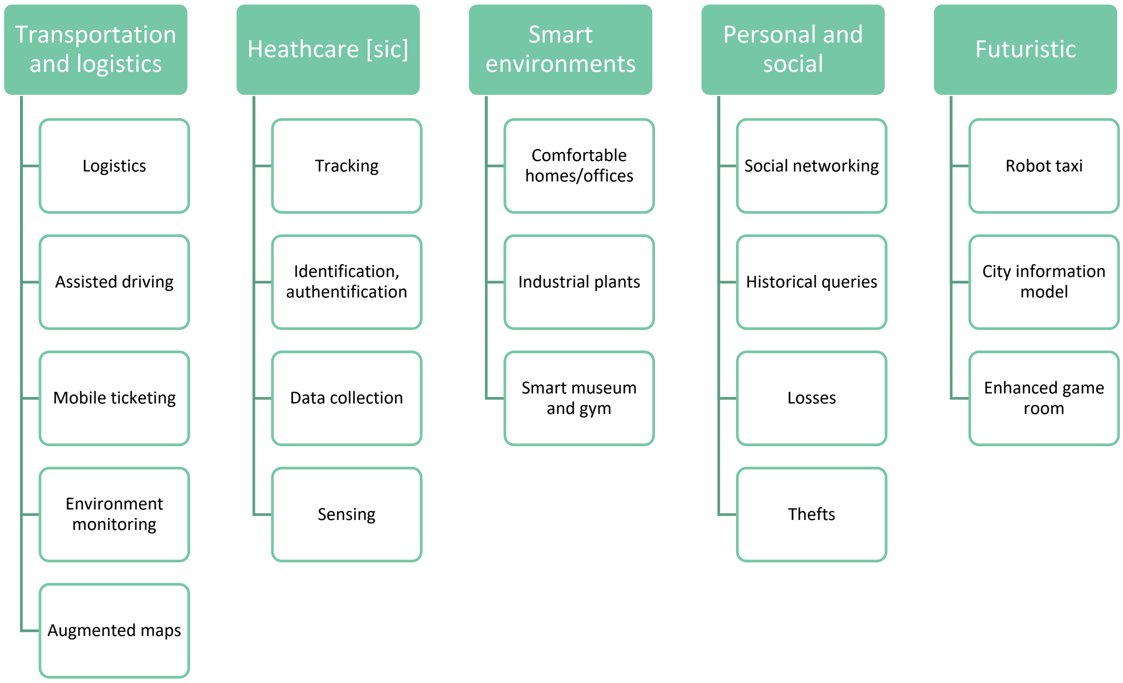

Figure 3 Applications domains and relevant major scenarios (Atzori et al., 2010)

It is predicted that by the year 2020 the total market of IoT will grow to 1.7 trillion US dollars (from 655 billion in 2014) and the amount of connected devices will be more than 30 billion (IDC, n.d.). But this is in general, the total Internet of Things paradigm in all different domains. In this research the focus lies on the built environment and so on the urban Internet of Things. Implementing the urban Internet of Things is an important part of the smart-city concept. Within the urban environment, different domains are formulated on which the IoT is expected to have great impact (Zanella et al., 2014):

I. Waste management

In many modern cities, waste is a primary issue. The collection and storage of waste is expensive and the storing itself is a problem. Implementing sensors that can register the level of load of waste containers can improve the efficiency by which the containers are emptied. Because on forehand one knows which containers are full, the collectors only have to visit those containers. This results in a more efficient route and therefore lower costs.

II. Pollution management

Within this topic, two types of pollution are distinguished: air pollution and noise pollution. The first topic includes the measurement of air quality. The European Union officially adopted a 20-20-20 Renewable Energy Directive for the next decade. This directive includes a 20% decrease of greenhouse gas emissions compared to 1990, 20% decrease of energy consumption due to more efficiency and a 20% increase of the use of renewable energy (European Parliament and the Council of the European Union, 2009). The IoT can provide the means to monitor air pollution.

Noise pollution on the other hand is more about decreasing nuisance and so improving the quality of life. When cities have specific laws to reduce noise at certain places during certain times of the day, this could be monitored continuously with IoT. Besides, using special algorithms to analyse the noise can increase the safety of a location because accidents or fights can be noticed. However, privacy is an important issue in this.

III. Traffic management

Traffic, and especially the congestion of traffic, is of great importance for city authorities and citizens. Authorities can specifically target locations that cause problems, especially in combination with air/noise pollution. Particularly for traffic flows, cameras can be used. For citizens, traffic congestion information can be of great help to select the fastest route to their location. The GPS of their vehicle can be connected to the traffic management system to spread traffic more equally.

IV. Energy management

Internet of Things can attribute to monitoring a city’s energy use. By implementing sensors that measure energy use of different services such as street lights, traffic lights, control cameras, heating of public buildings, a clearer overview can be given of what energy is used by what service. A detailed overview identifies the main energy-consuming sources and offers the opportunity to make those sources more efficient.

V. Smart parking

With the use of sensors at parking places citizens could be able to see where parking spots are available. This can save energy and reduce emissions from cars. Another advantage of smart parking could be a system that recognises (via RFID or NFC) if a car has certain privileges such as permission to park on slots reserved for disabled or residents. Collected data from the sensors can give insights in the amount of parking places needed.

VI. Smart lighting

Smart lighting can contribute to the 20-20-20 directive (European Parliament and the Council of the European Union, 2009) because it can establish a more efficient use of energy. Smart lighting can adjust the density of light to the time of the day or the weather condition. Also, it can adjust to the amount of people: lower when there are no people around and brighter when more people are around. Because street lights exist of a dense network throughout a city, they can also be used to hold other sensors or to offer Wi-Fi service.

In this section a summery has been given of the different fields of the Internet of Things. It appeared that by implementing ICT-applications, the IoT can influence six different fields in the urban environment significantly: waste management; pollution management; traffic management; energy management; smart parking; smart lighting. In the next section, a closer look is taken to what kind of data is generated by these fields.

2.1.2. Role of data

In multiple articles big data is mentioned as the result of Internet of Things (Batty, 2013; Hashem et al., 2016; Shemshadi et al., 2017; K. Zhang et al., 2017). But the notion 'big data' is probably the biggest buzzword in science (Frith, 2017), so a good understanding of what big data means in this research is vital. In Appendix 1, an extensive study on big data in relation with smart cities is included. Concluded from this study was that the data generated in a smart city has volume, is velocity, has variety, has value and is veracity.

Recent trends show that data collected in the urban environment should be "open data", Open data is data collected in the public environment, the data is findable and accessible without the need of registration or payment and can be used with an open license, open data is machine-readable, contains metadata, has not been edited, does not pose any privacy risks and falls within the law.

2.1.3. Conclusion

In this section an in-depth research to what is needed to make a city smart(err) has been conducted. It appeared that the underlayer of a smart city is data. To collect data, an infrastructure is needed onto which sensors can be connected (the IoT paradigm). Apart from anything that is possible in the sense of services within a smart city, an infrastructure is needed to create connectivity. In the article "What Exactly Is a SMART CITY?" (Guerra, 2017) the goal of a smart city is summarised as improving the *quality of life* for its citizens through technical means ultimately creating more *sustainable* cities. A smart city is able to do this by means of a digital infrastructure with sensors that are able to produce real-time data. The measured big data can play an important role in offering insights into hidden patterns, correlations and other insights that can help the city be more *efficient*. Besides, big data from a smart city can accelerate the process of *business models* due to the above mentioned insights (Hashem et al., 2016). The role of data in a smart city is to create valuable insights to what is happening in a city. In this description there are a few notions that draw the attention: quality of life, sustainability, efficiency and business models. The creation of data in the urban environment has impact on various factors within a city. In the next section, a closer look is taken to the potential outcomes of making a city smarter.

2.2. Smart city frameworks

In the previous sections, the concept of smart cities was investigated: what smart cities are and on which topics in city management they have the greatest impact. Furthermore, an understanding has been given of the data produced in a smart environment. While there is no set definition found in literature, there are fields found in the urban environment on which the IoT can have an impact (Zanella et al., 2014). Connectivity appeared to be an important factor in developing a smart city. In this section, a closer look is taken to what factors drive a successful implementation of smart city technology. The effect of smart city technology is also studied more in depth

2.2.1. Driving factors

The next step is to understand which factors are important in a successful Smart City development. In 2012 Chourabi et al., developed one of the first frameworks for smart city initiatives. This framework includes eight factors which can be used to study and determine success factors of smart city initiatives (figure 4):

1. Management and organisation
2. Technology
3. Governance
4. Policy
5. People and communities
6. Economy
7. Built infrastructure
8. Natural environment

In the framework, a distinction is made between two types of variables: Outer factors and inner factors. The outer factors (governance; people and communities; economy; built infrastructure; natural environment) are the factors that are more influenced by the implementation of smart city technology than they are influencing. The inner factors (policy; technology; management and organisation) are the more influencing factors. The technology in this case are the ICTs that make the internet of things possible. Technology is considered the meta-factor since this factor could heavily influence all the other factors. The management and organisation-factor is based on e-governance as most studies in 2012 were focussed on IT. Challenges within this topic are the resilience to change and different goals/diversity. An important strategy is the use of well-trained project teams and the involvement of the end-user. The involvement of the end-user has appeared to be one of the most important factors in the creation of smart cities (Jessen, 2015). The third driving factor is policy: policies are influenced by various political factors (council, government, political agendas), however, institutional readiness is important for smooth implementation of smart city technology. This means removing legal and regulatory barriers (Chourabi et al., 2012).

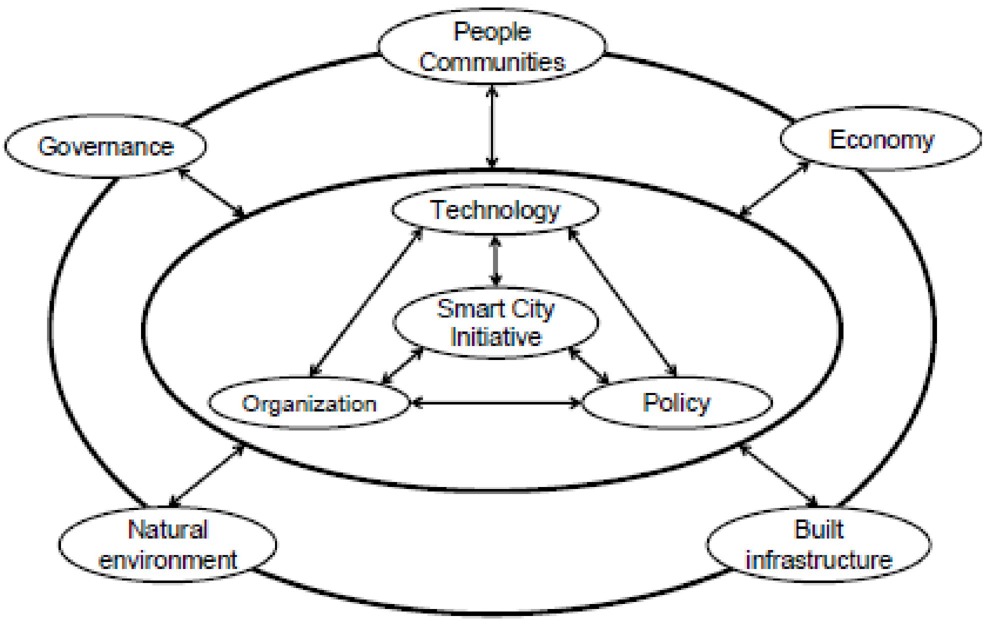

Figure 4 Smart city initiatives framework (Chourabi et al., 2012)

A second framework, which is more recent, is developed by Barth et al. (2017). In the development of this framework, the researchers investigated 31 cities all over the world that are related to the notions of “knowledge city”, “smart city”, “digital city” and “creative city”. Because the researchers took a broader scope in types of cities, the notion “information city” is used. The result is a comprehensive catalogue of essential characteristics of smart cities (figure 5) (Barth et al., 2017):

1. Information and knowledge related infrastructures
2. Economy and labour markets
3. Spaces
4. Politics and administration
5. Location factors
6. Information behaviour
7. Problem areas

Barth et al. (2017) identified five subsystems of the system smart city. Information and knowledge related infrastructures are the basis on which economy; spaces; politics and administration and location factors are built. Politics is pointed as one of the key objectives as well as economy: Barth (2017) identified five driving key branches in the development towards a smart city:

- Information and communication sector
- Financial and insurance companies
- Professional, scientific and technical companies
- Education sector
- Arts, entertainment and recreation sector

Added to this are the variables “information behaviour” and “problem areas”. Information behaviour includes the information literacy of individuals: the abilities of creation and representation as well as of searching and finding information (Stock & Stock, 2013).

Furthermore, there are basically three problem areas, of which gentrification is the first. Individuals with a low income are dispelled from attractive downtown locations and/or individuals with a low income cannot move to informational cities due to this low income. Secondly, the researches pointed out an issue that is especially the case in Arab cities as well as Singapore. Due to the extremely well paid international professionals, and very low wages foreign workers, the local population is faced to feeling like strangers in their own county. Attached to this is the third issue: cities lose their identity as the same global-architects and construction companies design and construct these cities, which result in the design of exchangeable cityscapes.

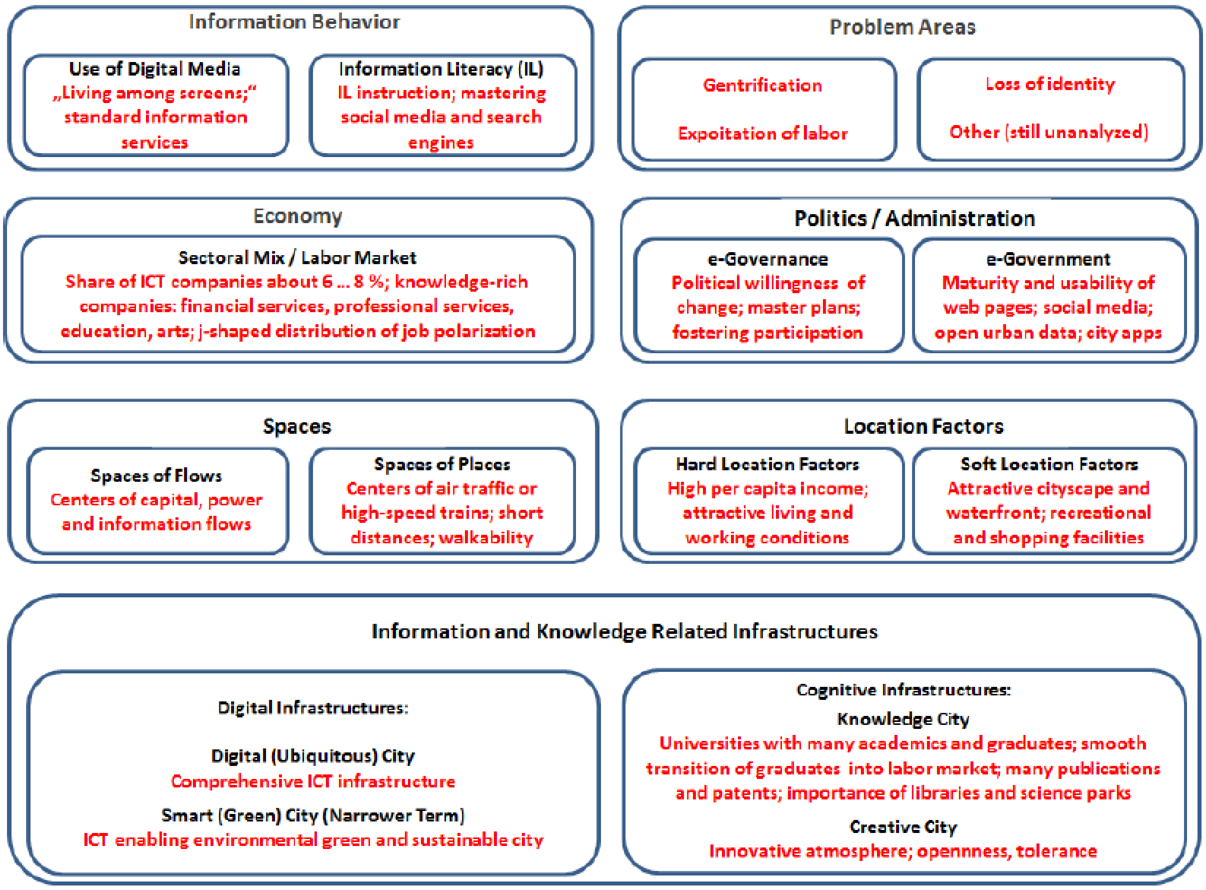

Figure 5 Conceptual framework of smart cities (Barth et al., 2017)

One of the most recent studies in the field of frameworks (Yigitcanlar et al., 2018) is based on existing frameworks. The research is based on 78 studies, of which 26 studies were focussed on frameworks. In total 17 frameworks were proposed or found in the 26 studies. Furthermore, there are multiple drivers for smart cities identified: technology; community; policy. Of the 78 studies used, 14 articles were based on smart cities and communities; 25 articles were based on technology and 13 articles on smart cities and policy. This model does not include management and organization as an important driver or outcome, it points out communities as driver. Management and organization is in here accommodated under two parts (Yigitcanlar et al., 2018). First as an outcome: being able to manage and organise a city in a better way (domain government). Secondly under “policy”, policy plans should describe how to implement smart city technology in a strategic way and how to overcome challenges (Chourabi et al., 2012).

The drivers influence the outcomes which are split up in four different domains:

1. Economy: productivity and innovation
2. Society: liveability and wellbeing
3. Governance: governance and planning
4. Environment: sustainability and accessibility

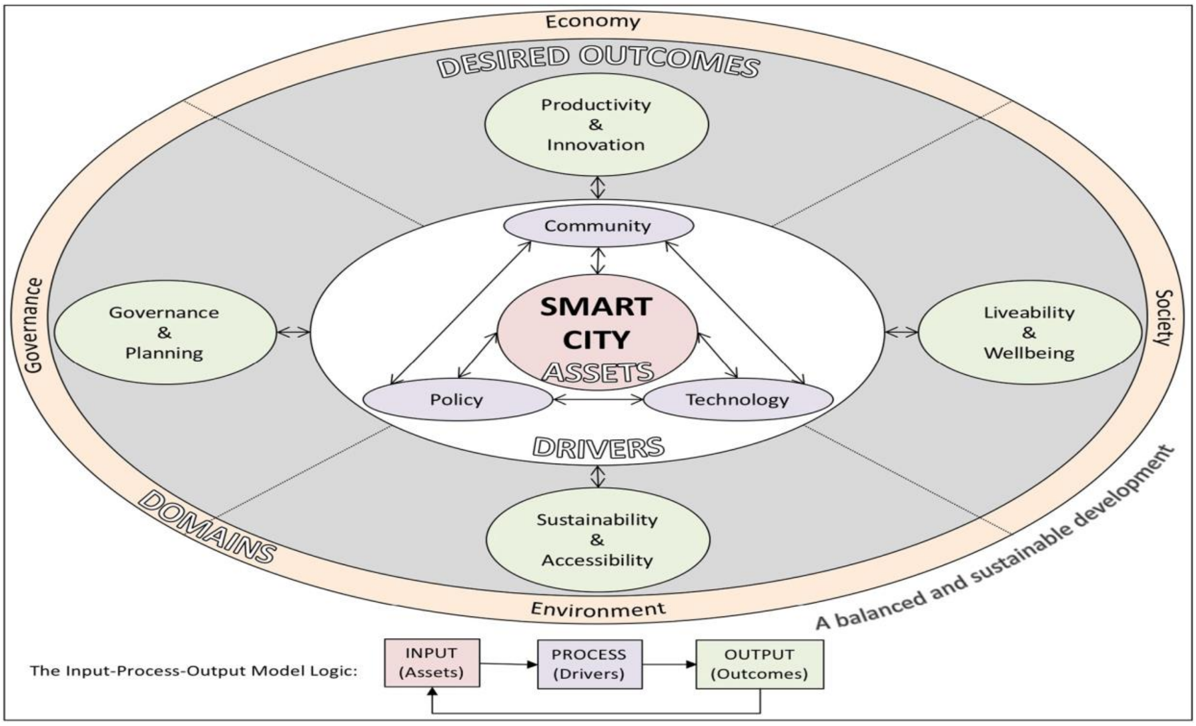

Figure 6 Multidimensional smart city framework (Yigitcanlar et al., 2018)

When a closer look is taken to the building blocks, similarities are observed between the models of Chourabi et al. (2012) and Yigitcanlar et al. (2018). The building blocks make it possible to make drivers measurable.

Table 1 gives an overview of the similarities between the models. The drivers in the smart city initiatives framework become measurable thanks to the building blocks of the conceptual framework. Important to mention is the fact that Chourabi et al. (2012) pointed people and communities as outcome. More recent studies show that for the development of a smart city cocreation with the community is essential (Albino et al., 2015; Jessen, 2015; Yigitcanlar et al., 2018). The drivers with the determining variables are:

- Management/organization and policy:
    - Political willingness to change
    - Existence of master plans
    - Open urban data
    - Use of social media
    - Use of easy understandable webpages to supply information
- Technology
    - ICT infrastructure is needed to create a digital (ubiquitous) city. A distinction is made between new-built cities where the ICT is implemented in private houses and existing cities where an evolved urbanity is confronted with a reconstruction of the community as a living organism.
- Community:
    - Companies
    - Spaces of flows (economic welfare) and spaces of places (urban density)
    - High income
    - Attractive living and working conditions
    - Facilities

Table 1 Comparison frameworks (drivers are bold)

		(Barth et al., 2017)				
		Information and knowledge related infrastructures	Economy and labour markets	Spaces	Politics and administration	Location factors
(Chourabi et al., 2012)	**Management & organization**				X	
	Technology	X				
	Governance				X	
	Policy				X	
	People and communities		X			X
	Economy		X	X		
	Natural environment					X
(Yigitcanlar et al., 2018)	**Community**		X	X		X
	Policy				X	
	Technology	X				
	Economy		X	X		
	Society					X
	Environment					X
	Governance				X	

This section gives an understanding of a smart city in the sense of input (drivers) and output. To create a smart city, three variables are pointed out as essential (policy; technology; community). The government needs to have policies, including the willingness to transform to a smart city. The willingness needs to be translated to the implementation of technology to which location-specific services are developed in collaboration with the community. Although the factors on which a smart city has an influence are known, further research to what exactly influences these outcome-variables is needed. It answers the question why one should choose for developing smart city policies, technologies and services in the first place.

2.2.2. Why a smart city?

In this chapter, a closer look is taken to the outcome of the realisation of a smart city. As discussed in the previous section there are drivers and outcomes (the factors influenced by the drivers). The desire to change these outcomes is potentially the reason to develop a smart city. The used outcome-variables are:

- Economy
- Governance
- Environment (sustainability and accessibility)
- Society (liveability and wellbeing)
- Potential problem areas

Understanding what a smart city is, makes clear why smart cities are being developed. For governments this is because in a smart city resources can be used more efficiently (and the city can thus be more climate friendly). Implementing the IoT into the urban environment, the generation of big data about the status of an area can add to this. This is important to keep cities liveable as the expectation is that by 2050 66% of the world's population will be living in an urban environment. Added to this is the growing world population which means that the world's urban populations will grow with 2.5 billion people by 2050 (UNDESA, 2014).

Next to the growing urbanization, Jessen (2015) found three other topics that are of influence in the decision to develop a smart city. These topics correspond with the found outcomes in the previous chapter:

- Demographic transition (environment and potential problem areas)
- Quality of Life (society)
- Economic performance (economy)

2.2.2.1. Demographic transition

The demographic transition describes the process of increasing population in the region with the lowest resources. Growing populations do need resources and a smart city can contribute by using resources very efficiently. The same is important for the urbanization.

However, the demographic transition also influences the composition of the population living in an area. Barth et al. (2017) stressed out in this sense that individuals of a lower social class could be expelled from the attractive downtown locations due to their lower income. Hollands (2008) found this in the search to what a 'real' smart city is. One finding was that a smart city offers benefits (to make a city attractive) for highly desirable knowledge-based employees. Colding & Barthel (2017) also mentioned this in their study on who the winners and losers of the smart city are. This process is called gentrification.

The demographic transition is two-sided. On the one side, governments must deal with the growing population in cities and the lack of resources. The need for resource efficient cities arises from that. On the other side, the implementation of a smart city can cause gentrification.

2.2.2.2. Quality of Life

The quality of life and economic performance are closely related. For a long time, official statistics were focused on the economy. Individuals were considered productivity subjects. This resulted in a large part of a society being excluded from statistics as particularly males had a job. Only from the 1990's, more social factors were included in quality of life statistics (Sabbadini & Maggino, 2018).

The quality of life is a broad notion which has no set definition. However, Jessen (2015) compared different definitions. What came forward from this comparison is that quality of life is subjective to the individual. The quality of life can differ from one to another, whilst living in the same area. The most extended definition described by Jessen (2015) is the quality of life as defined by the University of Toronto (n.d.): "The degree to which a person enjoys the important possibilities of his or her life". This definition is summarised in figure 7.

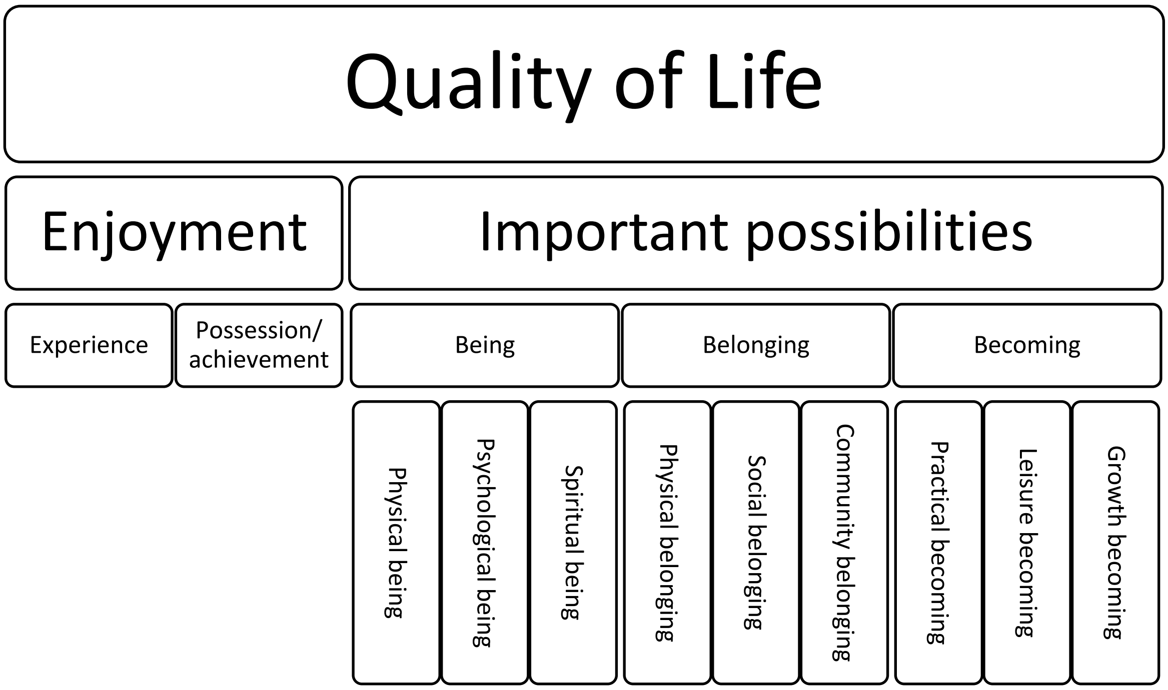

Figure 7 Quality of Life definition University of Toronto (Jessen, 2015)

While there is no set definition, there are still statistical institutes that do research on the quality of life in areas. To understand better how an actual "number" is given to the quality of life, a closer look is taken to two institutes that study the quality of life. The first example of quality of life measurement is from Eurostat (the statistical office of the European Union). Eurostat measures the quality of life based on 8+1 dimensions (Eurostat, 2015). The 8+1 dimensions are used complementary to the gross domestic product (GDP). This was traditionally used to measure the economic and social development of an area. The +1-dimension concerns the overall experience of life. This dimension refers to the personal achievement of life satisfaction and well-being. The eight dimensions concern the functional capabilities that citizens need:

1. Material living conditions
2. Productive or main activity
3. Health
4. Education
5. Leisure and social interactions
6. Economic and physical safety
7. Governance and basic rights
8. Natural and living environment

The model of the University of Toronto and the model used by Eurostat have resemblances. The "Being" part of the Toronto-model is the equivalent of the health-dimension in the Eurostat model. The "Belonging" part refers to material living conditions, leisure and social interactions, governance and basic rights and natural and living environment. The last part from the Toronto-model, "Becoming", is similar to productive or main activity, education and economic and physical safety in the Eurostat model.

Another example is the "Leefbaarometer" (liveability meter) developed by the Ministry of the Interior and Kingdom Relations of The Netherlands. This model is made to measure the quality of life in Dutch districts and neighbourhoods. This model includes 5 dimensions (Leidelmeijer, Marlet, Ponds, Schulenberg, & Van Woerkens, 2014): houses, physical environment, facilities, residents and safety. As discussed, houses, residents (high income) and physical environment are drivers for a smart city. The smart city paradigm can influence the facilities and the safety in an area. These two variables are responsible for 49% of the determination of the quality of life in an area (figure 8).

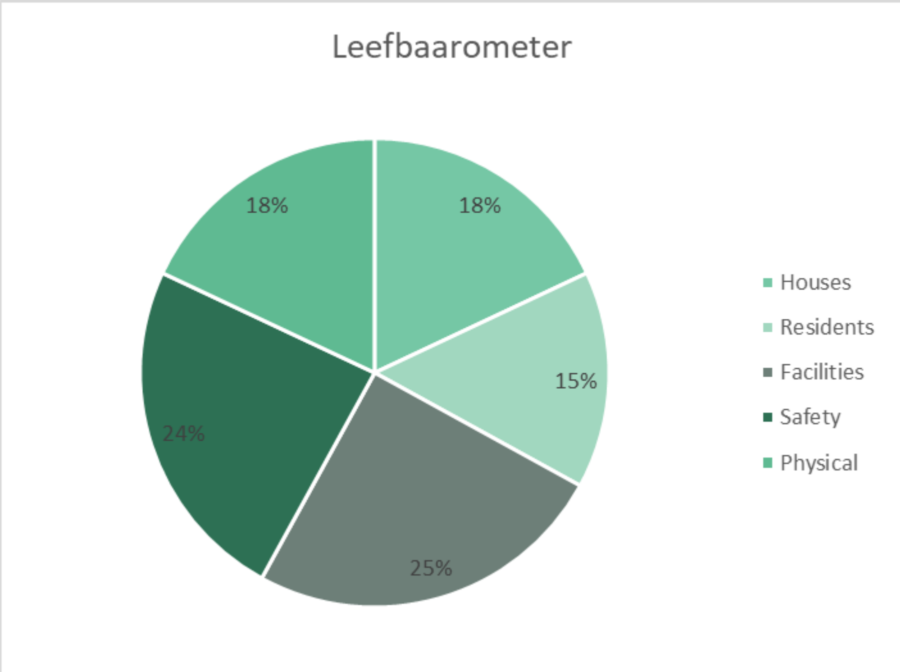

Figure 8 Distribution of variables in Leefbaarometer (Leidelmeijer et al., 2014)

The Leefbaarometer has nine different levels, the basis of the Leefbaarometer is the national average: between “ample” and “good”.

1. Very insufficient
2. Largely insufficient
3. Insufficient
4. Weak
5. Sufficient
6. Ample
7. Good (national average)
8. Very good
9. Excellent

Differences between the Leefbaarometer, the Toronto and Eurostat model are that the Leefbaarometer takes the urban environment into account. The individual part is not included as the individual variables are very hard to measure. Comparing the dimensions of a smart city (Albino et al., 2015) to the dimensions of the quality of life results in table 2.

Table 2 Matrix comparing Albino et al. (2015) dimensions with QoL definitions

Smart city dimensions (Albino et al., 2015)	**(University of Toronto, n.d.)**	**(Eurostat, 2015)**	**(Leidelmeijer et al., 2014)**
A city's networked infrastructure that enables political efficiency and social and cultural development.		X	X
An emphasis on business-led urban development and creative activities for the promotion of urban growth.	X	X	
Social inclusion of various urban residents and social capital in urban development.	X	X	X
The natural environment as a strategic component for the future.	X	X	X

The dimensions of a smart city are similar to the dimensions of the quality of life. Besides, more studies claim that the implementation of smart cities increases the quality of life. Guerra (2017) states that the goal of a smart city is to increase the quality of life for its citizens through technological means, ultimately creating more sustainable cities. Meijer (2016) also describes that governments use smart city technologies to grow the urban economies and quality of life.

2.2.2.3. Economic performance

As mentioned, the economic performance is closely related to the quality of life. However in the sense of quality of life, the economics are focused on the economic safety of individuals: additional financial resources when needed, but also human and social resources such as welfare and support mechanisms created by society (Eurostat, 2013). Smart cities can be of importance in the creation of business. It is the data collected via the Internet of Things that creates opportunities: the data collected in a smart environment can uncover hidden patterns, correlations and other insights. This enables entrepreneurs to find a business opportunity or existing companies to improve their services to their customers (Hashem et al., 2016).

To conclude, the implementation of a smart city can help a city to be more sustainable when there is a shortage of resources. This especially occurs in areas where the population is growing. Furthermore, implementing smart technology can improve the quality of life for the residents living in that area. Finally, the local economy can be improved using the data collected in the smart environment (figure 9).

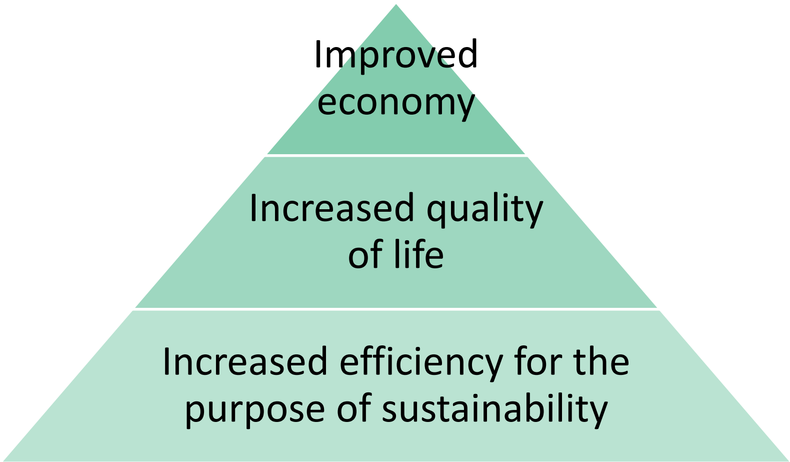

Figure 9 Why a smart city

2.2.3. Conclusion

In this section the various studies conducted to smart city frameworks have been explored. Frameworks are developed as an answer to the fact that there is no set definition of what a smart city is. From the discussed frameworks, it appeared that there are certain drivers in a smart city and certain outcomes. The drivers are the variables that influence the outcome, however, drivers themselves are also influenced by the implementation of smart city technology. Besides technology, policy and community are the other drivers.

2.2.3.1. Drivers

Policy

Policy is defined as “A course or principle of action adopted or proposed by an organization or individual” (Policy [1], n.d.). A policy for a smart city is based on a need. As discussed this could be the increasing number of people living in an urban area. Cities must cope with a growing number of residents and are forced to be more sustainable. Smart city technology can offer a solution for this; therefore, a city can set out a course to implement smart city technology in the urban environment. Having a policy for smart city is needed to start the action of implementing smart city technology (figure 10). The policy for smart city is based on the community.

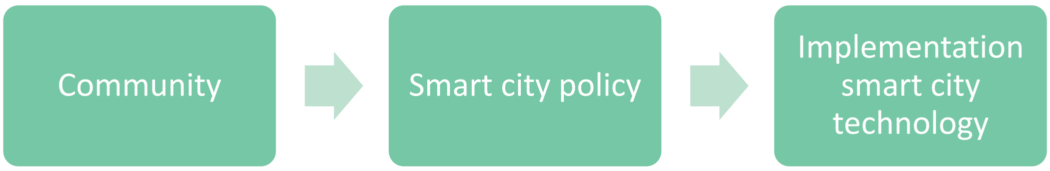

Figure 10 First policy, then technology

Community

The notion community is defined as "A group of people living in the same place or having a particular characteristic in common." (Community [1], n.d.). In the sense of a smart city this includes everybody that is living in, working in or visiting a city.

For the implementation of smart city technology with regard to community, three building blocks from Barth et al. (2017) with parameters are important. The location is one of them. This includes high capita per income, an attractive area to live and work but also recreational facilities. An attractive area to work is related to the space of flows and space (economic welfare) of places (urban density). The urban density includes a large population on a relative small surface area but also short (walking) distances, public transport and business districts (power, money and information).

The question that remains is, what the driving role of the community exactly is. Community in every location differs due to city specifics: the types of companies, the culture, etc. Therefore, the community is what a smart city serves. Smart city services should be specific determined by the residents, companies (workers) and visitors. This is also concluded by Jessen (2015):

> *How to exactly create it is impossible to answer, because every city is different and constantly changing. Therefore the smart city must be built with the help of those people who are the experts, the citizens.* (Jessen, 2015)

Developing a smart city starts with a community that wants and needs to be more efficient and have the opportunity to interact more with their environment. Form this, policy should be developed for smart city, which is also a driving factor in the proves to develop a smart city. When both community and policy are present, the technology can be developed, on which finally smart city services can be developed, based on the specific needs of the community.

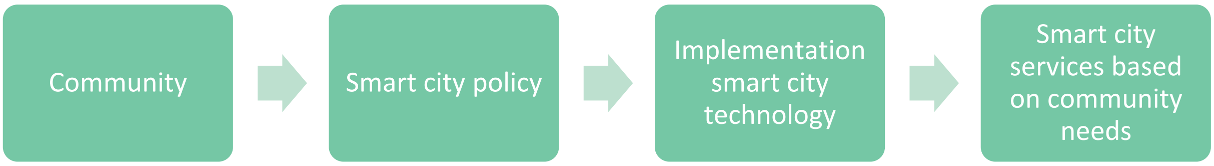

Figure 11 Driving process smart city

To implement smart city technology, the area should have a high urban density and thus a high need for more efficiency regarding resource usage. The population should have a relatively high income and the area should be attractive.

2.2.3.2. Outcomes

From the different frameworks (Barth et al., 2017; Chourabi et al., 2012; Yigitcanlar et al., 2018) appeared that the implementation of smart cities has certain results. These results are the reason why a city could be turned into a smart city, as the services that could be offered in a smart city are able to influence the level of sustainability, liveability, the wellbeing (quality of life) and the local economy. Figure 12 gives a simplified overview of the outcome-process as a result of the implementation of smart city services based on community needs (the last step in the driving process for smart cities: figure 11).

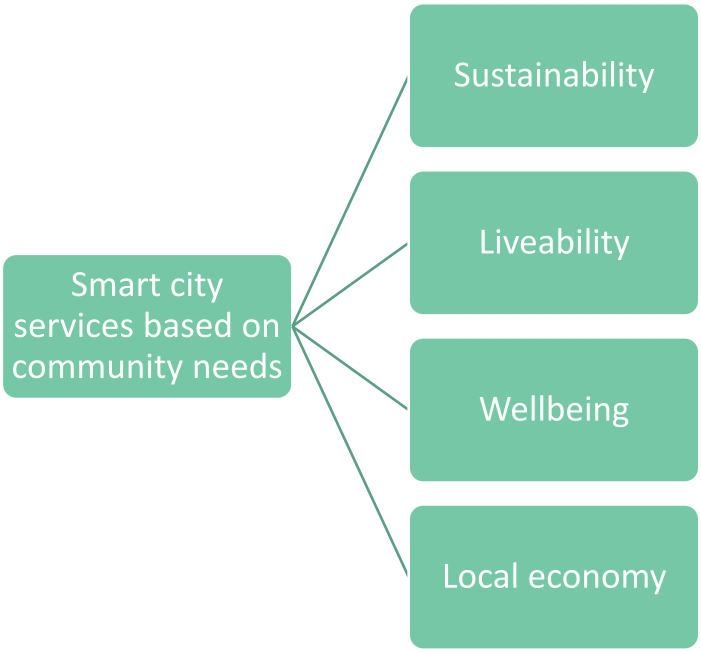

Figure 12 Outcome process smart city

It is very important to make the distinction between the implementation of smart city services and the actual services running on this technology. The technology itself is not responsible for an improvement of the concerning factors. However, first the technology must be implemented before services can be offered. In the rest of this reports, the distinctions between driving factors and the outcomes will be used as structure. In the next section, the factor community will be studied more in depth.

2.3. Attractiveness urban areas

The smart city paradigm can improve several factors in how the area is experienced (Barth et al., 2017; Chourabi et al., 2012; Yigitcanlar et al., 2018), while it can influence via the IoT only six topics (Zanella et al., 2014). Combining these two topics would result in endless potential services which can be implemented. It is however important to take the demographic composition into account. The driving factor community is split up in three main groups: companies, residents and visitors. The focus of this section is to give an understanding of what kind of facilities or services are important for the three target groups. As the factor "technology" will be discussed in the next chapter (case study Strijp-S), the community factor is studied from literature.

2.3.1. Residents

The first group considered are the residents. An interesting process that gives an understanding of what makes an area attractive for residents is gentrification. The notion gentrification coined by Ruth Glass (1964) and defined as:

> *"One by one, many of the working-class quarters of London have been invaded by the middle-classes—upper and lower. Shabby, modest mews and cottages—two rooms up and two down—have been taken over, when their leases have expired, and have become elegant, expensive residences .... Once this process of 'gentrification' starts in a district it goes on rapidly until all or most of the original working-class occupiers are displaced and the whole social character of the district is changed."*

What already comes forward in this first definition is that certain lower-class neighbourhoods are attractive for higher-class residents, even though the residences are relatively small. Understanding what makes an area attractive for residents can help in the development of smart city services for residents. According to Clay (1979) the gentrification process exists of four stages. It starts with artists and/or design professionals that have the skills and time to renovate vacant homes, which they do for themselves. Following upon this, some early investors start to renovate vacant houses and some promotional activities are done by real estate agents. The third stage is marked by media attention and larger scale urban renewal. Also, the government starts to put more effort in the area: safety and security and the public space are being improved. The number of small businesses and retailers increases. The fourth and last stage is reached when the urban transformation is done, and the area has become an expensive (real estate values) and attractive area. The aim of a smart city is not to pursue gentrification, but the process makes clear what residents are looking for: safety and security, improved care for public space and a variety in small businesses. The availability of parking spaces for residents is also indicated as important facility (van Kempen, 2017). It all comes back to the quality of life for residents.

2.3.2. Business

From an historic point of view, businesses are attracted by the availability of resources and the possibility to transport goods (close to a river). Richard Florida (2002) stated in the book that the creative class is nowadays of more importance in relation to the availability of resources and transport infrastructure. Instead of people moving to where there is work, companies move to where the creative class is. The creative class can be indicated by three T's:

- Tolerance
- Technology
- Talent

First, it is important to make an area interesting for employees (section 2.3.1). Second, areas that can supply data and information about the users of that area are interesting for businesses. As discussed, urban data can play an important role in the founding and improvement of business models. Furthermore, van Kempen (2017) identified that services supporting the interaction are important. One can think of high-quality meeting rooms, equipped with Wi-Fi communication tools. But also, a smart kiosk where rooms can be booked, and visitors can be managed. Management of information streams, security and comfort are important notions in services offered for businesses.

2.3.3. Visitors

isitors are the group of people that come to an area just incidental. This could be guests of residents or companies, but also tourists. Oxford Dictionaries defines the noun “tourist” as “A person who is travelling or visiting a place for pleasure.” (Tourist [1], n.d.). The definition shows that visitors are especially interested in gaining experiences. To attract visitors, especially services from the fun and entertainment category are of interest.

2.3.4. Conclusion

From this section it can be derived that different parts of the community of a certain area have different needs. Residents and businesses both have a need for safety and security, while visitors have more needs for fun and entertainment. Since businesses are attracted by "the creative class" residents can also be an attractive force for businesses. On the other side, residents have a need for businesses and retailers as well. This results in a vicious circle.

2.4. Financial feasibility

Until this point, the notion of smart city has been discussed with regard to the drivers and outcomes. The drivers describe the factors that are of importance for a successful transformation to a smart city, the outcomes are the factors that are influenced by the implementation of smart city technology. Until this point the financial feasibility has not yet been considered but is of course important as investments must be done to implement the technology.

Posthumus, Speekenbrink, Bonte, Loots & Philipson (2017) investigated the business case for smart public nodes. Smart public nodes are based on regular lampposts. Most of the lampposts in the Netherlands are part of an infrastructure that use out-dated technology. Since this infrastructure needs to be replaced, the lampposts offer the opportunity to implement smart technologies. Furthermore, lampposts are widespread throughout cities. The transition from regular lamppost to smart public nodes, which can offer more than just illumination: smart city services. In terms of costs and benefits: the technology needs the investment and the services are going to bring the benefits.

In the study of the business case for smart public nodes (Posthumus et al., 2017), a value case approach was used. In this approach, a selection of eight services was made from a "long list" for further research. The selected services exist of:

- Small cells
- Sniffer
- Camera security services
- Crowd control
- Smart parking
- Smart lighting
- ITS
- Wi-Fi

In Appendix 2 a description per service is included. The authors of the study on smart public nodes (Posthumus et al., 2017) used the word "services" to describe the above-mentioned technologies. It can be discussed however if these are actual services or so-called enablers. The term "service" implies that the product could be sold to end-users as such. This is not the case with the above-mentioned "services". For example, Wi-Fi is a platform that could enable multiple services such as internet access for events, additionally the organisation of the event can use the Wi-Fi as communication tool to their guests via push-messages. Another example is smart lighting, which could be used for safety issues, but also connected to a sports app to show a running route. Therefore, decided is to describe the used technologies as "enablers for smart city services".

2.4.1. Function areas

As different enablers can support different types of services, not all the enablers should be implemented in all types of areas. A focus on decreasing costs while maximizing the incomes resulted in the design of different function types (Posthumus et al., 2017). This is related to what is discussed in section 2.3, that a different composition of the community results in a different need for services (in this case enablers). Table 3 gives an overview of the different function areas and a description per function type.

Table 3 Function areas (Posthumus et al., 2017)

Functional area	**Description**
Main traffic routes	All main (arterial) roads, local roads not integrated in residential or industrial areas, bus lanes and continuous cycle routes with own character.
Water and banks	Banks of canals or similar waterways or water surfaces. Note that banks of drainage ditches are considered part of the functional area in which they lie.
Business area	Areas aimed mainly at industrial/commercial activity. This building type is mainly industrial or office building. Some residential usage if dictated by industrial/commercial activity.
Transition area	Parts of the “rural area” that are under development. At the end of development, the areas will be re-designed as part of the appropriate functional area.
Rural areas	Rural area usually outside the boundaries of the “built-up area”. Usually used for agriculture and natural purposes with or without recreational function. Includes large scale forest areas
City centre area	City centre, high quality shopping area, downtown.
Shopping centre area	Such areas encompass neighbourhood shopping facilities plus other public facilities such as district centres, railway station, school, sports hall etc. Like “City centre area” in function, but lower density
Suburban-green	Urban green space that serves the needs of more than a single quarter or neighbourhood. Including sports fields, allotments and town commons. Extensive (residential) construction occurs.
Residential area	Residential, with some (limited) commercially used premises.

2.4.2. Enablers per function area

Now the function types are discussed, as well as the different enablers included in the study, these two are combined (Posthumus et al., 2017). Table 4 gives an overview of which enabler is selected for which function area. The number 1 represents the implementation of an enabler in the area, and 0 means that the enabler is not implemented. What strikes is that there are no suitable enablers included in the TNO study (Posthumus et al., 2017) for the “water and banks” function area. Furthermore, the denser the area is, the more services are selected. This is in line with what has been found in the literature review: high-density urban areas with commercial activities. The “main traffic routes” function area is included in the model; however, this research has an urban focus.

Table 4 Implementation enabler per function area (Posthumus et al., 2017)

	Small cells	Sniffer	Camera security services	Crowd control	Smart parking	Smart lighting	ITS	Wi-Fi
Suburban green	0	1	1	0	0	1	0	0
Rural area	0	1	0	0	0	1	0	0
City centre area	1	1	1	1	1	1	0	1
Main traffic routes	1	1	0	0	0	0	1	0
Transition area	0	0	1	0	0	1	0	0
Water and banks	0	0	0	0	0	0	0	0
Business area	1	0	1	0	0	1	0	0
Shopping centre area	1	0	1	1	0	1	0	1
Residential area	1	1	1	0	0	1	0	0

2.4.3. Feasibility enablers

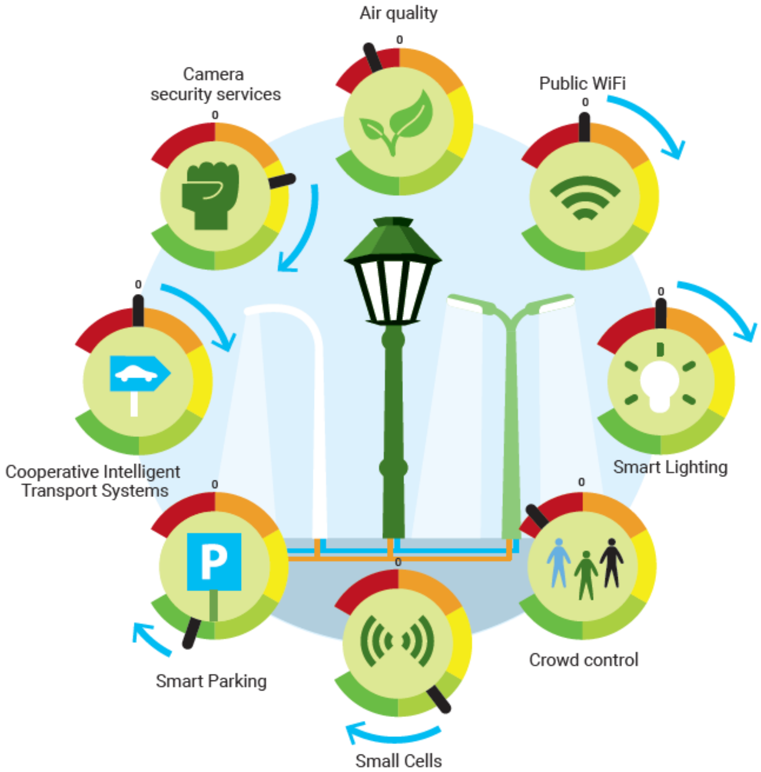

Figure 13 Financial feasibility per enabler (Posthumus et al., 2017)

Figure 13 gives an overview of the feasibility, which shows that there is a difference between the enablers. Most feasible enablers are “smart parking” and “small cells”, while sniffers (air quality) together with crowd control is not considered financially feasible at all. These enablers however add to the quality of life. The study (Posthumus et al., 2017) focussed on “maximum benefits reached at minimum costs”.

2.5. Conclusion

This chapter was used to give understanding to the notion of smart cities. Despite the fact that there are numerous definitions to what a smart city is and could be, it can be concluded that a general agreement in the literature was that creating connectivity is necessary in order to develop a smart city. The connectivity creates a platform for IoT. The IoT makes it possible to influence six different aspects in the urban environment: waste; pollution; traffic; energy; parking; lighting. From taking a closer look to how the IoT influences these aspects, it can be concluded that data is the key factor. Depending on what kind of IoT is implemented, it is possible to offer numerous services.

Creating connectivity and offering smart city services effects the urban environment. The quality of life may be increased, the sustainability increases, and the local economy can be improved. These results help in the increased need for efficiency in urban environments/cities.

Technology and data are the aspects that in theory make a city smart: making it possible to be more efficient with resources. Technology however is of course not the only factor of importance when developing a smart city. Different frameworks are compared which made a distinction between smart city drivers and smart city outcomes. Technology is one of the drivers, together with “community” and “policy”. These drivers are important to consider when searching for locations to develop as smart city.

The community can also be described as the potential market for smart city services. Therefore, the demographic composition is of importance for the selection of the types of services to be offered in a specific area. From the literature, function types are derived which can be used to classify neighbourhoods. As the smart city concept is still under development, it is not possible to assign specific services to these function types. The attributes selected per function type are called enablers (part of the IoT): platforms that make certain types of services possible. Implementing the enablers is inseparable from implementing services: it depends on which enablers are implemented, which services can be developed. The services influence certain fields of the urban environment: liveability and wellbeing (quality of life), sustainability and local economy (the outcome). The balance between implementing enablers (investment) and income from these enablers is important to create maximum value with the least costs. The demographic composition of the community determines this. Table 4 represents the overview of which enabler should be implemented in what function type

The next chapter is an introduction to the case study which will compare the found literature to what is done in practice. This includes how a smart city is built: the different components, what type of services/enablers are implemented so far and what can be learned. While in this chapter more understanding was given to the community-driver, the next chapter will focus on the technology/connectivity and how and what is done to create the connectivity at Strijp-S.

3. Case: Strijp-S

In the previous chapter the notion smart city has been studied in literature. From this study came forward that there are certain factors, which can function as a driver and certain outcomes. The factor community is one of these driving-factors. The demographic composition was translated in certain function areas which are attached to so called smart city service enablers. Another driver is technology: the technique to achieve connectivity. The aim of this chapter is to apply the found theory to Strijp-S, the former factory site of Philips. Furthermore, while the literature was used to make the notion “community” concrete, this chapter will be used to make the technology concrete. This is done by first comparing the results from the literature study to the case Strijp-S. From the literature, four main conclusions were drawn:

- Connectivity makes the smart city.
- For a financially feasible implementation of smart city technology, certain drivers are needed.
- Implementation of smart city technology results in certain outcomes.
- The community-driver influences what kind of enablers are implemented.

The case Strijp-S is chosen because in this area, connectivity in terms of smart city technology in the urban environment, is present. Therefore, the drivers and outcomes will be analysed for Strijp-S. Furthermore, the way in which the smart city Strijp-S is built up will be discussed. Finally, the enablers found in the literature will be compared to the enablers present at Strijp-S. This will give understanding to what can be learned from Strijp-S, regarding smart city technology.

3.1. Drivers and outcomes Strijp-S

The drivers and outcomes from implementing smart city technology have been discussed in chapter 2. These were derived from literature. In this chapter those are applied to Strijp-S. Table 5 gives an overview of the factors found in the literature and their presence at Strijp-S. The drivers of smart city technology are relatively easy to measure in this case: technology and policy are present, and the community-factor reaches the requirements. In terms of function areas, the area would be classified as city centre area (section 2.4.1). The area has a high urban density, offers shopping facilities and has an extensive catering industry present.

Especially the outcomes are interesting to discuss. As the area was a former factory district, there could not be spoken of a quality of life as there were no residents. In the redevelopment of Strijp-S, the option of living was added. This is the same for the “local economy”, at first one company (Phillips) was located at Strijp-S, now there are 650. So, the local economy increased, and liveability was created. It is however hard to say if these developments were less if smart city technology was not implemented. However, as the developments of the area were done hand in hand with the implementation of smart city technology it can be concluded that smart city technology indeed offers the opportunity to improve the quality of life and the local economy. To support this conclusion, for each outcome, an example is given.

The quality of life is improved using smart lighting. As discussed in the literature (section 2.2.2.2), safety is an important factor in the quality of life. Smart public lighting offers, in combination with (sound)cameras, an increased safety in the area. These cameras can discern incidents that the smart public lighting can anticipate. Furthermore, emergency services and people in the area can be notified. Via these technologies, the safety in the area is increased and so the quality of life.

The increase of the growth of the local economy is also discussed in literature. The most valuable point for the increase of the local economy is the data available which can show hidden patterns and correlations in the environment. This could lead to new business opportunities or an improvement of services for existing businesses based on data. An example of the increase of business opportunity is the iCity Tender. The aim of the tender was to challenge SME entrepreneurs and start-ups to develop business ideas which connect people and their surroundings. The living lab Strijp-S functioned as test platform for this (VolkerWessels iCity, 2016). In total eight businesses were selected which received a subsidy to further develop their idea.

Finally the sustainability is an outcome of smart city technology: an example in this case is the smart housing project at Strijp-S (VolkerWessels iCity, n.d.). In this project, houses are equipped with DC power supply, which makes it possible to directly use power generated by solar panels. Furthermore, the heavy energy consumers (washing machine, dryer) are connected to a smart energy management system, which determines when these heavy energy consuming machines can be used: only when there is enough sustainable energy available. When there is too much energy available, this can be stored in a local battery. In this way, the apartments contribute to the sustainability of the area, using smart technology.

Table 5 Drivers and outcomes Strijp-S

	Factor	Applicable to Strijp-S	Source
Drivers	Technology	Yes	(Glasvezelgids, 2016; Goulden, 2015; VolkerWessels, 2017)
	Policy	Yes	(Gemeente Eindhoven, 2016)
	Community	Yes	(CBS, 2017b; Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2016)
Outcome	Quality of Life	Yes	(CBS, 2017b)
	Local economy	Yes	(CBS, 2017b)
	Sustainability	Yes	(VolkerWessels iCity, n.d.)

The factors that can function as driver at Strijp-S and also the outcomes-factors can be related to smart city technology. In the next section a closer look is taken at how exactly the smart city is built at Strijp-S.

3.2. Smart city layers

In the previous sections of this study, connectivity appeared to be an important factor in the development of smart cities. The connectivity is realised via a data infrastructure. This infrastructure is for Strijp-S defined as an area-wide, high quality, connected communication and control backbone (Goulden, 2015) and is one of the three layers Strijp-S recognises as part of a smart city. The other two layers are the cloud and the liveable layer (figure 14).

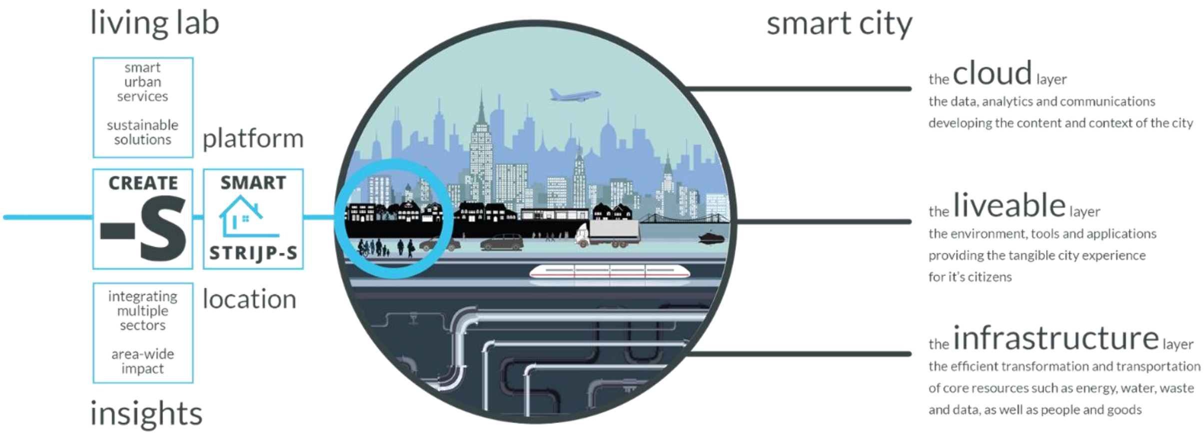

Figure 14 Smart city layers Strijp-S (Goulden, 2015)

Implementing a data infrastructure requires new types of investments in the urban environment. These new types of investments also need other models to earn back the investment: new business models. One could ask why to research how to have a positive return on investment. If there is no positive return on investment in the first place, why would there be a need for smart cities? Jessen (2015) summarised the answer to 'why smart cities' as follows:

> *The smart city is efficient with resources and can provide thorough analysis that help solve the problems related to these trends. Additionally, the quality of life and economic performance can be enhanced by a smart city. The services themselves can enhance the quality of life by solving needs that are currently not fully addressed. While the development process of these services has the potential enhance economic performance by creating new opportunities.* (Jessen, 2015)

The services in a smart city improve the quality of life, but the services in a smart city need to be tailored to the needs of the particular location (Meijer et al., 2016). The tailored services function in the liveable layer and the cloud layer. Nevertheless, the type of area and the developed services, a backbone (the infrastructure layer) that creates connectivity is needed. The investment in this layer should be returned via the other two layers (figure 14). Structures for smart cities are found in literature as well. Schleicher, Vögler, Dustdar & Inzinger (2016) described the SOS (Smart city Operating System), an operating system which is a framework around which the applications can be built. The need for a standardised platform was already stressed out by Gubbu, Buyya, Marusic & Palaniswami (2013), where a "plug 'n play" system with an interoperable backbone was suggested.

3.2.1. Infrastructure

The case Strijp-S in Eindhoven is built around the need for public lighting. The public lighting is seized as an opportunity to develop Strijp-S as a smart area. The lighting is part of the so-called backbone for a smart city. This section will elaborate on this backbone, to understand of what parts it exists. The precise purpose of the backbone is to be a flexible “plug-in” infrastructure, that can support energy and data access to smart city technologies. Therefore, the following parts are elements of the backbone:

1. Energy supply
    a. For public lighting
    b. For electric vehicle charging
    c. For smart city services
2. Data
    a. Optical fibre cable active
    b. Optical fibre cable redundant
3. Smart City Hub
4. Smart public nodes

The energy supply and the data are using cables that are laid through the area. On the one side, the cable will be connected to the smart city hub. A smart city hub is a computer that is able to manage the data collected from the smart city, but also to control the smart services. An example of how a smart city hub functions is defined by Liu, Heller & Nielsen (2017). The architecture designed for data from a smart city is especially designed to be able to handle heterogeneous, privacy sensitive data. The system is based on ETL (Extract, Transform and Load). It collects the data, transforms it into usable and safe data to use and sends it to the data consumer. In the case of Strijp-S this is, for example, parking data that is send to the parking operator Mobility-S. An overview of the framework is given in figure 15.

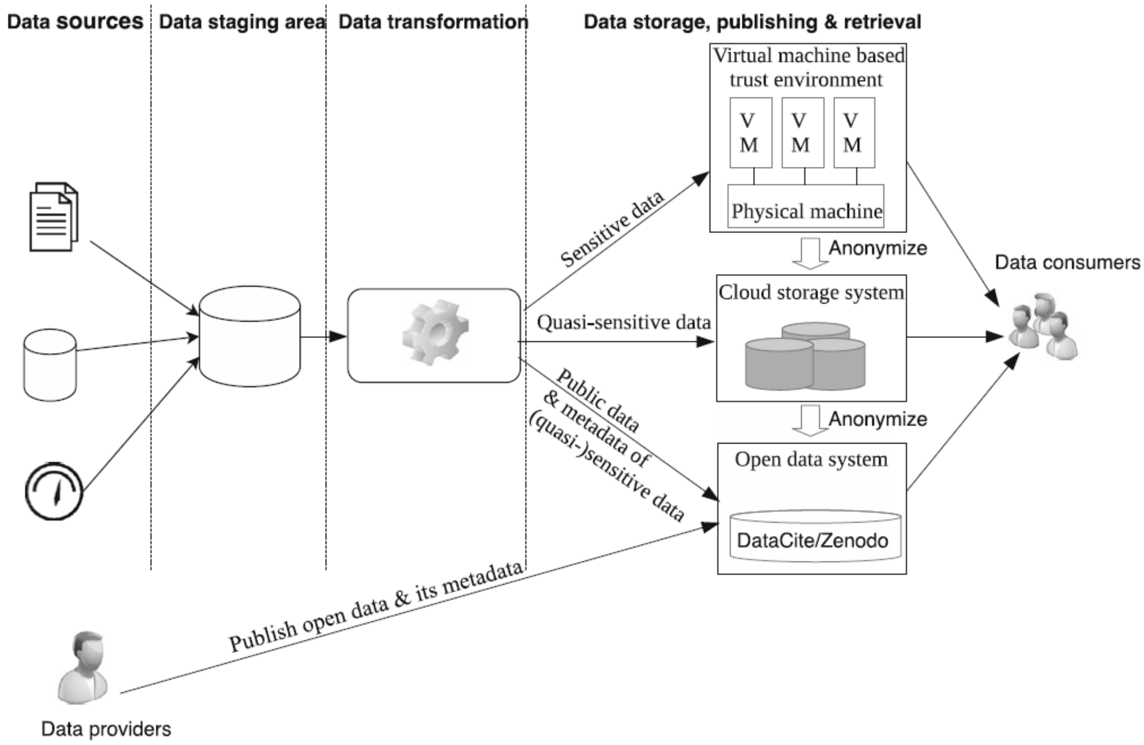

Figure 15 Architecture of CITIESData framework (Liu et al., 2017)

3.2.1.1. Costs backbone Strijp-S

An estimation for the costs for the backbone at Strijp-S has been made. In this the construction costs are included, but also the monthly costs like energy and maintenance contracts. In the next chapter, these numbers are used to set key figures for the implementation of smart city technology in an area. Table 6 and table 7 give an overview of the costs.

Table 6 Construction costs smart city hub and backbone Strijp-S

Object	**Price**	**Depreciation time**
Equipment smart city hub	€ 108,000[1]	20 years
Hardware smart city hub	€ 90,000	5 years
Glass fibre Strijp-S	€ 112,000	20 years
Mobility-S (smart parkin) hardware and glass fibres	€ 142,000	20 years
Hardware office-S (smart offices)	€ 170,000	5 years
Glass fibre houses	€ 72,000	20 years
Total	**€ 649,000**	

Table 7 Periodic costs smart city hub Strijp-S

Rent (including electricity)[2]	€ 500	Per month
Maintenance UPS	€ 2,500	Per year
Maintenance air conditioner	€ 1,500	Per year
Total	**€10,000**	**Per year**

The last part of the backbone exists of smart public nodes. These nodes are the access points in the urban environment to plug in or use smart city services. At Strijp-S the smart public nodes are the lampposts. Lampposts are the perfect item to fulfil this function, as their density in urban environments is very high: in the municipality of Eindhoven, 49,139 lampposts (Eindhoven Open Data, 2017) are spread over 88.87 km^2 (CBS, 2017a). For Strijp-S in specific, 994 lampposts (Eindhoven Open Data, 2017) are spread over a surface area of 0.3 km^2 . The costs for realizing a backbone are built up as follows:

$$€\ Digging + €\ Casing + €\ Fibers + €\ Smart\ Public\ Nodes + €\ Smart\ City\ Hub$$

The costs for digging depend on the type of situation the smart city is created in. At Strijp-S, groundwork for making the area suitable for living and working had to be done. The implementation of the casing and fibres was done simultaneously. The groundworks included the construction of new infrastructure, new built buildings and renovation works (redevelopment of the area). Costs for implementing the cables in an area that is not under development, would bring more costs for digging. So, an important factor in the decision

[1] The costs for the smart city hub are not representative as a second-hand server is used. The new price for an equivalent is € 500,000

[2] This price is not representative as the building is owned by the developer. Normally the rent for the same area would be € 1,000 per month including electricity.

whether to create a smart city (and so to construct the backbone) is the status of an area: are renovations or is redevelopment needed or not.

3.2.2. Liveable layer

The liveable layer (figure 14) is the layer in which the services offered are available. These services are split up in three different tracks (Goulden, 2015). Each track has his own characteristics and types of services. In this section, a closer look is taken at these tracks and how the typical services influence the urban environment.

1. Safety and comfort, is defined as:

> *Quality of life needs to include the quality of the environment in which the person lives, and as such bears a close relationship to the theme of safety, security and comfort. In the urban context there is an intriguing potential dichotomy between perceived, experienced and actual safety and security.* (Goulden, 2015)

Safety and comfort services are focussed on increasing the quality of the environment: increased sustainability, better air quality, etc. Furthermore, the quality of life is related to these types of services: safety and security. The quality of the environment is closely related to the quality of life (Eurostat, 2015).

2. Mobility and energy, is defined as:

> *Transportation tends to favour economic development as it facilitates the flows of people, goods, energy and information. The structure of these flows in terms of origin, destination, routing and mode will in turn impact urban spatial organization and the evolving design and implementation of urban resources.* (Goulden, 2015)

The result of implementing the mobility and energy track (M&E track) is more related to the economic development of an area. These services that fall under the M&E track provide to a lesser extend the basic needs, like safety and comfort, but more in the sense of performing activities in the area. However, sustainability is also an important notion in this track, especially in the sense of energy. Services that make efficient use of energy possible, management of renewable energy sources and information management fall under this track.

3. Enjoyment and entertainment, is defined as:

> *The area of Strijp-S plays an important and dynamic role in supporting the social and entertainment needs of both local residents as well as the wider city and even regional and national citizens. A growing number of events and activities attract a diversity of visitors; on occasion focused on specific cultural and social interest groups and increasingly attracting a broader international audience.* (Goulden, 2015)

In the citation above two user-groups are mentioned: residents and visitors. The services in this track focus on the social and entertainment needs of both groups. This service-track adds to the quality of life as well, but more to the “belonging”-areas (University of Toronto, n.d.)(Figure 7).

The three service-tracks have some similar characteristics as well as differences. The safety and comfort and the enjoyment and entertainment tracks are more concentrating on the quality of life. However, the safety and comfort services attribute to the basic needs: safe environment, clean air, protection, while the enjoyment and entertainment services have more a social focus. The mobility and energy track offer the opportunity to use resources more efficiently, which is interesting for businesses as well as for residents, who can profit from lower energy bills. In addition to the service tracks, potential services are defined by Cisco and Park Strijp Beheer (Cisco Systems International B.V., 2013). Based on the potential services, service profiles are defined based on the users of an area (residents, businesses and visitors). Businesses are especially attracted by mobility and energy services, while residents have a more equal spread mix between the tracks and visitors have a greater need for fun and entertainment services. The complete explanation and service profiles can be found in Appendix 3.

3.2.3. Cloud layer

While the data infrastructure makes the actual transportation of data possible, the cloud layer develops content and puts the data into context (of 'adds context to the data' of 'provides context for the data'). The services offered in the liveable layer are able to function, based on the cloud layer. The infrastructure layer offers the opportunity to communicate and the cloud layers describes how to communicate. As this study focuses on the smart city technology (infrastructure) and the enablers, the cloud layer is left out of the scope.

3.3. Enablers Strijp-S

Now that the infrastructure and the service-tracks for Strijp-S have been discussed, it is time to analyse what is implemented in the area. In the description of the liveable layer (section 3.2.2) the word "service" was used to describe the different tracks. Since Strijp-S is a living lab and therefore multiple services are tested next to each other, the focus here will lie on the enablers (IoT) implemented so far. Figure 16 gives an overview of the services that are tested and/or in use at Strijp-S and which enabler they use. The red dots are the connection between the enabler and the service. This shows the variety of information that can be collected, and the services offered, but also that sensors and services are not communicating with each other yet. However, it also points out that multiple investments are done in different services. The graph (figure 16) shows the services at Strijp-S to give a better understanding of how enablers are used. Obviously more services are conceivable.

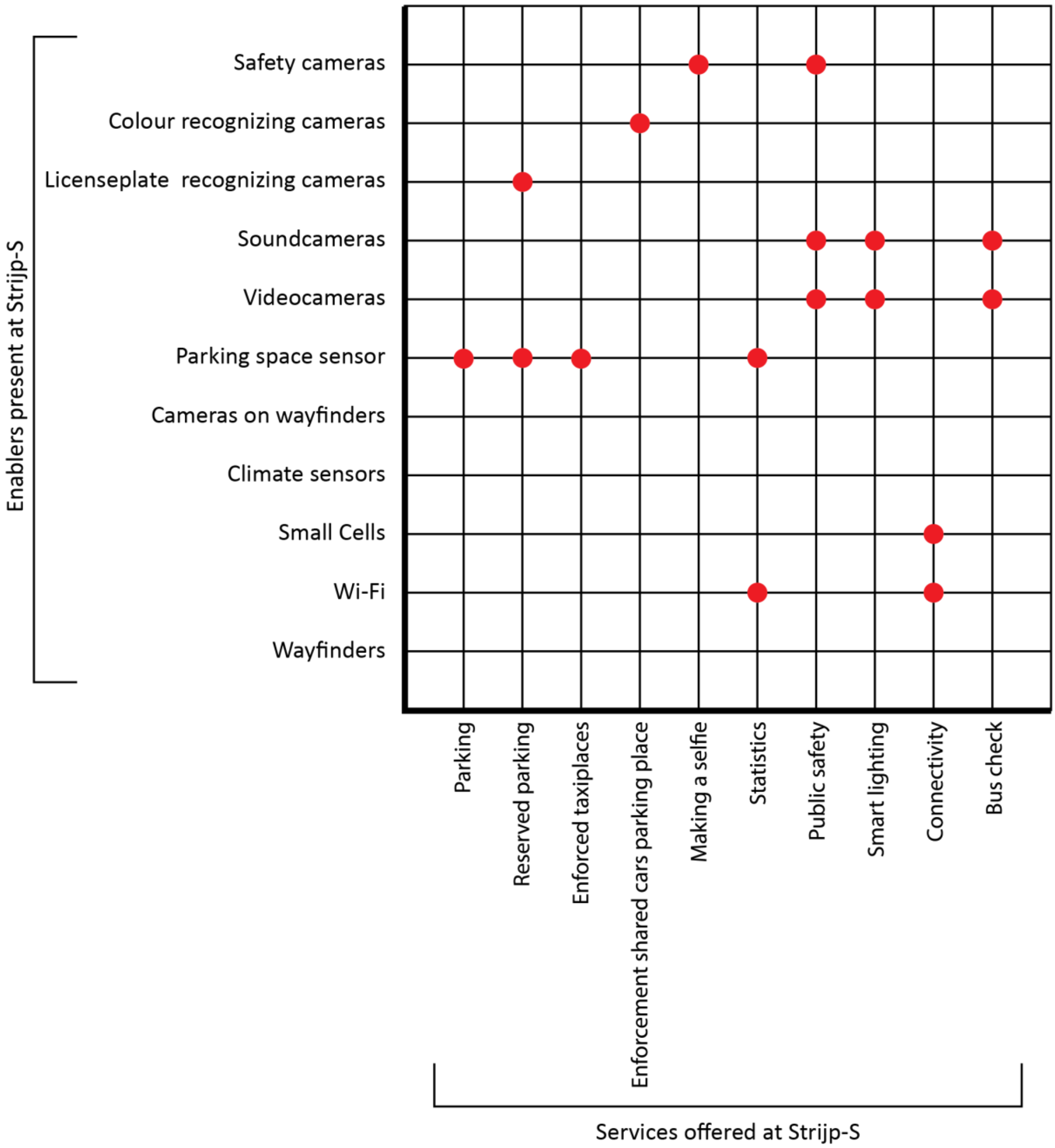

Figure 16 Enablers used by services Strijp-S

From literature, enablers per function area are selected (section 2.4.2). These enablers are compared with the enablers present at Strijp-S in figure 17. What strikes is that there are no enablers implemented that support Intelligent Transport Systems (ITS). This corresponds with the earlier discussed function area "City centre area". Furthermore, it stands out that there are multiple enablers implemented at Strijp-S that match with the enablers selected by Posthumus et al. (2017). The fact that Strijp-S is a living lab explains this: multiple systems are tested and developed next to each other.

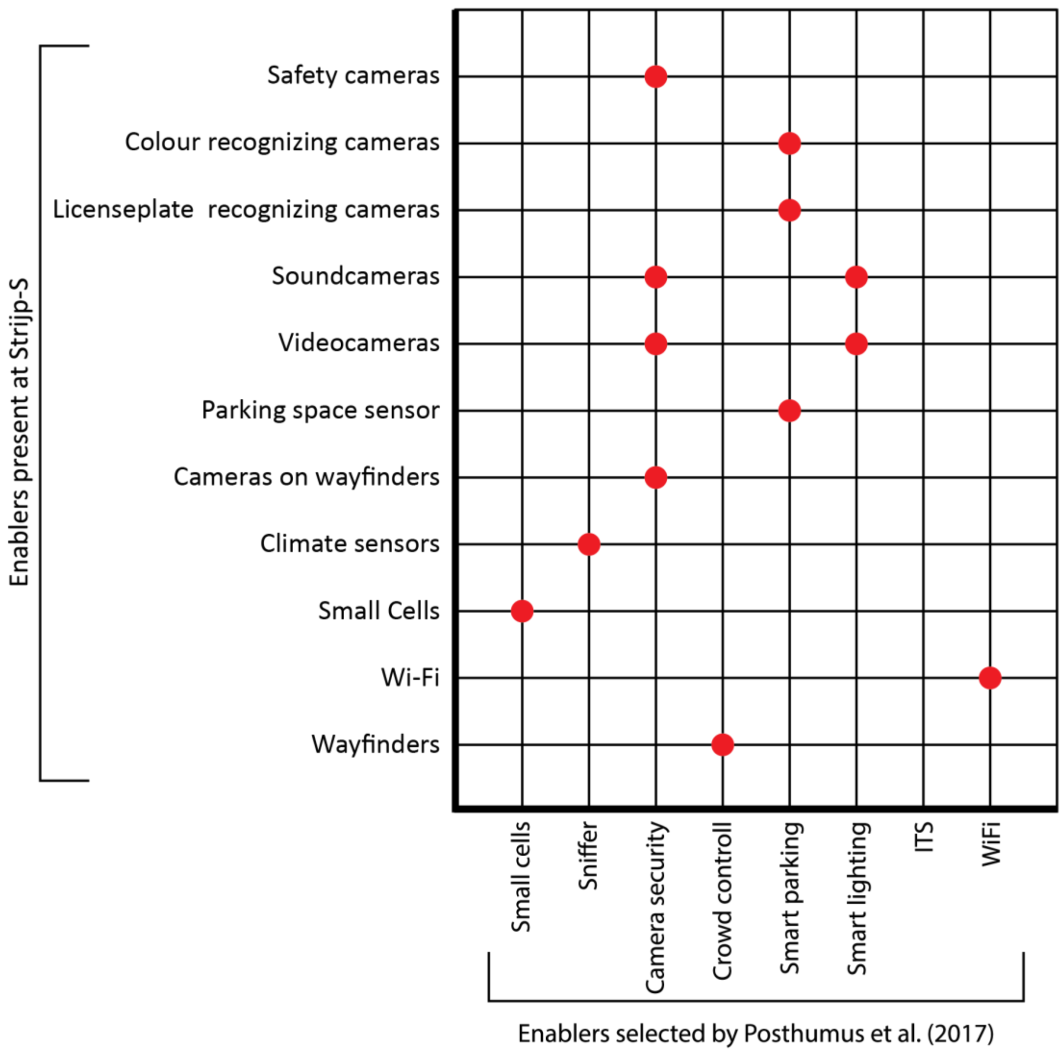

Figure 17 Enablers from literature versus enablers at Strijp-S

3.4. Conclusion

The aim of this chapter was to answer the question what could be learned from the implementation of smart city technology at Strijp-S. First the potential drivers and possible outcomes were checked, and it appeared that both types of variables are present. The implemented smart city technology indeed effects the found potential outcomes as found in literature: quality of life, sustainability and economy. With regard to the drivers (technology, policy and community) the technology at Strijp-S is implemented as a backbone which enables the connectivity. Several enablers are connected to this backbone, which match with the enablers found in literature for a “city centre area”. For developing services based on the implemented enablers, Strijp-S uses three different service tracks. Most important to conclude from this is that mobility and energy services have the largest impact regarding businesses and so local economy. To summarize what can be learned from Strijp-S with regard to which factors influence the financial feasibility of implementing smart city technology is how the infrastructure makes the connectivity possible.

The found theory is validated using the case Strijp-S, the factors that can function as a driver are found at Strijp-S together with the potential outcomes. The next chapter takes a closer look at how these factors influence each other and how they influence the financial feasibility.

4. Methodology

In the previous chapters the smart city was studied with regard to a financial feasible implementation. For this literature was studied and validated by means of a case: Strijp-S. The aim of this chapter will be to research how the found factors (drivers and outcomes) will influence each other and so the financial feasibility of the implementation of smart city technology. As there are multiple drivers and multiple outcomes influencing the financial feasibility, a method that allows to model all factors in a systematically way is required. Since the question that will be answered in this chapter is complex and dynamic, a System Dynamics approach is selected to find an answer.

This method offers the opportunity to clearly present a complex system, like an urban environment. A system dynamics approach is used often in business decisions; however, the approach is suitable for project management as well. As Sterman (2000) formulates it as follows:

> *The goal of systems thinking and system dynamics modelling is to improve our understanding of the ways in which an organization's performance is related to its internal structure and operating policies, including those of customers, competitors, and suppliers and then to use that understanding to design high leverage policies for success.* (John D. Sterman, 2000)

The model will be designed based on theories found in literature as well as the results from Strijp-S but will be applied to multiple other areas in the Netherlands to increase the variety in the input. These areas are selected by Park Strijp Beheer B.V. based on demographic characteristics.

4.1. System Dynamics

The approach exists of two major steps: first is the design of a causal loop diagram to give understanding about the causal relations between variables (section 4.1.1). The second step is the design of a Stocks and Flow Model (section 4.1.2). As mentioned in the section 1.3 of this thesis, the Stocks and Flow Model offers the possibility to capture flows in stocks and to do analysis based on the results. Once the SFM is running, a sensitivity analysis will be conducted (section 4.1.4) followed by creating different scenarios (section 0). For the modelling of the CLD and the SFM the software Vensim will be used.

The validation of the model is done based on three different perspectives: the technical-perspective, the content-perspective and the outcome-perspective. With the technical-perspective is meant that the method is correctly implemented. In two sessions with dr. ir. N.P. Dellaert of the Industrial Engineering & Innovation Sciences department of the Eindhoven University of Technology the implementation of the System Dynamics Approach is verified. The content-perspective is done in collaboration with the company Park Strijp Beheer B.V., they provided the needed figures in relation to Strijp-S. The last perspective is the outcome-validation. This validation can be found in section 0, the calibration of the model. In this section, the outcomes of the model are compared to statistics provided by the CBS.

4.1.1. Causal Loop Diagram

The causal loop diagram is an effective way to represent the feedback structure of a system. The diagram exists of variables that are linked to each other with arrows when there is a causal link (John D. Sterman, 2000).

Figure 18 shows the complete causal loop diagram. The CLD is based on the smart city drivers and the smart city outcomes. Therefore, the following parts are included:

1. Drivers
    a. Technology loop
    b. Community loop
        i. Policy
2. Smart city technology enablers
3. Outcomes
    a. Economy
    b. Quality of Life

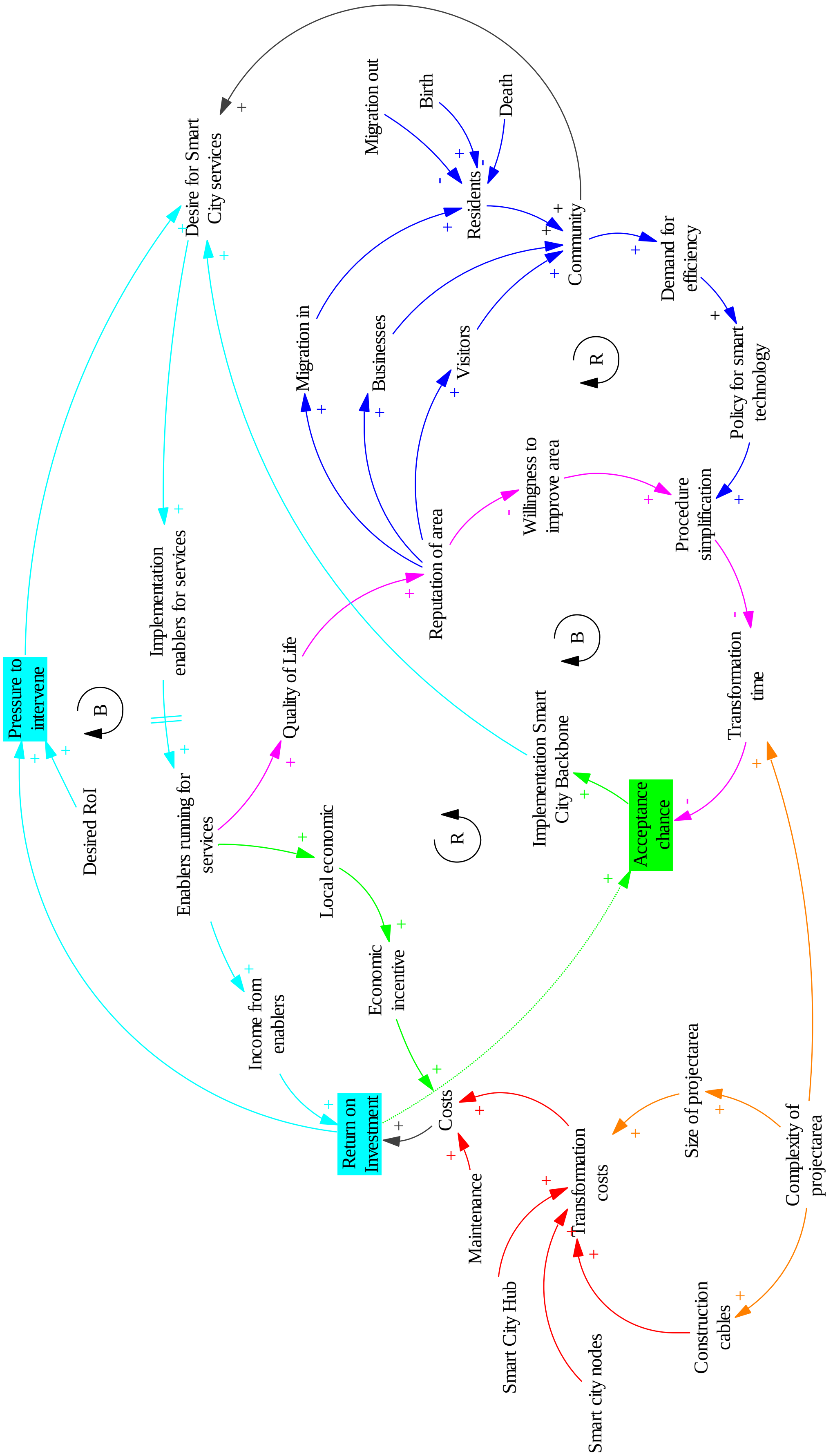

Figure 18 Complete causal loop diagram

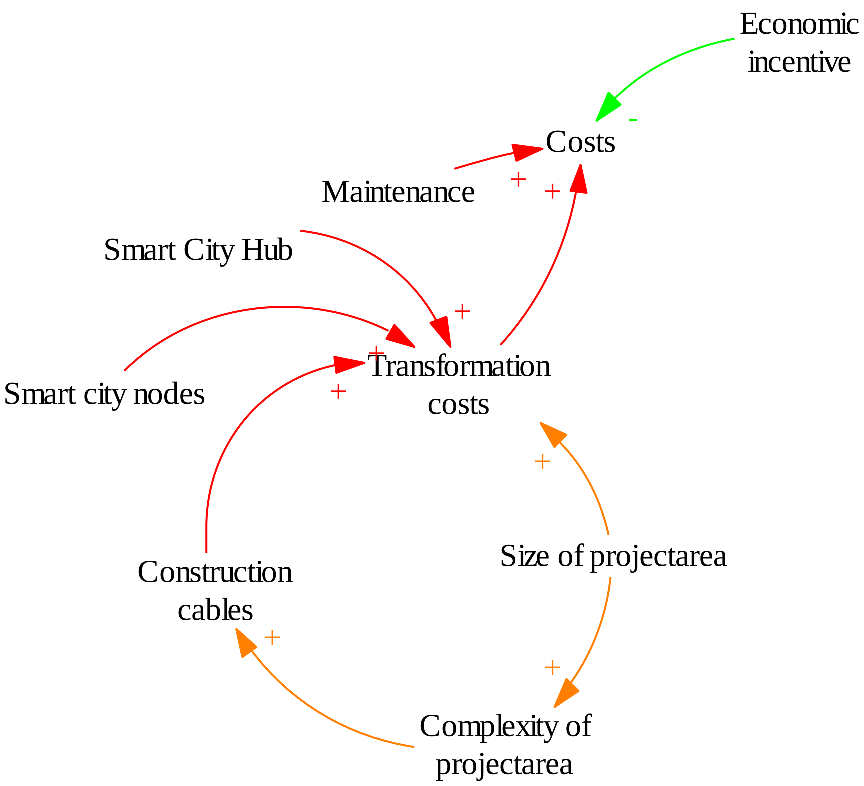

Figure 19 Costs for Smart City

The first part discussed is the technology-driving loop. With regard to financial feasibility, the technology requires an investment, which in this loop is considered as 'Costs'. The costs exist of maintenance costs and transformation costs. The transformation costs exist of the construction of the backbone, this is what changes the area to a smart city area: it realises the connectivity. The transformation costs are influenced by the construction costs for the backbone. The size of the project area determines the amounts that are required to create the backbone. As explained in section 3.2.1.1, the costs exist of smart city nodes, the smart city hub and the fibres. It is important to mention that the transformation costs are costs that apply only once when the decision is taken to transform an area into a smart area. The maintenance costs are recurring costs. This loop represents the technology-driver in the smart city.

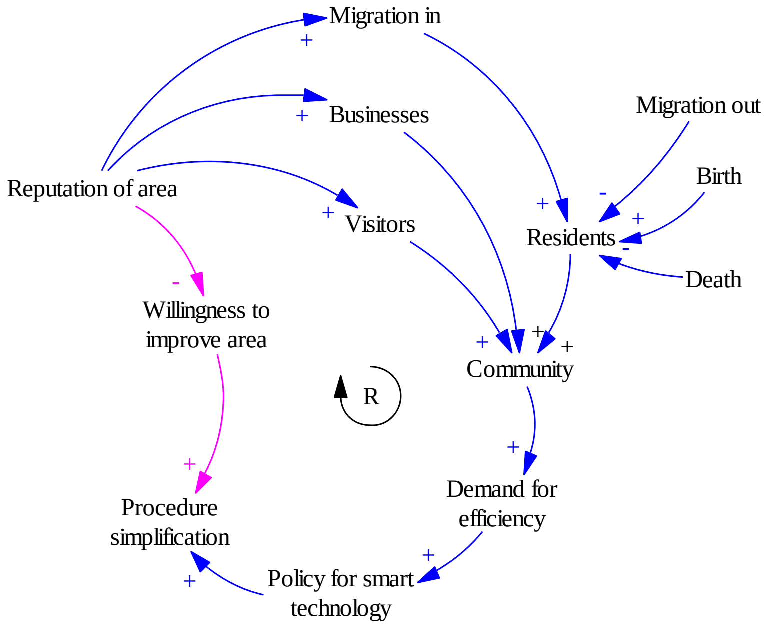

Figure 20 Community loop

The community part for smart cities (figure 20) includes the users of the area and so the demand for a smart city. It represents the community-driver and the policy-driver. The larger the community in an area, the greater the need to be more efficient with resources. Efficient use of resources is what smart cities try to establish (Albino et al., 2015; Eremia et al., 2017). The demand for efficiency determines if a policy for smart technology will be developed. The community exists of residents, businesses and visitors. The increase or decrease of the community is the result of the reputation of the area.

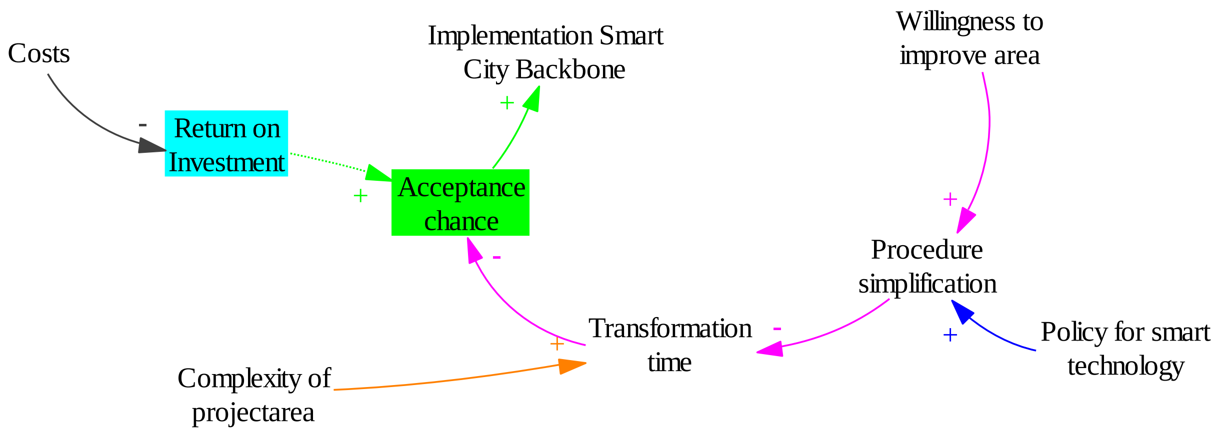

Figure 21 Acceptance chance

Now that the driving-parts are discussed, it is time to see how these parts are related to the implementation of smart city technology. Figure 21 shows how the technology part (the investment) is linked to the acceptance chance variable. On the other side, the policy-variable influences the procedure simplification. The procedure simplification is important as smart city technology is relatively new and therefore governments lack experience. For this reason, the simplification of procedures influences the transformation time, which has a positive effect on the acceptance chance of the project. Furthermore, the transformation time is also influenced by the complexity of the project. A positive acceptance chance for a smart city project results in implanting smart city technology.

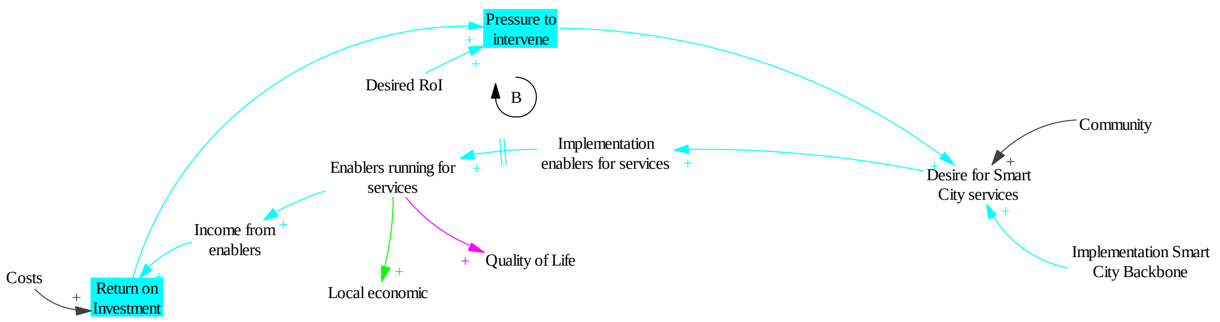

Figure 22 Enabling-loop

When the backbone is implemented, this results in a desire for smart city services. As discussed, services are based on the specific needs and desires of the community of a location. Therefore, is decided to use enablers (see section 2.4.2) to determine the revenue and so the return on investment. This revenue is necessary to earn back the investment done for the backbone and the implementation of enablers. Therefore, a balancing loop (figure 22) is added to the model. The pressure to intervene is based on the desired return on investment and the actual return on investment, and therefore influences the desire for smart city services. This results in the development of services. Between the development and the actual running a delay is added, because the development of services and implementing of enablers takes time. More enablers result in more income.

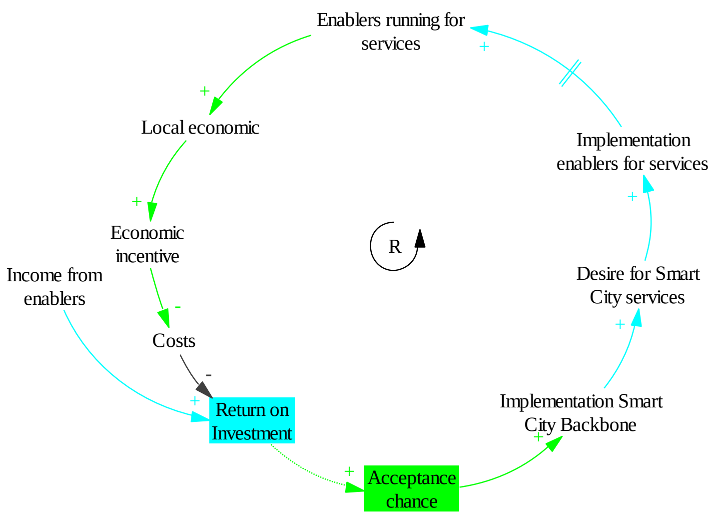

Figure 23 Economic outcome loop

The reinforcing economic loop (figure 23) describes how when the costs increase, the acceptance chance to implement smart city backbone decreases. Without the implementation of the smart city backbone, there is no desire for smart city services and so no smart city enablers will be implemented. This results in no improvement of the economy. As found in the literature, data collected by a smart city can reveal hidden patterns and correlations in order to support business owners in improving their services (Hashem et al., 2016). Lower economic health affects the possible support from the government (economic incentive), so the costs for developing a smart city for the private party rises. The economic incentive is important in this loop, because the smart city is a concept that takes place in the urban environment. Besides an interesting business case, the municipality benefits from the implementation of smart city technology. This loop is related to the economy-outcome.

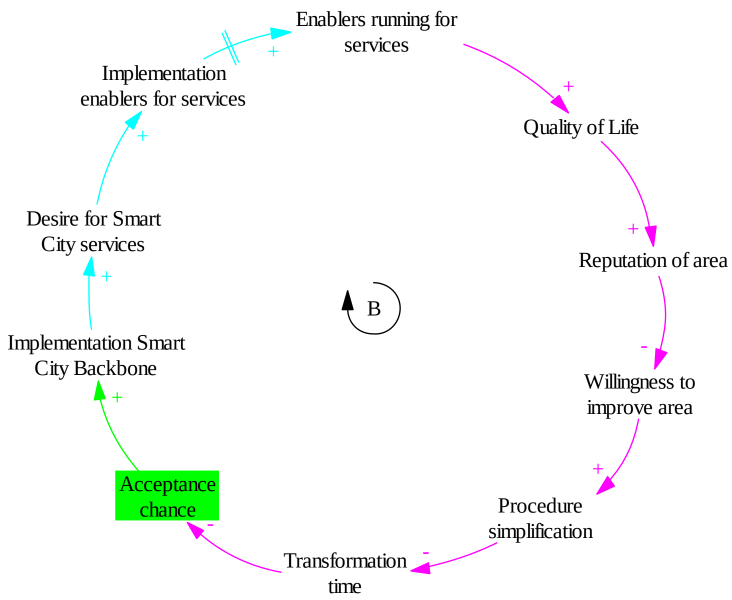

Figure 24 Quality of Life loop

The second outcome-loop is the balancing quality of life loop (figure 24). When smart city technology is implemented, and the enablers are running, the quality of life will increase. This results in a higher reputation of the area. When the reputation of the area increases, the willingness to improve the area will decrease. This influences the simplification of the implementation process negatively, which makes the transformation time longer which results thereafter in a lower chance of acceptance.

The complete causal loop diagram is shown in figure 18. The different loops are combined into one large causal loop diagram. The CLD gives understanding to all the variables that are found in the literature. The three main drives are included: Technology, community and policy. The composition of the community determines the policy and eventually the types of services. The technology, especially the costs will determine whether the implementation will be feasible or not. The CLD will be used as a map for the next step: the stock and flow model (SFM).

4.1.2. Stock and Flow Model

Following the Causal Loop Diagram (CLD), the Stock and Flow Model (SFM) is developed. The biggest difference between both models is the fact that the factor time is added to the SFM. This makes the SFM a working model. As the case Strijp-S is used in this research, also the corresponding Strijp-S applies. The timeframe used in the model is from 2010 to 2040. The years 2010 – 2017 serve as the timeframe for testing if the model runs correctly: results from a model run are compared with data from the Dutch Statistical Office (CBS). The time step in this model is one month ($\frac{1}{12} \approx 0.08333$). The next step is determining the stocks, flows, constants and auxiliary variables.

An overview of the complete Stock and Flow Model is given in figure 25. In total, the model exists of nine stocks, which are connected through flows. In this section, each stock will be discussed. First the drivers are discussed, then the implementation of smart city technology and the enablers, thirdly the outcomes are presented. Finally, constraints for implementing smart city technology are discussed. A complete overview of all causal relations of the model is included in Appendix 3, the overview of calculations is included in Appendix 5.

To get the model running, each variable needs an equation. In this section, it will be discussed how the equations are built up. Table 8 gives an overview of the sources of the different data used. The data selected to discuss in this chapter is based on the case Strijp-S. In section 4.2 other neighbourhoods are also implemented in the model.

Table 8 Overview sources

Variable	Data source	Database
Population	Strijp-S	Planning en prognoses Strijp-S (Stam+de Koning, 2017)
Quality of Life	Leefbaarometer	Dutch Ministry of the Interior and Kingdom Relations
Economic strength	Bruto Regionaal Product	
Investment	Strijp-S	
Income and costs services	TNO Smart Public Nodes	(Posthumus et al., 2017)

In figure 25, the complete SFM is presented, where some of the variables are colour coded. The red shaded variables are the input-variables. These will be filled in when there is an area studied using the model. The green shaded variables are the outcome variables. In section 4.3, the values of these variables are discussed. The pink shaded variables are part of the different scenarios that will be used in when researching the suitability of different areas for smart city technology.

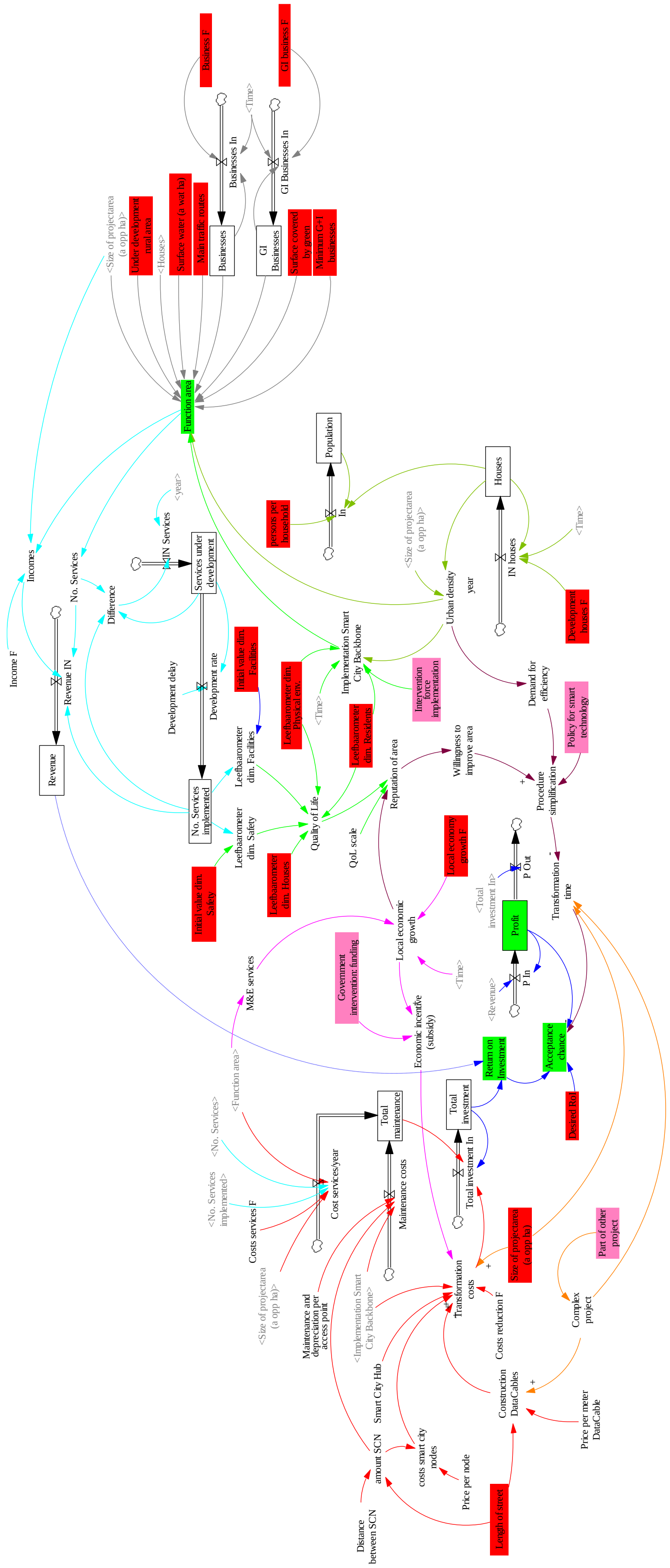

Figure 25 Complete Stock and Flow Model

4.1.2.1. Drivers

Technology

The first part of the SFM consists of the technology-part (figure 26) and is based on the technology loop from the CLD (figure 19). The technology part consists of two stocks: Total investment and total maintenance.

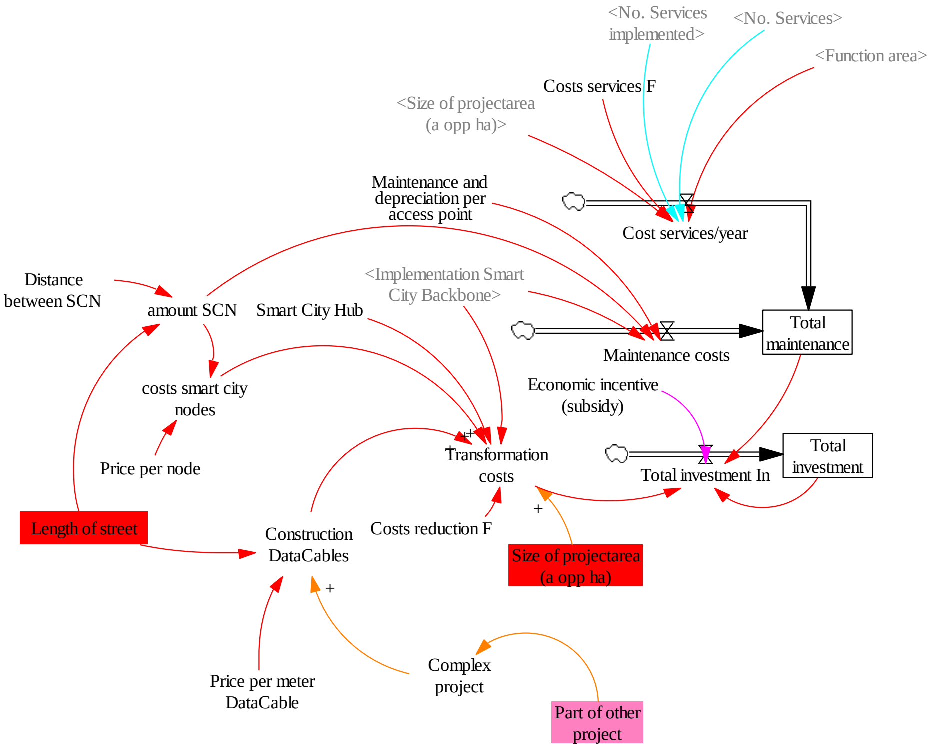

Figure 26 Technology part SFM

The maintenance stock has two incoming flows: costs for the enablers per year and the maintenance costs for the backbone. The costs for the enablers per year is determined by the type of function selected for the area considered. Maintenance costs of the smart city infrastructure are based on research conducted by TNO (2017). In a case study of the city of Almere, the costs are estimated to be € 1,572 per access point (Smart City Node) per year. In this amount the following costs are included:

- Depreciation Smart City Hub
  - Server itself
  - Hardware: switches, firewalls, etc.
- Rent of server area and energy
- Depreciation glass fibres
  - Fibres urban space
  - Fibres smart parking
  - Fibres residents
  - Fibres offices

The maintenance costs influence the "total investment" stock. However, also the transformation costs are linked to this stock, which include the costs for building the data infrastructure that realises the connectivity. The costs for the infrastructure are based on the data collected at Strijp-S (section 3.2.1.1). The price per node for the infrastructure includes placing and connecting to power supply. On average in an urban environment there is a lamppost every 20 meters. Therefore, the total length of the street is considered as well. Important to mention is that not every lamppost needs to be a smart-pole: based on the coverage of the smart services, every other lamppost should be connected to the grid. This means that every 40 meters, a smart lamppost should be implemented. Placing of the data cable, which is the connection to the smart city hub costs € 50 per meter cable. The costs shown in table 6 include also costs for smart parking. These costs are not included in the initial investment, as they are related to a service. Of course, the costs are only made when the "implementation smart city backbone" is positive.

Table 9 Costs for backbone at Strijp-S

Price per node (lamppost)	€ 2,000 per 40 meters
Length of the street	In meters
Construction data cables	€ 50 per meter cable
Smart City Hub	€ 500,000 per 30 ha

The construction of data cables is influenced by the complexity of the project. It is expected that the implementation of smart city technology (the backbone) is only feasible when it can be combined with another urban project. At Strijp-S this is the case as the area is simultaneously redeveloped from industry area to urban area. If the implementation is not combined with another project, the construction of the data cables will be, estimated by the contractor of data cables, twice as expensive. The value of "complex project" is binary. The 0 stands for an area where no redevelopment projects are planned, which makes it a complex project. 1 is for areas where the implementation of smart city technology can be combined with other projects.

Community

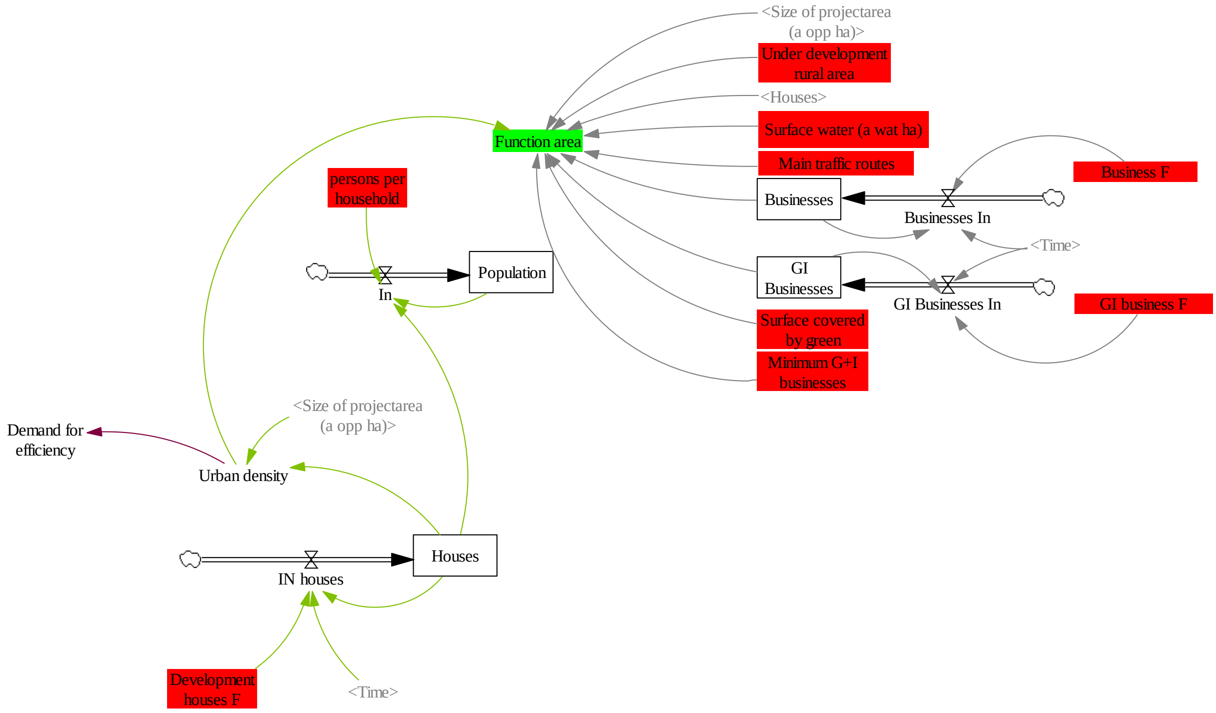

Figure 27 Community-part SFM

The community part of the model exists of the determination of the function area. To determine the correct function type for an area, for each area indicators are selected. In Appendix 6 the selection flowchart is included showing how the correct function area is selected based on the linked variables. In this section, the variables “businesses”; “GI businesses”; “population” and “houses” are explained more thoroughly.

Businesses

Businesses are, together with residents, part of the community. In the CBS “Kerncijfers wijken en buurten” (CBS, 2017b) business establishments are included. The different types of businesses included in this study are based on the key branches defined by Barth (2017):

- Trade and catering (var. a_bed_gi).
- Transport, information and communication companies (var. a_bed_hj).
- Financial services and real estate companies (var. a_bed_kl).
- Business services (var. a_bed_mn).
- Culture, recreation and other services (var. a_bed_ru).

According to the CBS (2017b), in 2017 there were 620 companies registered at Strijp-S. However, the development of Strijp-S is not finished yet. 35,450 m^2 offices were delivered in total in 2017 (Stam+de Koning, 2017). This means that an average office is $\frac{35450}{620} \approx 57.18\ m^2$. The 57 m^2 average office space is used to estimate the number of businesses in the future at Strijp-S. The total number of businesses registered to Strijp-S will be 1,544. An overview of businesses per building is included in Appendix 7, table 32. Table 10 shows the estimated development of businesses per year. The numbers are included as a lookup variable in the Stock and Flow Model.

The difference in type of business is used to select the appropriate function area. The types of business that can be found typically in shopping areas and/or city centres are the businesses with the trade and catering (var. a_bed_gi) classification. In 2017, 75 businesses were registered with G+I classification (CBS, 2017b). The expected growth is calculated the same way as the total number of businesses: $\frac{35450}{75} \approx 472.37\ m^2$. Every 472.37 m^2, there is one G+I classified business. The total amount of expected businesses with G+I classification is included in Appendix 7, table 32. Table 10 shows the estimated development of businesses per year. The numbers are included as a lookup variable in the Stock and Flow Model.

Table 10 Estimated number of businesses at Strijp-S

Year	New businesses	Total smart city businesses	New G+I businesses	Total G+I businesses
2017	120	620	14	75
2018	21	641	3	78
2019	491	1,132	59	137
2020	175	1,307	21	158
2021	98	1,404	12	170
2022	0	1,404	0	170
2023	140	1,544	17	187
2024	0	1,544	0	187
2025	0	1,544	0	187
2026	0	1,544	0	187
2027	0	1,544	0	187
2028	0	1,544	0	187
2029	0	1,544	0	187
2030	0	1,544	0	187
2040	0	1,544	0	187

Houses and population

The variables discussed next are the population and number of houses. The population at Strijp-S has been changed due to the ongoing redevelopment of the area. The central bureau of statistics therefore does not have trustworthy figures regarding residents of the area. Appendix 7, table 33 shows an overview of the redevelopment at Strijp-S. The aim is to develop 4,000 houses in total. As there are no plans for the fields A, B, C and D, the estimated number of houses on these fields is based on the need to reach the 4,000 houses. To estimate the population at Strijp-S, the eventual number of houses is multiplied by the average household size in Eindhoven: 1.9 persons per household (CBS, 2017b). In total the population at Strijp-S is estimated to grow to 7,600 persons. Table 11 shows the estimated development of houses per year. The numbers are included as a lookup variable in the Stock and Flow Model.

Table 11 Estimated number of houses developed per year

Year	New houses	Total houses
2012	198	198
2013	277	475
2014	0	475
2015	0	475
2016	0	475
2017	598	1,073
2018	168	1,241
2019	675	1,916
2020	385	2,301
2021	489	2,790
2022	0	2,790
2023	335	3,125
2024	0	3,125
2025	875	4,000
2026	0	4,000
2027	0	4,000
2028	0	4,000
2029	0	4,000
2030	0	4,000
2040	0	4,000

In the stock and flow diagram, the variables are implemented separately because the number of households is needed for different parts of the model. The variable "migration in" is determined by the lookup variable "houses in area", which includes the data of table 11 "new houses", and the ratio "persons per household". For other areas, which are not under development, a constant value is used: the number of residents in 2017 according to CBS data (2017b).

Urban density

Finally, the urban density is included in the community part. The urban density is important because this variable determines whether there is a need for efficiency or not. The urban density is split up in five different levels by the CBS (2017c):

1. Highly urbanized — on average more than 2,500 addresses per km^2.
2. Strong urban — on average between 1,500 and 2,500 addresses per km^2.
3. Moderately urban — on average between 1,000 and 1,500 addresses per km^2.
4. Little urban — on average between 500 and 1,000 addresses per km^2.
5. Not urban — on average less than 500 addresses per km^2.

The central bureau of statistics in the Netherlands considers areas that have more than 1,500 addresses per km^2 as a city (Staatsblad, 1997). Especially cities are the areas where population grows while resources are decreasing, and the quality of life needs to be monitored. Therefore, areas with density 1 and 2 are considered to have a demand for efficiency.

Policy

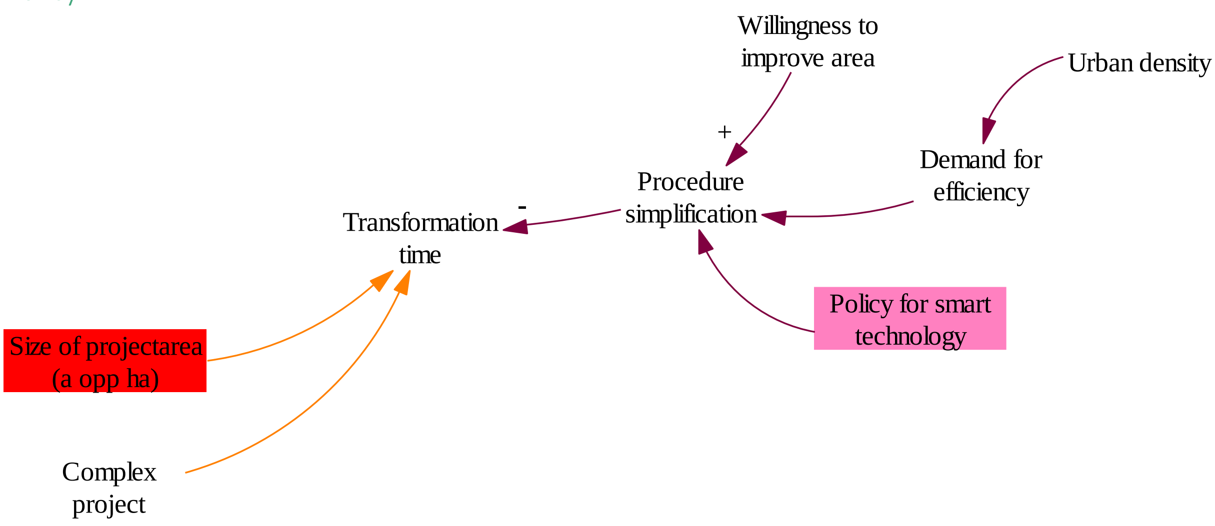

Figure 28 Policy part SFM

The last driver included in the model is the policy (figure 28). The policy-variable is related to the “procedure simplification”, together with the “Demand for efficiency” and “Willingness to improve area”. The policy for smart city technology is pointed out as one of the drivers for a smart city, so this variable is essential to be positive (Yes (1)). The second constraint is a “Yes (1)” for “Demand for efficiency” OR “Willingness to improve the area”. The “willingness to improve the area” is based on the reputation of the area. A “bad” reputation creates willingness to improve the area, while areas with a “normal” or “good” reputation do not have the need to be improved.

Table 12 gives an overview of the possible outcomes. If there is both a demand for efficiency and willingness to improve the area, there will be a positive procedure simplification because the smart city technology can contribute to both issues at the same time.

Table 12 Determining "procedure simplification"

Demand for efficiency	Policy for smart technology	Willingness to improve area	*Procedure simplification*
No (0)	No (0)	No (0)	*No (0)*
Yes (1)	Yes (1)	No (0)	*Yes (1)*
No (0)	Yes (1)	No (0)	*Yes (1)*
Yes (1)	No (0)	No (0)	*No (0)*
No (0)	No (0)	Yes (1)	*No (0)*
Yes (1)	Yes (1)	Yes (1)	*Yes (1)*
No (0)	Yes (1)	Yes (1)	*Yes (1)*
Yes (1)	No (0)	Yes (1)	*Yes (1)*

In addition to this, the "procedure simplification" influences the transformation time. The transformation time is highly dependent on the specific project, nonetheless the procedure simplification, size of the area and the fact whether the implementation of smart city infrastructure is part of an urban redevelopment project have an influence. It is impossible to predict the actual transformation time, so a relative duration is predicted on a scale from 1 to 6, where 1 is the shortest transformation time and 6 the longest. Table 13 gives an overview of the different variables and the result. Appendix 8 includes the explanation of the classification of the "size of project area".

Table 13 Transformation time

Procedure simplification	Complex project	Size of project area	Transformation time
Yes (1)	Yes (1)	Medium ($\leq 64\ ha$)	3
		Large ($> 64\ ha$)	4
	No (0)	Medium ($\leq 64\ ha$)	1
		Large ($> 64\ ha$)	2
No (0)	Yes (1)	Medium ($\leq 64\ ha$)	5
		Large ($> 64\ ha$)	6
	No (0)	Medium ($\leq 64\ ha$)	3
		Large ($> 64\ ha$)	4

4.1.2.2. Implementation Smart City Technology

After discussing the drivers for the smart city, it is time to take a closer look at the smart city enablers. Figure 29 shows the enablers part of the SFM. This includes three stocks: "Revenue", "Enablers under development" and "No. Enablers implemented".

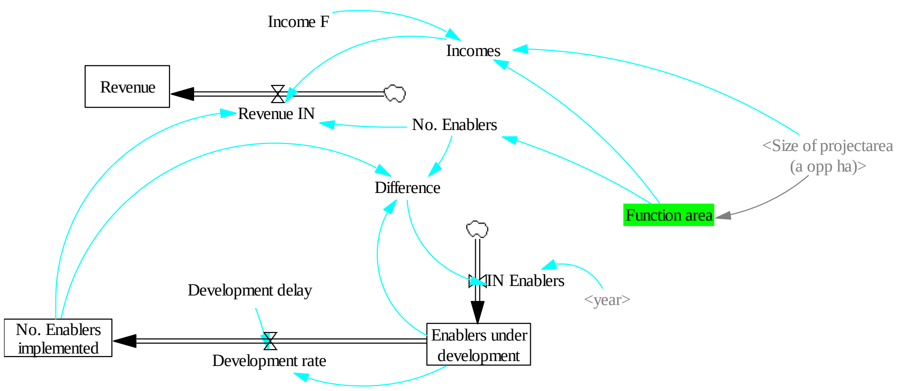

Figure 29 Enablers part SFM

Enablers

This part of the SFM starts with the function area. The type of function area determines what kind of enablers will be implemented (see section 2.4.2). The overview of the enablers per function area is repeated in table 14. The selection of enablers determines the first stock: "Enablers under development". This stick is influenced by the difference of enablers already developed and the number of enablers that is needed. From the "Enablers under development" the enablers flow to the "No. of enablers implemented". This flow is influenced by a delay: the development time.

Table 14 Implementation enabler per function area (Posthumus et al., 2017)

	Small cells	Sniffer	Camera security services	Crowd control	Smart parking	Smart lighting	ITS	Wi-Fi
Suburban green	0	1	1	0	0	1	0	0
Rural area	0	1	0	0	0	1	0	0
City centre area	1	1	1	1	1	1	0	1
Main traffic routes	1	1	0	0	0	0	1	0
Transition area	0	0	1	0	0	1	0	0
Water and banks	0	0	0	0	0	0	0	0
Business area	1	0	1	0	0	1	0	0
Shopping centre area	1	0	1	1	0	1	0	1
Residential area	1	1	1	0	0	1	0	0

Revenue streams enablers

The third stock in this part of the model represents the revenue, which is based on the selected function area and the services implemented (see table 15). The numbers are based on the TNO research (Posthumus et al., 2017). The revenues start to come in whenever the enablers are developed.

Table 15 Income per ha per function area (Posthumus et al., 2017)

Function code	Function area	income/ha/year
1	Main traffic routes	€ 96.00
2	Water and banks	€ -
3	Business area	€ 544.47
4	Transition area	€ 448.47
5	Rural area	€ 103.35
6	City centre area	€ 11,855.59
7	Shopping centre area	€ 2,113.51
8	Suburban green	€ 448.47
9	Residential area	€ 544.47

Costs enablers

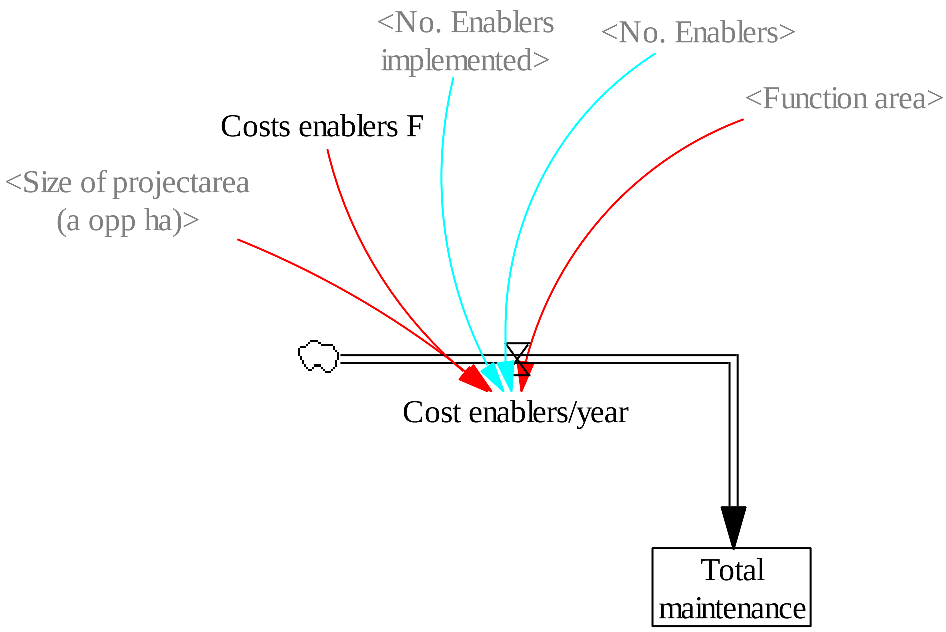

Figure 30 Costs enablers per year port SFM

Besides revenue streams, the implementation of enablers results in costs (figure 30). The stock related to this has been discussed before in section 4.1.2.1, however, the flow regarding the costs of the enablers per year was only mentioned shortly. The costs for implementing the selected enablers are based on the hardware, the surface one device covers and the surface of the whole area. For the costs, the same is done as for the revenue streams: calculated per function area (Appendix 9). The costs are based on the TNO research (Posthumus et al., 2017), however, costs for the sniffer and Wi-Fi-P technology were missing. Assumed is that Wi-Fi-P has the same CAPEX/OPEX costs as Wi-Fi. For sniffer sensors, the same costs as for smart cameras are used in the calculations. Table 16 gives an overview of the costs per year per ha for smart city technology for the different function areas.

Table 16 Costs per ha for smart city technology per function area

Function Code	**Function area**	**Price/ha/year**
1	Main Traffic Routes	€ 1,317.70
2	Water and banks	€ -
3	Business area	€ 888.16
4	Transition area	€ 361.36
5	Rural area	€ 381.60
6	City centre area	€ 1,471.66
7	Shopping centre area	€ 1,093.16
8	Suburban green	€ 589.86
9	Residential area	€ 1,191.66

4.1.2.3. Outcomes

Now it is to time to implement the outcomes in the model: the economy, the quality of life and the financial feasibility.

Economy

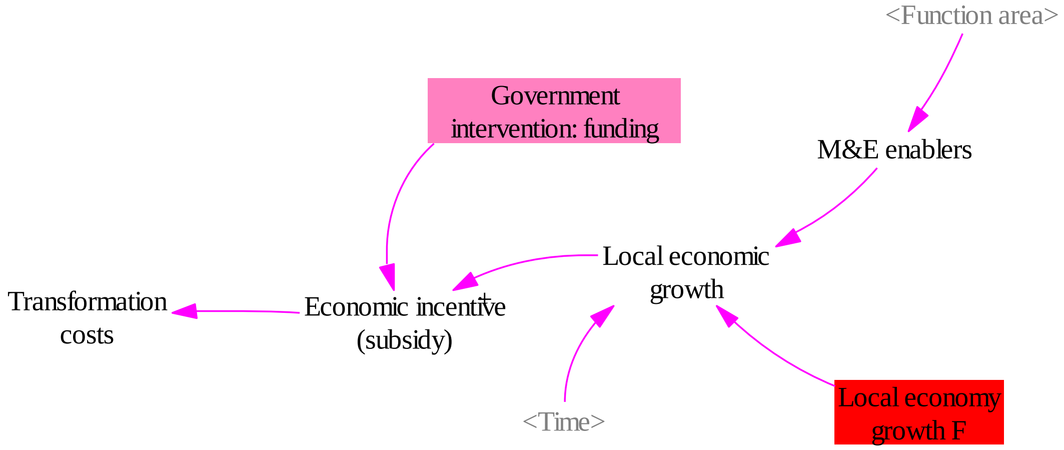

Figure 31 Economy part SFM

The economy part of the SFM (figure 31) is a combination of the status of the economy before the smart city technology is implemented and the effect of implementing smart city enablers. These two parts are combined in "Local economic growth". The already existing economy is based on regional figures from the year 2010 – 2021. Appendix 10 includes these figures. Secondly, the "local economic growth" is influenced by the smart city enablers aimed at mobility and energy track (Goulden, 2015). As discussed in section 3.2.2, the mobility and energy track has mostly an effect on the local economy. Therefore, the enablers used in the model are analysed to what track they belong (Appendix 11). Depending on the selected function type, M&E services are implemented. The implementation of these services effects the local economy. The overview of the effect on the local economy is included in table 17.

Table 17 Increase local economy based on M&E services

# M&E services in profile	Effect on local economy	Maximum increase of local economy
0	No effect on local economy	+ 0%
1	Small effect on local economy	+ 0.25%
2	Small effect on local economy	+ 0.25%
3	Significant effect on local economy	+ 0.5%

The last step of the economic part of the SFM are the variables "economic incentive" and the "Government intervention: funding". The reason a government would offer subsidy, is that smart city technology has the potential to attribute to urban issues like high urban density, pollution, etc. The "Economic incentive" is influenced by two variables: the local economy (growth) and government intervention. The three levels in the economy growth are used in combination with three levels of governmental intervention. The governmental intervention has a maximum value of 8, starting with 0 and an increment of 4. Depending on the economic growth change this level is multiplied by 0.5 (growth $\geq 1\%$ AND $< 3\%$) or by 1 (growth $\geq$ 3%). The result is a percentage that is subtracted from the total costs. An overview is given in table 18.

Table 18 Economic incentive

Economic growth	**Government intervention: funding**	**Economic incentive**	**Economic incentive**
$< 1\%$	0	0	0
$\geq 1\%\ AND < 3\%$	0	$0.5 \cdot "government\ intervention: funding"$	0
	4		2
	8		4
$\geq 3\%$	0	$1 \cdot "government\ intervention: funding"$	0
	4		4
	8		8

The economic incentive affects the transformation costs. At Strijp-S the municipality is involved for 50% of the project. This is used as a maximum for the economic incentive: with a maximum value for economic incentive, the government offers a subsidy amounting to 50% of the costs. An overview is given in table 19.

Table 19 Reduction transformation costs

Economic incentive	**Reduction transformation costs**
0	0%
2	12.5%
4	25.0%
6	32.5%
8	50.0%

Quality of life

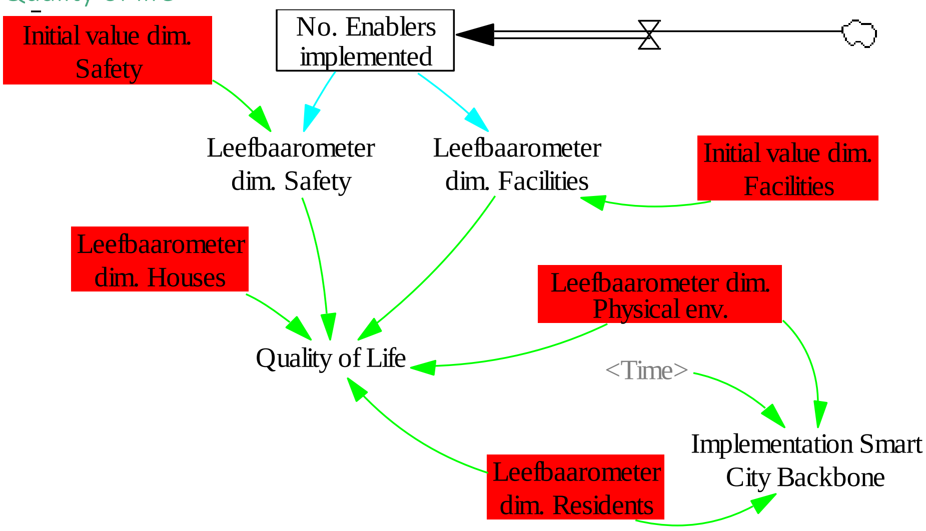

Figure 32 Quality of Life part SFM

A complex part in the SFM is the quality of life (figure 32). It is both part of the driver community, as a constraint, and a variable influenced by the implementation of smart city technology. In section 4.1.2.4 the included constraints of the smart city technology are further discussed. First a closer look is taken at how smart city technology influences the Quality of Life. As discussed, the quality of life in the Netherlands is calculated by the Leefbaarometer (section 2.2.2.2). The value of the Leefbaarometer is the basis for the quality of life. The Leefbaarometer uses 100 indicators in total, but in this research only the five weighted dimensions are used to prevent that the model will become too complex. The national average in the Netherlands is 4.16315, which is on the border of "ample" and "good" (Table 20). The scores per neighbourhood are published as difference from this average. Depending on the score of the neighbourhood, the quality of life is determined using a nine-level scale (Leidelmeijer et al., 2014). The score "very insufficient" is 0% of the possible quality of life and the score "excellent" is 100% of the possible quality of life. The steps in between are all equally sized. This results in the distribution as shown in table 21. As the average of the Netherlands is between ample and good, the quality of life is 66.7% of what it could be.

Table 20 Distribution scales Leefbaarometer

Leefbaarometer scales	**From %**	**Till %**
Very insufficient	0.0%	11.1%
Largely insufficient	11.1%	22.2%
Insufficient	22.2%	33.3%
Weak	33.3%	44.4%
Sufficient	44.4%	55.6%
Ample	55.6%	66.7%
Good	66.7%	77.8%
Very good	77.8%	88.9%
Excellent	88.9%	100.0%

If the average score is 66.7% and the average value of the Leefbaarometer is 4.16315, the maximum score is $\frac{4.16315}{66.7\%} \approx 6.2416$. Based on the national average of the Netherlands and the maximum score possible, the maximum scores per dimension can be determined.

Table 21 Maximum score possible in Leefbaarometer

Dimension	**Weight**	**Maximum value possible**
Houses	18.0%	1.12349
Residents	15.0%	0.93624
Facilities	25.0%	1.56040
Safety	24.0%	1.49799
Physical	18.0%	1.12349

The smart city services only affect the "Leefbaarometer dim. Facilities" and "Leefbaarometer dim. Safety" (figure 32). In the best case, the scores for these dimensions are 100%. The score 100% in the model will be reached when all services are implemented. The maximum amount of services implemented is 8. It depends on the type of neighbourhood how many are implemented (section 4.1.2.2), the formula to calculate the new score for “Leefbaarometer dim. Facilities” and “Leefbaarometer dim. Safety” is:

$$\frac{max.\ value\ dimension - (average\ value\ dimension + initial\ value\ dimension)}{8} \cdot number\ of\ services\ implemented + initial\ value\ dimension$$

Reputation of area

The reputation of the area is a combination of the quality of life and the local economy, so the following formula can be used: $Quality\ of\ Life + Local\ economy\ scale$ (Table 20). The result is a number between the 0 and 10. The first five levels (0-4) stand for a bad reputation, number 5 – 7 describe an average reputation, level 8 - 10 describe a good reputation.

Table 22 Local economy

Local economic growth	**Change of reputation of area**
$< 1\%$	-1
$\geq 1\%\ AND < 3\%$	0
$\geq 3\%$	1

Table 23 Reputation of area

Result formula	**Reputation of area**
0	Bad (0)
1	Bad (0)
2	Bad (0)
3	Bad (0)
4	Bad (0)
5	Normal (1)
6	Normal (1)
7	Normal (1)
8	Good (2)
9	Good (2)
10	Good (2)

Financial feasibility

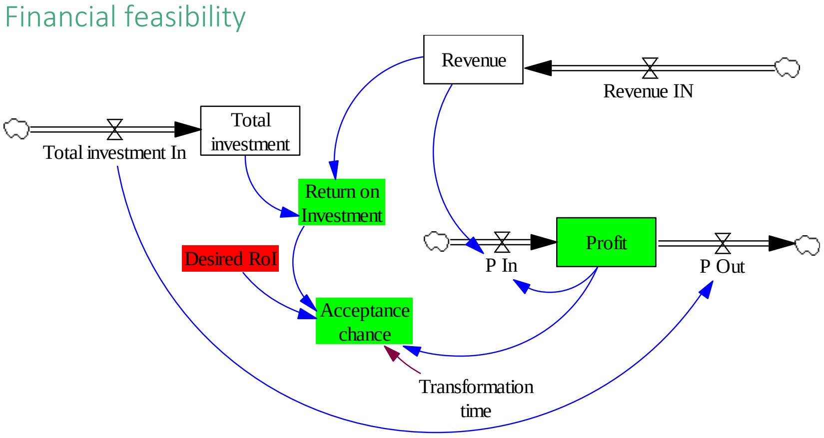

Figure 33 Financial feasibility part SFM

The last part of the SFM is the financial feasibility of implementing smart city technology (figure 33). The financial feasibility is based on the investments and revenue and summarized in the variable “Acceptance chance”. The chance of acceptance is highly dependent on the “Return on Investment” and “Profit”: if there is a positive profit, the acceptance chance is high. A positive “ROI” and a short “Transformation time” result in an advice to do further research: medium acceptance chance. The transformation time must be as short as possible, because the ICT-sector (where the IoT is part of) is a high-speed market. If it takes a long time to get the infrastructure up and running, there is a chance that the used technologies are already outdated before they are used. If there is no positive return of investment and there is a negative profit or there is a long transformation time, the acceptance chance will be low. The acceptance chance is split up in three different levels: 0, 1 and 2. 0 means no chance of acceptance and 2 means that the project can be accepted. If the result is 1, this means there is a positive return on investment expected, but there is a higher risk due to the transformation time. See table 24 for the complete overview.

Table 24 Acceptance chance

Profit	$\boldsymbol{RoI}$	**Transformation time**	**Acceptance chance**
> 0	-	-	2
< 0	$RoI \geq Desired$	< 4	1
	$RoI \geq 0$	< 4	1
	$RoI \geq Desired$	> 4	0
	$RoI \geq 0$	> 4	0
	$RoI < 0$	-	0

4.1.2.4. Constraints

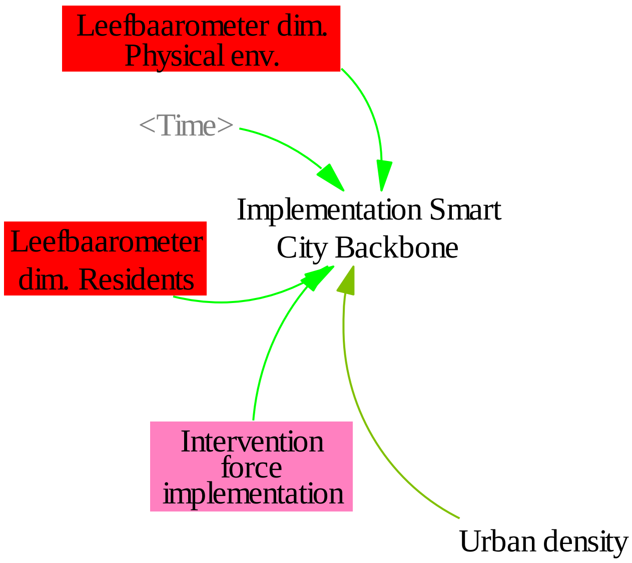

Figure 34 Constraint part SFM

In the literature, a number of minimum requirements were found for an area with regard to the outcome quality of life and the urban density (section 2.2.3). Therefore, the variable “Implementation Smart City Backbone” is added. This variable is negative when the minimum requirements are not reached. The requirement for urban density is ≤ 2. The attractive living and working environment is included in the physical environment dimension of the Leefbaarometer (Leidelmeijer et al., 2014). “High income residents” is not directly included in the “residents” dimension, however, other variables that are related to this are. The two dimensions require a certain level for a successful implementation of smart city technology. The “Leefbaarometer dim. Physical env.” is considered more important as more variables included in this dimension are applicable. Therefore, this dimension needs to score at least 50% of the potential QoL (0.56174) in the Leefbaarometer. The “Leefbaarometer dim. Residents” is less important as the smart city technology could also attract higher-income residents due to the increase in facilities. The score used as a minimum in the model is 40% of the maximum score possible (0.37450). To prevent that the model is applying smart city technology in the past (2010-2017), this variable is forced to be 0 if $Time < 2017$. As an intervention, the variable “force implementation” is added. If this variable is set to 1, the smart city backbone is implemented without taking the other variables into account.

4.1.3. Calibration and running

In the previous section is explained how the model is built. This section will focus on getting the model running and the calibration of the model

4.1.3.1. Calibration

As discussed, data for Strijp-S is implemented in the Stock and Flow diagram. Fours stocks included in the model are based on the development of the area:

1. Population
2. Houses
3. Businesses
4. G+I businesses

To determine the growth, the development of the different buildings and the corresponding surface areas for businesses and the number of houses together with the average household size are used. Based on this data, formulas are created to predict the values of these variables. To see if the model gives truthful results, Vensim offers a “ReferenceMode”. In ReferenceMode, existing data can be added and compared to the result of the model. For the years 2010 – 2017 data from the CBS is known for the above-mentioned variables, so the ReferenceMode can be used.

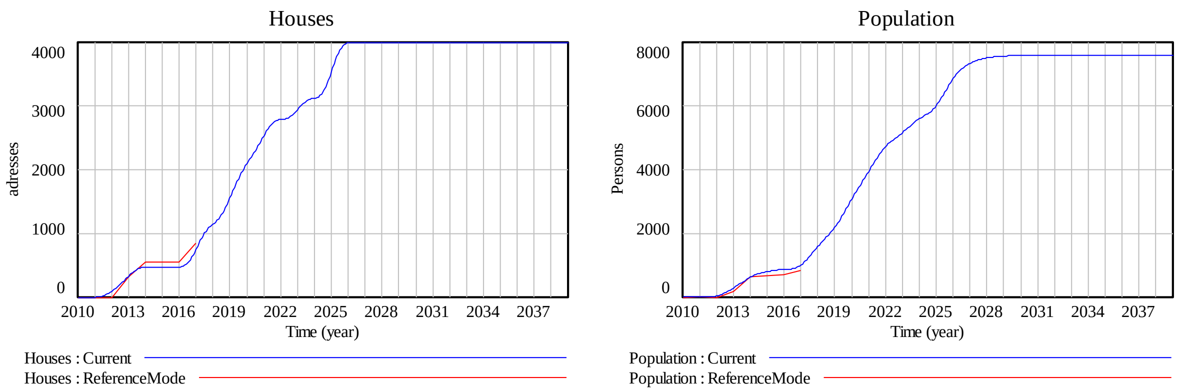

Figure 35 Run "Current" and "ReferenceMode" Houses (left) Run "Current" and "ReferenceMode" Houses (right)

The number of houses at Strijp-S in the "current" mode is similar to the "ReferenceMode" (figure 35). The two lines are not equal but show the same behaviour. The difference can be explained by the fact that CBS data is one data point per year while the model generates twelve data points per year. The variable population shows a slight difference, but the "current" run follows the line of the "ReferenceMode" (figure 35).

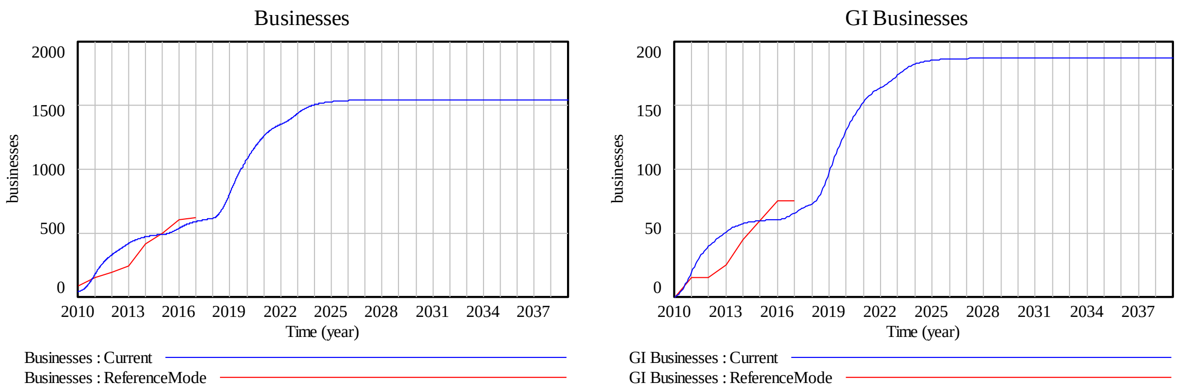

Figure 36 Run "Current" and "ReferenceMode" Businesses and GI Businesses

The variable "Businesses" and "GI Businesses" show some deviation between the "ReferenceMode" and the "Current" (figure 48). The two runs do not show a structural difference. For example, a lower number is shown in "ReferenceMode" for the years 2011–2015, followed by a higher number for the years 2015 – 2017.

4.1.3.2. Running

Now that the model is calibrated, the next step is to run the model for Strijp-S. In order to see if the outcomes of the model meet the expectations for Strijp-S. Figure 37 shows four graphs as a result. The function area after the complete development is 6: city centre area. This matches with the vision of Strijp-S (Goulden, 2015). The function area “city centre” includes the following enablers (table 4):

- Small cells
- Sniffer
- Camera security services
- Crowd control
- Smart parking
- Smart lighting
- Wi-Fi

The enablers included at Strijp-S until this point (figure 17) match the above-mentioned enablers. Furthermore, the return on investment and profit are expected to grow after the implementation of a smart city technology and a larger market due to the increase in residents and businesses in the area.

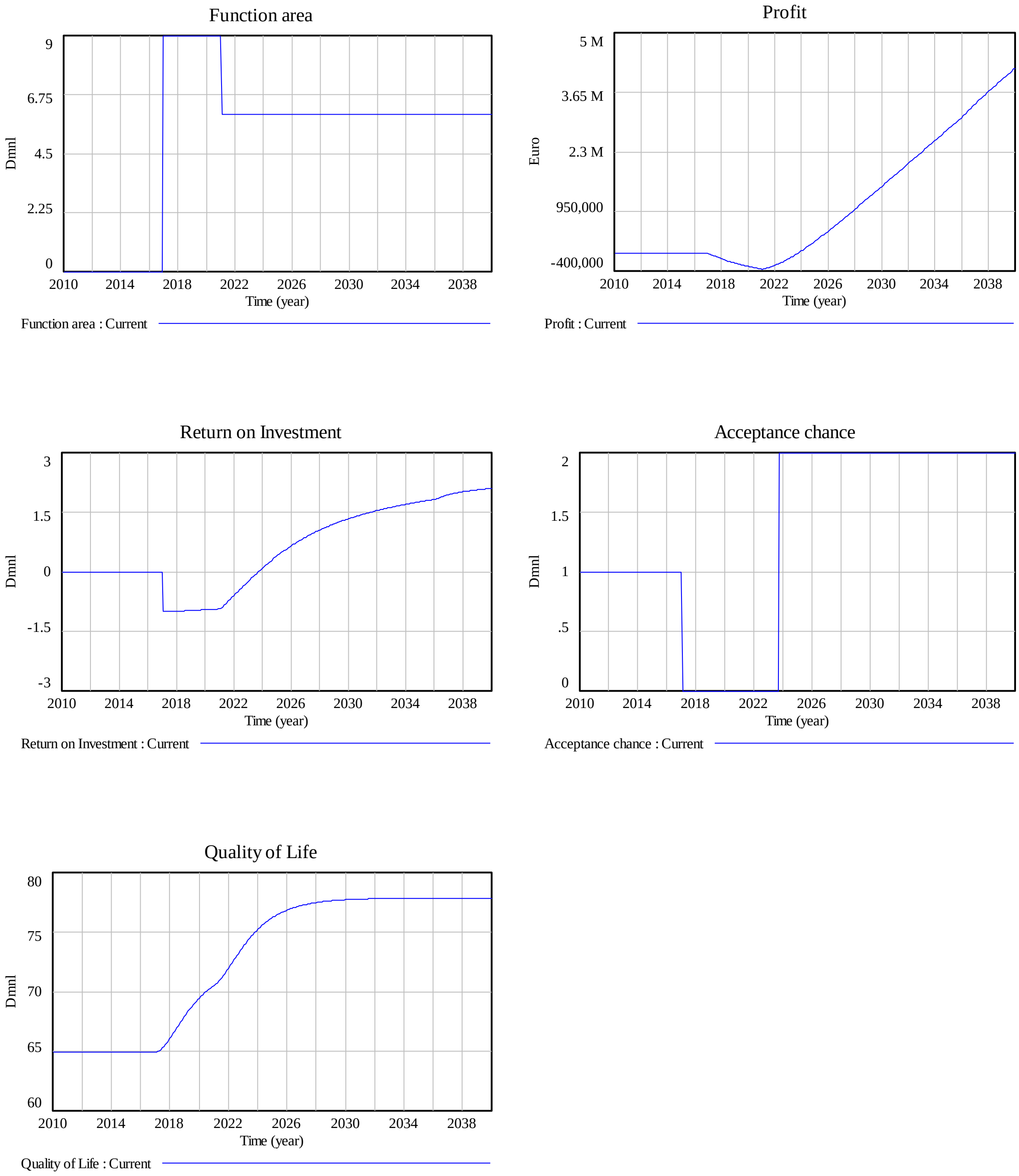

Figure 37 Results Strijp-S

4.1.4. Sensitivity analysis

To better understand the working of the model and to understand which factors the largest impact on the financial feasibility have, a sensitivity analysis is conducted. Nineteen variables are tested on five different levels:

- Minimal value possible
- Basis -10%
- Basis value
- Basis +10%
- Maximal value possible

The sensitivity analysis exists of two parts. In the first part, the variable “Intervention: force implementation” is set to 0. This variable overrules the model regarding the choice to implement smart city technology or not. In the second part, the “Intervention: force implementation” is set to 1 to evaluate the results from the first part for which the model had a negative result for “Implementation Smart City Backbone”. Figure 38 shows the decision flowchart for the sensitivity analysis.

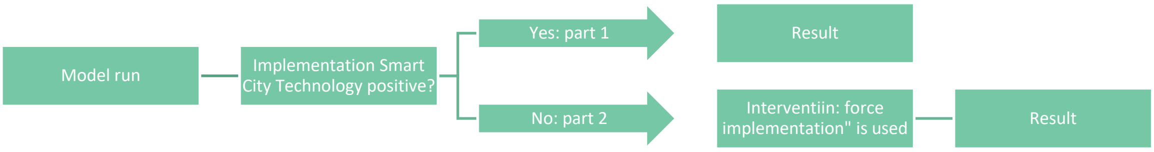

Figure 38 Decision flowchart sensitivity analysis

With regard to the five different levels, the “basis values” are based on the values for Strijp-S, except for the governmental intervention. This variable has three possible values (0, 4, 8) while the value for Strijp-S is already 8. Therefore, is decided to set the “basis value” for this variable to 4. Table 32 gives an overview of the input data used in the sensitivity analysis.

The outcomes the following variables are evaluated: Function area; Year when the ROI is larger than 0%; the ROI in year 2040; Acceptance chance in year 2040 and Quality of Life in year 2040. The complete outcome of the sensitivity analysis can be found in Appendix 12, but an overview of the result is given in (

table 26). This overview shows the difference of each level compared to the “basis value”. The values in the “Difference in ROI>=0” part is presented in years, the values in “Difference in ROI year=2040” are presented as a percentage difference from the “basis value”. The acceptance chance is a dimensionless variable. It can have the values 0, 1 and 2, so the results in “Difference in acceptance chance year=2040” are presented as dimensionless difference from the “basis value”.

The result is on the one hand surprising as most variables do not have a large impact when changing the values. One explanation for this is that the combination of different variables determines the function type of the area. The function type of the area determines for a large part the revenue and costs. In literature it is found that only high-density urban areas are feasible for smart city technology. The revenue and costs for the different function types also show this behaviour: only the function area city centre (6) has a positive result (section 2.4.3). Furthermore, the “length of the street” and the “size of project area” are critical variables. This can be explained by the fact that both factors have the largest impact on the investment costs and the revenue. The “development delay” also has an influence but is less critical.

Table 25 Input sensitivity analysis

Variable	**unit**	**Min**	**-10%**	**Basis**	**+10%**	**Max**
Part of another project	code	0	n/a	**1**	n/a	1
Policy for smart technology	code	0	n/a	**1**	n/a	1
Governmental intervention: funding	code	0	n/a	**4**	n/a	8
Businesses	businesses	0	1,390	**1,544**	1,698	5,000
GI businesses	businesses	0	168	**187**	206	1,000
Minimum G+I businesses	businesses	0	138.2	**153.522**	168.9	800
Houses	addresses	0	3,600	**4,000**	4,400	14,000
Size of project area	ha	1	27	**30**	33	13,000
Length of the street	meters	1	1,126	**1,251**	1,376	50,000
Leefbaarometer						
Houses		-0.738132	-0.031974	**-0.029067**	-0.026160	0.374122
Residents		-0.615110	0.034631	**0.038479**	0.042327	0.311768
Facilities		-1.025183	0.055129	**0.061255**	0.067380	0.519614
Safety		-0.984176	-0.181676	**-0.165160**	-0.148644	0.498829
Physical environment		-0.738132	-0.039186	**-0.035624**	-0.032062	0.374122
Rural area under development	code	0	n/a	**0**	n/a	1
Main Traffic Route	code	0	n/a	**0**	n/a	1
Surface covered by green	code	0	n/a	**0**	n/a	1
Development delay	years	0.0	1.8	**2.0**	2.2	4.0
Economy growth	percent	-5.0%	1.6%	**1.8%**	2.0%	5.0%
Desired ROI	percent	0	4.5%	**5%**	5.5%	10%

Table 26 Result sensitivity analysis

Difference from basis	Difference in RoI>=0					Difference in RoI year=2040					Difference in acceptance chance year=2040				
Variable	Min	-10%	Basis	+10%	Max	Min	-10%	Basis	+10%	Max	Min	-10%	Basis	+10%	Max
Part of another project	-0.34		0		0	-4%		0%		0%	0		0		0
Policy	0		0		0	0%		0%		0%	0		0		0
Governmental intervention: funding	-0.17		0		0.25	-2%		0%		2%	0		0		0
Businesses	0	0	0	0		0%	0%	0%	0%	-136%	0	0	0	0	2
GI businesses		0	0	0	0	-137%	0%	0%	0%	0%	2	0	0	0	0
Minimum G+I businesses	-0.42	-0.4	0	-0.42		0%	0%	0%	0%	-137%	0	0	0	0	2
Houses		0	0	0	0		0%	0%	0%	0%		0	0	0	0
Size of project area		-0.2	0	0.08		-135%	-8%	0%	8%		2	0	0	0	1
Length of the street	1.33	0.16	0	-0.17		176%	8%	0%	-7%	-137%	0	0	0	0	2
Leefbaarometer															
Houses	0	0	0	0	0	0%	0%	0%	0%	0%	0	0	0	0	0
Residents		0	0	0	0		0%	0%	0%	0%	1	0	0	0	0
Facilities	0	0	0	0	0	0%	0%	0%	0%	0%	0	0	0	0	0
Safety	0	0	0	0	0	0%	0%	0%	0%	0%	0	0	0	0	0
Physical environment		0	0	0	0		0%	0%	0%	0%	1	0	0	0	0
Rural area under development	0		0		0	0%		0%		0%	0		0		0
Main Traffic Route	0		0			0%		0%		-142%	0		0		2
Surface covered by green	0		0		0	0%		0%		0%	0		0		0
Development delay	0.33	0.25	0	-0.17	-1.25	4%	1%	0%	-1%	-9%	0	0	0	0	0
Economy growth	-0.17	0	0	0	0.25	-2%	0%	0%	0%	2%	0	0	0	0	0
Desired RoI	0	0	0	0	0	0%	0%	0%	0%	0%	0	0	0	0	0

The second part of the sensitivity analysis focusses on the factors that gave an empty outcome in the first part (table 26). The empty outcome is due to the fact that the factor "Implementation Smart City Backbone" was negative with the set input. In this part, the "Implementation Smart City Backbone" is forced to be positive to see what the results would be when the constraints are discarded. The factors that are included in the second part are:

1. Houses minimum scenario (0 houses)
2. Size of project area maximum scenario (13,000 ha)
3. Leefbaarometer Residents minimum scenario (-0.615110)
4. Leefbaarometer Physical environment minimum scenario (0.738132)

Table 34 shows the results for these factors. The first two factors show a negative result for Return of investment ("ROI Y=2040") and therefore a negative result for "Acceptance chance" as well. The last two factors in table 27 do have an acceptance chance of 2, however there is a very low "Quality of Life Y=2040". From literature it is derived that only areas with already a certain level of quality of life can be feasible. Therefore, the value for "ROI Y=2040" is probably not representative.

Table 27 Forced implementation smart city backbone

				Outcome				
Variable	*Unit*	*Scenario of concern*	*Input*	*Function area*	*Year ROI=0*	*ROI Y=2040*	*Acceptance chance*	*Quality of Life Y=2040*
Houses	addresses	Min	0	3	-	-82.85%	0	70.48%
Size of project area	ha	Max	13,000	5	-	-82.92%	0	68.64%
Leefbaarometer: Residents		Min	-0.615110	6	2020.84	215.51%	2	63.89%
Leefbaarometer: Physical environment		Min	-0.738132	6	2020.84	215.51%	2	65.34%

With concluding the sensitivity analysis, the model is ready to use for different areas in the Netherlands. From the sensitivity analysis it appeared that the function area will play an important role in the potential revenues in an area. The factors that are added as interventions ("part of another project"; "policy for smart city technology"; "Governmental intervention: funding") have the greatest effect on the timeline, that is on the time needed to reach the desired ROI. Furthermore, the "length of street" influences the return on investment heavily. With a change of 10% in length, the ROI changes 8%. The "length of street" determines the size of the investment for the smart city backbone and so it takes up a large part of the total investment in the project area. The model now has run, it is calibrated, and the most sensitive factors are pointed out. The next step is designing different scenarios which can be used to test different areas.

4.1.5. Scenarios

As preparation for the next section (section 4.2), scenarios will be designed, based on a selection of four variables. These scenarios are needed to test the considered areas all in the same way. This section first discusses the design of scenarios and then the results when applied to the case Strijp-S.

4.1.5.1. Scenario design

The model includes four variables that will be used to tweak the results. These variables are:

1. Policy for smart technology (yes/no)
2. Part of another project (yes/no)
3. Government intervention: funding (0 ,4, 8)
4. Force implementation (yes/no)

These variables have been chosen to be included in the scenario design because they can be changed over time or are not a direct characteristic of a project location. The first three of the four variables are related to the policy-driver of smart city technology. The reason this driver is chosen to be part of the scenario design, is that policy is not directly a characteristic of an area. Governments determine policy, and this can change through new insights. The fourth variable, “Part of another project”, is added to the scenario design because this variable is related to the technology-driver. If the implementation of smart city technology is part of another urban project, this influences the construction of data cables. If the implementation is not part of another project, the construction of the cables is considered two times as high.

Based on these four variables, five scenarios are developed. The first scenario (scenario A) is the actual situation in the area considered. Scenario B is called “Procedure simplification”, it aims at shortening the transformation time by assuming there is a policy for smart technology. Furthermore, the “Government intervention: funding” is set to 4. The third scenario (scenario C) sets the “Government intervention: funding” to 8 and the “Force implementation” to 1, which means that the smart city technology is implemented without taking the constraints into account. Based on these settings, the scenario is called “Governmental intervention”. Scenario D has a different perspective then scenario B and C, this scenario is focused more on the project-side instead of the governmental-side, therefore, the “policy for smart technology” is 0, as well as the “Governmental intervention: funding” and the “Intervention: force implementation”. In this scenario, the project is assumed to be part of another project (“Part of another project” is 1). In the last scenario (scenario E) the situation as it is at Strijp-S, is applied to the considered area.

An overview of all the scenarios is given in table 28. In total 18 areas will be put in the model. For each area, the different scenarios will be run and the results for the variables “return of investment”, “profit”, “quality of life”, “acceptance chance” and “function area” will be evaluated.

Table 28 Overview scenarios

Scenario		**Policy for smart technology**	**Part of another project**	**Government intervention**	**Force implementation**
Scenario A	Current	*Real situation*	*Real situation*	*Real situation*	0
Scenario B	Procedure simplification	1	0	4	0
Scenario C	Governmental intervention	1	0	8	1
Scenario D	Project scenario	0	1	0	0
Scenario E	StrijpS scenario	1	1	8	0

It is expected that Scenario E will be the most profitable scenario, as the factors have the most favourable setting. Furthermore, the “governmental intervention” and “Part of another project” have an impact on the transformation costs. It is expected that when the setting of these factors is positive, the investment is less in the beginning and so the ROI is positive sooner. The “Policy for smart city technology” influences the “Acceptance chance”. When the project is not profitable, but there is a policy for smart city technology, the “Acceptance chance” will be 1, which means further research could result in a financially feasible project.

4.1.5.2. Scenarios applied to Strijp-S

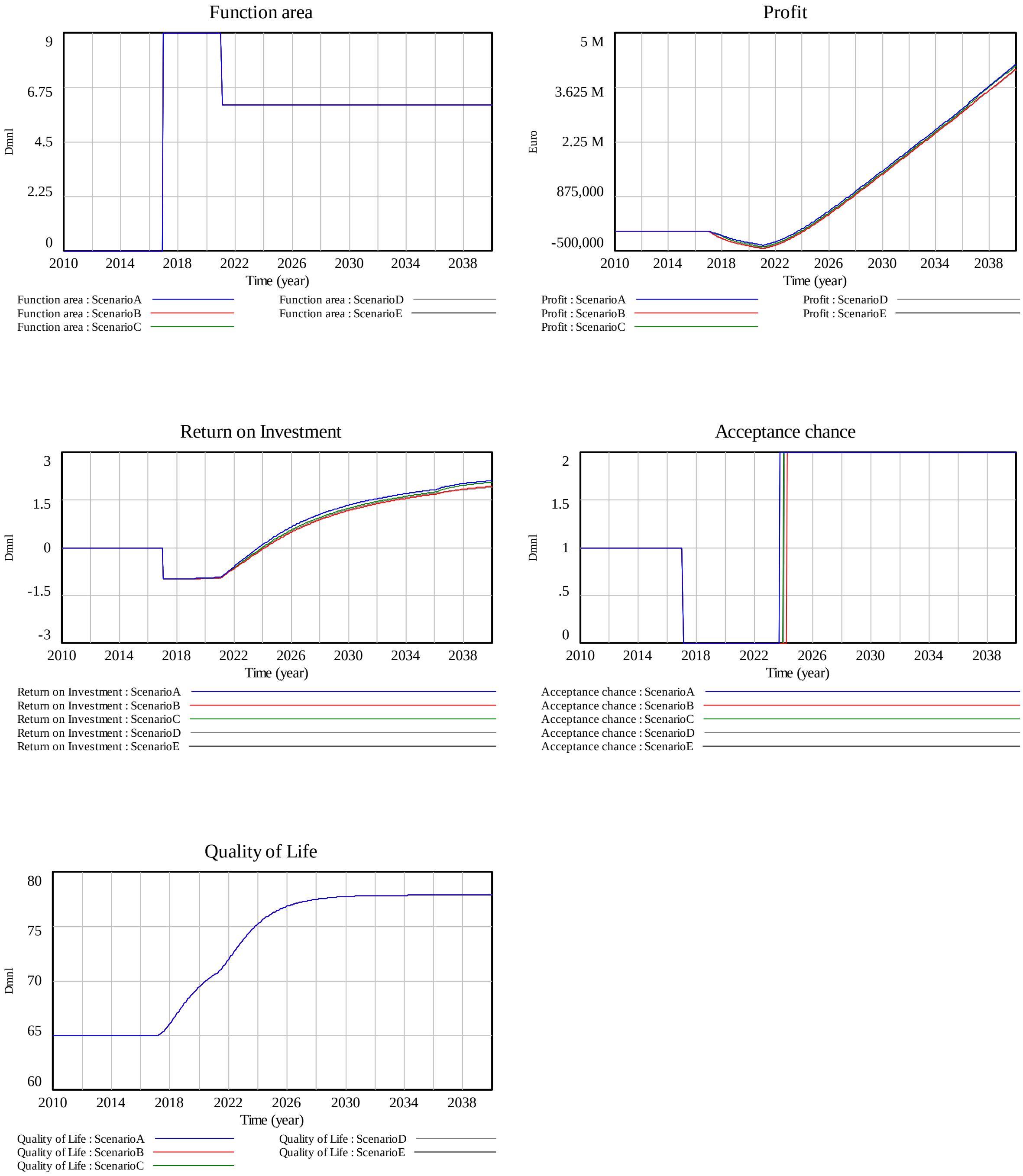

Figure 39 Results scenarios Strijp-S

The case Strijp-S will be used to see what the effect is of the different scenarios. In the calibration part, already Scenario A and the “reference mode” are shown (figure 37). In the case of Strijp-S, Scenario E and Scenario A are the same as scenario E applies the situation of Strijp-S. Figure 37 includes the five graphs of the outcomes when all five scenarios are applied. In this section, these results will be discussed.

What strikes is that the scenarios have no effect on the function area. This makes sense as the factors used in the scenario design are not related to the community-part of the SFM. Also, the “Quality of Life” is the same for all scenarios. The scenarios mainly influence the financial feasibility of the particular project.

The next graphs are the “Profit” and the “Return on Investment”. These two are related to each other, so their behaviour is also linked. Scenario A and Scenario C in this case are most profitable, and so have the highest ROI as well. This can be explained due to the fact that in both cases the “Government intervention: funding” is high. Scenario B and Scenario D are quite similar in both graphs. Both scenarios give the lowest result regarding the “Profit” and the “Return on Investment”. This is due to the fact that the “Governmental intervention: funding” is only 4 in Scenario B and even 0 in Scenario D. In the last mentioned, this difference is reduced by the fact that the variable “Part of another project” is positive (1).

The “Acceptance chance” is influenced by the profitability and the transformation time. So as each scenario in this case was profitable, the “Acceptance chance” is 2 in every scenario. However, this outcome shows that the scenarios mainly influence the timeline of the financial feasibility. Scenario E (and Scenario A in the case of Strijp-S) is the most profitable scenario. Followed by Scenario C, Scenario B and finally Scenario D. Changing the governmental funding has the largest impact on the profit: it takes the longest time to recoup the investment.

4.1.6. Conclusion

In this section the relations between the different factors has been studied. The drivers are connected to the outcomes via the implementation of smart city enablers. A special focus was placed on the financial feasibility. First the CLD was made to see how the causal relations are between the different factors. Secondly, the SFM was developed based on the CLD. A SFM offers the possibility to measure the state of a system in time. The sensitivity analysis showed which factors are most important, i.e. the ones that have the largest impact on the investment costs. To be able to use the model in a consistent way, scenarios were designed to test different areas. The SFM is the answer to the sub question regarding in what way the factors influence the financial feasibility. Now that the factors and the relations between the factors and the financial feasibility are known, the model will be put into practice by introducing different areas in the Netherlands.

4.2. Selection areas

The SFM model is built and calibrated and the scenarios are designed and ready to use. In this section, the different areas that will be evaluated for their financial feasibility of the implementation of smart city technology will be selected. The first seven areas are selected by Park Strijp Beheer because these areas are seen as potential smart city areas. These areas are:

- Centrum 1 in Schijndel (Meierstad)
- Meinerswijk / De Praets (Arnhem)
- Vaartbroek (Eindhoven)
- Cartesius (Utrecht)
- Besterd (Tilburg) (Spoorzone)
- Paleiskwartier ('s Hertogenbosch)
- Seingraaf (Duiven)

The other eleven areas selected are as follows:

- De Veste (Brandevoort, Helmond)
- Bloemhof (Rotterdam)
- Kop Zeedijk (Amsterdam)
- Stadscentrum (Nijmegen)
- Kortenbos (Den Haag)
- Schilderskwartier (Woerden)
- Centrum Ede (Ede)
- Veendam-centrum (Veendam)
- Spakenburg (Bunschoten)
- Stadskanaal Centrum (Stadskanaal)
- Weijpoort (Bodegraven Reeuwijk

These other eleven areas are selected based on their demographic characteristics. Areas with different characteristics are selected to better understand what kind of areas are suitable for the implementation of smart city technology. In the selection of different areas, the different input-variables are taken into account to create a diverse selection. One constraint is that figures of the Quality of Life (Leefbaarometer) must be available. Also, the geographic location is considered to make sure the areas used are spread over the Netherlands. Furthermore, the following factors are taken into account:

- Surface Area (small/large)
- Quality of Life (low/high)
- Province (local economy)
- Areas that are known for implementing smart technologies as well
- Function type of the area
- Rural or urban area

Appendix 13 includes the reasoning behind selecting the other eleven. An overview of all the areas and their geographic location is shown in figure 40. The blue pins in the figure represent the areas selected by Park Strijp Beheer B.V., the red pins are the other selected areas. The next section will discuss the results found when running the model with the different areas.

Figure 40 Geographic locations of selected areas

4.3. Results

In this section, the results of running the different areas in the SFM will be discussed. These results help to point out the most important factors in the financial feasibility to implement smart city technology. In total 18 areas are reviewed, this section will be used to discuss the results of the areas in comparison with one another. However, in Appendix 14, Appendix 15, Appendix 16, Appendix 17 and Appendix 18 all the separate results of the individual areas are included.

The results from the different areas have some similarities, which already came forward in the Calibration and running section: the most important factor is the function type of the area. Therefore, the results are discussed per function area, starting with “City centre areas”. In figure 41 the behaviour of the profit is put together for the areas with the function type “city centre”. Two cases are noticeable: Bloemhof in Rotterdam and Kop Zeedijk in Amsterdam. The first area shows a profit of zero, which means that the technology is not implemented in this area, even though it is a high-density area. The quality of life is too low (55%). This is not the case for Kop Zeedijk in Amsterdam, the quality of life meets the basic requirements. The Kop Zeedijk in Amsterdam has a negative profit and a decreasing line: this area is not profitable. Taking a closer look, it appeared that Kop Zeedijk has a very small surface area and relatively a lot of streets. When the ratios of street length (in meters) to surface area (in hectares) are calculated, the two mentioned areas have the highest ratios (table 29). The area with the lowest ratio also has the highest profit. The lengths of street therefore have a large impact on whether the project can be feasible. The complete overview of the results of the city-centre areas can be found in Appendix 14.

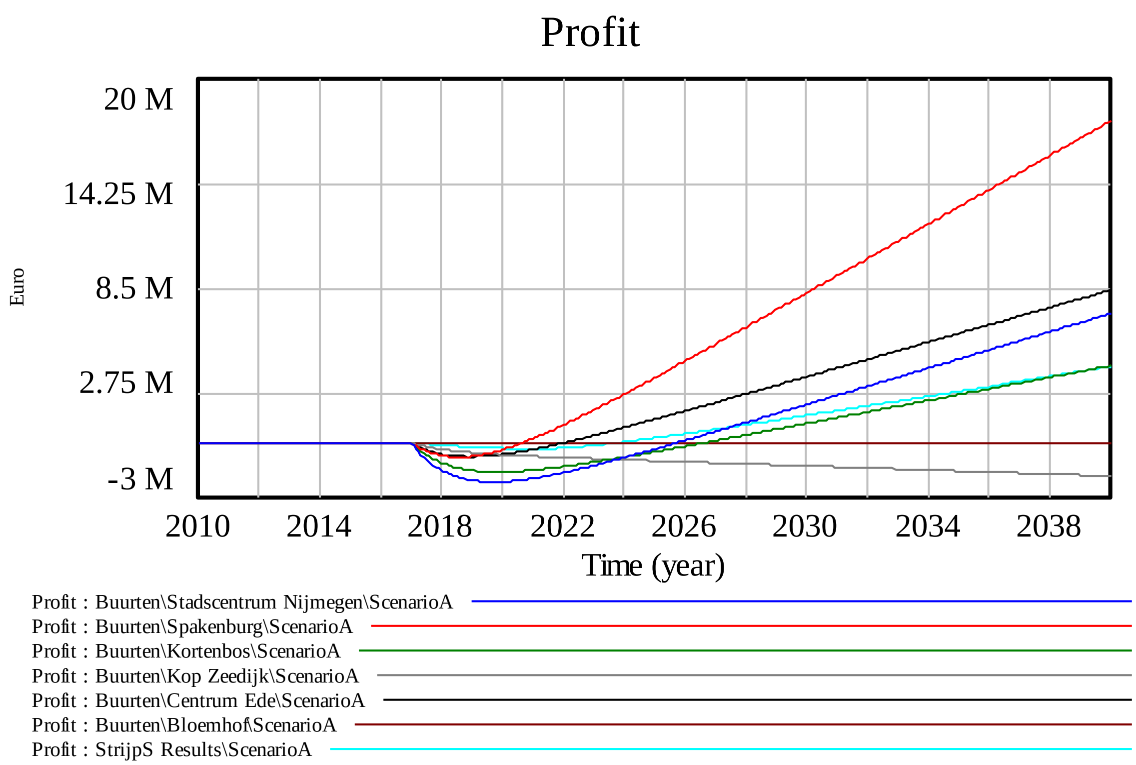

Figure 41 Profit neighbourhoods with function area "Residential area"

Table 29 Length of street and surface area city-centre-neighbourhoods

Neighbourhood	**Length of street (meter)**	**Surface area (ha)**	**Meter street/ha**
Spakenburg	3700	105	35.2
Strijp-S	1251	30	41.7
Centrum Ede	4000	61	65.6
Stadscentrum Nijmegen	11300	91	124.2
Kortenbos	8300	62	133.9
Bloemhof	13000	79	142.9
Kop Zeedijk	3000	6	500

Furthermore, eight out of the eighteen selected areas were classified as residential. Residential areas are relatively high-density urban areas, which is a requirement for smart city technology. Most of the selected areas met the requirements for the quality of life, except for Veendam-Centrum. However, it appeared that the costs for implementing the selected enablers are higher than the potential revenue per hectare. Figure 42 gives an overview of the profit (negative) in the different areas. The large difference between the areas has a direct link with the "length of street" in the area: the higher the amount of length of street (table 30), the larger the loss. The complete overview of the results for all the residential areas can be found in Appendix 15.

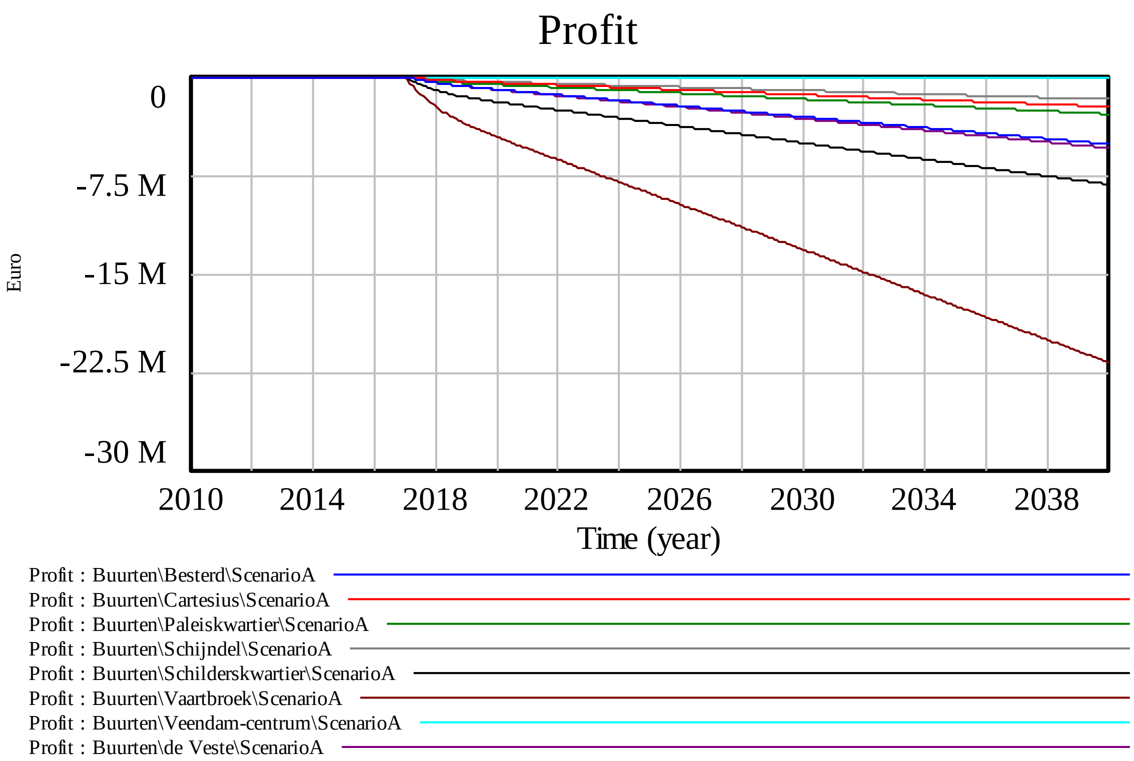

Figure 42 Profit neighbourhoods with function area "Residential area"

Table 30 Length of street and surface area different "Residential areas"

Neighbourhood	**Length of street (meter)**	**Surface area (ha)**
Schijndel Centrum 1	1424	16
Schepenbuurt, Cartesiusweg e.o.	2000	21.4
Paleiskwartier	2100	49
Besterd	5000	18
De Veste	5000	41
Schilderskwartier	6500	96
Veendam-Centrum	10000	137
Vaartbroek	20200	101

The function area "shopping centre" was selected once: for Stadskanaal. According to the expected costs per hectare (table 16) and the expected income per hectare (table 15) profit should be made. An explanation for this is the fact that the costs for the services do not include the costs for the backbone. In the model, these costs are added which causes the losses. Figure 43 shows the profit-graph for Stadskanaal, only Scenario C shows a loss. Which means that for the other scenarios, the "implementation smart city technology" stayed 0. This because the area is not eligible because the urban density is 3 (instead of ≤ 2). All the results for Stadskanaal can be found in Appendix 16.

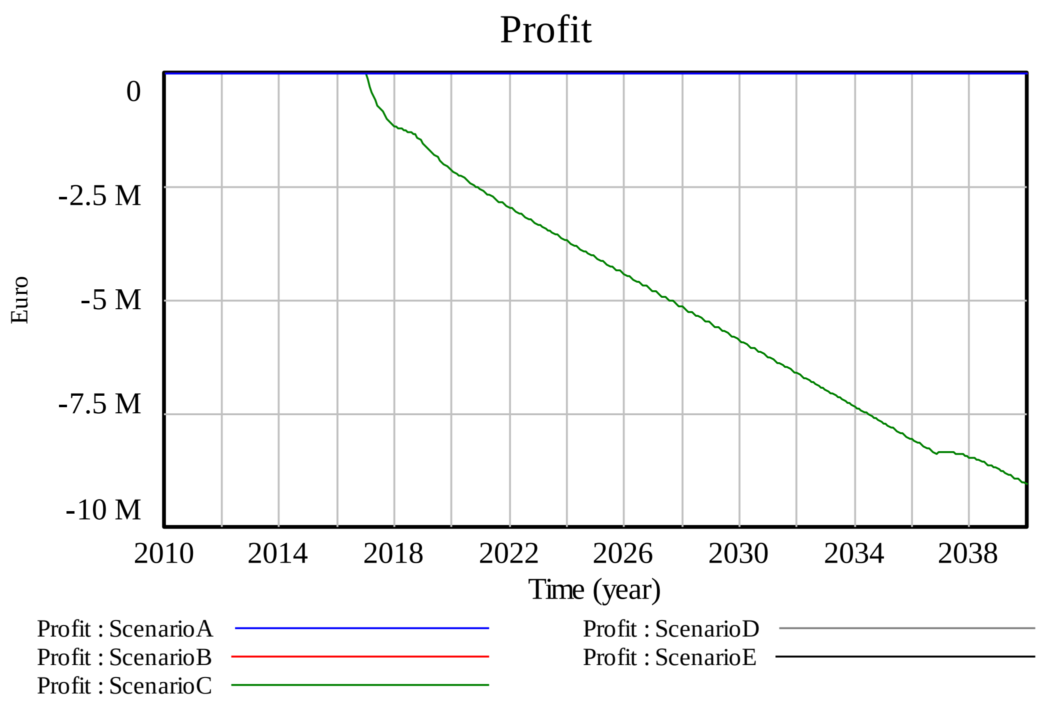

Figure 43 Stadskanaal profit graph

The previous discussed areas were all related to a city: at least an urban density of 3. The neighbourhoods Meinerswijk, Seingraaf and Weijpoort are an exception to this. Seingraaf is indicated as “business area”, which makes sense as there are no houses developed at all. Since the urban density is too low, the variable “implementation smart city technology” remained 0, however in Scenario C, where the smart city technology is forced, the result is negative. For Scenario A, Scenario B, Scenario D and Scenario E the “Acceptance chance” is 1, which means that further research is advisable to see if the project can be made feasible. Figure 44 shows the profit graph and the acceptance chance graph, Appendix 17 shows all the results for this neighbourhood. The area Seingraaf is also a very small location: only one street. Therefore, this model is not suitable. This also comes forward when the actual figures are implemented (figure 45), available due to the fact that there was a tender process to develop this area as a smart area (City Developer-S, 2017). The difference can be explained due to the fact that such a small area does not need a smart city hub. A control box placed along the road meets the requirements and so the expenditures can be lowered. The model structure is slightly changed to be able to put the figures in. The model used can be found in Appendix 18.

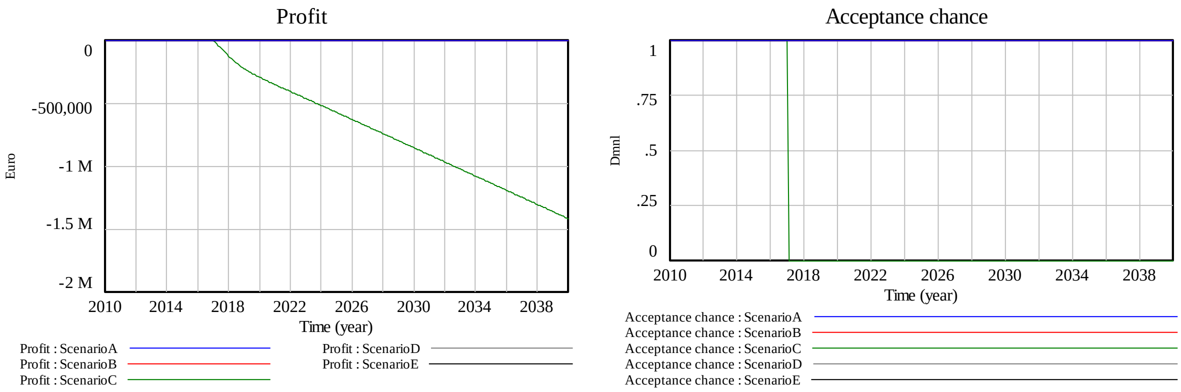

Figure 44 Profit and acceptance chance Seingraaf

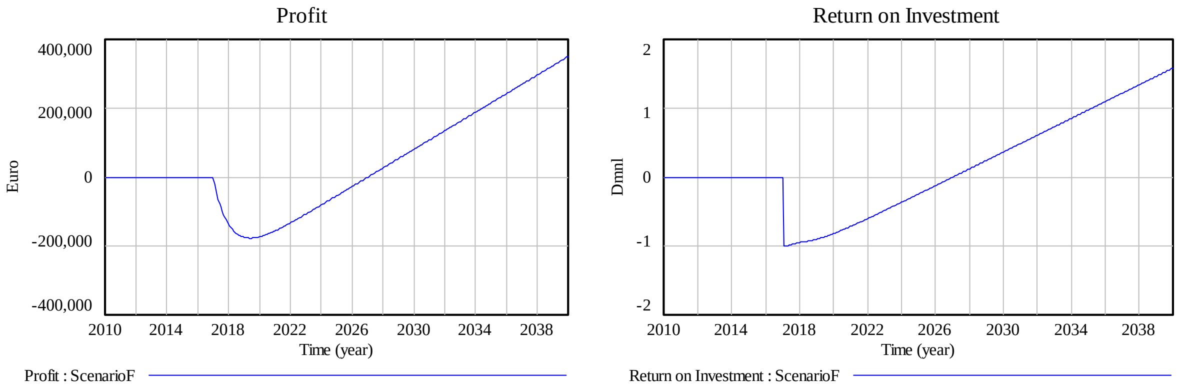

Figure 45 Actual results Seingraaf

Meinerswijk and Weijpoort have similar qualities. They both have a very low urban density of 5. This means that they are rural areas. However, Meinerswijk is an area which is under development (KondorWessels Projecten, n.d.), this makes it an transition area. The biggest difference between the two function areas is that for transition areas camera security is implemented instead of climate sensors (sniffers). As there were no figures known regarding sniffers, the result is not completely representative. To compare the two different function areas, a sixth scenario (Scenario F) is designed for Meinerswijk (figure 46). In this scenario, the area is no longer under development, which results in another function area: rural area. From the result in figure 46, it can be derived that the losses are bigger when the area is a rural area. The complete results for both neighbourhoods can be found in Appendix 18.

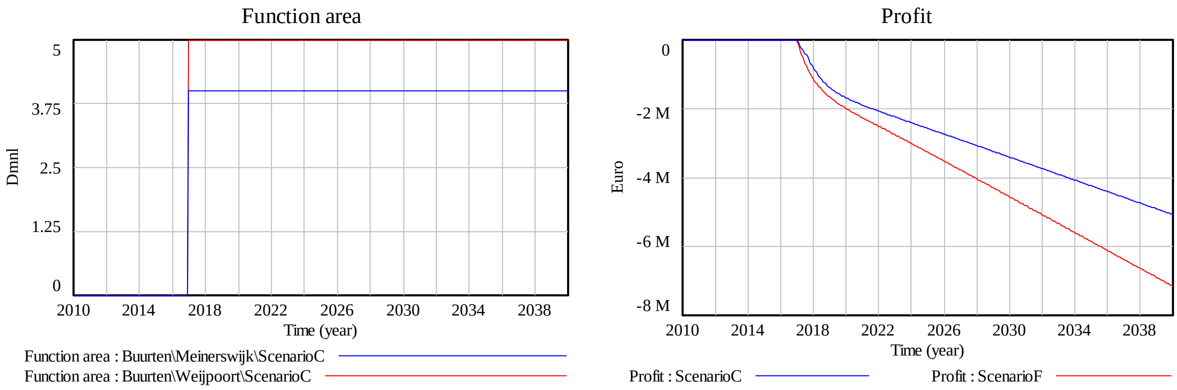

Figure 46 Results function area Meinerswijk and Weijpoort and profit Meinerswijk including Scenario F

In general, in all the cases where the technology was implemented, an increase of quality of life was shown. Furthermore, the results show that only dense urban areas with more than 153 G+I businesses can be profitable (city centre areas). Even the different scenarios do not change this. The scenario which has the largest effect in most cases is Scenario C: the locations which are indicated in advance as not suitable still show what would happen if the technology is implemented anyway. The case Bloemhof is a good example of this: the model shows a positive result from the year 2028, however from literature, it is found that the smart city technology needs a certain level of quality of life. The other scenarios especially affected the speed the desired ROI was reached. Another interesting result can be derived from the areas Seingraaf and Kop Zeedijk. Both locations have a small surface area (15.3 and 6 hectares), which resulted in extraordinary expenses for the smart city hub. Using known figures for Seingraaf, this was proven. Another area where this may apply is Schijndel Centrum 1 (16 hectares).

This section was used to gain more insight into the areas that are suitable for implementation of smart city technology. However, the results are only limited to these 18 areas and the factors included in the model. Future research could focus on implementing more smart city enablers so that more function types become feasible.

5. Conclusion

The goal of this research was to find what areas are suitable to be transformed into a smart city, furthermore, the aim was to find what factors are important to make a smart city financially feasible. This goal resulted in the following question:

> *What factors of an area characterise a smart city and which of these factors influence the financial feasibility of implementing smart city technology and what is the relation between these factors?*

To answer this question, six sub questions were drafted:

1. What makes a smart city?
2. What is the result of the implementation of smart city technology?
3. What factors make an area suitable for the implementation of smart city technology?
4. What types of areas are there in the Netherlands and what are differences between them regarding financial feasibility?
5. What can be learned from the implementation of smart city technology at Strijp-S
6. In what way do these factors influence the financial feasibility?

To determine what makes a smart city, what the result is of the implementation of smart city technology and what factors cause a successful implementation of smart city technology, a literature study was conducted. In this literature study it was concluded that there are multiple factors which are important as drivers for smart city technology and that there are several factors in the urban environment influenced by the implementation of the technology.

The variables that are related to a successful implementation and the variables that are influenced by the implementation are related to what makes a smart city: connectivity. Connectivity is created by offering a platform which different systems in the urban environment can use to communicate with each other. This platform is the basis to which the IoT can be connected, on which services can then be installed.

To understand the smart city concept better, a closer look is taken to what smart city technology accomplishes. Creating connectivity and applying the IoT on which services can be installed in the urban environment can result in certain outcomes. The Quality of Life, the local economy and the sustainability of an area can be positively influenced. On the other side, creating connectivity requires an investment.

However, not every area is suitable to transform into a smart city by facilitating connectivity. The literature pointed out variables which can function as driving factors: community, technology and policy. The community describes the composition of an area. As there are numerous compositions of a community conceivable, different function types for areas are used to describe the composition of an area. In the literature study in regard to community and the different function areas, the needs in terms of smart city enablers were pointed out. The enablers in a smart city environment will provide the turnover but, on the other hand, also require an investment. The literature provided a selection of enablers per function area to keep the investment minimal whilst maximizing the outcomes. Furthermore, a government needs to have policy to implement smart city technology which in turn will make the transformation a success. The third driver, technology, is needed to facilitate the connectivity in an area.

The most important result from looking into the case Strijp-S was the way the connectivity was created in this area. The smart city development in this area is based on three different layers: infrastructure (facilitating the connectivity), the liveable layer (serving the community), the cloud layer (data processing). In terms of technology, the infrastructure at Strijp-S gave insight in how this smart city driver can look like in practise. Using a System Dynamics approach, all the found factors are brought together into a model that shows how these factors influence the financial feasibility of the implementation of smart city technology and how the outcome-factors are influenced by the implementation of the smart city enablers. The results of using the developed model are two-fold. First different scenarios pointed out that governmental interference can increase the speed with which the implementation of smart city technology can become financially feasible. If a government provides an economic incentive and focus on shortening the required procedures, the implementation can become more interesting regarding financial feasibility. This is in relation to the policy-driver of smart cities: if there is policy for smart cities, then governments are more likely to be willing to support the smart city project. Secondly, the result of running the model including different areas from the Netherlands pointed out what factors regarding community and technology are important: a high-density urban area with relatively high-income residents, an attractive physical environment and a significant amount of businesses in the catering and retail sector. In this study, this type of area was classified as “city-centre areas”.

5.1. Scientific relevance

The study exists of an analysis of recent published articles and an analysis of a case study. The result of both parts is combined using a System Dynamics approach. This approach allows the combination of the theory with what is done in practice. A tool is developed which can give an indication if an area is suitable for smart city technology or not. Already numerous research has been conducted into frameworks in where smart cities function, of which several are discussed in this study. But this study goes further with adding actual figures regarding investments and benefits. Furthermore, the model developed brings science into practice by allowing the model to be applied to other areas then the case study Strijp-S.

5.2. Societal relevance

The societal relevance of this study is expressed by better understanding what areas are suitable for smart city technology. As found in the literature, smart city technology has a positive effect on the quality of life, furthermore, data collected in smart areas can reveal hidden patterns and correlations which could lead to new businesses or an improved service from existing businesses with a stronger economy as result. Besides, smart city technology generates data, which allows users of an area to be more efficient with resources and therefore be more sustainable.

5.3. Recommendations

This study is conducted based on Strijp-S, which is a living lab, a test centre for smart city technology. This resulted in several subsidies from the European Union. This could give a distorted picture, as in the future smart city projects should be self-sustaining. Therefore, further research to more precise figures is necessary. Furthermore, the enablers in this study could be extended in order to make other function types beside “city-centre areas” financially feasible. Finally, this study based the facilitating of connectivity on a glass fibre infrastructure as is done at Strijp-S. Future research should focus on other (less expensive) ways of creating connectivity in order to make the smart city concept more financially feasible.

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Appendices

Appendix 1. Big data in smart cities

Big data can be generated by smart cities. The found literature proves that the data generated by urban IoT meets the condition of the five notions. In the comparison of the five notions of big data for smart cities, it appeared that the definition from IDC suits best for the aim of this research:

> *Big data technologies describe a new generation of technologies and architectures, designed to economically extract value from very large volumes of a wide variety of data, by enabling high-velocity capture, discovery, and/or analysis. (Gantz & Reinsel, 2011)*

The definition not only includes the raw data but also enhances the fact that data needs processing and analysation before value can be extracted from it.

A first attempt to describe data management was done by Doug Laney (2001). Laney defined a 3-dmodel existing of volume, variety and velocity. These three notions arose from the increased data management challenges in e-commerce (Laney, 2001). *Volume* describes the generation and collection of masses of data. With *velocity* is meant the continuous (timeless) generation of data and analysing this data. This should be conducted fast to maximize the value of data. The *variety* describes the various types of data: video, audio, text, numbers. Data is unstructured or semi structured (Chen, Mao, & Liu, 2014). This three-V model, or 3-d model as Laney (2001) named it, is the basis for what is now called big data.

The International Data Corporation (IDC) defines big data as

> Technologies that describe a new generation of technologies and architectures, designed to economically extract value from very large volumes of a wide variety of data, by enabling high-velocity capture, discovery, and/or analysis (Gantz & Reinsel, 2011).

From this, four V's can be derived: volume, variety, velocity, value. The four V model was highly recognised since it highlights the meaning and necessity of big data (Chen et al., 2014). The four V model adds the notion Value to the three-V model. As can be derived from the definition used by IDC, value means the extraction of information from data (Gantz & Reinsel, 2011).

Another four-V model for big data is described by Kaur (2017). This model is based on a citation from Gartner Inc. (n.d.):

> *Big data is high-volume, high-velocity and/or high-variety information assets that demand cost-effective, innovative forms of information processing that enable enhanced insight, decision making, and process automation (Gartner Inc., n.d. as cited in; Kaur & Sood, 2017).*

In this definition, the three-V model can also be derived, however, a different fourth parameter is added to this definition: variability. The variability of big data is determined by analysing the three other V's of the model and it specifically related to analysing data streams (Kaur & Sood, 2017). Big data has variability; however, it should be as small as possible as it can influence results. As there is no evidence found that variability is an indicator for big data, the notion will not be considered for a smart city.

Furthermore, the notion veracity is argued to be important in the next generation data management systems (Berti-Equille & Ba, 2016). IBM (as cited in Herschel & Miori, 2017) divided big data also into four dimensions, adding veracity to the three-V model. Veracity is influenced by the volume, variety and velocity of data. It describes the quality of the data, which is the extent to which data is uncertain or inaccurate (IBM, 2014).

In total five different notions that describe big data are derived. Volume, Velocity and Variety are the basis to which two other notions are added: Value and Veracity. An overview is given in table 31. For this research, value is an important aspect, as the focus lies on generating revenue streams in smart cities. Therefore, the definition as stated by IDC (Gantz & Reinsel, 2011) will be leading.

Table 31 Overview of V-notions related to big data

V-notion	Description	Source
Volume	The size of the data. The collection and generation of masses of data.	(Chen et al., 2014; Gantz & Reinsel, 2011; Gartner Inc., n.d.; Herschel & Miori, 2017; IBM, 2014; Kaur & Sood, 2017; Laney, 2001)
Velocity	The rapidity by which data is generated. It also relates to the timeliness of big data.	(Chen et al., 2014; Gantz & Reinsel, 2011; Gartner Inc., n.d.; Herschel & Miori, 2017; IBM, 2014; Kaur & Sood, 2017; Laney, 2001)
Variety	The different types of data generated. Examples are but not limited to: video, audio and text.	(Chen et al., 2014; Gantz & Reinsel, 2011; Gartner Inc., n.d.; Herschel & Miori, 2017; IBM, 2014; Kaur & Sood, 2017; Laney, 2001)
Value	Includes the technology to extract economic benefits from extracting information from a large volume of a wide variety of data which is continuously generated.	(Chen et al., 2014; Gantz & Reinsel, 2011)
Veracity	Veracity relates to the usability of data, the quality. The extent to which data is inaccurate or incomplete.	(Berti-Equille & Ba, 2016; Herschel & Miori, 2017; IBM, 2014)

The question that should be answered now is whether data generated in a smart city is big data, starting with variety. **Variety** in smart cities can be found in the different types of sensors (IoT) potentially used and the data they generate: video sources, audio sources, statistics, text are all generated in a IoT environment in a city. Following on from this Zanella et al. (2014) developed a system architecture for smart cities. The architecture takes different sources and networks standards into account, it shows the complexity of the communication needed in a smart city. An architecture that is more focussed on the different types of input is the construction frame of big data technologies for smart cities (Hashem et al., 2016, fig. 2). Both researches show that data collected in a smart city knows variety.

The rapidity by which data is generated and collected in smart cities matters to meet the velocity-requirement. **Velocity** in a smart city can be recognized in real-time or in near-real-time data production and analysation. Several cities already implemented platforms that make real-time data available for use. Examples are: Rio de Janeiro, opened an analytics centre that draws all systems together; New York opened a one-stop data analytic hub where terabytes of data run through on a daily basis; Santander opened an augmented real-time app; London communicates live feeds or real-time data to citizens through so-called city dashboards (Kitchin, 2014). The fact that cities build systems around the urban IoT to analyse real-time data confirms that data from a smart city is velocity.

Volume of data in a smart city is hard to determine. The **volume** is highly influenced by the number of sensors implemented in the urban environment. The latest forecasts from Forbes (2017) summarizes several predictions about the IoT by 2020. The global IoT market will grow from $157 billion in 2016 to $457 billion in 2020 of which smart cities will be one of the three dominating sub-sectors. Smart cities will be responsible for 26% of the global IoT market according to GrowthEnabler (as cited in Columbus, 2017). Furthermore, the more data is generated the smarter a city can be, as data gives objective, neutral measures that are free of political ideology. Data is an essential part of a smart city vision (Kitchin, 2014).

The fourth V, **value**, is an important issue in the question why one should develop a smart city. Smart cities in the sense of urban IoT are developed because it appeared that most common characteristics of a smart city include enabling political efficiency and emphasis on business-led urban development and creative activities (Albino et al., 2015). The smart city is efficient with resources and due to data collection and thorough analysation it can provide answers to problems in these fields. The economic strength can be enhanced by the smart city (Jessen, 2015). Value is inseparable from smart cities, as urban technology is often implemented to be more efficient with resources and services.

Veracity describes the quality of data collected. To maintain the quality, it is important to incorporate mechanisms that result in reliable data sources and to prevent the discard of data due to noisy sources. Causes of lower data quality are for example loss of GPS signal due to tall buildings or disrupted wireless sensor networks (Chauhan, Agarwal, & Kar, 2016). Multiple examples of systems that try to increase or maintain the quality of data have been developed (as cited in Chauhan et al., 2016). One example described by Chauhan et al. (2016) is the Run-Time Event Calculus (RTEC). This system matches several sources to generate common composite events to identify mismatches. The development of such systems proves that data generated by a smart city must deal with veracity.

Big data can be generated by smart cities. The found literature proves that the data generated by urban IoT meets the condition of the five notions. In the comparison of the five notions of big data for smart cities, it appeared that the definition from IDC suits best for the aim of this research:

> *Big data technologies describe a new generation of technologies and architectures, designed to economically extract value from very large volumes of a wide variety of data, by enabling high-velocity capture, discovery, and/or analysis. (Gantz & Reinsel, 2011)*

The definition not only includes the raw data but also enhances the fact that data needs processing and analysation before value can be extracted from it.

Open data & linked data

Data generated in the public environment of Eindhoven should be available without any legal or technical barriers for commercial and non-commercial use. Exceptions are data that include privacy-sensitive data, these kind of data should be enabled to the public in accordance with the law for protection of personal information (Mayor and Alderman of Eindhoven, 2015).

The government of the Netherlands defines open data with eight different assumptions (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, n.d.):

1. Data should be shared anytime when it falls within the frameworks of the law. It must take the open government act and it should not pose any kind of risk with regard to privacy.
2. Open data is free for everybody, no costs should be charged for using data.
3. There are no copyrights applicable and data can be used freely.
4. Open data is accessible without the need to register of subscribe.
5. Open data is machine readable.
6. Open data contains source information and is not aggregated, it contains metadata.
7. Open data is as complete as possible and without any unnecessary edits (raw data).
8. Open data is findable.

To summarize these eight assumptions in one sentence: Open data is data collected in the public environment, the data is findable and accessible without the need of registration or payment and can be used with an open license, open data is machine-readable, contains metadata, has not been edited, does not pose any privacy risks and falls within the law.

Tim Berners-Lee described the semantic web and linked data in 2006. Later, in 2010, Berners-Lee added a proposal for a five-star ranking system for open (linked) data. The system starts with one star, which includes enabling data in any kind of format, this includes photos or a scan, as long as it has been made public at all. The five stars from Berners-Lee (2006):

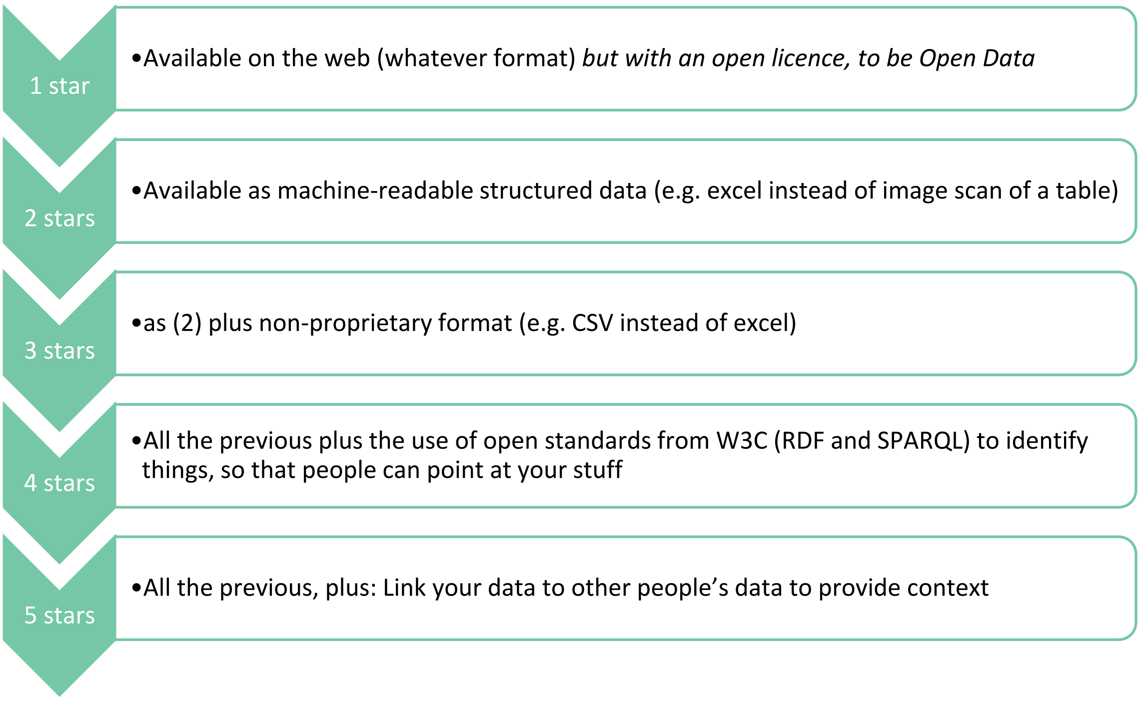


Figure 47 Five star linked open data ranking (Berners-Lee, 2006)

The starring-model of Berners-Lee shows the differences in open data and in linked data. Open data at its best is equal to the four-star ranking. Data is in the format of an open standard and readable by both humans and machines. The five-star ranking turns open data into linked open data. Data can be combined with other sources and provide context so that a person or machine can explore the web of data (Berners-Lee, 2006)

Appendix 2. Overview services

Small cells	The small cell antenna detects the mobiles of the mobile users. This data can be analysed and monitored by the network operations centre. To all wireless connected devices, affordable broadband is provided
Sniffer	Required sensors measure different types of values, like CO2, micro dust, temperature and humidity.
Camera security services	Deterrence of violence, de-escalation of violent situations or law enforcement are the goals of this service. The value of this service is a reduction in the cost to society of violence
Crowd control	Sensors like cameras, Bluetooth or Wi-Fi antennas can detect the amount of people in a particular area (density), and possibly their location. Results can be shown on a dashboard of the police or a safety centre, possibly also provided to law enforcement or emergency service personnel on site
Smart parking	Relevant data like licence plates, vacant or occupied parking spaces, need for a parking space, comes from the parking spaces, cars and road networks. This is detected by RFID number plate recognition sensors, camera sensors, road sensors at parking spots and mobile devices of car drivers.
Smart lighting	The data subjects are road users like cars, buses, cyclists, and pedestrians. Sensors like Radar and PIR (passive infrared sensor), embedded road sensors or cameras provide real-time data on road load and save this data local, in the smart public node. Over the backhaul network, this data will be aggregated and serves as input for variable lighting level. The data can be visualized by a dashboard.
C-ITS	Corporative Intelligent Transport Systems. C-ITS is a concept in which mobile road users such as vehicles and the road side infrastructure get engaged in mutual information exchange to align their behaviours and intentions such that traffic conditions can be optimized.
Wi-Fi	A single physical Wi-Fi-based connectivity network owned and operated by a neutral broker/operator is envisaged. Depending on the requirements of end-users, access to specific data/connectivity offerings (e.g. the internet, private networks) is provided.

Appendix 3. Service profiles

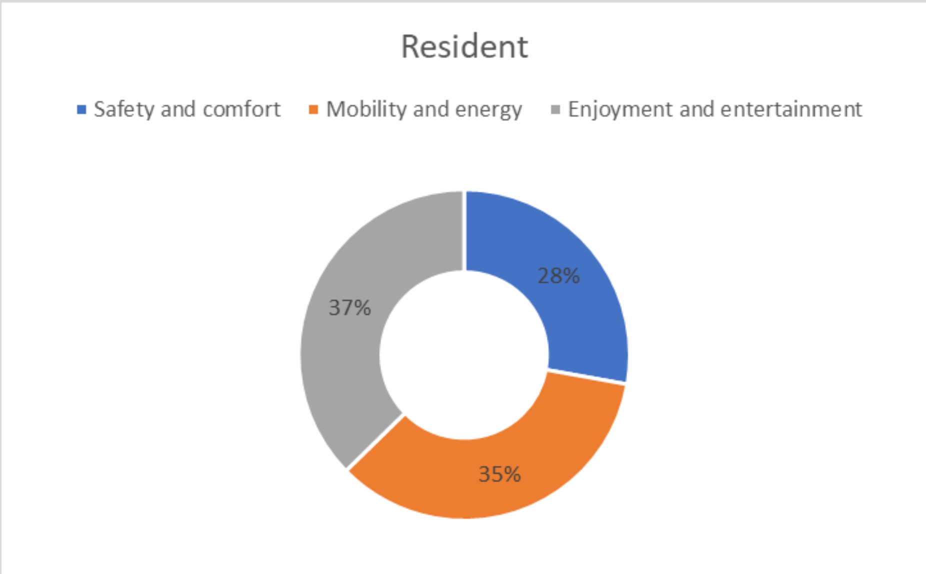
Besides the services that are already implemented, research is conducted by Cisco and Park Strijp Beheer to potential services (Cisco Systems International B.V., 2013). In total a list of 77 potential services is developed, spread over five topics.

1. Public safety and security services
2. Building common area services
3. Healthcare services
4. Residential tenants
5. Business tenants

These services are found in several discovery workshops.

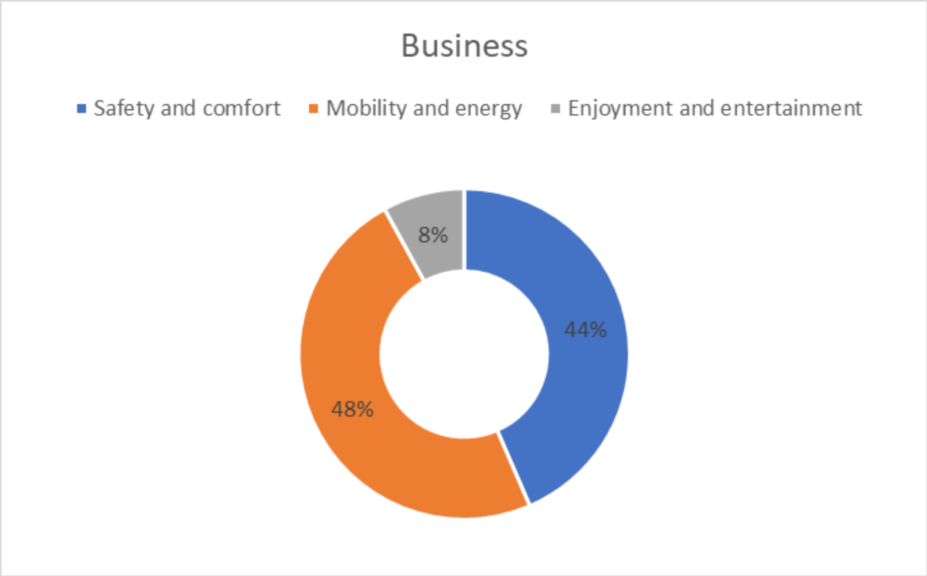
The existing services and the potential future services are analysed. Per service, the potential customer (business, resident or visitor) is determined, as well as the service type. In this section, the different profiles are discussed.

Residents



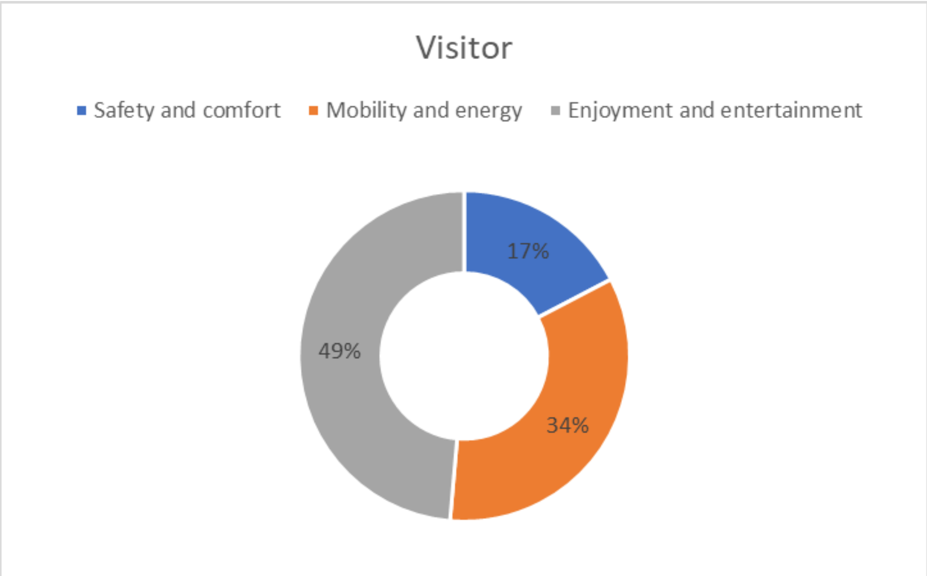
The quality of life is pointed out as one of the most important factors for residents. Therefore, services that add to the increase of the quality of life are important for residents. All kind of services that increase the comfort of residents are of importance. That explains the equal distribution between the three possible tracks. Residents have a need to live in a safe environment, but also to be productive and performing a main activity: practical becoming. This results in an importance of mobility and energy services. The enjoyment and entertainment track has also a big influence on the quality of life, which explains the large share of this track in the profile.

Business



The mix of services for business customers is characterised by the high potential for mobility and energy services, followed by the safety and comfort services. Enjoyment and entertainment services are not that interesting for business customers. The fact that mobility and energy services are of interest for businesses is no surprise. Already in the explanation of what mobility and energy services are, Goulden (2015) stressed out that: "Transportation tends to favour economic development as it facilitates the flows of people, goods, energy and information".

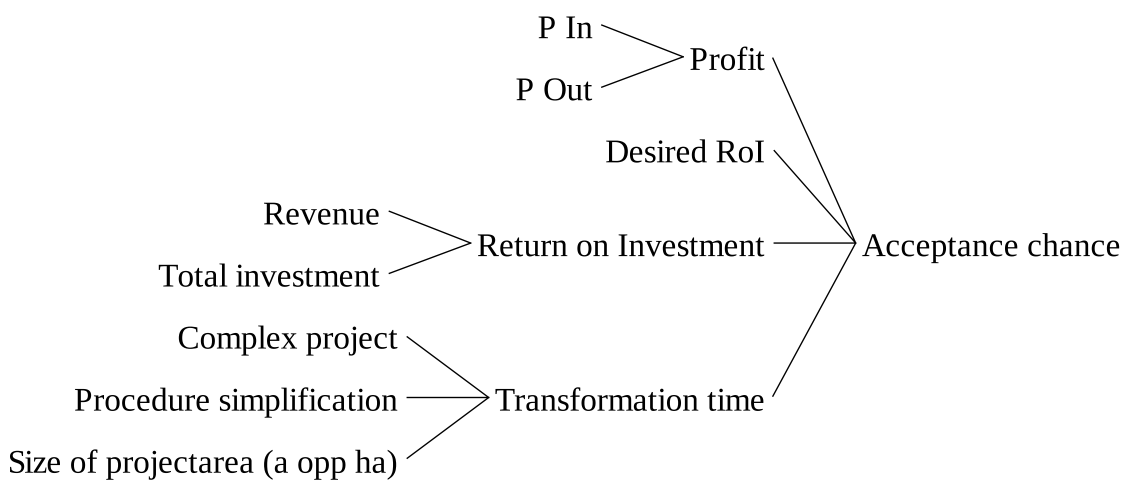
Visitors



While the profiles for residents and visitors are similar, the profile for the visitors is quite different. The enjoyment and entertainment services is the most important track. This can be explained by the fact that visitors are not present in the area on a regular basis, like residents who live in the area, of business customers who work every day in the area. Visitors have a higher need to be entertained. Another explanation is that the smart city can function as an attraction itself. There are not many areas yet where the smart city is visible and directly accessible for individuals.

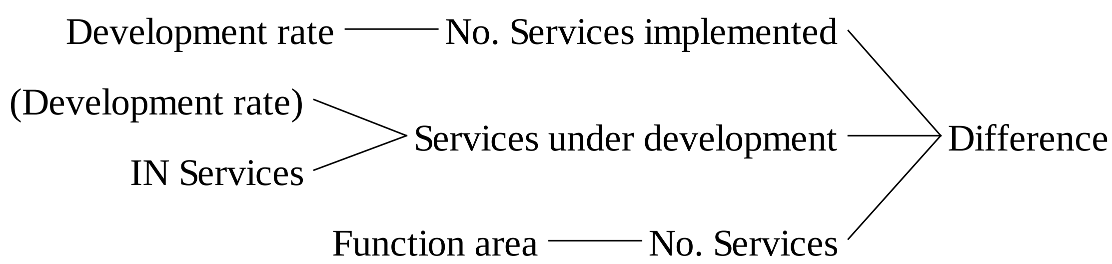
Appendix 4. Causal Relations SFM

1) Acceptance chance

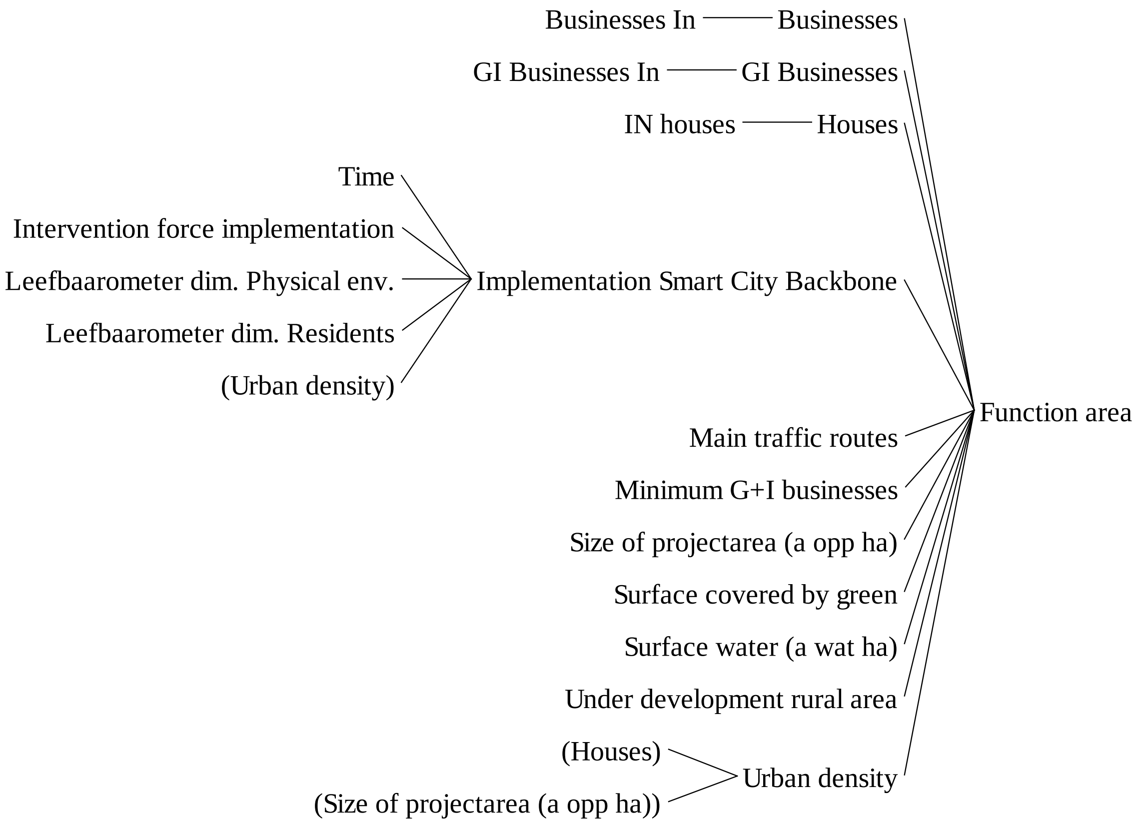


2) Businesses

3) Difference

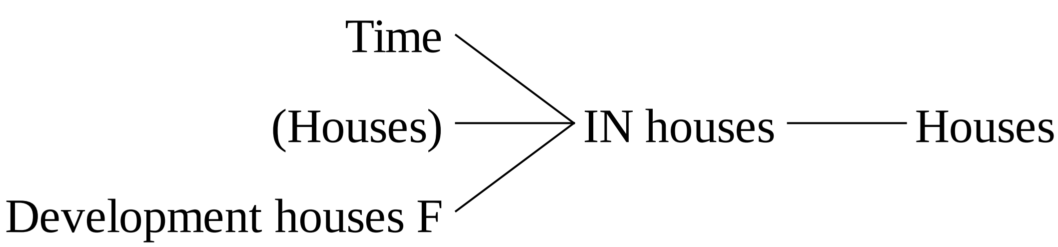


4) Function area

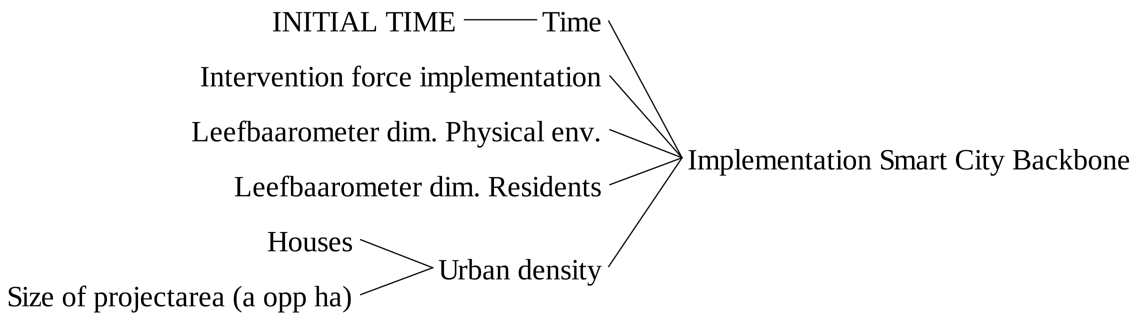


5) GI Businesses

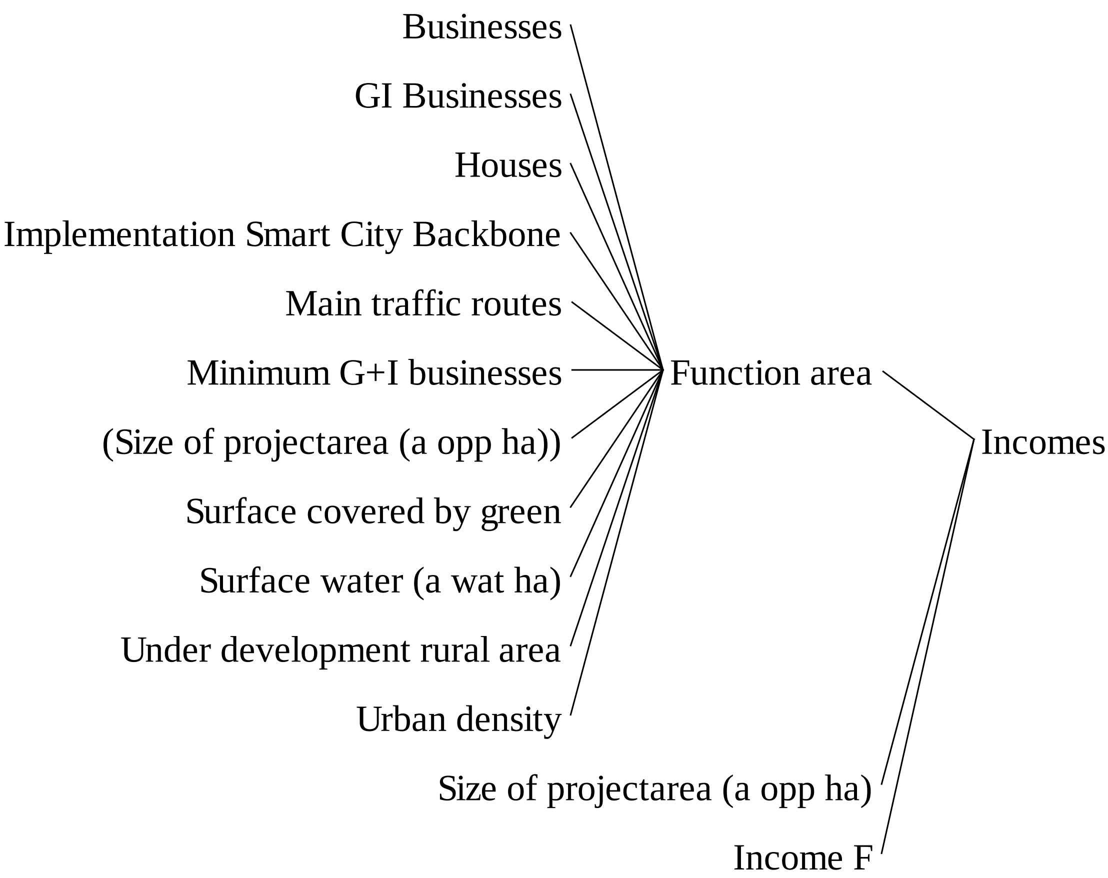
6) Houses



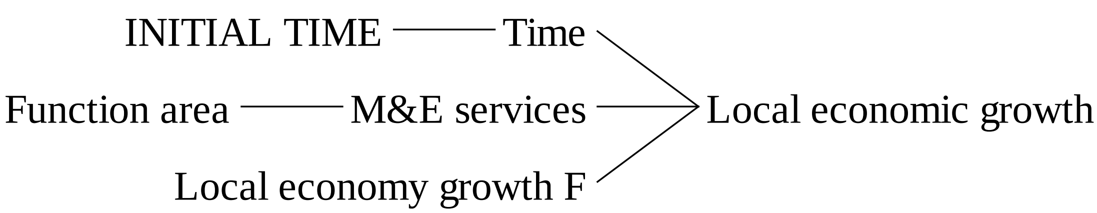
7) Implementation Smart City Backbone



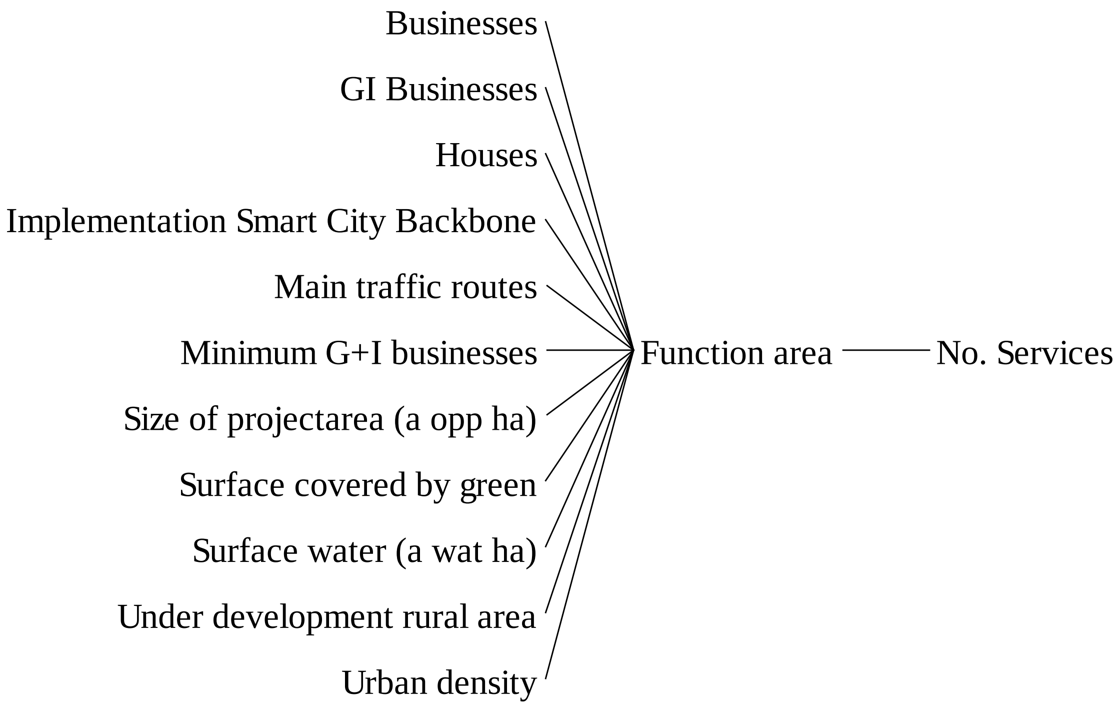
8) Incomes



9) Local economic growth

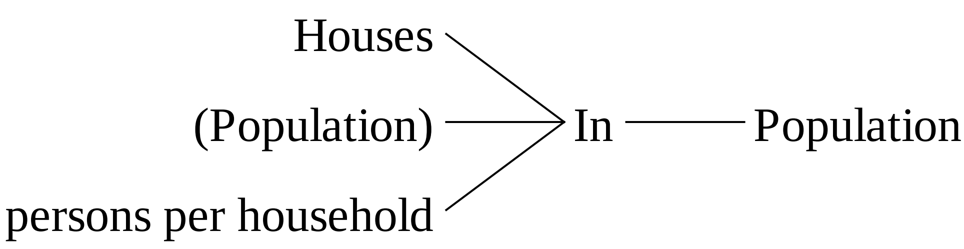


10) No. Services

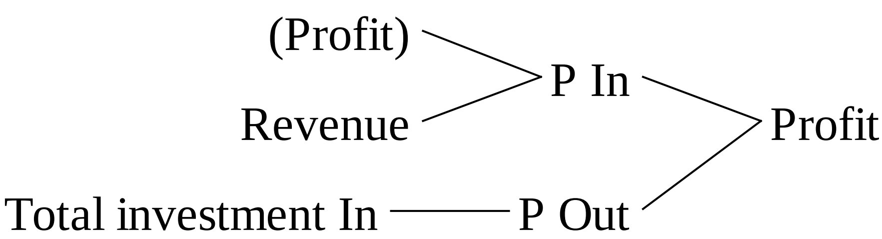


11) No. services implemented

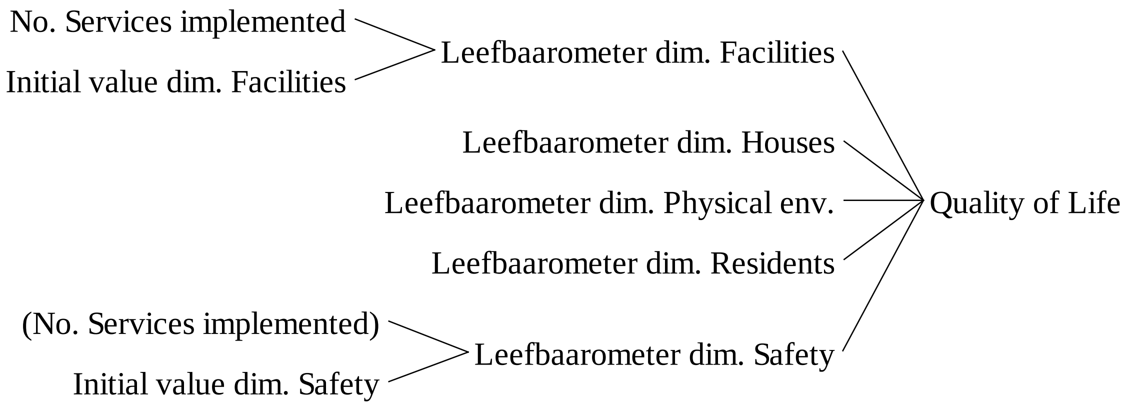
12) Population



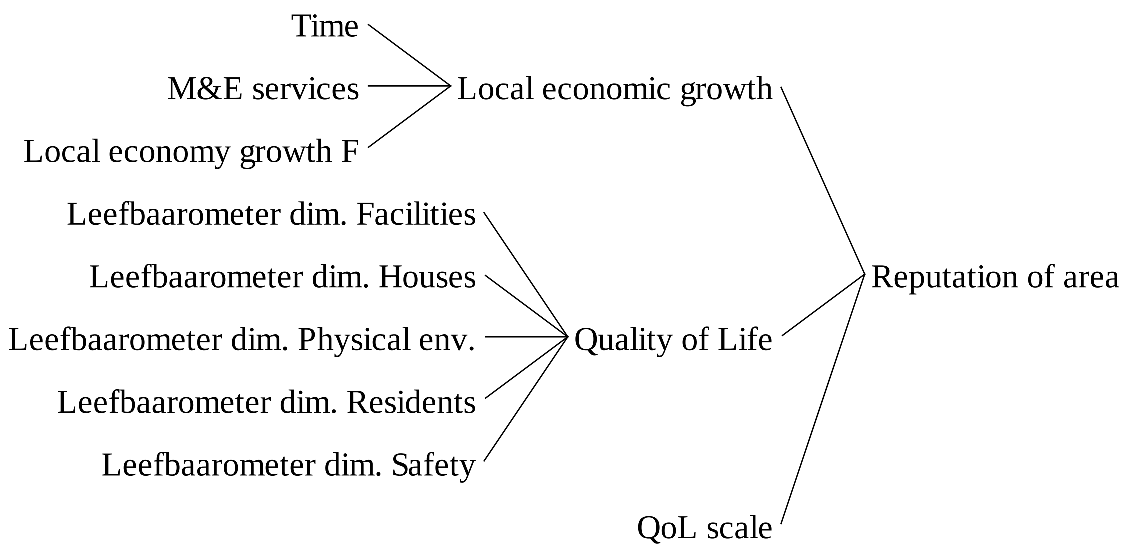
13) Profit



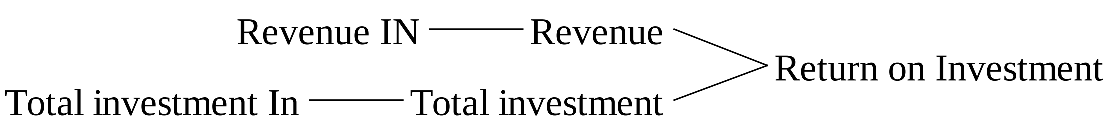
14) Quality of Life



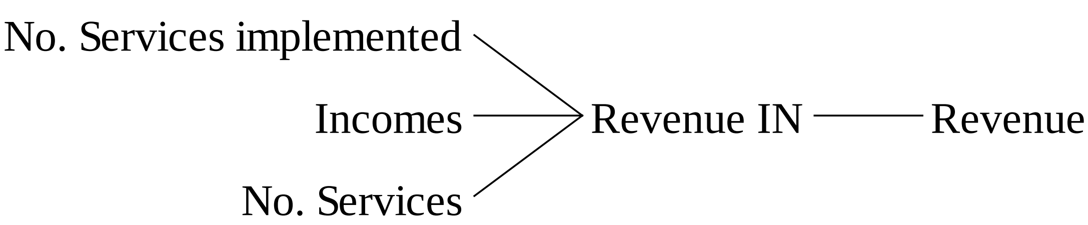
15) Reputation of area



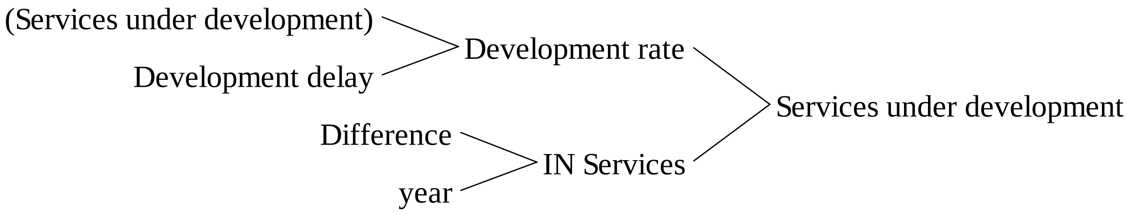
16) Return on Investment



17) Revenue

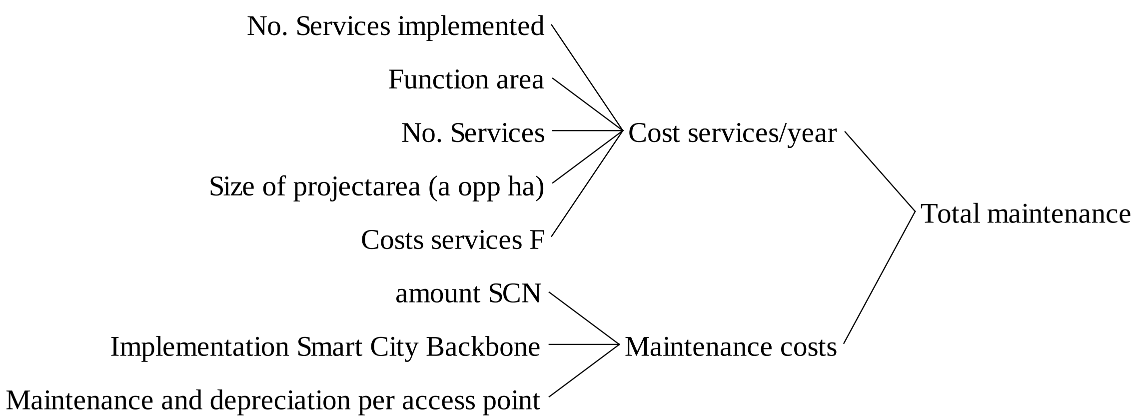


18) Services under development

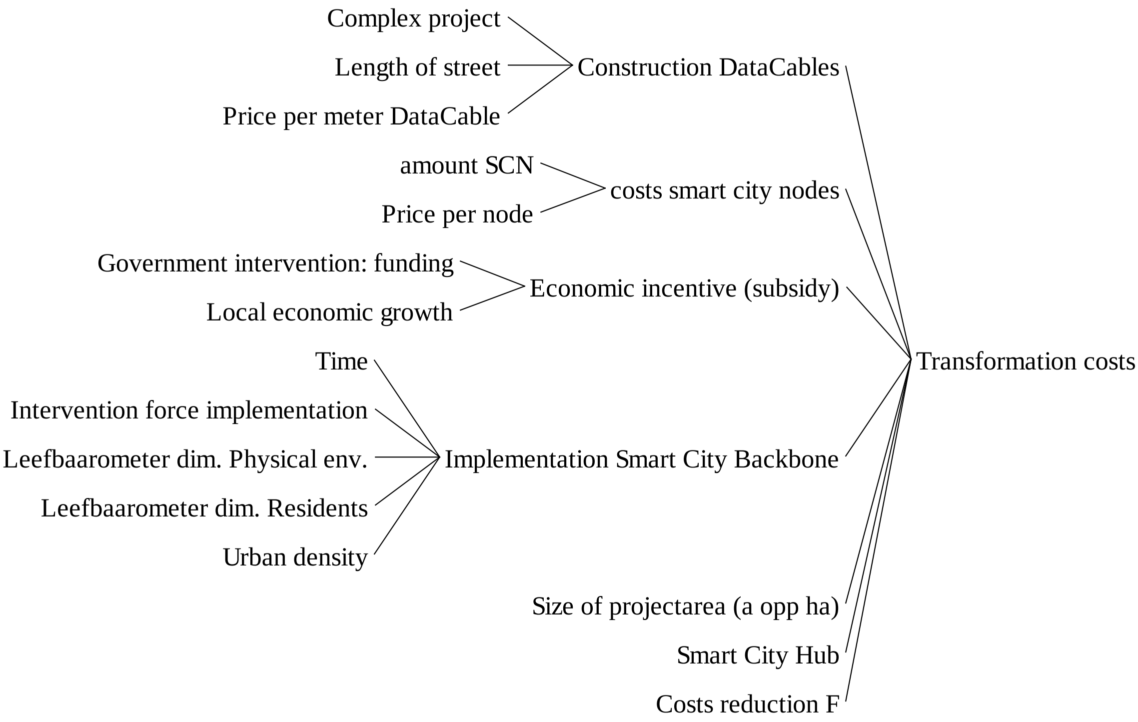


19) Total investment

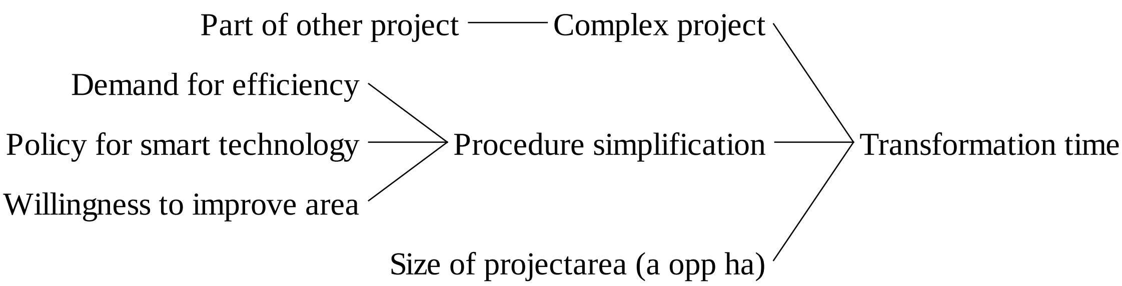
20) Total maintenance



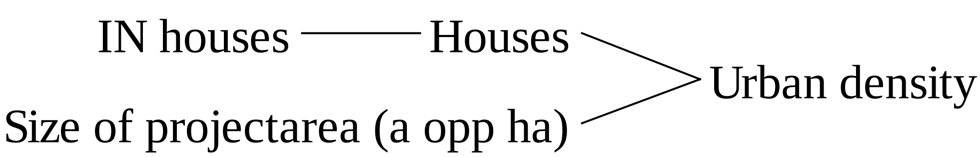
21) Transformation costs



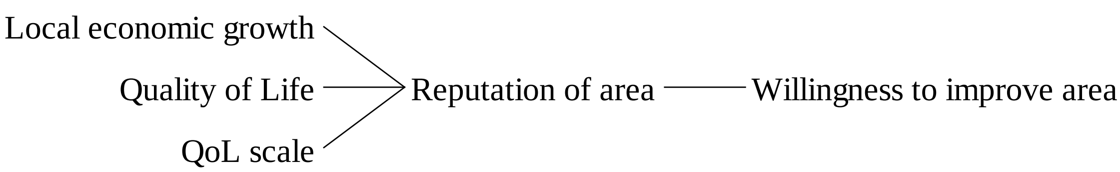
22) Transformation time



23) Urban density



24) Willingness to improve area



Appendix 5. Calculations

(01) Acceptance chance=
IF THEN ELSE(Profit>0, 2, IF THEN ELSE(Return on Investment>=Desired ROI:OR:
Return on Investment>=0:AND:Transformation time<4, 1, 0))
Units: Dmnl [0,2]

(02) amount SCN=
Length of street/Distance between SCN
Units: pcs

(03) Business F(
[(2010,0)-(2040,2000)],(2010,52),(2011,402),(2012,428),(2013,500),(2014,500
),(2015,500),(2016,500),(2017,620),(2018,641),(2019,1132),(2020,1307),(2021
,1404),(2022,1404),(2023,1544),(2040,1544))
Units: businesses/year

(04) Businesses= INTEG (
Businesses In,
40)
Units: businesses

(05) Businesses In=
Business F(Time)-Businesses
Units: businesses/year

(06) Complex project=
IF THEN ELSE(Part of other project=1, 0, 1)
Units: Dmnl [0,1]

(07) Construction DataCables=
IF THEN ELSE(Complex project=0, Length of street*Price per meter DataCable
, Length of street*Price per meter DataCable*
2)
Units: Euro

(08) "Cost services/year"=
IF THEN ELSE(Function area<>0, (Costs services F(Function area)*"Size of projectarea
(a opp ha)"
)/"No. Services"*"No. Services implemented", 0)
Units: Euro/year

(09) Costs reduction F(
[(0,0)-(10,1)],(0,0),(2,0.125),(4,0.25),(6,0.375),(8,0.5))
Units: Dmnl

(10) Costs services F(
[(0,0)-(10,2000)],(1,1317.7),(2,0),(3,888.16),(4,361.36),(5,381.6),(6,1471.66
),(7,1093.16),(8,589.86),(9,1191.66))
Units: Euro/ha/year

(11) costs smart city nodes=
amount SCN*Price per node
Units: Euro

(12) Demand for efficiency=
IF THEN ELSE(Urban density=1:OR:Urban density=2, 1, 0)
Units: Dmnl [0,1]

(13) Desired ROI=
0.08
Units: Dmnl [0,0.1,0.005]

(14) Development delay=
2
Units: year [0,2,0.5]

(15) Development houses F(
[(2011,0)-(2041,900)],(2012,198),(2013,277),(2014,0),(2015,0),(2016,0),(2017
,598),(2018,168),(2019,675),(2020,385),(2021,489),(2022,0),(2023,335),(2024
,0),(2025,875),(2026,0),(2041,0))
Units: adresses

(16) Development rate=
Services under development/Development delay
Units: service/year

(17) Difference=
MAX("No. Services"-"No. Services implemented"-Services under development,
0)
Units: service

(18) Distance between SCN==
40
Units: meter/pcs

(19) "Economic incentive (subsidy)"=
IF THEN ELSE(Local economic growth>=0.01:AND:Local economic growth<0.03,
"Government intervention: funding"*0.5, IF THEN ELSE(Local economic growth
>=0.03, "Government intervention: funding"*1, 0))
Units: Dmnl

(20) FINAL TIME = 2040
Units: year
The final time for the simulation.

(21) Function area=
IF THEN ELSE(Implementation Smart City Backbone=1, IF THEN ELSE(Main traffic
routes
=1, 1, IF THEN ELSE(("Size of projectarea (a opp ha)"
/2)<="Surface water (a wat ha)", 2,IF THEN ELSE(Businesses>Houses, 3, IF THEN ELSE
(Urban density<=3, IF THEN ELSE(
GI Businesses<="Minimum G+I businesses", IF THEN ELSE(Surface covered by green

=1, 8, 9), IF THEN ELSE(Urban density<=2
, 6, 7)), IF THEN ELSE(Under development rural area=1, 4, 5))))), 0)
Units: Dmnl [0,9]

(22) GI business F(
[(2010,0)-(2040,200)],(2010,6),(2011,49),(2012,52),(2013,61),(2014,61),(2015
,61),(2016,61),(2017,75),(2018,78),(2019,137),(2020,158),(2021,170),(2022,
170),(2023,187),(2040,187))
Units: businesses

(23) GI Businesses= INTEG (
GI Businesses In,
0)
Units: businesses

(24) GI Businesses In=
GI business F(Time)-GI Businesses
Units: businesses/year

(25) "Government intervention: funding"=
0
Units: Dmnl [0,8,4]

(26) Houses= INTEG (
IN houses,
0)
Units: adresses

(27) Implementation Smart City Backbone=
IF THEN ELSE(Time<2017, 0, IF THEN ELSE(Intervention force implementation
=1:OR:"Leefbaarometer dim. Physical env.">=-0.187623:AND:"Leefbaarometer dim.
Residents"
>=-0.249976:AND:Urban density<=2,1, 0))
Units: Dmnl [0,1]

(28) In=
(Houses*persons per household)-Population
Units: Persons

(29) IN houses=
(Development houses F(Time))/year
Units: adresses/year

(30) IN Services=
Difference/year
Units: service/year

(31) Income F(
[(0,0)-(10,20000)],(1,96),(2,0),(3,544.47),(4,488.47),(5,103.35),(6,11855.6
),(7,2113.51),(8,488.47),(9,544.47))
Units: Euro/year/ha

(32) Incomes=
IF THEN ELSE(Function area<>0, Income F(Function area)*"Size of projectarea (a opp ha)"
, 0)
Units: Euro/year

(33) INITIAL TIME = 2010
Units: year
The initial time for the simulation.

(34) "Initial value dim. Facilities"==
0.0612546
Units: Dmnl

(35) "Initial value dim. Safety"==
-0.16516
Units: Dmnl

(36) Intervention force implementation=
0
Units: Dmnl [0,1,1]

(37) "Leefbaarometer dim. Facilities"=
((1.5604-(1.04079+"Initial value dim. Facilities"))/8)*"No. Services implemented"
+"Initial value dim. Facilities"
Units: Dmnl [?,1.5604]

(38) "Leefbaarometer dim. Houses"==
-0.0290672
Units: Dmnl

(39) "Leefbaarometer dim. Physical env."==
-0.0356239
Units: Dmnl

(40) "Leefbaarometer dim. Residents"==
0.0384791
Units: Dmnl

(41) "Leefbaarometer dim. Safety"=
((1.49799-(0.99916+"Initial value dim. Safety"))/8*"No. Services implemented"
)+"Initial value dim. Safety"
Units: Dmnl [?,1.49799]

(42) Length of street=
1251
Units: meter [?,?,1]

(43) Local economic growth=
IF THEN ELSE("M&E services"=3, (Local economy growth F(Time)+0.005), IF THEN ELSE
("M&E services">0, (Local economy growth F(Time)+0.0025), Local economy growth F

(Time)))
Units: Dmnl

(44) Local economy growth F(
[(2009,-0.06)-(2040,0.06)],(2009,-0.052),(2010,0.019),(2011,0.035),(2012,
-0.006),(2013,0.009),(2014,0.019),(2015,0.034),(2016,0.025),(2017,0.037),(
2018,0.029),(2019,0.027),(2021,0.018),(2040,0.03))
Units: Dmnl

(45) "M&E services"=
IF THEN ELSE(Function area=6, 2, IF THEN ELSE(Function area=1:OR:Function area
=7, 1, 0))
Units: service

(46) Main traffic routes=
0
Units: Dmnl [0,1,1]

(47) Maintenance and depreciation per access point==
1572
Units: Euro/year/pcs

(48) Maintenance costs=
IF THEN ELSE(Implementation Smart City Backbone=0, 0, (Maintenance and
depreciation per access point
*amount SCN))
Units: Euro/year

(49) "Minimum G+I businesses"=
153.522
Units: businesses

(50) "No. Services implemented"= INTEG (
Development rate,
0)
Units: service

(51) "No. Services"=
(IF THEN ELSE(Function area=1, 3, IF THEN ELSE(Function area=2, 0, IF THEN ELSE
(Function area=3, 3, IF THEN ELSE(Function area=4, 2, IF THEN ELSE(Function area
=5, 2, IF THEN ELSE(Function area=6, 7, IF THEN ELSE(Function area=7, 5, IF THEN ELSE
(Function area=8, 3, IF THEN ELSE(Function area=9, 4, 0))))))))))
Units: service

(52) P In=
Revenue IN
Units: Euro

(53) P Out=
Total investment In
Units: Euro

(54) Part of other project=
1
Units: Dmnl [0,1,1]

(55) persons per household=
1.4
Units: Persons/adresses [1,5,0.1]

(56) Policy for smart technology=
0
Units: Dmnl [0,1,1]

(57) Population= INTEG (
In,
0.1)
Units: Persons

(58) Price per meter DataCable==
50
Units: Euro/meter

(59) Price per node==
2000
Units: Euro/pcs

(60) Procedure simplification=
IF THEN ELSE(Policy for smart technology=1, 1, IF THEN ELSE(Demand for efficiency =1:AND:Willingness to improve area=1, 1, 0))
Units: Dmnl [0,1]

(61) Profit= INTEG (
P In-P Out,
0)
Units: Euro

(62) QoL scale(
[(0,0)-(101,10)],(0,1),(11.1,1),(11.11,2),(22.2,2),(22.22,3),(33.3,3),(33.33 ,4),(44.4,4),(44.44,5),(55.6,5),(55.66,6),(66.7,6),(66.77,7),(77.8,7),(77.88 ,8),(88.9,8),(88.99,9),(101,9)

)
Units: Dmnl

(63) Quality of Life=
(((0.74937+"Leefbaarometer dim. Houses")/1.12349)+((0.62447+"Leefbaarometer dim. Residents"
)/0.93624)+((1.04079+"Leefbaarometer dim. Facilities")/1.5604)+((0.99916+"Leefbaarometer dim. Safety"
)/1.49799)+((0.74937+"Leefbaarometer dim. Physical env.")/1.12349))/5*100
Units: Dmnl

(64) Reputation of area=

IF THEN ELSE(Local economic growth<0.01, (QoL scale(Quality of Life)-1),
IF THEN ELSE(Local economic growth>=0.03, (QoL scale(Quality of Life)+1),
QoL scale(Quality of Life)))
Units: Dmnl [0,10]

(65) Return on Investment=
IF THEN ELSE(Total investment=0, 0,((Revenue-Total investment)/Total investment
))
Units: Dmnl

(66) Revenue= INTEG (
Revenue IN,
0)
Units: Euro

(67) Revenue IN=
IF THEN ELSE("No. Services"<>0, Incomes*("No. Services implemented"/"No.
Services"
), 0)
Units: Euro/year

(68) SAVEPER =
TIME STEP
Units: year [0,?]
The frequency with which output is stored.

(69) Services under development= INTEG (
IN Services-Development rate,
0)
Units: service

(70) "Size of projectarea (a opp ha)"=
30
Units: ha [1,200,1]

(71) Smart City Hub=
150000/30
Units: Euro/ha

(72) Surface covered by green=
0
Units: Dmnl [0,1,1]

(73) "Surface water (a wat ha)"=
0
Units: ha

(74) TIME STEP = 0.08332
Units: year [0,?]
The time step for the simulation.

(75) Total investment= INTEG (

Total investment In,
0)
Units: **undefined**

(76) Total investment In=
Total maintenance+Transformation costs-Total investment
Units: **undefined**

(77) Total maintenance= INTEG (
"Cost services/year"+Maintenance costs,
0)
Units: Euro

(78) Transformation costs=
IF THEN ELSE(Implementation Smart City Backbone=0, 0, (costs smart city nodes
+((Smart City Hub)*"Size of projectarea (a opp ha)")+Construction DataCables
)*(1-Costs reduction F ("Economic incentive (subsidy)")))
Units: Euro

(79) Transformation time=
IF THEN ELSE(Procedure simplification=1, IF THEN ELSE(Complex project=1,
IF THEN ELSE("Size of projectarea (a opp ha)"<=64, 3, 4), IF THEN ELSE("Size of projectarea (a opp ha)"
<=64, 1, 2)), IF THEN ELSE(Complex project=1, IF THEN ELSE("Size of projectarea (a opp ha)"
<=64, 5, 6), IF THEN ELSE("Size of projectarea (a opp ha)"<=64, 3, 4)))
Units: Dmnl [1,6,1]

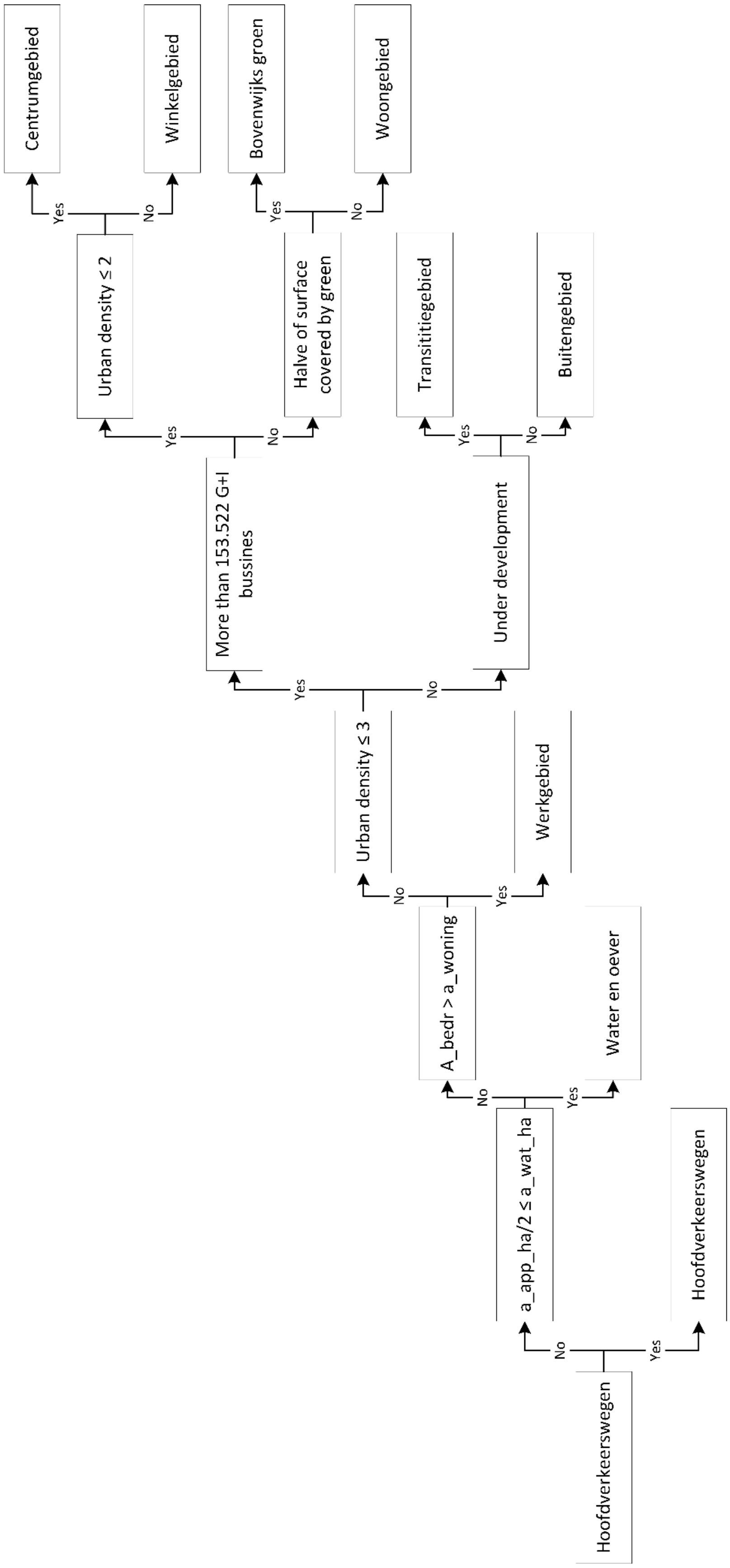
(80) Under development rural area=
0
Units: Dmnl [0,1,1]

(81) Urban density=
IF THEN ELSE(((Houses/"Size of projectarea (a opp ha)")*100)<500 , 5, IF THEN ELSE
(((Houses/"Size of projectarea (a opp ha)")*100)<1000,4,IF THEN ELSE (((Houses
/"Size of projectarea (a opp ha)")*100)<1500,3,IF THEN ELSE(((Houses/"Size of projectarea (a opp ha)"
)*100)<2500,2,1))))
Units: Dmnl [5,1]

(82) Willingness to improve area=
IF THEN ELSE(Reputation of area<=4, 1, 0)
Units: Dmnl [0,1]

(83) year==
1
Units: year [1,1]

Appendix 6. Function area flow-chart



Explanation flow chart per function area:

1. Main traffic routes
   - Highways, no specific variables determine this type of function area. The function area is specifically for highways and not for urban areas.
2. Water and banks
   - Areas with half of the surface area covered with water ($\frac{a\_opp\_ha}{2} \leq a\_wat\_ha$)
3. Business area
   - More businesses than houses
4. Transition area
   - “Rural area” under development, assigned by hand.
5. Rural area
   - Areas with a very low urban density (ste_msv: ≥4)
6. City centre area
   - Areas with high urban density (ste_msv: 1 & 2) and the areas with the 5% ($\mu + 2\sigma = 40.35 + 2 \cdot 56.586 = 153.522$) most companies with an G+I indication (CBS, 2017c) (Figure 48 shows normal distribution a_bed_gi)
7. Shopping centre area
   - Areas with high urban density (ste_msv: 3) and the areas with the 5% ($\mu + 2\sigma = 40.35 + 2 \cdot 56.586 = 153.522$) most companies with an G+I indication (CBS, 2017c) (Figure 48 shows normal distribution a_bed_gi)
8. Suburban green
   - Same as “Residential area” but with halve of the surface area of the area covered by
     i) Sport facilities
     ii) Allotments/community garden
     iii) Park
9. Residential area
   - More houses than businesses ($a\_woning \leq (a\_bedr\_gi + a\_bed\_hj + a\_bed\_kl + a\_bedr\_mn + a\_bedr\_ru)$) and areas with less businesses than 153.522. The urban density needs to be ≥ 3.

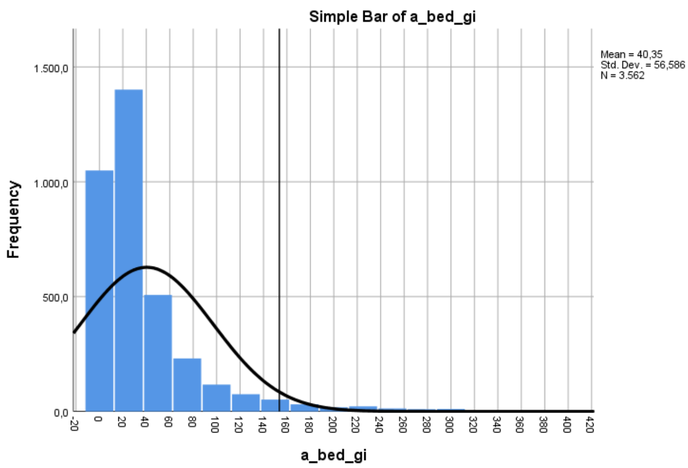


Figure 48 Distribution companies G+I indication in high-density urban areas.

Appendix 7. Community tables

Table 32 number of businesses per building

Building		**Surface businesses (m2)**	**Delivery**	**# businesses**	**# G+I businesses**
Klokgebouw	O	3,000	2010	52	6
Apparatenfabriek		20,000	2011	350	42
SAS-3	E	1,500	2012	26	3
	Anton & Gerard	4,100	2013	72	9
Space-S	G	6,500	2017	114	14
Blok 61 & 63	R	350	2017	6	1
Blok 59	Q	1,200	2018	21	3
Field	S1	375	2019	7	1
Field	S2	680	2019	12	1
Field	K	7,000	2019	122	15
Haasje over	I	8,000	2019	140	17
Field	P	12,000	2019	210	25
Field	F	1,000	2020	17	2
Field	T	1,000	2020	17	2
Field	U	8,000	2020	140	17
Toren Nico	N	580	2021	10	1
Field	V	5,000	2021	87	11
Field	J	8,000	2023	140	17
Field	A, B, C, D		2025	0	0

Table 33 Overview number of houses (to be) built per building

Building		Surface area (m2)	# Houses	Delivery
SAS-3	E	18,500	198	2012
	Anton & Gerard	17,320	277	2013
Blok	61 & 63	14,700	196	2017
Space-S	G	23,500	402	2017
Blok	59	11,200	168	2018
Field	S1	12,000	120	2019
Field	S2	12,000	200	2019
Haasje over	I	29,000	230	2019
Field	K	18,000	125	2019
Field	F	25,000	235	2020
Field	T	15,000	150	2020
Field	V	20,000	189	2021
Toren Nico	N	25,000	300	2021
Field	J	35,500	335	2023
Field	A, B, C, D		875	2025

Appendix 8. Size of project area

Based on Zhang (2015), the project size influences the complexity of the project. The larger the project site, the more complex the project is. Therefore, the variable is split up in three different levels: small (0), medium (1), large (2). In the equation, this is included as a constant. The project area influences two variables: the transformation costs and the project complexity. The larger the area, the more complex the project is. On the other side, the larger the area is, the cheaper the project relatively is.

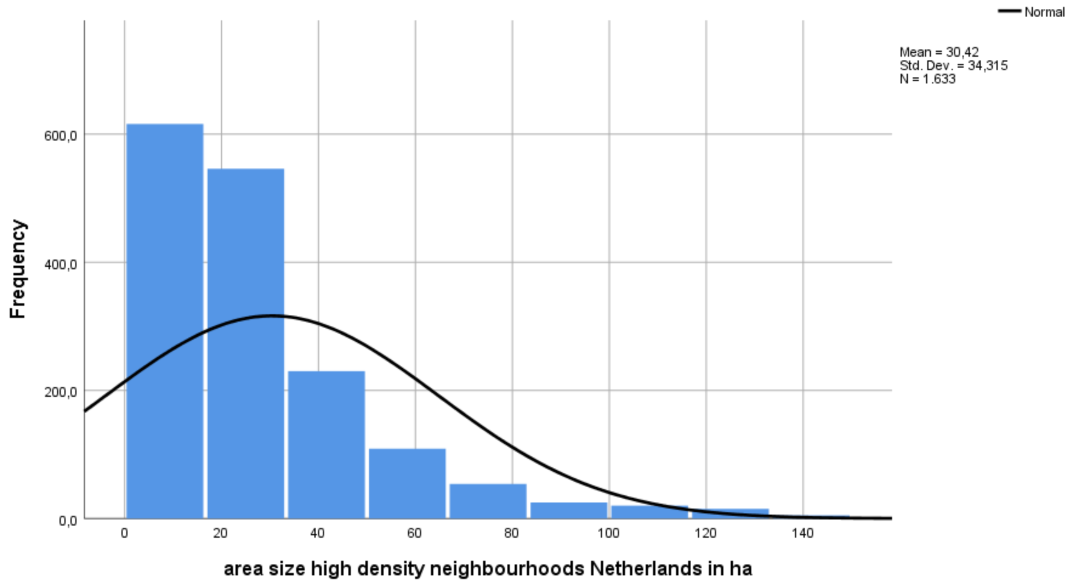


Figure 49 Distribution area size of high density neighbourhoods of the Netherlands (CBS, 2017b)

In figure 49 the distribution of area size of neighbourhood with a high level of urbanity is shown. The mean is 30.42 ha, with a standard deviation of 34.315. The mean found in the database (CBS, 2017b) is almost equal to the areas size of Strijp-S (30 ha). The areas with a size between $-1\sigma\ and\ 1\sigma$ are considered medium sized areas. In absolute numbers, all neighbourhoods with a size from 1 ha to 64 ha are considered medium. Single streets, or no complete neighbourhoods are considered small areas. Areas with a size larger than 64 hectares are considered large (Table 34)

Table 34 Area size coding

Area size in ha	Coding
Single street	Small (0)
Neighbourhood $\leq 64\ ha$	Medium (1)
Neighbourhood $> 64\ ha$	Large (2)

In this research, the focus lies on areas comparable with Strijp-S. Therefore, single streets will be left out of the research, as they use other systems than a Smart City Hub. Often wireless solutions and small servers are used; therefore, this model will not be suitable for these kinds of projects.

Appendix 9. Overview costs

	Small cells	Sniffer	Camera security services	Crowd cotrol	Smart parking	Smart lightenng	ITS	WiFi	CAPEX	OPEX	Effective coverage	Lifespan in yrs	price per ha per year
Smart camera			1	1	1		1		€ 2,000	€ 200	24.2	10	€ 208.26
Motion detection			1	1		1			€ 750	€ 75	24.2	10	€ 78.10
Road sensor					1				€ 75	€ 7.50	24.2	10	€ 7.81
Sniffer sensor		1							€ 2,000	€ 200	200	10	€ 201.00
WiFi								1	€ 2,000	€ 200	20	20	€ 205.00
WiFi-P							1		€ 2,000	€ 200	24.2	20	€ 204.13
LoRa/Narrowband IoT		1							€ 10,000	€ 100	200	20	€ 102.50
Small Cells/5g	1								€ 4,500	€ 600	125	20	€ 601.80
	€ 601.80	€ 303.50	€ 286.36	€ 286.36	€ 216.07	€ 78.10	#	€ 205.00					

Figure 50 Technology used per service, costs per technology and costs per service.

Appendix 10. Regional figures economic growth

The data is obtained from the CBS regional database. For years 2018 and 2019, the grow is estimated by the CPB (2018) to be respectively 2.9% and 2.7%. The CPB also predicted a national grow in the years 2020 and 2021 (CPB, 2017). There was no regional data available for this period

Table 35 Figures regional economy data

Province	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Groningen	10.4%	-2.9%	-0.5%	5.7%	-7.6%	-8.3%	-1.8%	-0.6%	2.9%	2.7%	1.8%	1.8%
Friesland	0.2%	3.7%	-2.6%	-1.9%	0.9%	1.2%	1.6%	2.3%	2.9%	2.7%	1.8%	1.8%
Drenthe	-1.2%	1.2%	-1.5%	-1.5%	2.2%	1.2%	2.0%	2.4%	2.9%	2.7%	1.8%	1.8%
Overijssel	-0.1%	3.3%	-3.4%	-1.1%	1.4%	2.8%	2.7%	3.4%	2.9%	2.7%	1.8%	1.8%
Flevoland	3.2%	2.0%	-1.0%	-2.6%	3.0%	2.9%	2.6%	4.2%	2.9%	2.7%	1.8%	1.8%
Gelderland	-0.2%	3.6%	-2.6%	-1.3%	1.6%	2.4%	2.3%	3.2%	2.9%	2.7%	1.8%	1.8%
Utrecht	-0.9%	0.9%	-1.3%	0.3%	0.7%	2.5%	2.5%	3.3%	2.9%	2.7%	1.8%	1.8%
Noord-Holland	1.6%	2.8%	-0.6%	1.5%	4.0%	3.6%	3.0%	3.7%	2.9%	2.7%	1.8%	1.8%
Zuid-Holland	0.4%	-0.4%	0.0%	-1.1%	1.4%	2.2%	2.1%	3.1%	2.9%	2.7%	1.8%	1.8%
Zeeland	5.3%	0.9%	-1.8%	-0.9%	2.4%	1.8%	2.0%	2.9%	2.9%	2.7%	1.8%	1.8%
Noord-Brabant	3.3%	3.5%	-0.6%	-0.9%	1.9%	3.4%	2.5%	3.7%	2.9%	2.7%	1.8%	1.8%
Limburg	2.2%	2.2%	-1.5%	-0.7%	0.2%	2.7%	2.2%	3.2%	2.9%	2.7%	1.8%	1.8%

Appendix 11. Enablers attached to service track

First the enablers are linked to a track (table 36). In the case of smart lighting, two tracks are selected two different types services can be developed based on smart lighting. Table 37 shows the number of enablers per track per function area, based on which enabler is implemented in which function area.

Table 36 Enabler linked to track

Track/Enabler	**Small cells**	**Sniffer**	**Camera security services**	**Crowd control**	**Smart parking**	**Smart lighting**	**ITS**	**Wi-Fi**
Safety and comfort	1	1	1	0	0	1	0	0
Mobility and Energy	0	0	0	1	1	0	1	0
Fun and entertainment	0	0	0	0	0	1	0	1

Table 37 Number of enablers per function type

Code	**Function area**	**Safety and comfort**	**Mobility and energy**	**Fun and entertainment**
1	Main traffic routes	2	1	0
2	Water and banks	0	0	0
3	Business area	3	0	1
4	Transition area	2	0	1
5	Rural area	2	0	1
6	City centre area	4	2	2
7	Shopping centre area	3	1	2
8	Suburban green	3	0	1
9	Residential area	4	0	1

Appendix 12. Sensitivity analysis (output)

Variable	unit	Min	-10%	Basis	10%	Max	Function area					Year RoI>=0					RoI year=2040					Acceptance chance Y=2040					Quality of life Y=2040				
							Min	-10%	Basis	10%	Max	Min	-10%	Basis	10%	Max	Min	-10%	Basis	10%	Max	Min	-10%	Basis	10%	Max	Min	-10%	Basis	10%	Max
Part of another project	code	0		1		1	6		6		6	2020.76		2020.42		2020.42	221.01%		229.14%		229.14%	2		2		2	77.85%		77.85%		77.85%
Policy	code	0		1		1	6		6		6	2020.42		2020.42		2020.42	229.14%		229.14%		229.14%	2		2		2	77.85%		77.85%		77.85%
Governmental intervention: funding	code	0		4		8	6		6		6	2020.59		2020.42		2020.17	223.98%		229.14%		234.46%	2		2		2	77.85%		77.85%		77.85%
Businesses	businesses	0	1390	1544	1698	5000	6	6	6	6	3	2020.42	2020.42	2020.42	2020.42	-	229.14%	229.14%	229.14%	229.14%	-82.14%	2	2	2	2	0	77.85%	77.85%	77.85%	77.85%	70.48%
GI businesses	businesses	0	168	187	206	1000	9	6	6	6	6	-	2020.42	2020.42	2020.42	2020.42	-83.68%	229.14%	229.14%	229.14%	229.14%	0	2	2	2	2	72.32%	77.85%	77.85%	77.85%	77.85%
Minimum G+I businesses	businesses	0	138.1698	153.522	168.8742	800	6	6	6	6	9	2020.84	2020.84	2020.42	2020.84	-	229.14%	229.14%	229.14%	229.14%	-83.68%	2	2	2	2	0	77.85%	77.85%	77.85%	77.85%	72.32%
Houses	adresses	0	3600	4000	4400	14000	0	6	6	6	6	-	2020.42	2020.42	2020.42	2020.42	-	229.14%	229.14%	229.14%	229.14%	-	2	2	2	2	65.95%	77.85%	77.85%	77.85%	77.85%
Size of project area	ha	1	27	30	33	13000	6	6	6	6	0	-	2020.59	2020.42	2020.34	-	-80.62%	210.14%	229.14%	246.50%	-	0	2	2	2	1	77.85%	77.85%	77.85%	77.85%	64.91%
Length of the street	meters	1	1126	1251	1376	50000	6	6	6	6	6	2019.09	2020.26	2020.42	2020.59	-	632.53%	248.32%	229.14%	211.96%	-85.36%	2	2	2	2	0	77.85%	77.85%	77.85%	77.85%	77.85%
Leefbaarometer																															
Houses		-0.738132	-0.031974	-0.029067	-0.026160	0.374122	6	6	6	6	6	2020.42	2020.42	2020.42	2020.42	2020.42	229.14%	229.14%	229.14%	229.14%	229.14%	2	2	2	2	2	65.23%	77.80%	77.85%	77.90%	85.03%
Residents		-0.615110	0.034631	0.038479	0.042327	0.311768	0	6	6	6	6	-	2020.42	2020.42	2020.42	2020.42	-	229.14%	229.14%	229.14%	229.14%	1	2	2	2	2	50.99%	77.77%	77.85%	77.93%	83.69%
Facilities		-1.025183	0.055129	0.061255	0.067380	0.519614	6	6	6	6	6	2020.42	2020.42	2020.42	2020.42	2020.42	229.14%	229.14%	229.14%	229.14%	229.14%	2	2	2	2	2	76.11%	77.84%	77.85%	77.86%	78.58%
Safety		-0.984176	-0.181676	-0.165160	-0.148644	0.498829	6	6	6	6	6	2020.42	2020.42	2020.42	2020.42	2020.42	229.14%	229.14%	229.14%	229.14%	229.14%	2	2	2	2	2	76.48%	77.82%	77.85%	77.88%	78.96%
Physical environment		-0.738132	-0.039186	-0.035624	-0.032062	0.374122	0	6	6	6	6	-	2020.42	2020.42	2020.42	2020.42	-	229.14%	229.14%	229.14%	229.14%	1	2	2	2	2	52.44%	77.78%	77.85%	77.91%	85.14%
Rural area under development	code	0		0		1	6		6		6	2020.42		2020.42		2020.42	229.14%		229.14%		229.14%	2		2		2	77.85%		77.85%		77.85%
Main Traffic Route	code	0		0		1	6		6		1	2020.42		2020.42		-	229.14%		229.14%		-97.22%	2		2		0	77.85%		77.85%		70.48%
Surface covered by green	code	0		0		1	6		6		6	2020.42		2020.42		2020.42	229.14%		229.14%		229.14%	2		2		2	77.85%		77.85%		77.85%
Development delay	years	1.0	1.8	2.0	2.2	4.0	6	6	6	6	6	2020.09	2020.17	2020.42	2020.59	2021.67	238.68%	231.07%	229.14%	227.18%	208.97%	2	2	2	2	2	77.85%	77.85%	77.85%	77.85%	77.80%
Economy growth	percent	-5.0%	1.6%	1.8%	2.0%	5.0%	6	6	6	6		2020.59	2020.42	2020.42	2020.42	2020.17	223.98%	229.14%	229.14%	229.14%	234.46%	2	2	2	2	2	77.85%	77.85%	77.85%	77.85%	77.85%
Desired RoI	percent	0	4.5%	5%	5.5%	10%	6	6	6	6	6	2020.42	2020.42	2020.42	2020.42	2020.42	229.14%	229.14%	229.14%	229.14%	229.14%	2	2	2	2	2	77.85%	77.85%	77.85%	77.85%	77.85%

Houses	adresses	0	3600	4000	4400	14000	3	6	6	6	6	-	2020.42	2020.42	2020.42	2020.42	-82.14%	229.14%	229.14%	229.14%	229.14%	0	2	2	2	2	70.48%	77.85%	77.85%	77.85%	77.85%
Size of project area	ha	1	27	30	33	13000	6	6	6	6	5	-	2021.09	2020.84	2020.76	-	-81.41%	197.12%	215.51%	232.12%	-82.36%	2	2	2	2	0	77.85%	77.85%	77.85%	77.85%	68.64%
Residents		-0.615110	0.034631	0.038479	0.042327	0.311768	6	6	6	6	6	2020.42	2020.42	2020.42	2020.42	2020.42	229.14%	229.14%	229.14%	229.14%	229.14%	2	2	2	2	2	63.89%	77.77%	77.85%	77.93%	83.69%
Physical environment		-0.738132	-0.039186	-0.035624	-0.032062	0.374122	6	6	6	6	6	2020.42	2020.42	2020.42	2020.42	2020.42	229.14%	229.14%	229.14%	229.14%	229.14%	2	2	2	2	2	65.34%	77.78%	77.85%	77.91%	85.14%

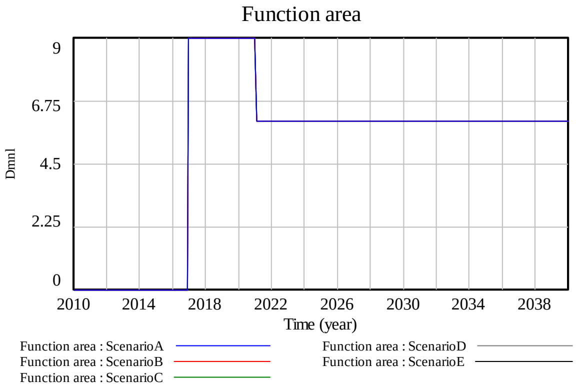
Appendix 13. Selection areas

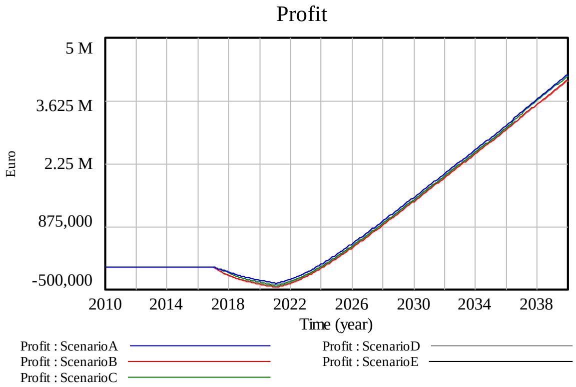
Table 38 Selection of additional areas

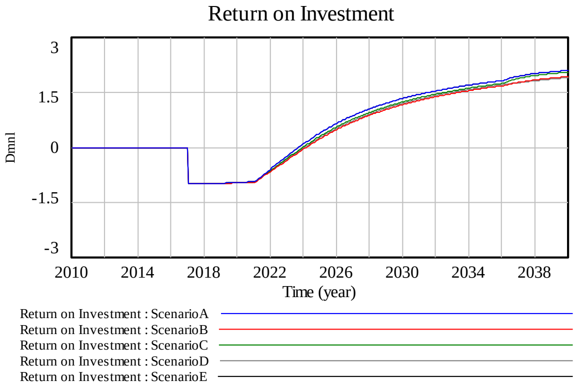
Area	Municipality	Reason of selection
De Veste (Brandevoort)	Helmond	Brandevoort has the ambition to become a smart city as part of the Brainport region ("Brainport Smart District," 2017)
Bloemhof	Rotterdam	Selected based on the low score in the Leefbaarometer (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2016)
Kop Zeedijk	Amsterdam	Selected based on the high score in the Leefbaarometer (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2016) and the small surface area (CBS, 2017b)
Stadscentrum	Nijmegen	This area contains a large amount of businesses and has a high urban density (CBS, 2017b)
Kortenbos	's Gravenhage	High-density urban area (CBS, 2017b)
Schilderskwartier	Woerden	Area with significant number of houses (CBS, 2017b)
Centrum Ede	Ede	High quality of life, average urban density (CBS, 2017b; Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2016)
Veendam-centrum	Veendam	Area with significant number of G+I businesses and a large surface area (CBS, 2017b)
Spakenburg	Bunschoten	This area is average on QoL, surface area and urban density (CBS, 2017b; Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2016)
Stadskanaal Centrum	Stadskanaal	Geographic location and average area (CBS, 2017b)
Weijpoort	Bodegraven-Reeuwijk	Selected because the area is rural, furthermore, the area is large and the quality of live is high. (CBS, 2017b; Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2016)

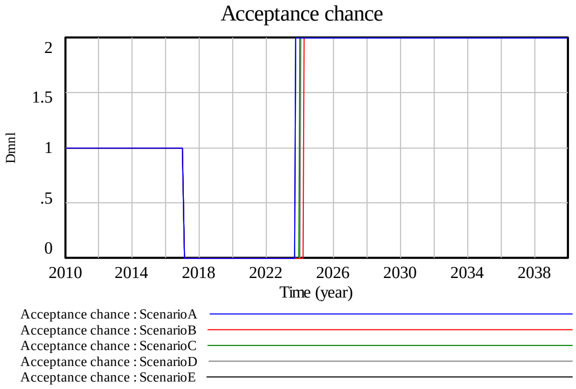
Appendix 14. City centre areas (results)

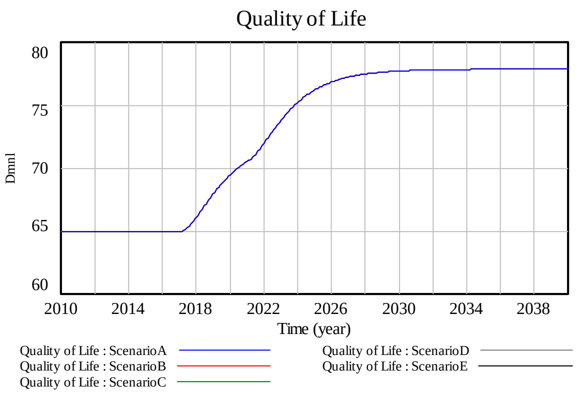
Strijp-S



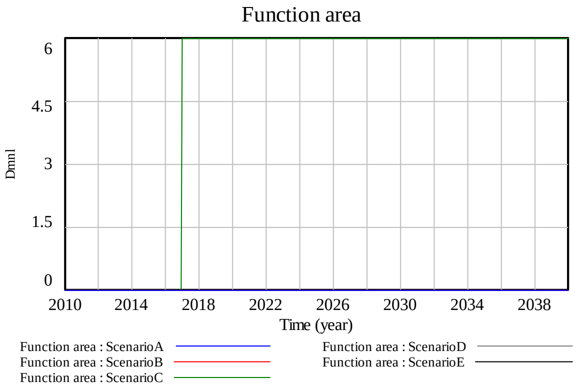


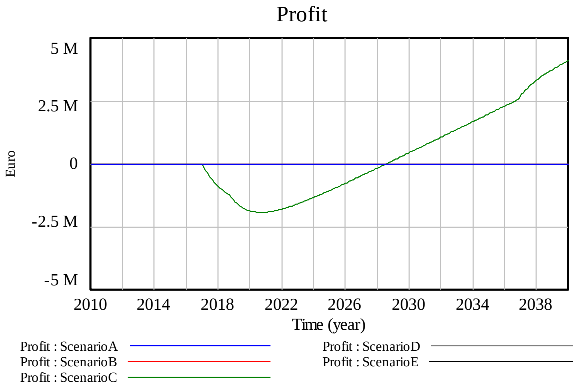


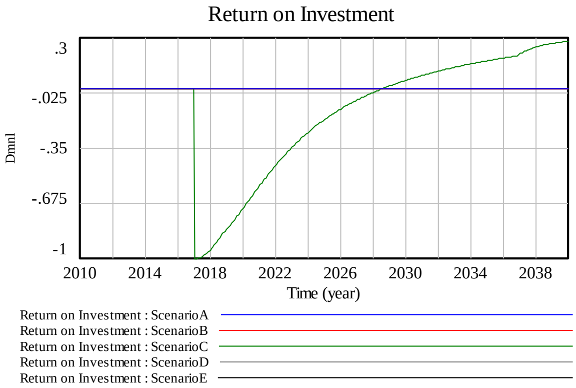


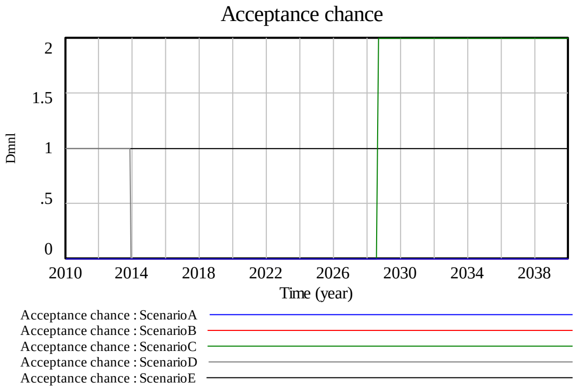


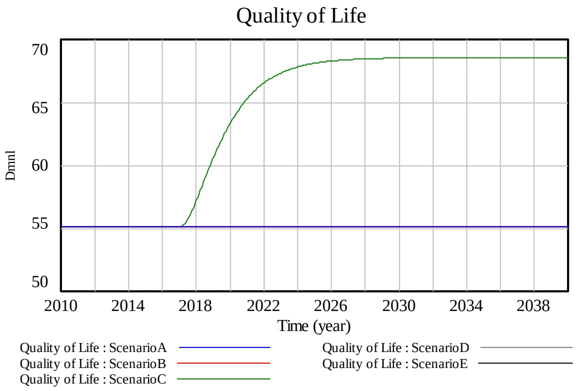
Bloemhof


Function area
6
4.5
3
1.5
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Function area : ScenarioA
Function area : ScenarioB
Function area : ScenarioC
Function area : ScenarioD
Function area : ScenarioE

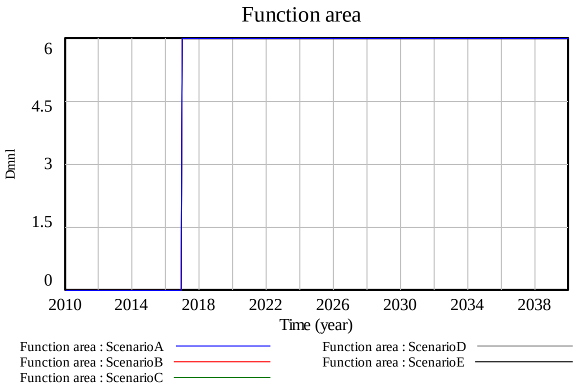

Profit
5 M
2.5 M
0
-2.5 M
-5 M
Euro
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Profit : ScenarioA
Profit : ScenarioB
Profit : ScenarioC
Profit : ScenarioD
Profit : ScenarioE

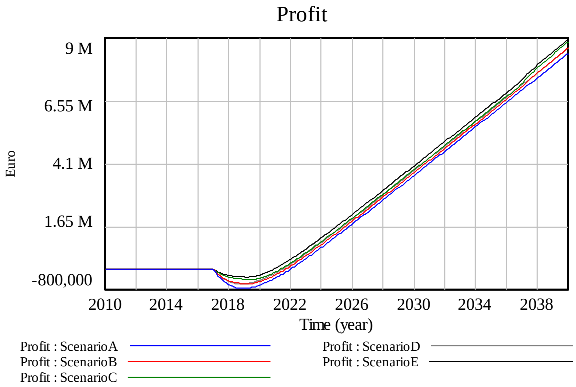

Return on Investment
.3
-.025
-.35
-.675
-1
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Return on Investment : ScenarioA
Return on Investment : ScenarioB
Return on Investment : ScenarioC
Return on Investment : ScenarioD
Return on Investment : ScenarioE

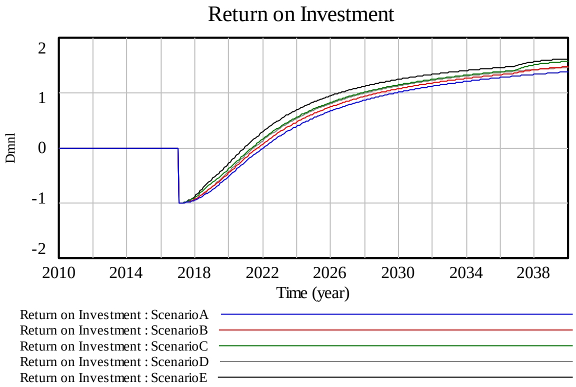

Acceptance chance
2
1.5
1
.5
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Acceptance chance : ScenarioA
Acceptance chance : ScenarioB
Acceptance chance : ScenarioC
Acceptance chance : ScenarioD
Acceptance chance : ScenarioE

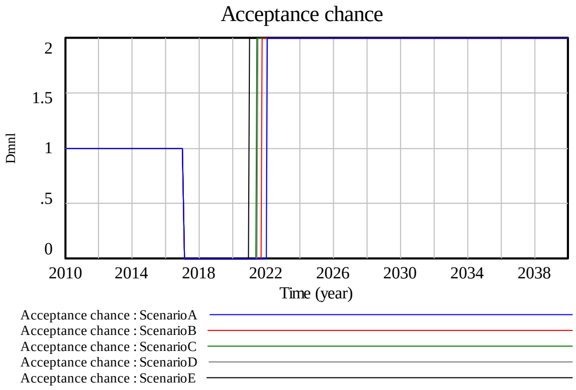

Quality of Life
70
65
60
55
50
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Quality of Life : ScenarioA
Quality of Life : ScenarioB
Quality of Life : ScenarioC
Quality of Life : ScenarioD
Quality of Life : ScenarioE

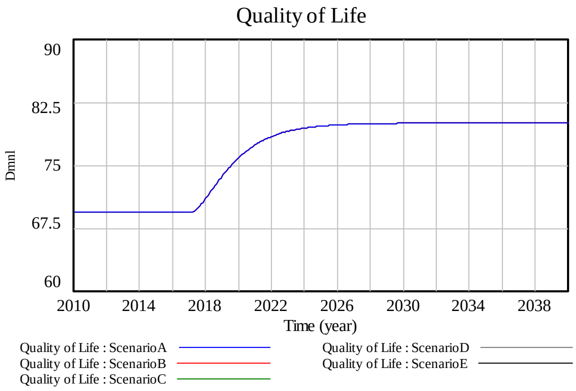
Ede


Function area
Dmnl
6
4.5
3
1.5
0
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Function area : ScenarioA
Function area : ScenarioB
Function area : ScenarioC
Function area : ScenarioD
Function area : ScenarioE

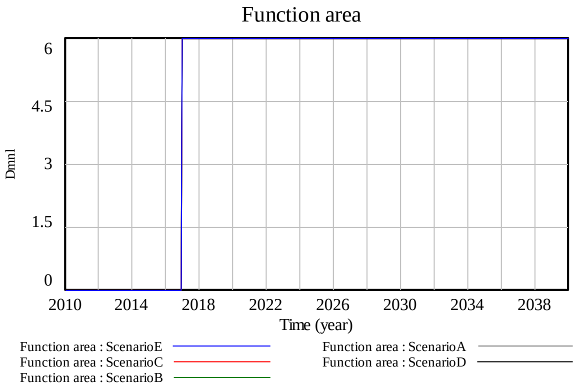

Profit
Euro
9 M
6.55 M
4.1 M
1.65 M
-800,000
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Profit : ScenarioA
Profit : ScenarioB
Profit : ScenarioC
Profit : ScenarioD
Profit : ScenarioE

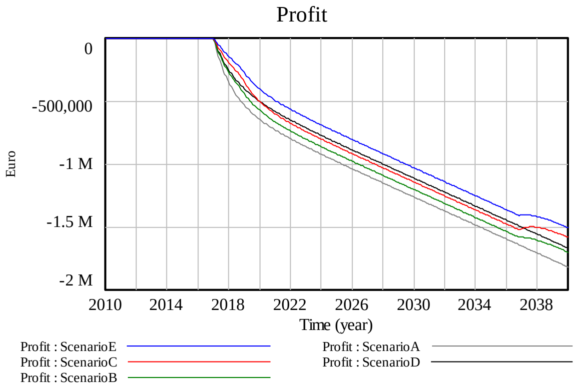

Return on Investment
Dmnl
2
1
0
-1
-2
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Return on Investment : ScenarioA
Return on Investment : ScenarioB
Return on Investment : ScenarioC
Return on Investment : ScenarioD
Return on Investment : ScenarioE

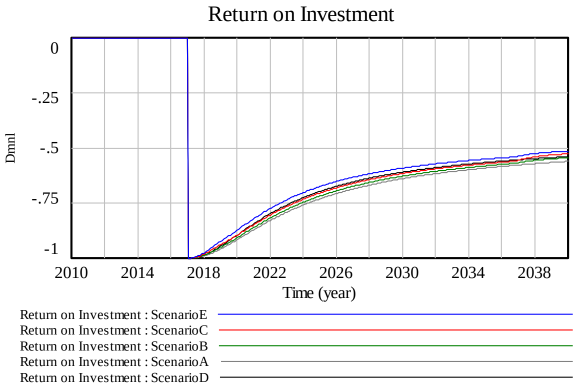

Acceptance chance
Dmnl
2
1.5
1
.5
0
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Acceptance chance : ScenarioA
Acceptance chance : ScenarioB
Acceptance chance : ScenarioC
Acceptance chance : ScenarioD
Acceptance chance : ScenarioE

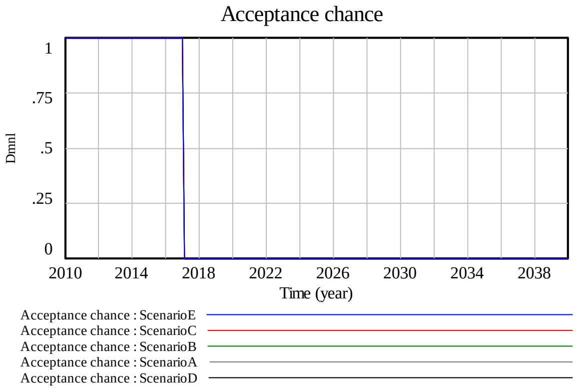

Quality of Life
Dmnl
90
82.5
75
67.5
60
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Quality of Life : ScenarioA
Quality of Life : ScenarioB
Quality of Life : ScenarioC
Quality of Life : ScenarioD
Quality of Life : ScenarioE

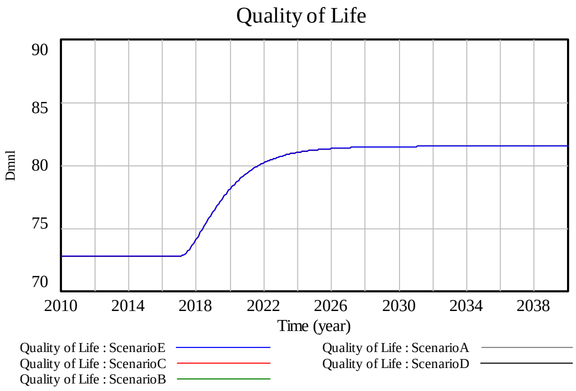
Kop Zeedijk


Function area
6
4.5
3
1.5
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Function area : ScenarioE
Function area : ScenarioC
Function area : ScenarioB
Function area : ScenarioA
Function area : ScenarioD

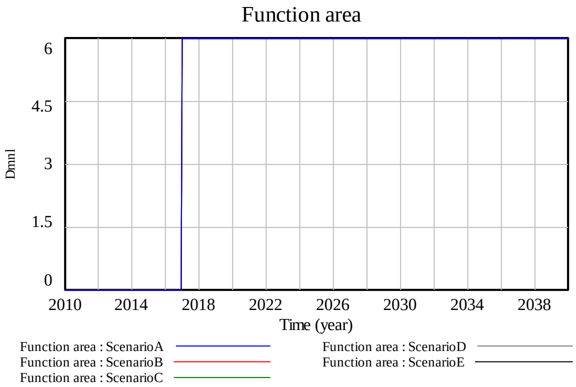

Profit
0
-500,000
-1 M
-1.5 M
-2 M
Euro
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Profit : ScenarioE
Profit : ScenarioC
Profit : ScenarioB
Profit : ScenarioA
Profit : ScenarioD

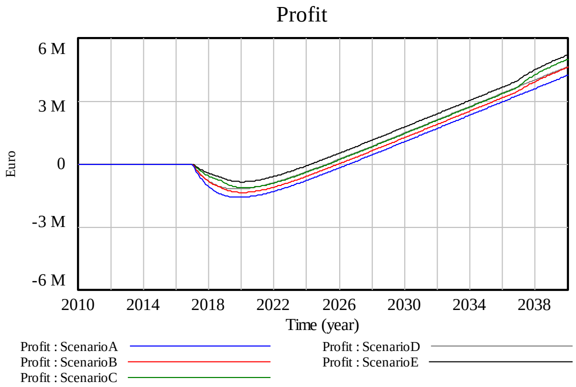

Return on Investment
0
-.25
-.5
-.75
-1
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Return on Investment : ScenarioE
Return on Investment : ScenarioC
Return on Investment : ScenarioB
Return on Investment : ScenarioA
Return on Investment : ScenarioD

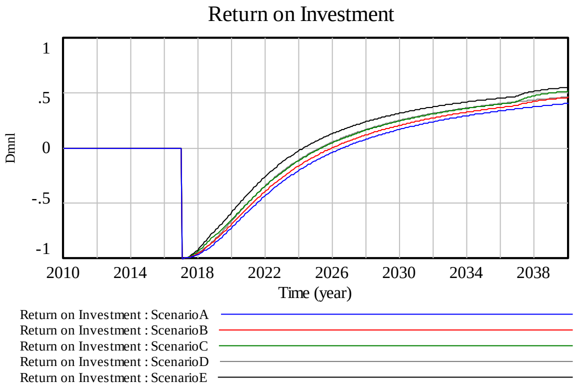

Acceptance chance
1
.75
.5
.25
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Acceptance chance : ScenarioE
Acceptance chance : ScenarioC
Acceptance chance : ScenarioB
Acceptance chance : ScenarioA
Acceptance chance : ScenarioD

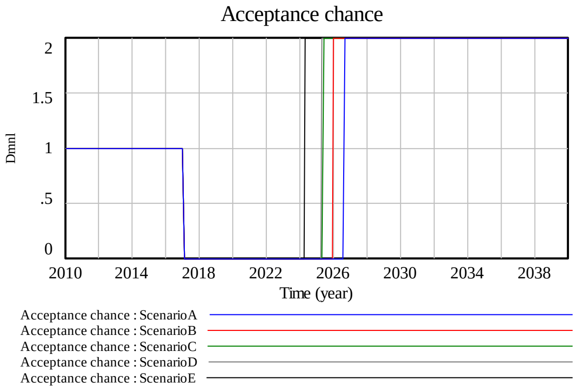

Quality of Life
90
85
80
75
70
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Quality of Life : ScenarioE
Quality of Life : ScenarioC
Quality of Life : ScenarioB
Quality of Life : ScenarioA
Quality of Life : ScenarioD

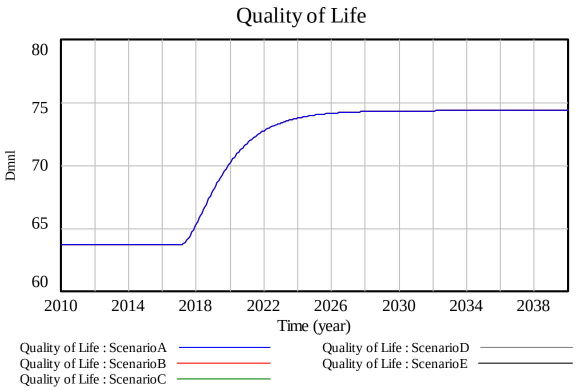
Kortenbos


Function area
6
4.5
3
1.5
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Function area : ScenarioA
Function area : ScenarioB
Function area : ScenarioC
Function area : ScenarioD
Function area : ScenarioE

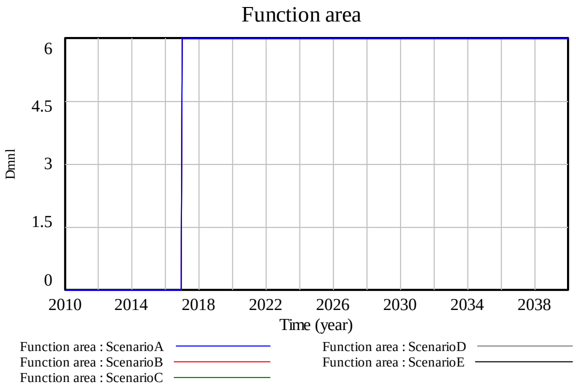

Profit
6 M
3 M
0
-3 M
-6 M
Euro
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Profit : ScenarioA
Profit : ScenarioB
Profit : ScenarioC
Profit : ScenarioD
Profit : ScenarioE

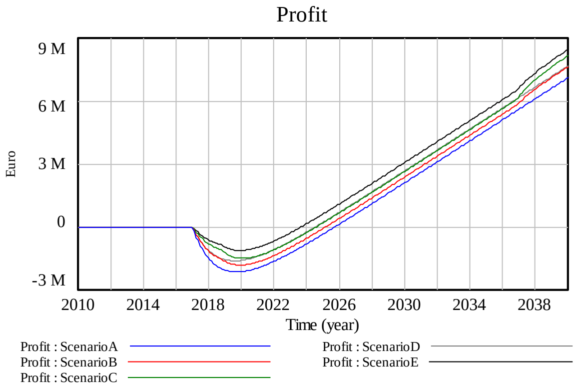

Return on Investment
1
.5
0
-.5
-1
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Return on Investment : ScenarioA
Return on Investment : ScenarioB
Return on Investment : ScenarioC
Return on Investment : ScenarioD
Return on Investment : ScenarioE

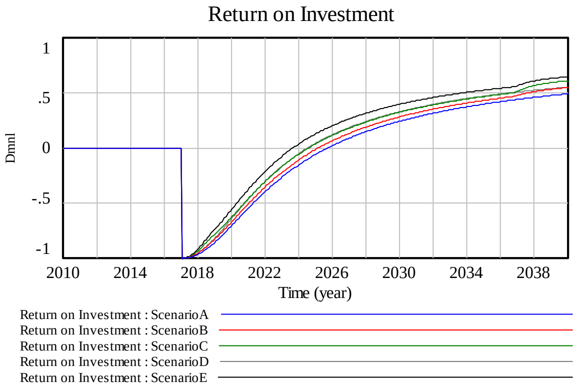

Acceptance chance
2
1.5
1
.5
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Acceptance chance : ScenarioA
Acceptance chance : ScenarioB
Acceptance chance : ScenarioC
Acceptance chance : ScenarioD
Acceptance chance : ScenarioE

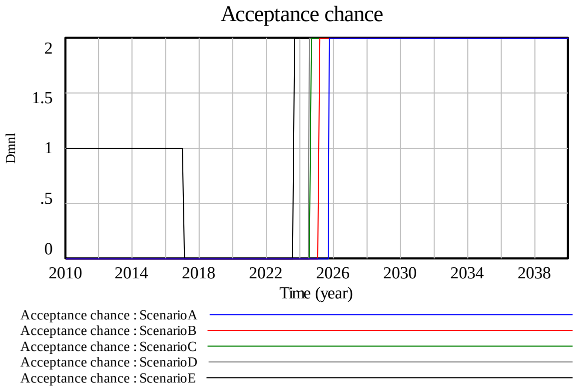

Quality of Life
80
75
70
65
60
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Quality of Life : ScenarioA
Quality of Life : ScenarioB
Quality of Life : ScenarioC
Quality of Life : ScenarioD
Quality of Life : ScenarioE

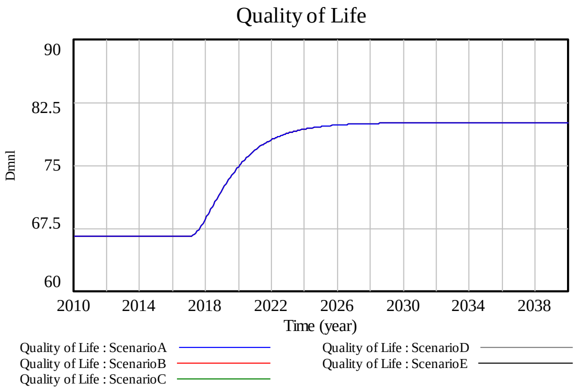
Nijmegen Stadscentrum



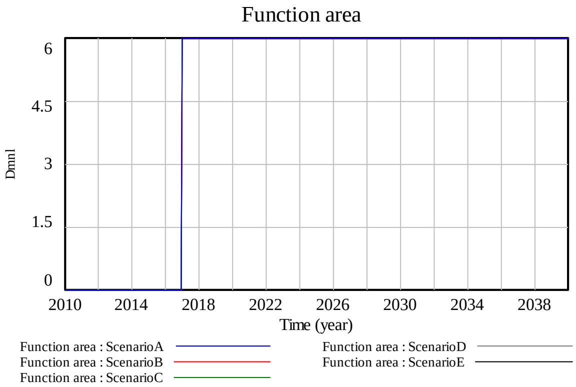


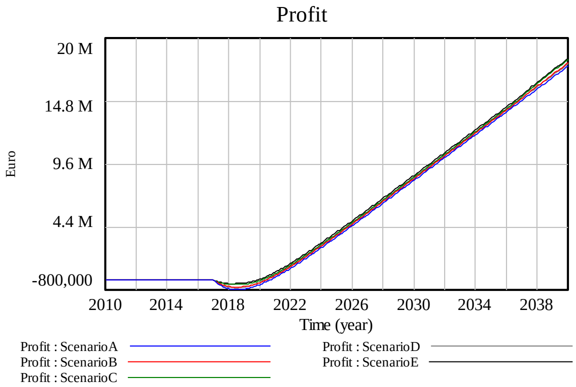


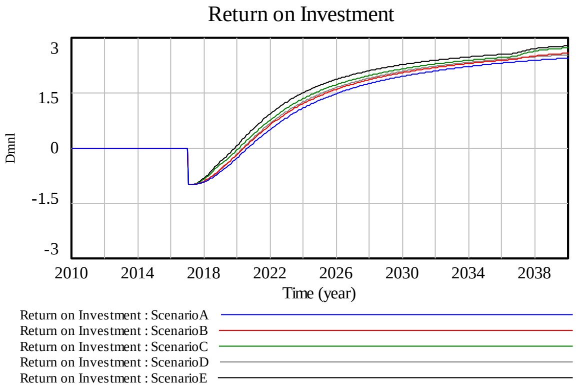


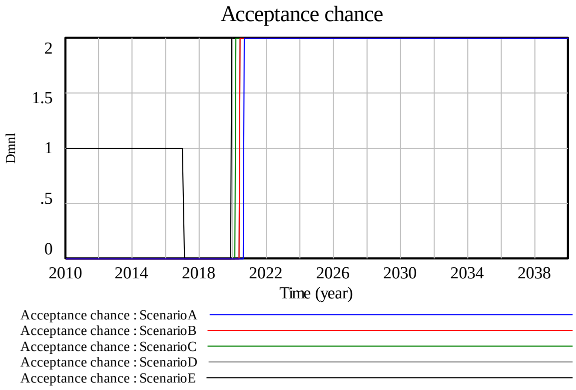


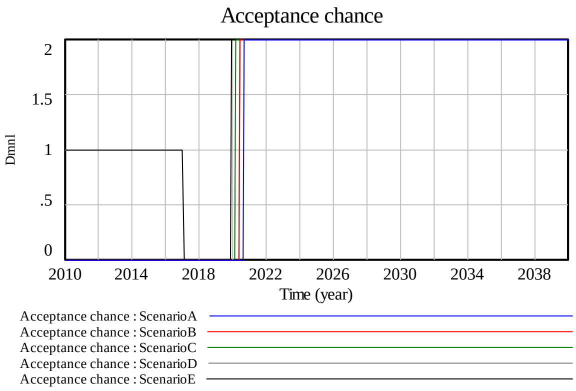
Spakenburg


Function area
Dmnl
6
4.5
3
1.5
0
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Function area : ScenarioA
Function area : ScenarioB
Function area : ScenarioC
Function area : ScenarioD
Function area : ScenarioE


Profit
Euro
20 M
14.8 M
9.6 M
4.4 M
-800,000
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Profit : ScenarioA
Profit : ScenarioB
Profit : ScenarioC
Profit : ScenarioD
Profit : ScenarioE

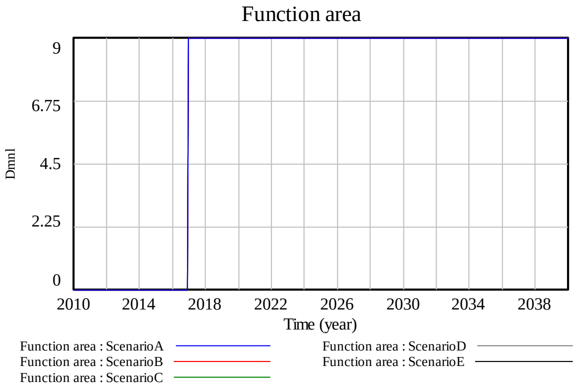

Return on Investment
Dmnl
3
1.5
0
-1.5
-3
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Return on Investment : ScenarioA
Return on Investment : ScenarioB
Return on Investment : ScenarioC
Return on Investment : ScenarioD
Return on Investment : ScenarioE

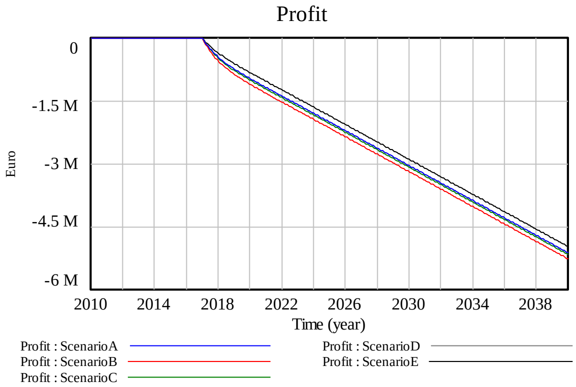

Acceptance chance
Dmnl
2
1.5
1
.5
0
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Acceptance chance : ScenarioA
Acceptance chance : ScenarioB
Acceptance chance : ScenarioC
Acceptance chance : ScenarioD
Acceptance chance : ScenarioE

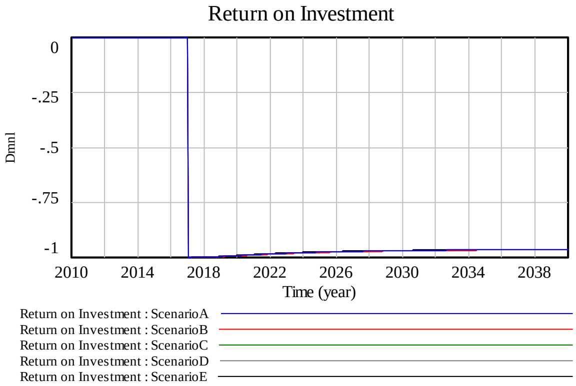

Acceptance chance
Dmnl
2
1.5
1
.5
0
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Acceptance chance : ScenarioA
Acceptance chance : ScenarioB
Acceptance chance : ScenarioC
Acceptance chance : ScenarioD
Acceptance chance : ScenarioE

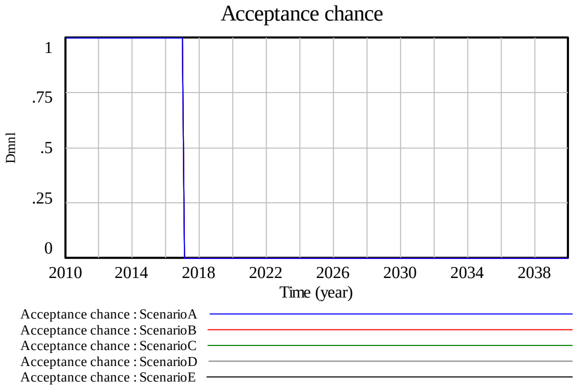
Appendix 15. Residential areas (results)

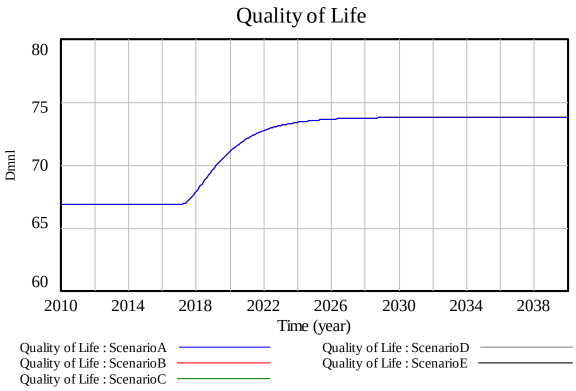
Besterd



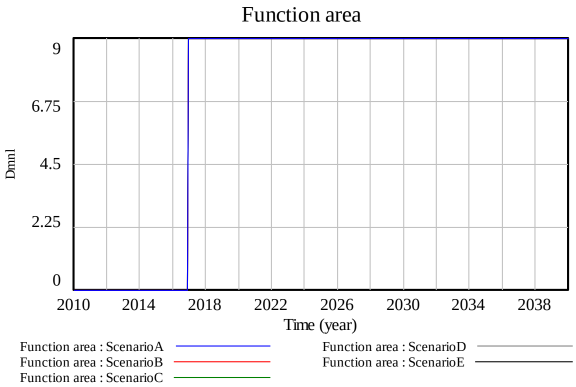


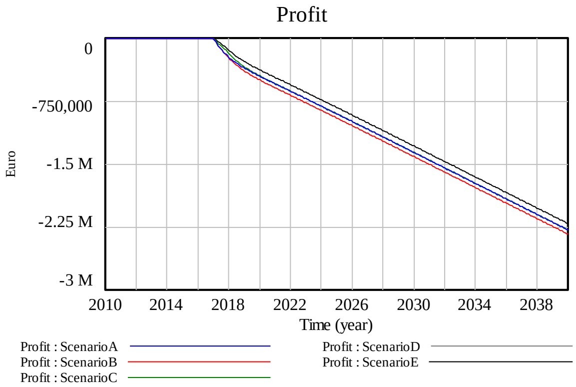


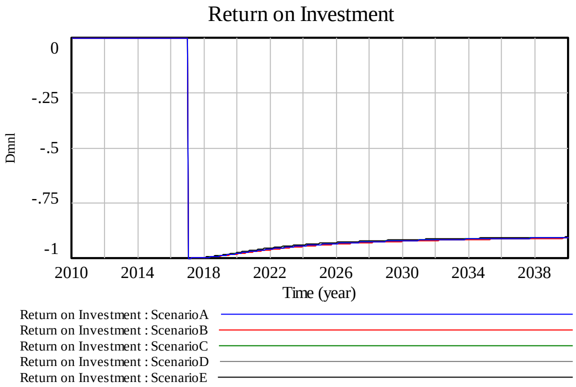


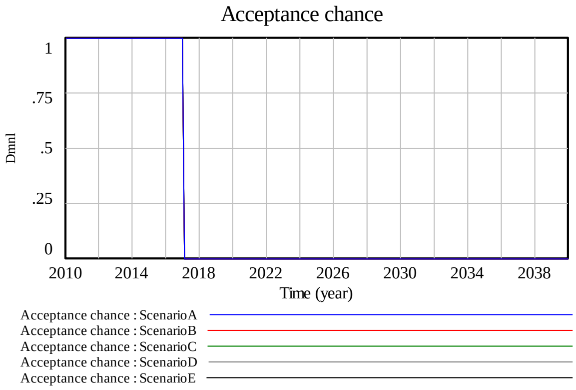


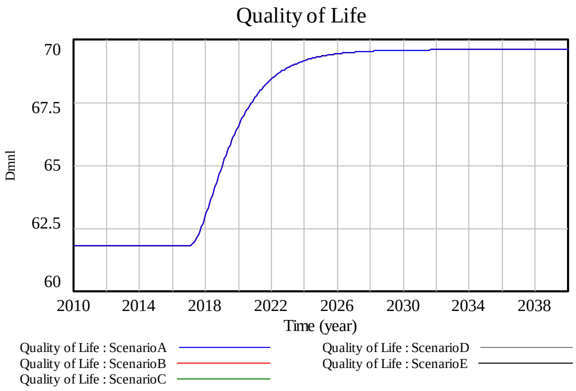
Cartesius


Function area
9
6.75
4.5
2.25
0
Dmnl
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Function area : ScenarioA
Function area : ScenarioB
Function area : ScenarioC
Function area : ScenarioD
Function area : ScenarioE

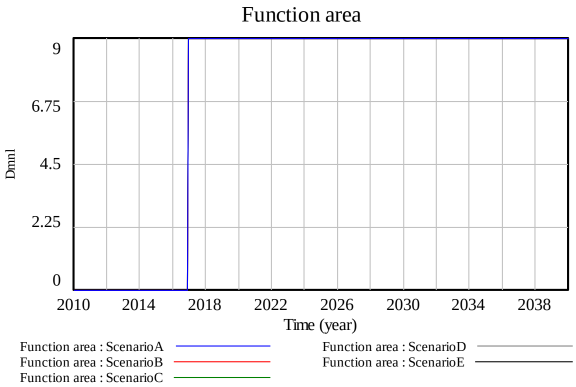

Profit
0
-750,000
-1.5 M
-2.25 M
-3 M
Euro
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Profit : ScenarioA
Profit : ScenarioB
Profit : ScenarioC
Profit : ScenarioD
Profit : ScenarioE

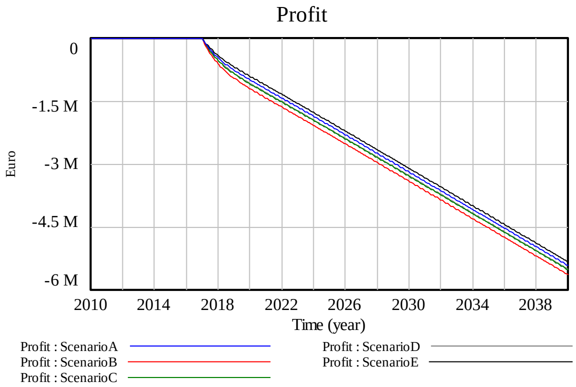

Return on Investment
0
-.25
-.5
-.75
-1
Dmnl
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Return on Investment : ScenarioA
Return on Investment : ScenarioB
Return on Investment : ScenarioC
Return on Investment : ScenarioD
Return on Investment : ScenarioE

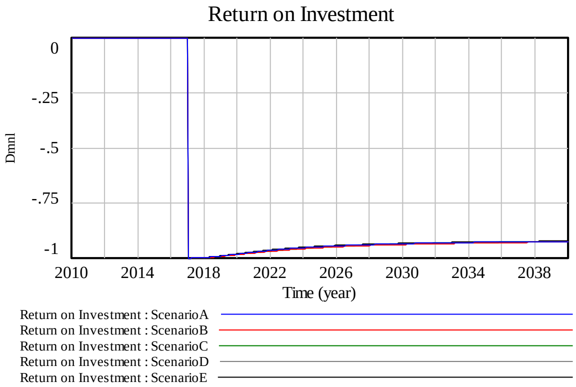

Acceptance chance
1
.75
.5
.25
0
Dmnl
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Acceptance chance : ScenarioA
Acceptance chance : ScenarioB
Acceptance chance : ScenarioC
Acceptance chance : ScenarioD
Acceptance chance : ScenarioE

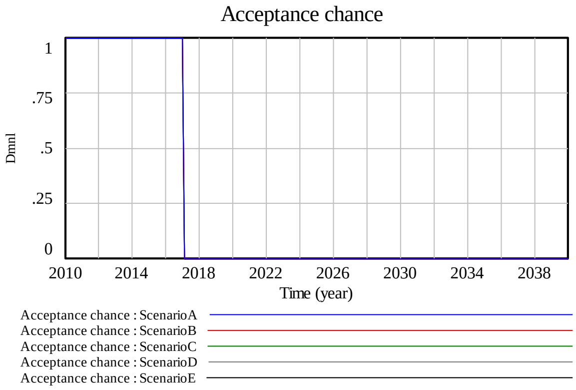

Quality of Life
70
67.5
65
62.5
60
Dmnl
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Quality of Life : ScenarioA
Quality of Life : ScenarioB
Quality of Life : ScenarioC
Quality of Life : ScenarioD
Quality of Life : ScenarioE

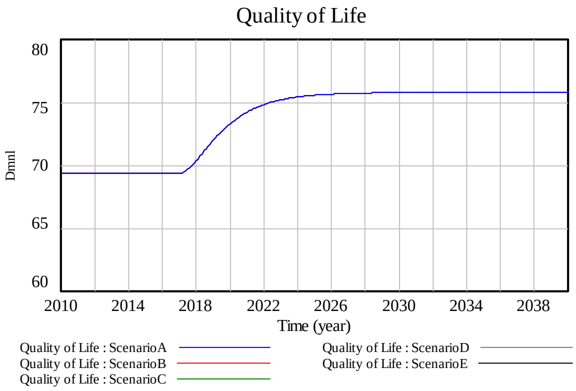
De Veste


Function area
9
6.75
4.5
2.25
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Function area : ScenarioA
Function area : ScenarioB
Function area : ScenarioC
Function area : ScenarioD
Function area : ScenarioE

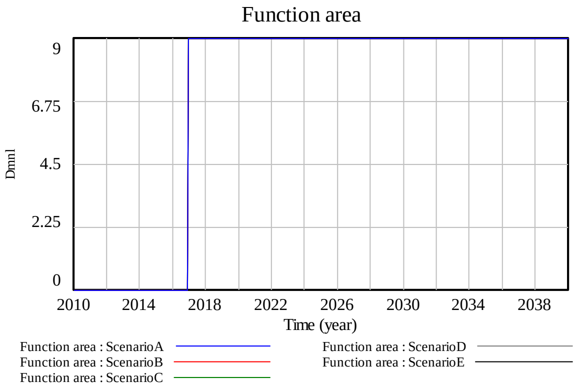

Profit
0
-1.5 M
-3 M
-4.5 M
-6 M
Euro
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Profit : ScenarioA
Profit : ScenarioB
Profit : ScenarioC
Profit : ScenarioD
Profit : ScenarioE

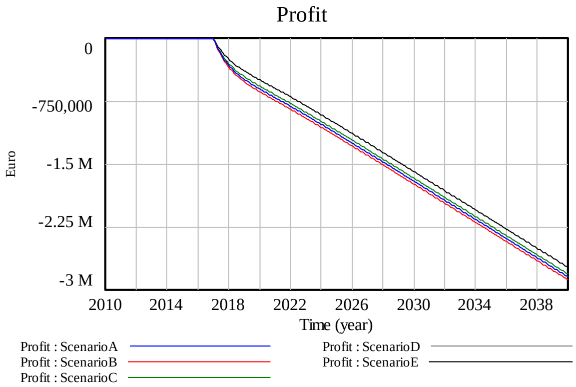

Return on Investment
0
-.25
-.5
-.75
-1
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Return on Investment : ScenarioA
Return on Investment : ScenarioB
Return on Investment : ScenarioC
Return on Investment : ScenarioD
Return on Investment : ScenarioE

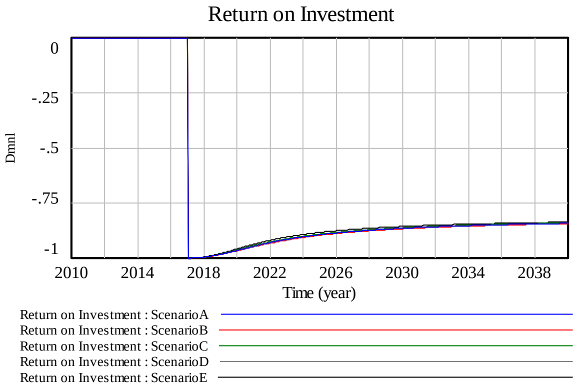

Acceptance chance
1
.75
.5
.25
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Acceptance chance : ScenarioA
Acceptance chance : ScenarioB
Acceptance chance : ScenarioC
Acceptance chance : ScenarioD
Acceptance chance : ScenarioE

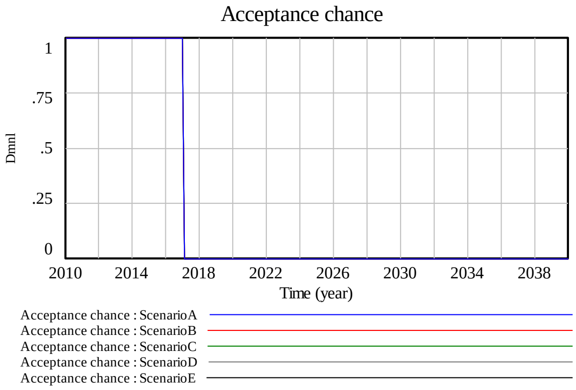

Quality of Life
80
75
70
65
60
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Quality of Life : ScenarioA
Quality of Life : ScenarioB
Quality of Life : ScenarioC
Quality of Life : ScenarioD
Quality of Life : ScenarioE

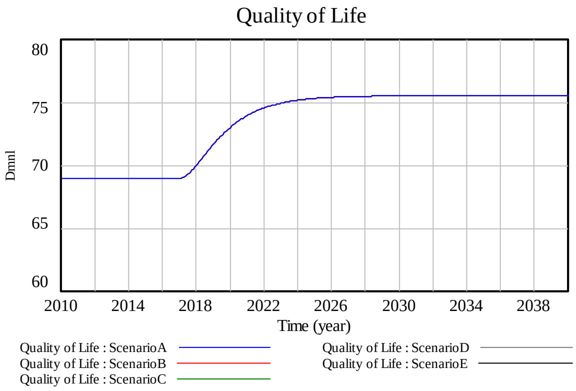
Paleiskwartier



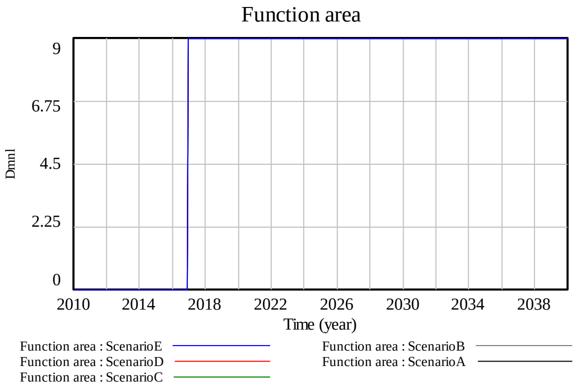


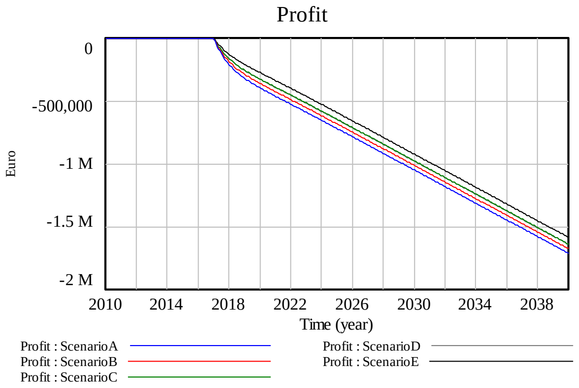


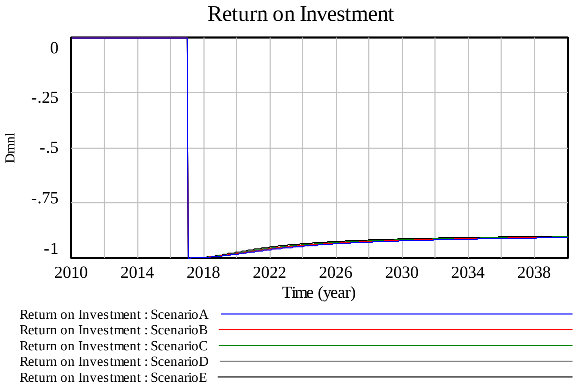


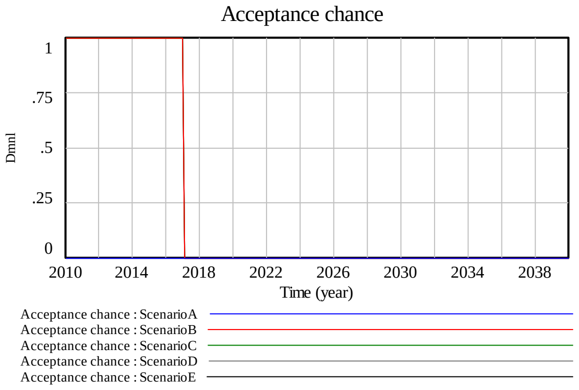


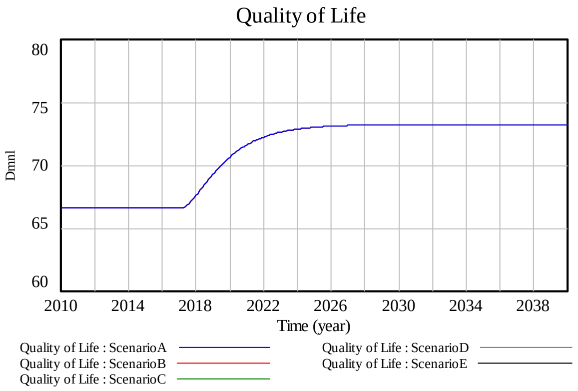
Schijndel


Function area
9
6.75
4.5
2.25
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Function area : ScenarioE
Function area : ScenarioD
Function area : ScenarioC
Function area : ScenarioB
Function area : ScenarioA

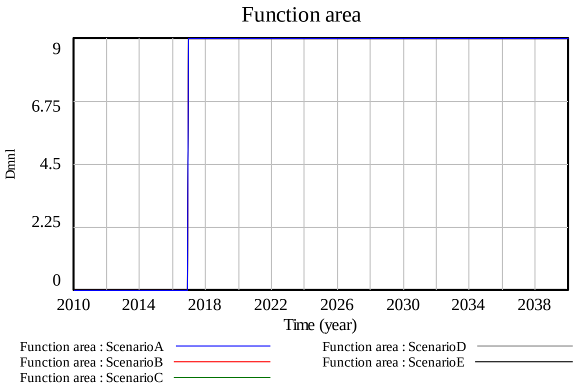

Profit
0
-500,000
-1 M
-1.5 M
-2 M
Euro
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Profit : ScenarioA
Profit : ScenarioB
Profit : ScenarioC
Profit : ScenarioD
Profit : ScenarioE

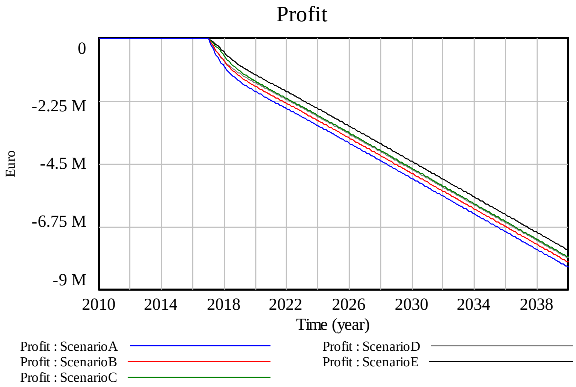

Return on Investment
0
-.25
-.5
-.75
-1
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Return on Investment : ScenarioA
Return on Investment : ScenarioB
Return on Investment : ScenarioC
Return on Investment : ScenarioD
Return on Investment : ScenarioE

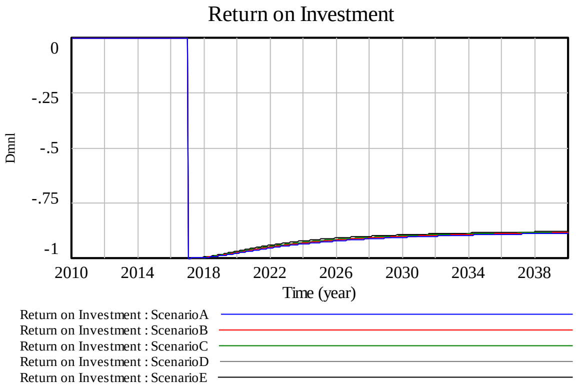

Acceptance chance
1
.75
.5
.25
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Acceptance chance : ScenarioA
Acceptance chance : ScenarioB
Acceptance chance : ScenarioC
Acceptance chance : ScenarioD
Acceptance chance : ScenarioE

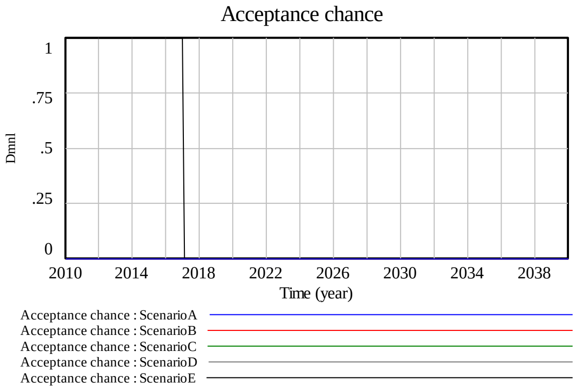

Quality of Life
80
75
70
65
60
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Quality of Life : ScenarioA
Quality of Life : ScenarioB
Quality of Life : ScenarioC
Quality of Life : ScenarioD
Quality of Life : ScenarioE

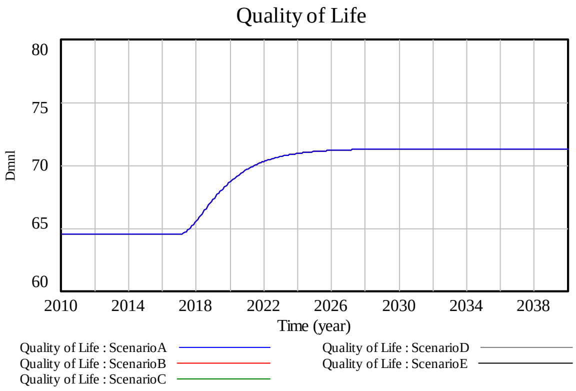
Schilderskwartier



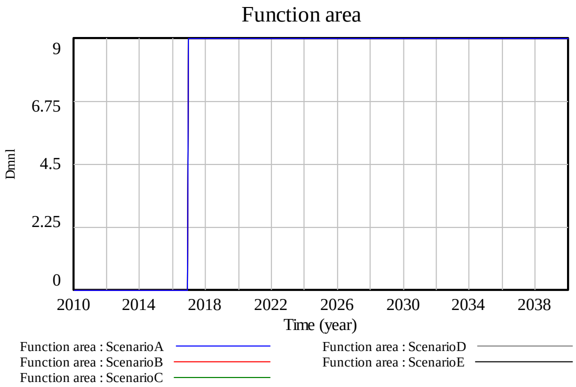


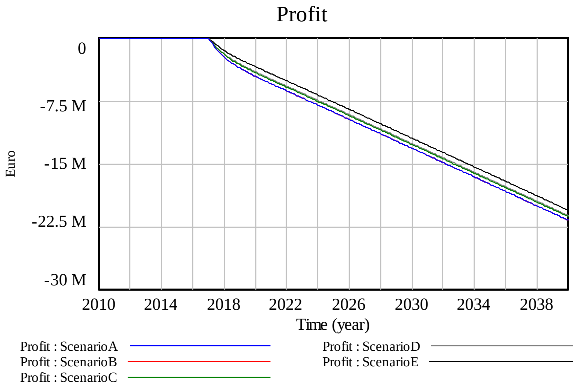


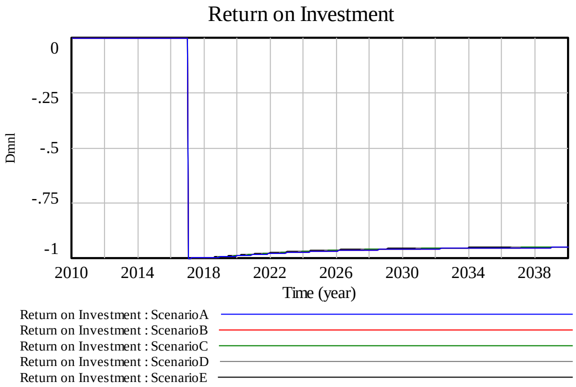


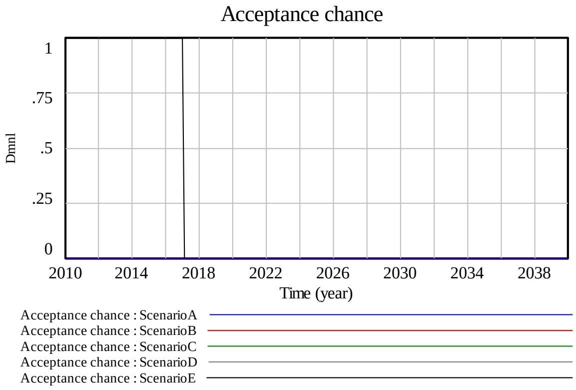


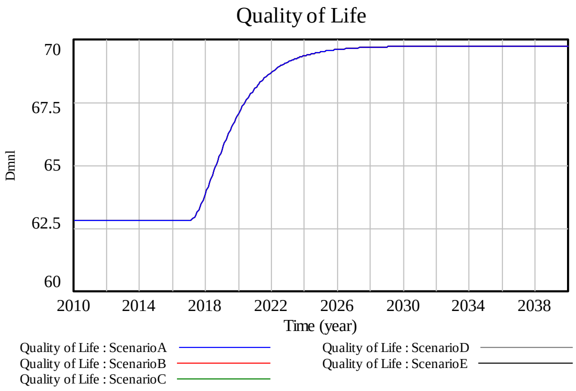
Vaartbroek


Function area
9
6.75
4.5
2.25
0
Dmnl
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Function area : ScenarioA
Function area : ScenarioB
Function area : ScenarioC
Function area : ScenarioD
Function area : ScenarioE

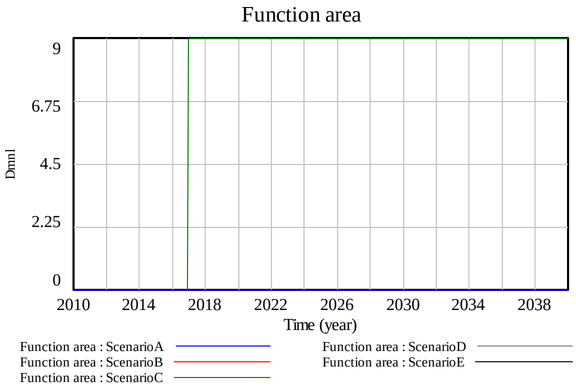

Profit
0
-7.5 M
-15 M
-22.5 M
-30 M
Euro
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Profit : ScenarioA
Profit : ScenarioB
Profit : ScenarioC
Profit : ScenarioD
Profit : ScenarioE

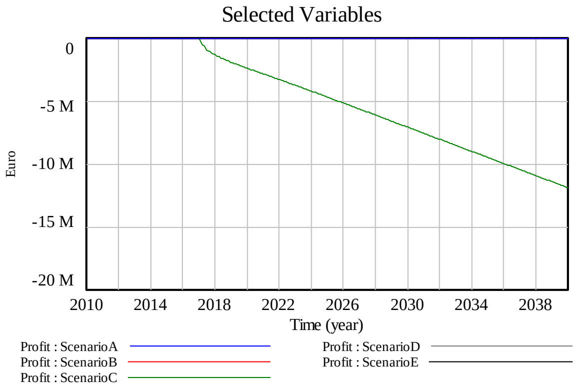

Return on Investment
0
-.25
-.5
-.75
-1
Dmnl
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Return on Investment : ScenarioA
Return on Investment : ScenarioB
Return on Investment : ScenarioC
Return on Investment : ScenarioD
Return on Investment : ScenarioE

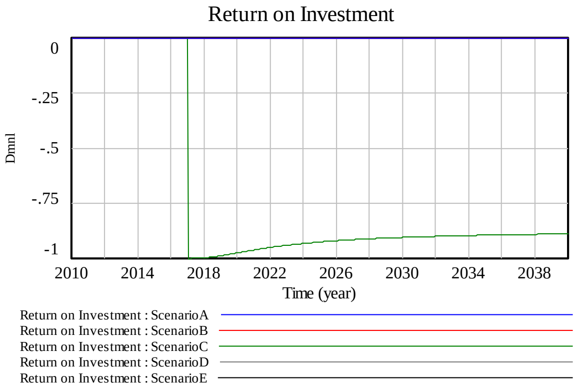

Acceptance chance
1
.75
.5
.25
0
Dmnl
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Acceptance chance : ScenarioA
Acceptance chance : ScenarioB
Acceptance chance : ScenarioC
Acceptance chance : ScenarioD
Acceptance chance : ScenarioE

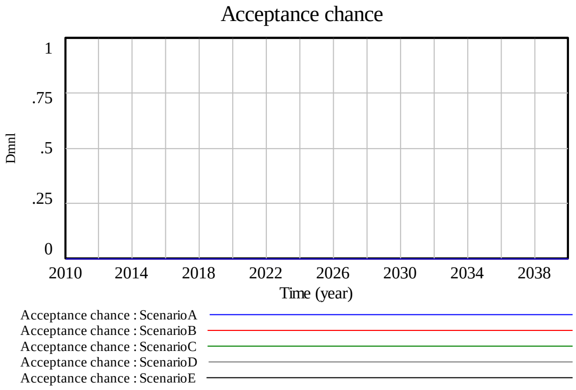

Quality of Life
70
67.5
65
62.5
60
Dmnl
2010
2014
2018
2022
2026
2030
2034
2038
Time (year)
Quality of Life : ScenarioA
Quality of Life : ScenarioB
Quality of Life : ScenarioC
Quality of Life : ScenarioD
Quality of Life : ScenarioE

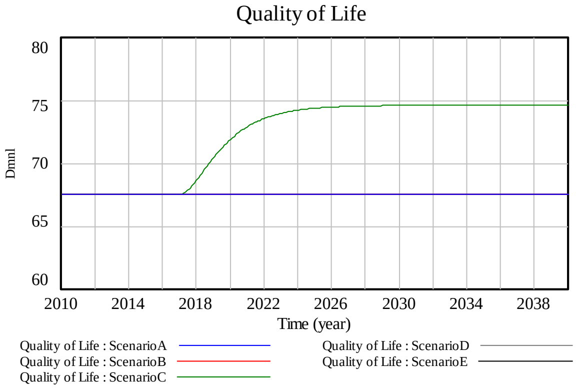
Veendam


Function area
9
6.75
4.5
2.25
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Function area : ScenarioA
Function area : ScenarioB
Function area : ScenarioC
Function area : ScenarioD
Function area : ScenarioE

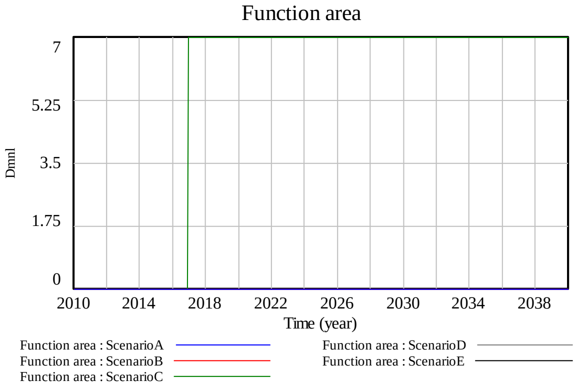

Selected Variables
0
-5 M
-10 M
-15 M
-20 M
Euro
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Profit : ScenarioA
Profit : ScenarioB
Profit : ScenarioC
Profit : ScenarioD
Profit : ScenarioE

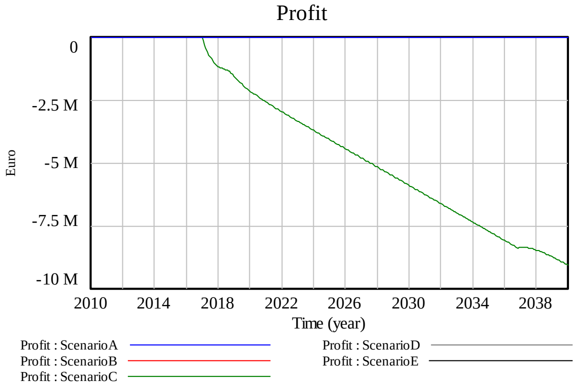

Return on Investment
0
-.25
-.5
-.75
-1
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Return on Investment : ScenarioA
Return on Investment : ScenarioB
Return on Investment : ScenarioC
Return on Investment : ScenarioD
Return on Investment : ScenarioE

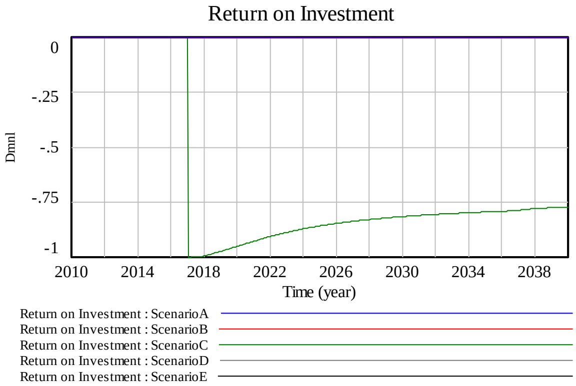

Acceptance chance
1
.75
.5
.25
0
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Acceptance chance : ScenarioA
Acceptance chance : ScenarioB
Acceptance chance : ScenarioC
Acceptance chance : ScenarioD
Acceptance chance : ScenarioE

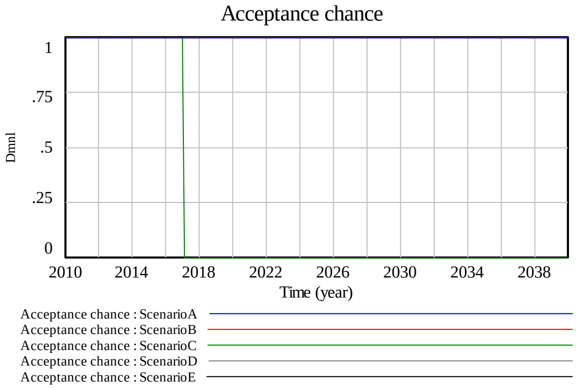

Quality of Life
80
75
70
65
60
Dmnl
2010 2014 2018 2022 2026 2030 2034 2038
Time (year)
Quality of Life : ScenarioA
Quality of Life : ScenarioB
Quality of Life : ScenarioC
Quality of Life : ScenarioD
Quality of Life : ScenarioE

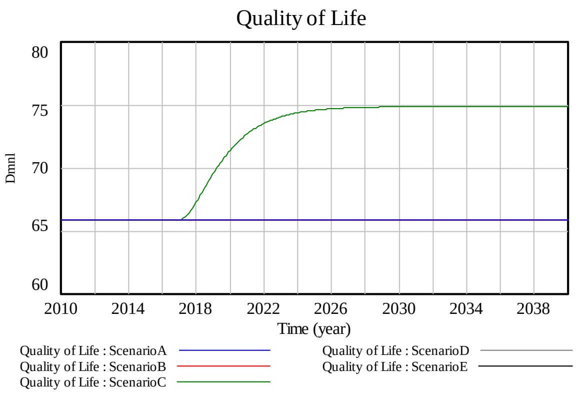
Appendix 16. Stadskanaal (results)







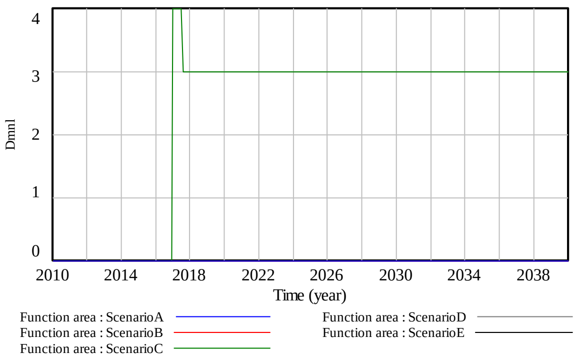




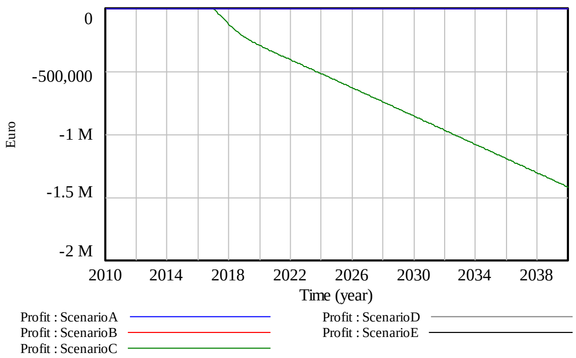
Appendix 17. Seingraaf (results)

Seingraaf

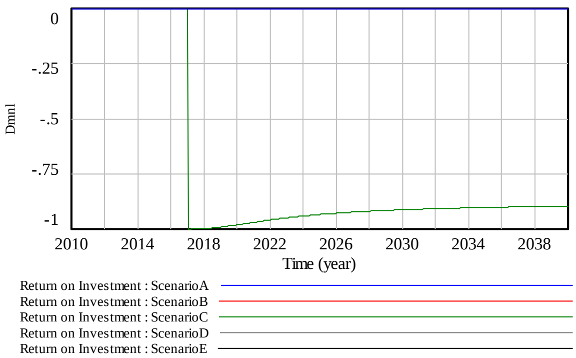
Function area



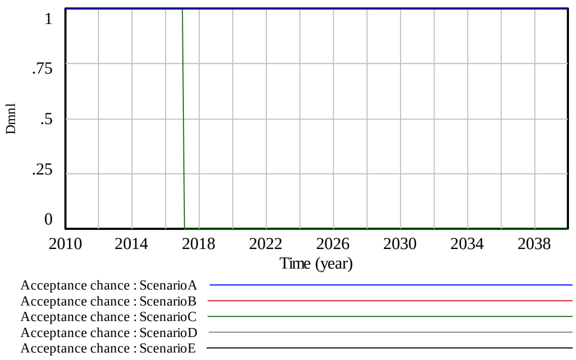
Profit



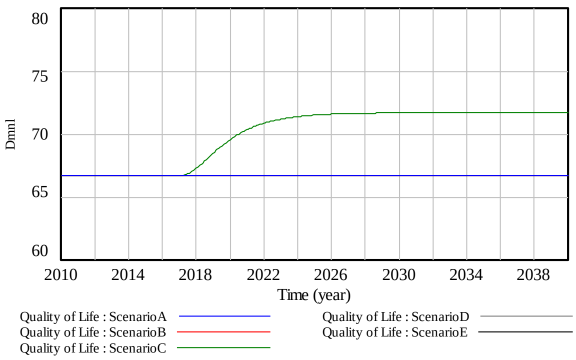
Return on Investment



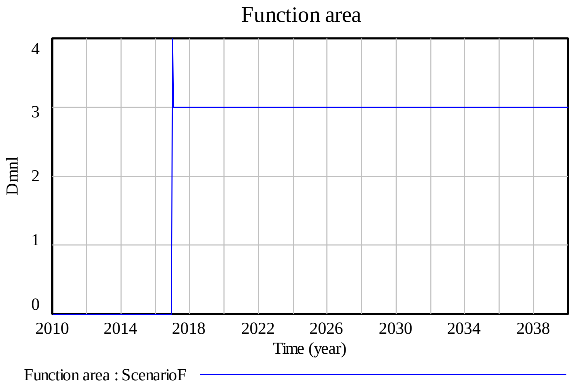
Acceptance chance

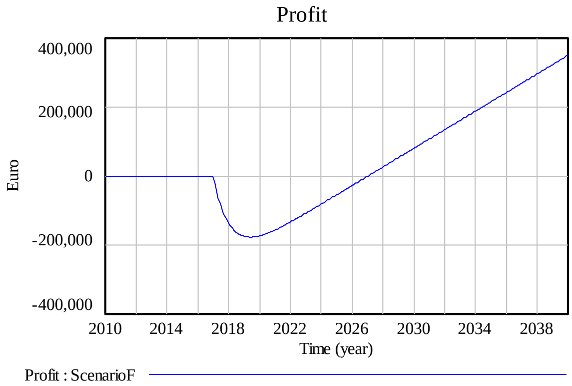


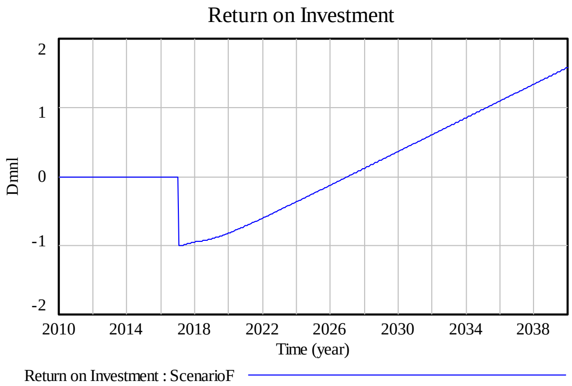
Quality of Life

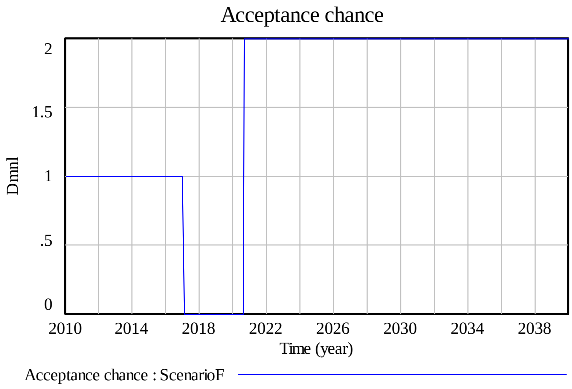


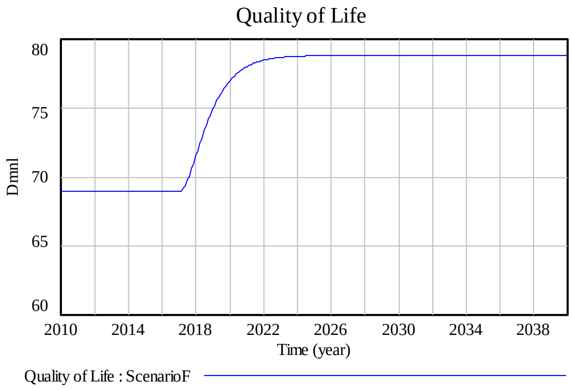
Seingraaf – reference











Appendix 18. Adjusted model for Seingraaf

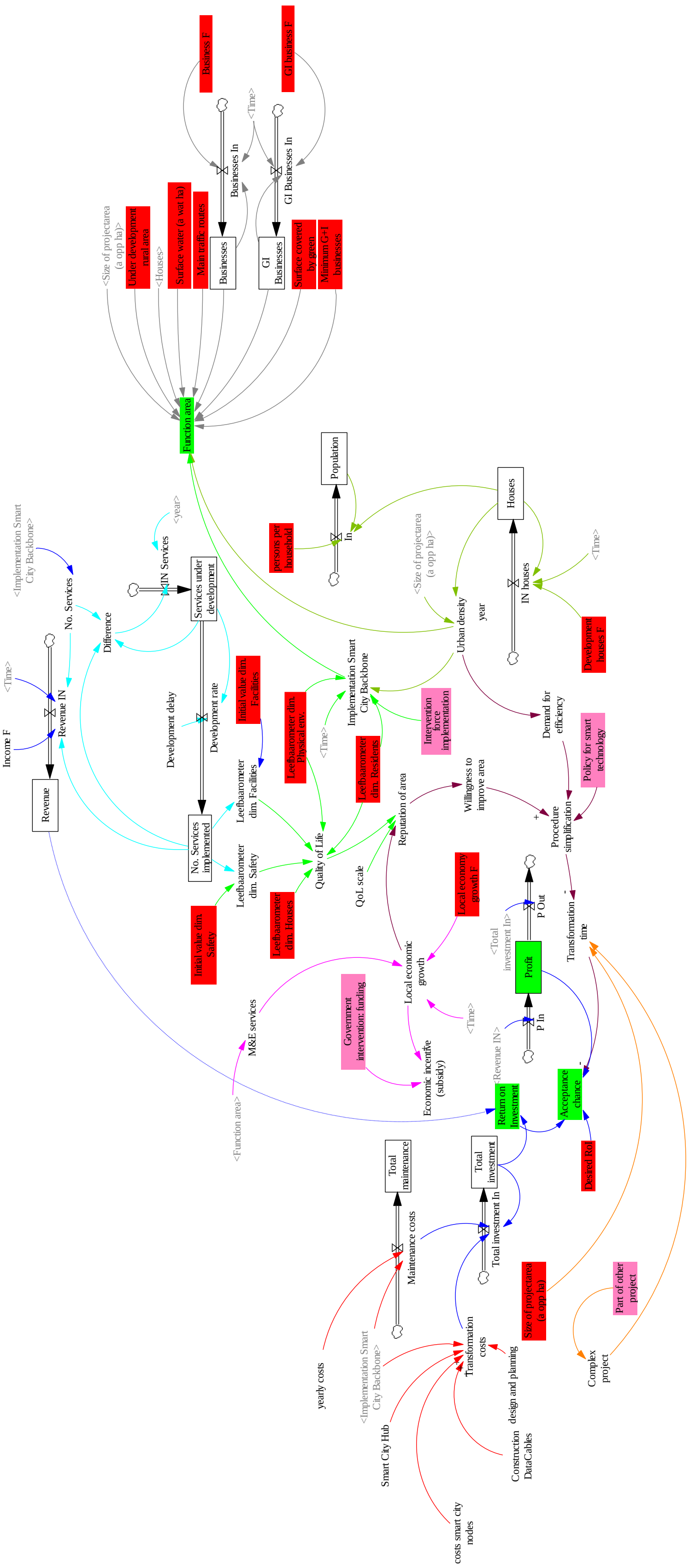
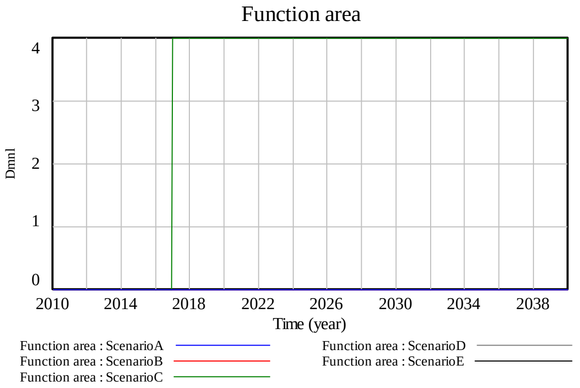
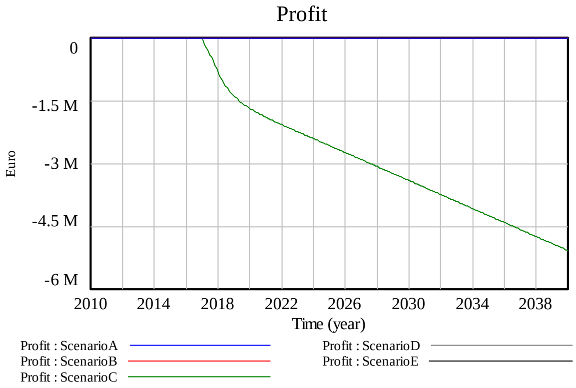


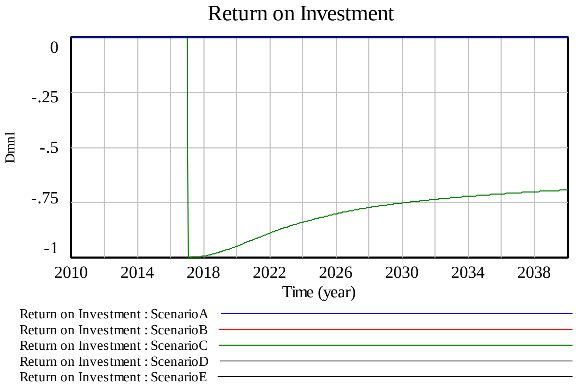
Figure 51 Adjusted SFM for Seingraaf

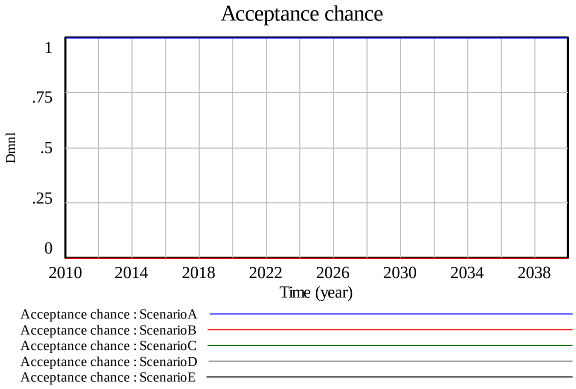
Appendix 19. Rural areas (results)

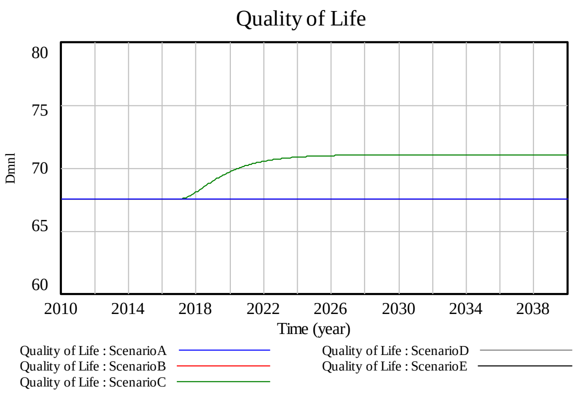
Meinerswijk



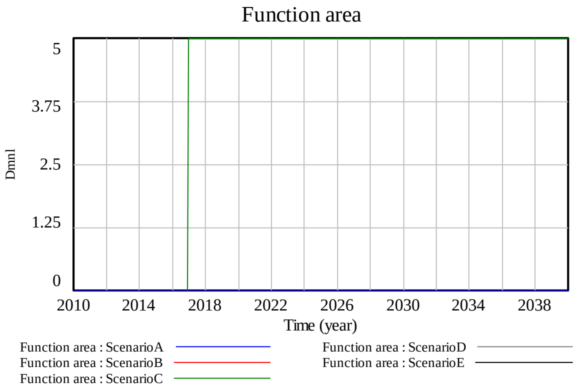


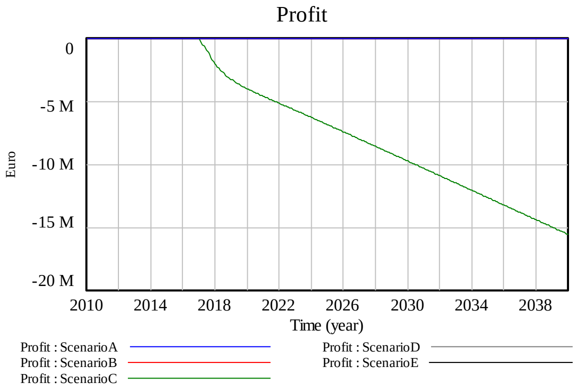


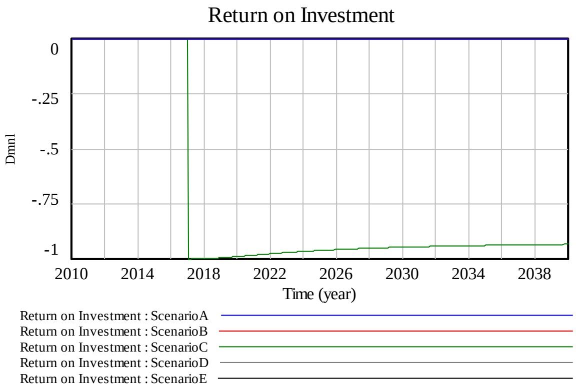


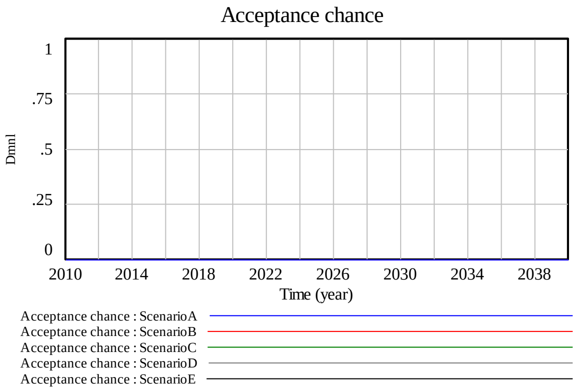


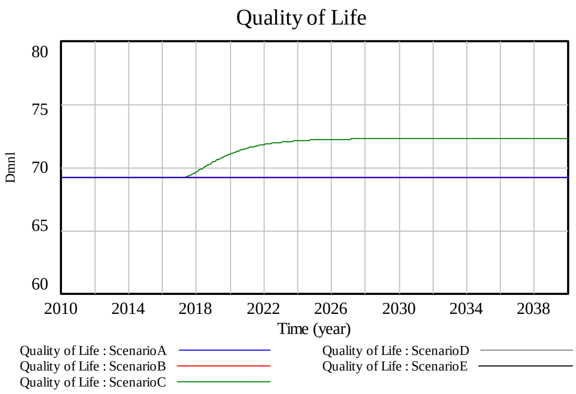
Nieuwerbrug











TU/e