Methodology for Spatial Assessment of Organic Waste Collection System Impacts in Amsterdam

Thesis Proposal, MSc Geomatics

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Contents

1. Introduction

This document describes the graduation research on spatial methodology for assessing the noise, odor, congestion, CO_2 emission and sustainability impacts caused by organic waste collection system scenarios in the city of Amsterdam. The research is the final part of the Master's Program of Geomatics, at Delft University of Technology. It is building up upon research and data provided by H2020 project *REPAiR – Resource Management in Peri-Urban Areas. Going Beyond Urban Metabolism*, led by prof. Arjan van Timmeren. In the following paragraphs the societal and scientific relevance of the project will be highlighted. This document describes the problem and its challenges followed by the research proposal to solve these challenges.

1.1. Societal Relevance

From a societal point of view, the challenge is found in the ambitions of the city of Amsterdam to become climate neutral (Circular Amsterdam et al., 2015). Therefore, the municipality aims at establishing Circular Economy. Since this research project is building up upon the *REPAiR* research, the following *REPAiR* definition by Arlati et al. (2017) of Circular Economy will be used:

> *Circular Economy is an economy based on renewability of all resources – energy, materials, water, topsoil (for food production) and air – while retaining or creating value, promoting positive systemic impacts on ecology, economy and society, and preventing negative impacts*

In 2015, an average Amsterdam inhabitant produced 92 kilograms of vegetable, fruit and garden waste (Municipality of Amsterdam, 2015a). However, only 3% of all organic waste produced in Amsterdam is recycled or reused (Circle Economy, 2014) although production of protein for animal feed, bio gas and building blocks for chemical industry is possible, resulting in many economic and sustainability benefits (Circular Amsterdam et al., 2015).

By collecting this vegetable, fruit and garden waste, regenerative resource flows can be established according to Circular Economy principles. However, many alternative spatial scenarios can be implemented to achieve this, differing in, for example, the location of collection containers, routes and schedule. These scenarios can have different impacts on the city, its inhabitants and the environment. Often, these impacts vary spatially in their importance and significance.

As stated in the Circular Economy definition, negative impacts should be minimized. Examples of negative impacts are nuisance to inhabitants (i.e. noise and odor pollution, increased congestion) and the amount of CO_2 emission. On the other hand, the definition states that positive systematic impacts should be promoted. In this case positive impacts are described by the extent to which the collection system is usable for city inhabitants (i.e. the system is more easily usable for inhabitants when collection points are located close to their households) and the total amount of waste collected.

1.2. Scientific Relevance

The impacts mentioned above differ from each other. In addition, multiple stakeholders are involved in deciding which scenarios to implement. This results in a complex decision making process. Therefore, there is a need to model different impacts and to integrate their assessment. Since both planning scenarios and their contexts are spatial, it is interesting to perform impact assessment using a spatial approach as well. According to Ferretti and Montibeller (2016), this will allow an impact assessment which is tractable by spatial planners.

To achieve this, a methodology can be used which combines the spatial capabilities of Geographical Information Systems (GIS) and the decision making capabilities of Multi Criteria

Assessment (MCA). In this field of research, both theoretical and practical research has been executed over the last two decades, but still it is very fragmented (Ferretti and Montibeller, 2016). This research project therefore aims at tackling three technical challenges.

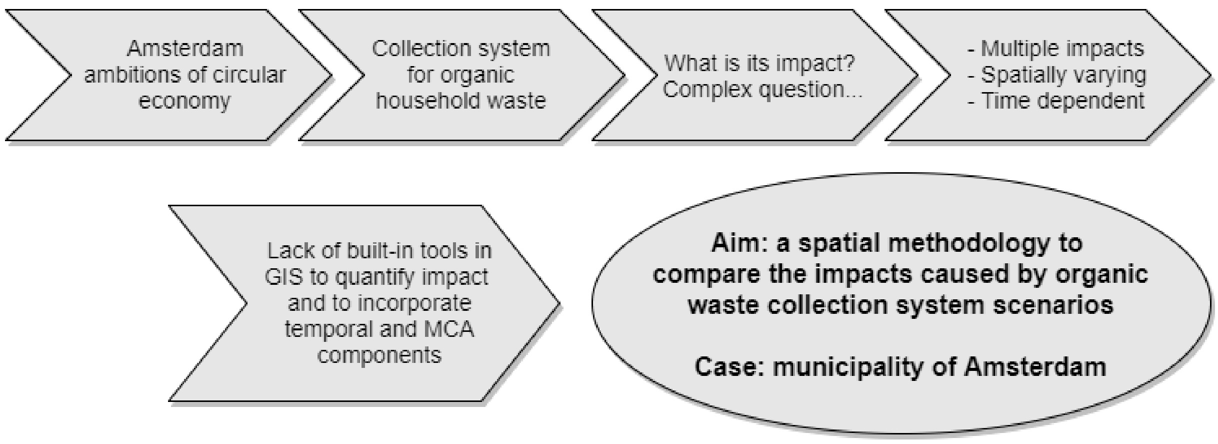
Firstly, the challenge is to model the different impacts spatially. GIS software allows for spatial data storing, management, analysis and visualization. However, no standard tools to spatially model impacts are available.

Secondly, incorporation of temporal factors in these impact models is identified as a challenge. As elaborated on in the previous paragraph, GIS can be used for modeling geographical phenomena. However, temporal components are inherent to geographical phenomena as well (Peuquet, 2005). For this research, examples of temporal factors are the moment of impact occurrence (i.e. the difference between day and night), duration of impact (i.e. minutes or hours) and the frequency with which the impact occurs (i.e. daily or monthly). Antunes et al. (2001) identifies a subject of further development of their proposed spatial impact assessment methodology by extending it with evaluation of cumulative effects in time.

Thirdly, the challenge lies in integration of the different impacts into an overall spatial assessment methodology by making use of MCA principles. Current GIS lack decision modeling capabilities. The field of MCA offers many possibilities to handle multiple and conflicting objectives and thereby enabling design, evaluation and even prioritization of scenarios. To be able to use these principles in GIS environment, a level of coherence has to be reached between the spatial data and the axiomatic foundations of the MCA methods (Ferretti and Montibeller, 2016).

The diagram in figure 1 shows the overview of the research relevance described above. Section 2 will elaborate on related research into the three technical challenges.

Figure 1: Relevance of the research



1.3. Reading Guide

This document starts with an overview of related work in section 2. In section 3, the main research question and its sub questions are defined. In addition, the scope of the research is set. Afterwards, section 4 describes the proposed methodology to answer the research questions. This section also states the tools, software and datasets needed. 5 describes the preliminary results. Section 6 concludes the document with a time planning for the project.

2. Related Work

This section presents an overview of the relevant literature which is linked to the project. The section is divided into four parts: researches on decision support for waste planning; spatial impact modelling; time in modelling; and Multi Criteria Spatial Decision Support Systems.

2.1. Decision Support for Waste Handling Planning

Metropolitan Solid Waste Planning Chang and Wang (1997) have developed a programming approach aiding at planning optimal Metropolitan Solid Waste systems, taking into account the fuzziness and complexity of system objectives. It quantifies different system scenarios in their costs and constraints. It focuses on the economic and environmental impact of noise, traffic congestion, air pollution and material recycling within the long term. Although the method takes into account spatial factors (location of system component, direction, distance) and temporal factors (moment in time) in its formulas to calculate costs (either economic or environmental), the impacts are not expressed spatially.

Waste Plant Decision Support Costi et al. (2004) developed an elaborate decision support method for solid waste plants, taking into account costs, constraints and impacts of a decision. However, it does not explicitly involve the spatial component.

2.2. Spatial Impact Modelling

GIS Core Concepts Sileryte et al. (2017) propose a tool to assist local and regional authorities in integrated spatial development for Circular Economy purposes: Geodesign Decision/Discussion Support Environment (GDSE). Such an environment requires impact modeling. To do this in a standardized way, they propose to model impacts using the five core content concepts of GIS. These are defined by Kuhn and Ballatore (2015) as: *Location*, *Field*, *Network*, *Object* and *Event*. *Locations* can describe static impacts on a specific location with irrelevant time stamps. *Fields* can describe impacts following the first law of geography: *everything is related to everything else, but near things are more related than distant things* (Tobler, 1970). Examples of these are cases where formulas describe any point or where interpolation or extrapolation can be used from known points. *Networks* describe phenomena which are related to each other in a way which is not necessarily spatial, such as health issues or material flows. *Objects* are able to represent either geographically located or non-geographically located objects, such as species or resources. Impacts on objects can be via network or via geographical relations, either temporal or non-temporal. *Events* can model any of the previous categories when it has a specific time of validity (i.e. start and end time).

Space in Modelling Kelly et al. (2013) identify four different ways to treat space in modelling. These are enumerated below:

1. *Lumped* spatial models: a model providing a single set of outputs for a spatial entity, for instance a model of a lake which does not consider the different parts of the lake explicitly.

2. *Region-based, compartmental* spatial models: a model providing a different set of outputs for each homogeneous sub-area of the total area modeled. Each area is homogeneous in one or more key characteristics, for instance a lake modeled in its shoreline vs. deeper parts, which are interacting in the model.

3. *Grid, cell or element-based* spatial models: a model providing sets of outputs on a uniform or non-uniform grid- or vector-based representation. Although neighboring features might share key-characteristics, they are still modeled separately.

4. *Continuous* spatial models: outputs described by partial differential equations for instance. This type can be used for theoretical results, but in practice often discretized in one of the above spatial models.

With current technologies, high resolution data and high processing power of data analysis is feasible in GIS, allowing for spatial disaggregation of indicators. On the contrary, some level of aggregation is often needed for data collection and reporting purposes (Miller et al., 2013) and desired to allow for convenient interpretation and presentation. Miller et al. (2013) identify two types of indicator aggregation which mask heterogeneity in results and therefore constrain the level of nuance in a model: *spatial aggregation* and *temporal aggregation*.

When aggregating at spatial level, a degree of arbitrariness is often found: for instance when using census units or postal codes. the *Modifiable Areal Unit Problem* (MAUP) describes that if units are defined arbitrarily, analysis results are arbitrarily as well (Miller et al., 2013). In case aggregation is desired or needed, ways to cope with this problem are development of optimal spatial units, spatial interpolation and sensitivity analysis taking into account different scales and zoning systems.

2.3. Time in Modeling

Peuquet (2005) describes different challenges and methods to describe time in geographical software such as GIS and geographical databases. The focus lies on describing phenomena, having both geographical and temporal component. However, temporal modeling of impacts is not specifically mentioned.

Similarly to space, Kelly et al. (2013) also identified four ways to deal with time in modeling. These are listed below:

1. *Non-temporal, static/steady state* models: a model without reference to time, only providing outputs for one specific state.

2. *Lumped discrete temporal/transient* models: a model providing outputs over a single period, for instance average value per year.

3. *Dynamic, quasi-continuous* models: a model providing outputs per time-step over a specific time period, for instance per day within a year.

4. *Continuous* models: a model providing output for each infinitely small time interval, often described by differential equations for theoretical modeling.

According to Miller et al. (2013), new capabilities and technologies allow for restricting temporal aggregation: frequent updates can for instance allow for modeling complex dynamics with greater sensitivity.

2.4. Multi Criteria Spatial Decision Support Systems

MCA Selection Ferretti and Montibeller (2016) states that despite the high number of different MCA methods, none can be seen as a *super method* appropriate to all decision making situations. Therefore, it is important to select the best fitting method for a specific purpose. To do so, they published an overview ((Ferretti and Montibeller, 2016), table 1) with guiding questions on how to select an MCA method for Multi Criteria Spatial Decision Support

Systems (MC-SDSS) design. This table provides four guiding questions, specific questions to them and proposed solutions of sets of possible methods and references to them. These guiding questions are:

1. What kind of results are needed?
2. How to gather inputs from stakeholders?
3. How to share the outputs of the analysis
4. What are the relevant characteristics of the problem in terms of compensability, uncertainty and interaction?

Based on these guiding questions possible solutions are provided in order to select an apt method for a specific MC-SDSS.

Approaches to Integration in Modeling Kelly et al. (2013) describes five approaches to integration in modeling. They can be described according to their typical fields of application, data types, the extent to which they incorporate space and time and the way they include scenarios.

Of these approaches, only the *Coupled Component Models* offers a comprehensive set of options to treat space and allowing possibilities to treat time. According to Kelly et al. (2013), Coupled Component Models is a hybrid, combining models from different disciplines, often used for integration of social, economic and biophysical model components. To be able to integrate these, disaggregation and aggregation of components is often needed. Coupled Component Models can be used to explore dynamic relationships between components. While the method allows for in-depth representation of components, some give in on depth in order to provide an on-breadth description of the entire system or due to limitations in resources. A disadvantage of the method is that many components have not been designed to be linked to others and therefore integrating them can be conceptually difficult.

According to Kelly et al. (2013), Coupled Component Models is one of the most commonly used approaches. The typical fields of application of Coupled Component Models are prediction and forecasting, system understanding and experimentation and decision-making and management. 18 studies applying Coupled Component Models are distinguished by Kelly et al. (2013). Possibly relevant for this research are: Delden et al. (2008, 2009); **?**); Rivington et al. (2007)

Aggregating Indicator Scores Antunes et al. (2001) propose a new Spatial Impact Assessment Methodology (SIAM) based on a case study assessing the environmental impact of a proposed highway in central Portugal. In this procedure, aggregation of impact indicators can be done in two ways. As is also highlighted by Ferretti and Montibeller (2016), a factor in indicator integration is the level of compensation allowed: can bad performances on one indicator be compensated by good performances on another one. An example of this is whether a bad performance in human safety can be compensated by good performance on sustainability. Antunes et al. (2001) proposes two different methods for indicator aggregation.

1. The first method is based on indicator weights, allowing for compensation. It is described by equation 1.

$$EI_j = \sum_{k=1}^{m}[w_k(\sum_{i=1}^{n} Q_{i,k}\frac{I_{k,i,j} - I_{k,i,0}}{IT_k}], \quad \forall j \subset J \tag{1}$$

2. The second method is based on including the least favorable indicator, with no compensation allowed It is described by equation 2.

$$EI_j = min\{\sum_{i=1}^{n} Q_{i,k} \frac{I_{k,i,j} - I_{k,i,0}}{IT_k}\}, \quad \forall j \subset J \tag{2}$$

For both equations the following applies: $\sum_{k=1}^{m} w_k = 1$; EI_j is the impact index of alternative j; m is the number of indicators; w_k describes the weight of indicator k; n is the number of classes in the environmental quality scale; $Q_{i,k}$ is the value of class i for indicator k; $I_{k,i,j}$ is the value to indicator k; $I_{k,i,0}$ is the value of indicator k when no alternative is implemented; IT_k is the total value of indicator k; and J described the set of planning alternatives.

Miller et al. (2013) also states that the level of compensation allowed is leading when choosing an aggregation method. Also, the conceptual debate on compensation for sustainability issues is described by Miller et al. (2013): *weak sustainability* implies that sustainability is reached when the net value of both natural and human-made capital is positive and therefore allows full compensation between them. *Strong sustainability* implies that natural resources are irreplaceable, and therefore allows no compensation. In total, four methods each with their own aggregation equation are presented. Of these four, the first method assumes full compensation, the second assumes no compensation and the latter two allow for intermediate approaches.

1. The first method Miller et al. (2013) mentions is *Simple Additive Weighting* (SAW). SAW is simple to use and understand. However, it is based on strong assumptions, such as allowing full compensation and independence of preferences (whereas dependencies among attributes are often found in complex decisions and no relative importance of attributes can depend on others). The SAW formula is shown in equation 3.

$$I_i = \sum_{j=1}^{n} w_j x_{ij}, \quad i = 1, ...m \tag{3}$$

where x_{ij} is the normalized indicator j for entity (geographic unit) i; w_j is the normalized weight of indicator j; n is the number of indicators; and m is the number of entities (i.e. geographic units).

2. The second method is called *Weighted Product* and assumes no allowance of compensation at all. The formula is shown in equation 4.

$$I_i = \prod_{j=1}^{n} (x_{ij})^{w_j}, \quad i = 1, ..., m \tag{4}$$

3. The third method addresses compensation in a more flexible way and is called *Weighted Displaced Ideal* (WDI). To use WDI, an ideal situation of the system has to be defined. WDI then identifies the system which is closest to this ideal.

$$I_i = [\sum_{j=1}^{n} w_j^p x_{ij}^p]^{1/p} \tag{5}$$

where $1 \leq p \leq \infty$ defines the distance metric: the way in which indicators are related. In case $p = 1$, the method is equal to the SAW method, in equation 5. In case $p = \inf$, the systems are compared to each other based on poorest performance over all indicators.

4. The fourth method is called *Ordered Weighted Averaging* (OWA) and is highly flexible regarding compensation. In OWA, weighted indicators are ordered by value, while a second *order weight* value reflects the position in this sequence of each single indicator.

$$I_i = \sum_{j=1}^{n} v_j z_{ij}, \quad i = 1, ..., m \tag{6}$$

where $z_{i1} \geq z_{i2} \geq ... \geq z_{in}$ is the sequence of n weighted indicators $(w_1 x_{i1}, w_2 x_{i2}, ..., w_n x_{in}$ arranged in weight descending order; v_j is a set of order weights, such that $0 \geq v_j \geq 1$ and $\sum_j v_j = 1$. The order weights determine how the logical operators are used on the indicator scores while aggregating. When choosing the order weights, it is determined whether the best system is defined based on its score on the least important indicator or, alternatively, on the most important one. Variation in order weights captures every possibility between them. The SAW method, can also be generated from OWA. To define order weights, several methods have been developed, some of which based on the *fuzzy set* concept (Miller et al., 2013).

Magnitude and Significance Antunes et al. (2001) describe the difference between impact *magnitude* and *significance*. Magnitude represents the difference in environmental quality between the state with or without implementation of a spatial planning scenario. Significance represents the importance that is assigned by experts or public to that difference.

Impact Integration on Different Spatial Scales Antunes et al. (2001) identify the problem that difference in spatial scales is often ignored when integrating impacts. This results in a situation where small scale impacts are absorbed by large scale impacts or the fact that small scale impacts are given the same weight and therefore introduce a bias in the evaluation. To overcome this problem, the study proposes the SIAM procedure which defines different environmental components (i.e. noise) with their own impact indicators (i.e. affected area size, number of people, sensitivity of species) and different spatial scales (i.e. project, local, regional, national). The methodology aggregates only indicators of the same environmental components and presents results per component and per spatial scale separately.

3. Research Questions

3.1. Research Question

The aim of this research is to answer the following main research question:

> *What spatial methodology is suitable to compare the impacts of organic waste collection system scenarios in Amsterdam?*

Three research goals can be linked to this research question.

1. The first goal is to assess the impact of a spatial planning scenario on its spatial context in a spatial manner.
2. The second goal is to incorporate temporal factors in this spatial assessment. Examples of temporal factors are moment in time, duration and frequency of the impact, which might affect the significance of the impact itself.
3. The third goal is to integrate the different spatial impacts in a coherent way, allowing for interpretation of the overall impact and comparison between the planning scenarios. This will be done by making use of existing MCA principles.

3.2. Research Sub Questions

To arrive at an answer, multiple sub questions have to be answered. Currently, the following preliminary sub questions are expected to be relevant:

1. To what extent do current impact assessment methodologies incorporate space?
2. What are suitability requirements to an MC-SDSS for organic waste collection systems?
3. What spatial data model can describe alternative planning scenarios and their context?
4. How can the magnitude of each impact be modeled spatially?
5. How can temporal factors be incorporated in this spatial model?
6. How can MCA principles be applied to integrate the different spatial impacts?
7. How does the spatial methodology compare to an existing non-spatial methodology?

3.3. Research Scope

The next paragraphs sum up the tasks of the research according to the *MoSCoW* framework, in order to set the scope clearly: *Must do* states the research elements which are necessary in order to complete the research; *Should do* describes the elements which are highly desirable to do, but not strictly necessary; *Could do* gives an overview of elements which would be nice to include in the research in case resources allow so; finally, *Will not do* lists the tasks which will not be performed in this research, but are still relevant and therefore interesting for the future.

Must do Research existing assessment methods; find and prepare usable data, scenarios and impacts; design the spatial assessment methods per impact; research the application of MCA aggregation principles for this purpose; design the spatial MCA methods; implement the methods using dummy spatial planning scenarios; compare the methods and describe their advantages and disadvantages

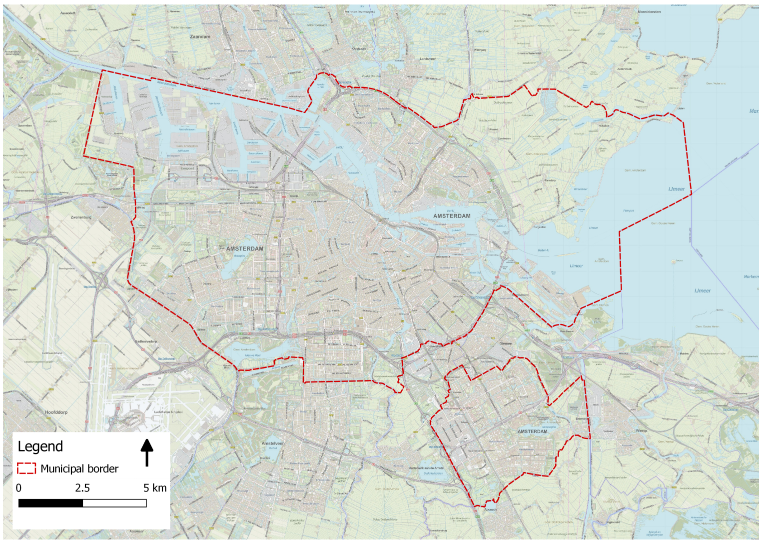
Should do Implement the method using real context data; validate methodologies using an existing non-spatial method

Could do Implement the method using real spatial planning scenarios; test the method with possible users

Will not do Use case expert knowledge for assigning weights to criteria or for impact significance research; incorporate MCA uncertainty principles in the method; address the MAUP problem in the methodology; design a user interface to the method; validate the impact magnitude and significance with measurements and surveys; measure the added value of the methodologies compared to a non-spatial method

Geographical Extent The geographical extent of this project is limited to the municipality of Amsterdam, the Netherlands. Figure 2 shows this extent. Within the municipality, 845.000 inhabitants were registered at the beginning of 2017 (CBS, 2017).

Figure 2: Geographical extent: Municipality of Amsterdam, the Netherlands. background map from (Publieke Dienstverlening op de Kaart, 2017)



Spatial Scale The spatial methodology will aim at assessing impacts around neighborhood level. This choice was made since the transport network and population statistics datasets are available at a similar level.

Scope of Impacts This research will define *impact* following Rooijen and Nesterova (2013); Cambridge University Press (2017) as:

The effect of a measure on a particular target group or situation affected

This research will be limited to two kinds of impacts: local short term impacts, expressing the level of nuisance to people living in surrounding areas of the planning scenario (noise, odor and congestion), and global long term impacts, expressing the level of sustainability achieved by implementing the scenario (CO_2 emission and amount of organic waste separately collected for recycling). Section 5 will further elaborate on the choices and definitions of each impact.

Moreover, the research will take into account three temporal factors in modeling the impacts: duration, moment in time and frequency.

Scope of Waste Types For this research, the following *REPAiR* definition of waste by European Parliament and Council (2008) will be used:

Any substance or object that the holder discards or intends or is required to discard

The research will scope down to fruit, vegetable and garden waste. This choice was made since the average quantity per Amsterdam inhabitant in 2015 of these waste types combined is known.

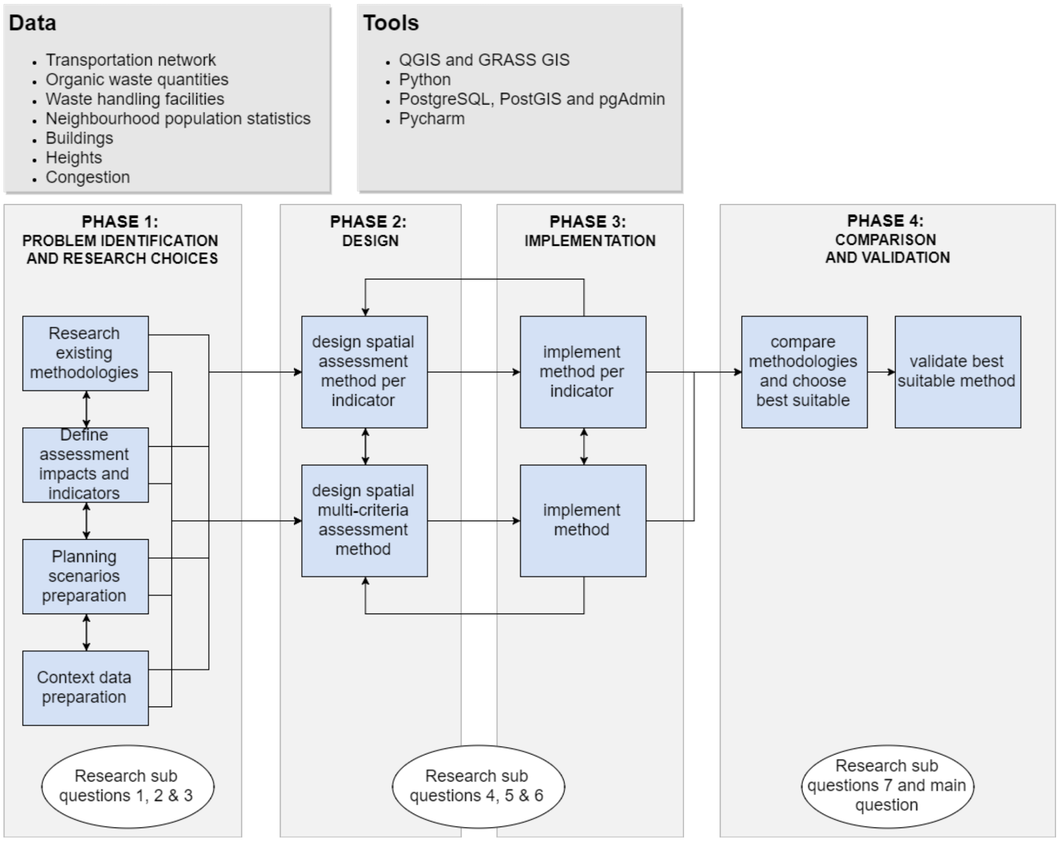
Temporal Scope This project is running from October 2017 until June 2018. Further elaboration on the realization of the project within the given time frame is given in the section 6 on Time Planning.

4. Methodology

4.1. Methodological Diagram

This section will describe the methodology proposed in order to address the challenges identified in section 1 and answer the research questions stated in section 3. The proposed methodology is visualized in diagrams. The methodology is divided into four phases: problem identification and research choices; design; implementation; and comparison and validation. In figure 3 a simplified version of the methodology is presented. In appendix A, the full diagram is included. For each phase, a short description of tasks and goals is given in the next paragraphs.

Figure 3: Simplified methodology overview



Phase 1. Problem Identification and Research Choices The core of this research phase is to clearly identify the research objectives and constraints. Moreover, it focuses on the link between this research project and related work. The goal of phase 1 is to have all information ready to be able to start experimenting and designing the conceptual assessment methods. Phase 1 can be divided into four parallel tracks:

1. *Existing assessment methodologies*: research existing planning assessment methods and the extent of their spatial possibilities; define suitability criteria for the methodology to design; choose an assessment method with similar capabilities which can be used for comparison and validation in the end. Goal of this track is to know which methods for similar cases are available for impact assessment.

2. *Assessment impacts*: define the impacts to assess on; define indicators to them and state their relations using weights and substitutability principles; research existing methods to calculate the chosen impacts. Goal of this track is to exactly know which impacts and indicators are to be assessed, how they relate to each other and how they are assessed by others.

3. *Spatial planning scenarios*: define the practical requirements of the planning scenarios; research how they can be described spatially and find or develop them. The goal of this track is to arrive at realistic and usable spatial planning scenarios.

4. *Data preparation*: define and obtain the context data and perform conversion, cleaning and processing operations on them to make them usable for testing and designing; setup GIS and database software. Goal of this track is to have all data and software ready for methodology designing.

Phase 1 answers research sub questions 1, 2 and 3. This document can be seen as a major step forward as far as phase 1 is concerned. In parts 2 and 5, the current state of this phase is described.

Phase 2. Design Phase 2 is about conceptual design of the spatial impact assessment methodology. To achieve this, theoretical research and practical experiments of possible approaches are used. The goal of this phase is to choose between possible approaches and to develop multiple suitable assessment methodologies. The phase can be divided into two parallel tracks:

1. *Assessment per indicator*: choose or develop concepts to assess each indicator spatially, based on existing ways, both in spatial dimension and temporal factors; experiment with them; design assessment per indicator; iterate. Goal of this track is to determine the possibilities of multiple assessment approaches per indicator for the research case.

2. *Multi indicator assessment*: choose or develop concepts to for multi indicator assessment, based on existing ways; experiment with them; incorporate MCA principles; iterate. Goal of this track is to determine the possibilities of multiple multi indicator assessment approaches for the research case.

Phase 3. Implementation In phase 3, the assessment methodologies designed in phase 2 are implemented on the spatial planning scenarios developed in phase 1. The goal of phase 3 is to arrive at successful implementation of multiple spatial impact assessment methodologies. It can be divided into two parallel tracks:

1. *Implementation per indicator*: apply the designed methodologies to the spatial planning scenarios per indicator; identify improvements. The goal of this track is to assess the scenario on each indicator in sensible ways for the research case.

2. *Multi indicator implementation*: apply the designed multi-indicator methodologies to the spatial planning scenarios; identify improvements. The goal of this track is to arrive at sensible multi indicator assessment methodologies for the research case.

Based on the implementation, the choice can be made to iterate over (steps of) phase 2 and 3 one or multiple times. Phase 2 and 3 together answer research sub questions 4, 5 and 6.

Phase 4. Comparison and Validation Phase 4 will compare the developed spatial impact assessment methodologies on suitability criteria for the research case. To do so, the Strengths Weaknesses Opportunities Threats (SWOT) principle is used. Moreover, they will be validated using an existing non-spatial methodology. The goal of phase 4 is to conclude whether a suitable spatial impact assessment methodology for the research case can be found from the research. It can be divided into two tracks:

1. *Comparison on suitability*: methodology comparison based on suitability criteria set in phase 1; performing a SWOT analysis on the methodologies. The goal of this track is to describe the performance of the methodologies

2. *Validation*: prepare impact assessment comparison method; apply it to the research case; validate the methodologies using the comparison method. The goal of this track is to describe the value of the developed methodologies compared to the existing one.

Phase 4 answers research sub question 7. Moreover, after all four research phases are successfully finalized, the answer to the main research question can be formulated.

4.2. Tools

The tools which are needed for the project are listed in table 1. Per tool, its purpose and source are stated.

Table 1: Tools to be used

Tool	Purpose	Source
QGIS	Spatial data visualization and analysis	https://www.qgis.org/nl/site/
GRASS GIS	Spatial data analysis	https://grass.osgeo.org/
Python	Coding language usable in QGIS	https://www.python.org/
PostgreSQL	Database for storage and analysis	https://www.postgresql.org/
PostGIS	Extension to PostgreSQL for spatial data	https://postgis.net/
pgAdmin	Database query tool	https://www.pgadmin.org/
PyCharm	Incorporation of existing and self-made data analysis tools in Python for QGIS	https://www.jetbrains.com/pycharm/

4.3. Datasets

Context Data In table 2, an overview is provided of the datasets of the city of Amsterdam needed for the project. To each dataset, its type and attributes are stated.

Spatial Planning Data The spatial planning scenarios differ on three components: collection points, routes along them and the collection schedule. Table 3 gives an overview of these components.

Table 2: Datasets to be used: the Amsterdam city context

Theme	Dataset	Type	Attributes
Waste handling	Transportation Network	Vector lines	speed limit [int]; type [str]
	Organic Waste Quantities	Vector polygons	quantity [kg/year]
	Waste Handling Facilities	Vector points	name [str]; type [str]
Population	Neighborhood population statistics	Vector polygons	number of inhabitants [int]; density of inhabitants [int/km^2]; average household size [flt]; percentage younger than 15 years [%]; percentage 15 to 25 years [%]; percentage older than 65 years [%]
Population/City	Buildings	Vector polygons	building type [str]
City	Height map	Raster	-
City	Congestion	Vector lines	traffic intensity [int/interval]; or congestion level
Background	Background	Raster	-

Table 3: Datasets to be used: planning scenarios

Datasets	Options	Type	Attributes
Containers	A. centralized and few; B. decentralized and many	Vector points	capacity [int]
Routes	A. many short routes; B. few long routes	Vector multi-lines	road type [str]; speed limit [int]
Schedule	A. twice a week; B. once every two weeks	Tabular; or Vector polygons	frequency [flt]; departure day and time [str]

5. Preliminary Results

In this section, the preliminary results of the project are described. These include research choices and decisions, results of tests and experiments and some first visual presentations of data and impact models.

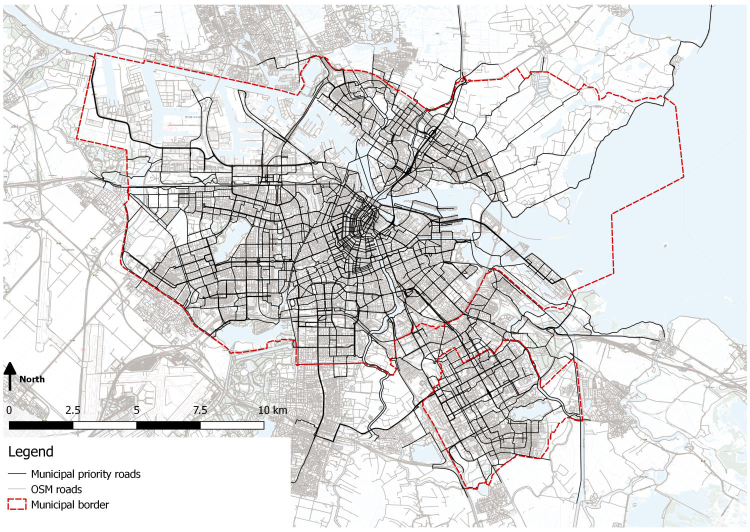
5.1. Context Data

As listed in table 2 in subsection 4.3, 8 different context datasets describing the city of Amsterdam are needed for the project. These were obtained and processed when necessary. The results are shown below.

1. Transportation Network (figure 4)

   Two types of road network datasets are interesting for the project. Firstly, the priority roads defined by the municipality are interesting, since they provide a granularity which is expected to be well suited for the project scope and since they have speed limit and transportation mode included as attributes. Secondly, the Open Street Map (OSM) dataset can be of use. This dataset is used by the municipality as well. It shows a higher granularity of the network and makes a more detailed distinction in road classes in its attributes, but lacks speed limits.

Figure 4: Transportation network, based on (GmbH, 2016; Municipality of Amsterdam, 2017)

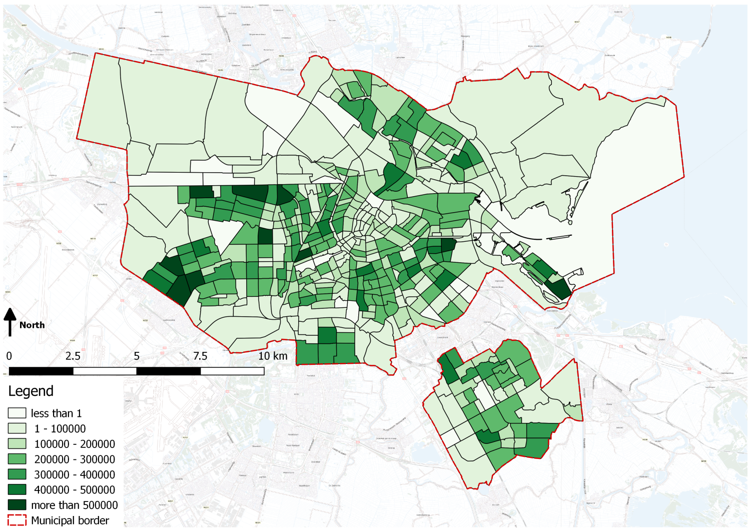


2. Organic Waste Quantities (figure 5)

   As described in section 1, 92 kilograms of vegetable, fruit and garden waste per inhabitant per year was produced in the city of Amsterdam in 2015. This quantity will be used for the research. To distribute this quantity spatially over the city, it will be assumed that this waste is fully produced in households. For now, the organic waste quantities are visualized per neighborhood, at the same level as the population statistics described later on. However, it would also be possible to estimate the quantities per building based on the buildings dataset, the housing dataset and the population dataset.

3. Waste Handling Facilities (figure 6)

Figure 5: Organic Waste Quantity [kg] per neighborhood in 2015, based on (Centraal Bureau voor de Statistiek, 2017; Municipality of Amsterdam, 2015a)



To the waste handling facilities, relative attributes are name, contact information and description. To the municipal ones, the title and web site are provided as attributes.

4. Population Statistics (figure 7)

   For population statistics, a very extensive dataset is available from the CBS, containing all neighborhoods with as attributes information such as total number of inhabitants, number of inhabitants for five different age categories, population density, number of households, percentage of households with children and average household size. To give an impression of the dataset, the population density per Amsterdam neighborhood is shown in this document.

5. Buildings (figures 8 and 9)

   As far as buildings and their inhabitants are concerned, different datasets can be used. Firstly, the Dutch Basisregistratie Addressen en Gebouwen (BAG) building dataset (figure 8) is complete for the municipality of Amsterdam. However, it does not contain building types. Secondly, the BAG housing dataset (figure 9) contains points for each housing unit. Per unit, it contains the function and floor area as attributes.

   An OSM dataset is also available and complete in geometry. However it is quite incomplete in its building classes attribute data. Therefore, it is not of use for this project. Data from the Top10NL topographical dataset is available as well, but does not provide the classes in a useful way either.

6. Height (figure 10)

   The raw data of AHN2 was used, as provided via PDOK. The more recent Digital Surface Model (DSM) of AHN3 does not cover the whole Municipality of Amsterdam and can therefore not be used.

7. Congestion

Figure 6: Waste handling facilities, based on REPAiR data and (Municipality of Amsterdam, 2017)

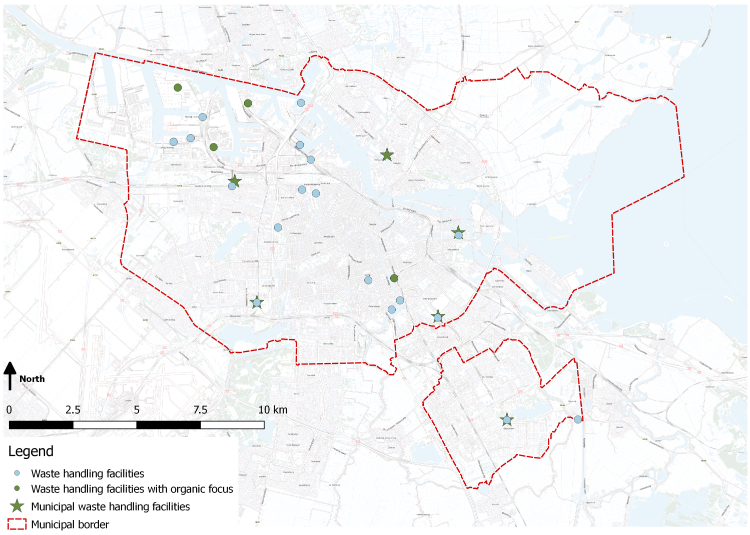


Figure 7: Population density per neighborhood, based on (Centraal Bureau voor de Statistiek, 2017)

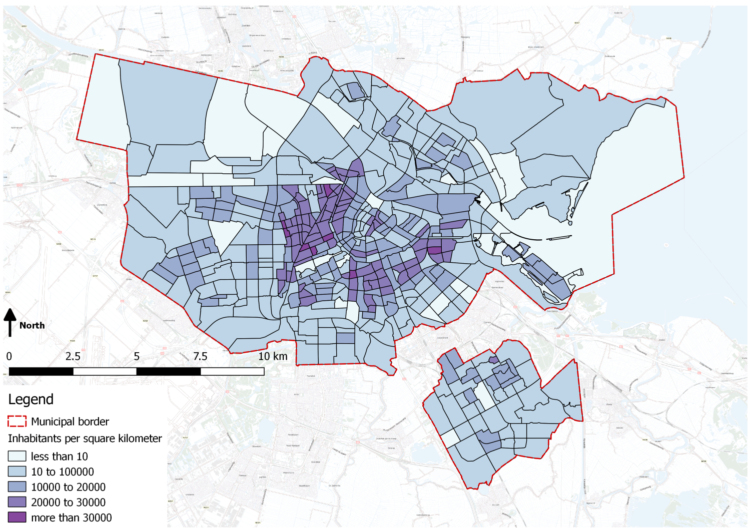


Figure 8: BAG Buildings, based on (NLExtract, 2017)

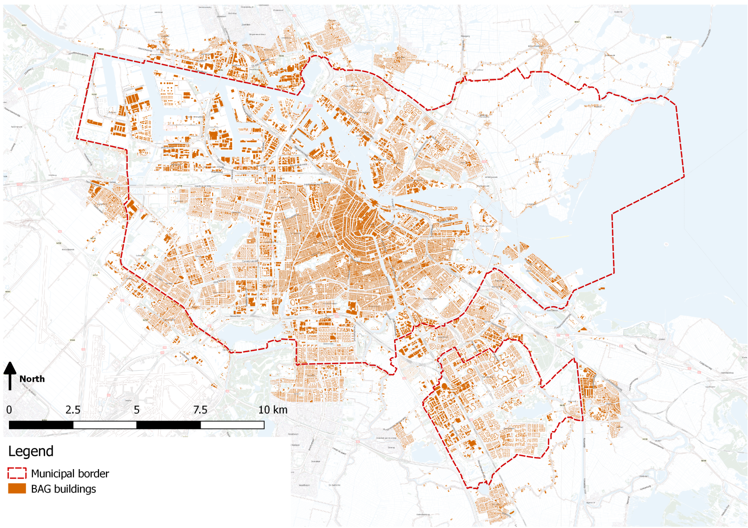


Figure 9: BAG Housing Units, based on (NLExtract, 2017)

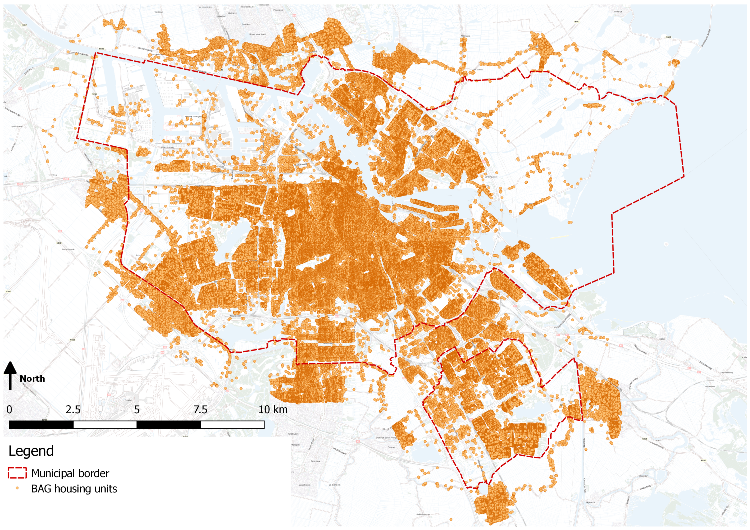
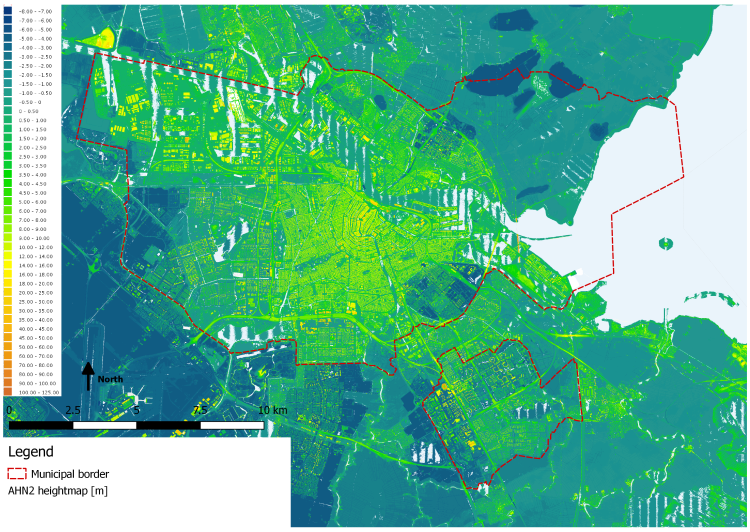


Figure 10: AHN2 Raw data, based on (Publieke Dienstverlening op de Kaart, 2017)



As a measure of congestion, traffic intensity data by Municipality of Amsterdam (2015b) will be used. Rush hours for congestion are defined as 07:00 to 09:00 AM and 04:00 to 06:00 PM.

8. Background (all maps)

   As background map, the PDOK Background Map Grey was used (Publieke Dienstverlening op de Kaart, 2017). It was used in all the above visualizations.

5.2. Spatial Planning Scenarios

Based on the data defined in section 4.3, three spatial planning scenarios were designed. Concept sketches of these are shown below in figure 11, as well as maps of the actual scenarios developed in figures 12, 13 and 14.

For development of the methodology, these three scenarios will be used for testing. However, in theory the methodology will be applicable to any scenario combining a set of points defining collection locations, a set of lines defining collection routes and a schedule similar in set-up to the schedules of the three scenarios for testing.

Spatially Composing the Scenarios The scenarios were composed from data by Municipality of Amsterdam (2017) on the location of existing waste collection containers in Amsterdam. The assumption was made that the *decentralized* containers would be next to all existing paper containers, while the *centralized* containers would be next to all existing plastic containers.

GRASS GIS was used to calculate routes along these containers. To do so, firstly the road network dataset was topologically cleaned. Subsequently, all containers were linked to the road network. Then, the Traveling Salesman tool was used to calculate the routes between these containers for each scenario. For scenario A, one route was made per city part (7 in total), while for scenarios B and C one route for the whole city was made. The GRASS GIS Traveling Salesman tool was applied taking length of road segments as costs. In addition, experiments were performed to use time as costs, by combining the known maximum speed and length into a time value. However, these experiments were not fruitful yet.

Figure 11: Conceptual sketches of 3 waste collection system scenarios. *Left*: Scenario A: decentralized collection points, many routes, low frequency; *Middle*: Scenario B: centralized collection points, few routes, high frequency; *Right*: Scenario C: decentralized collection points, few routes, high frequency

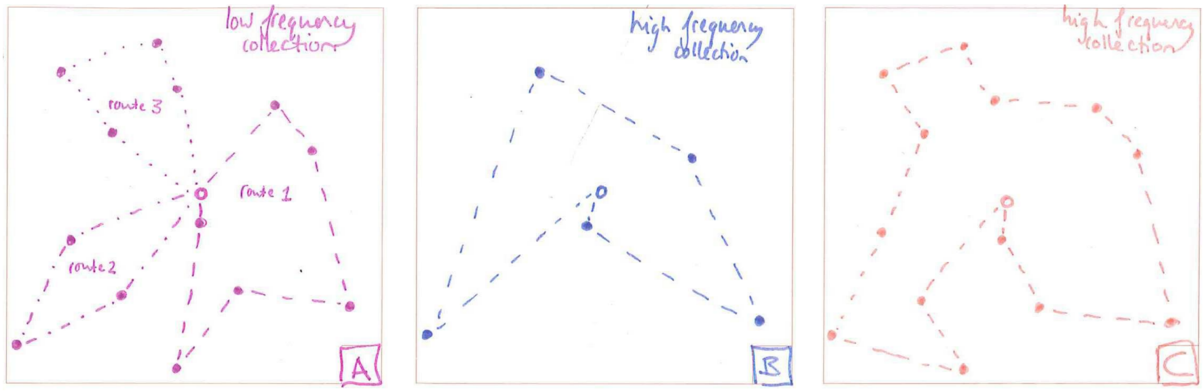


Figure 12: Waste collection system scenario A: decentralized, many routes and low collection frequency

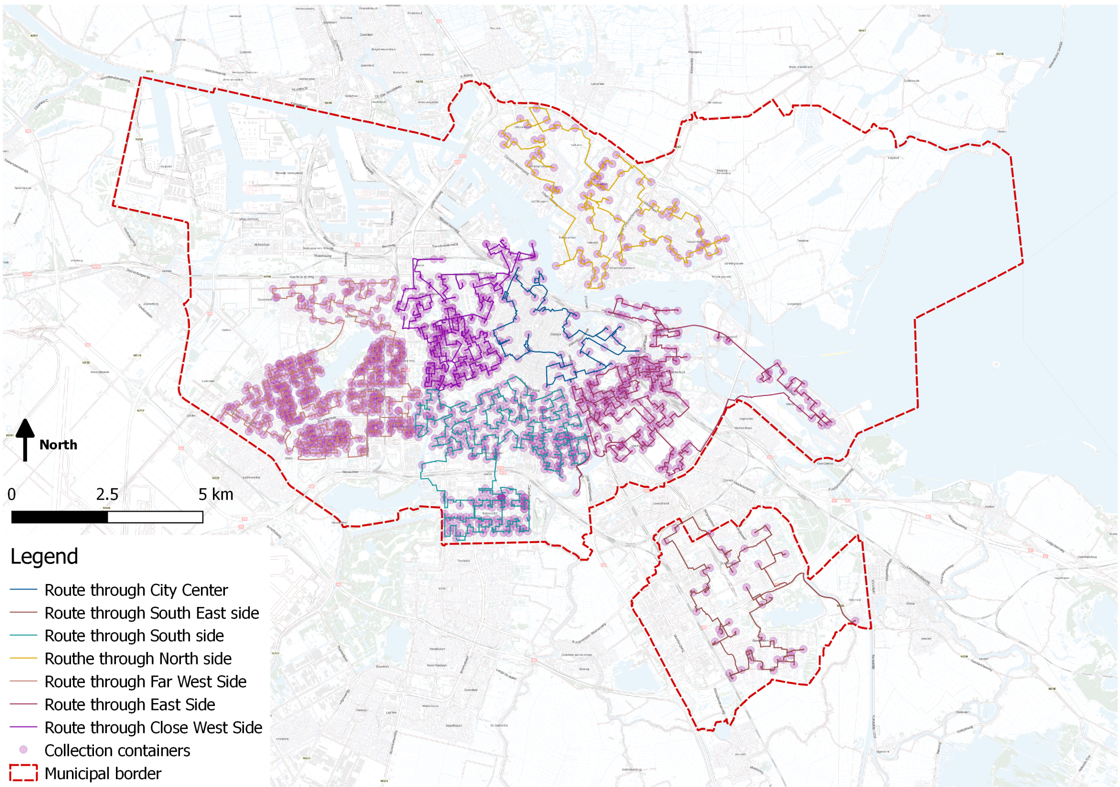


Figure 13: Waste collection system scenario B: centralized, few routes and high collection frequency

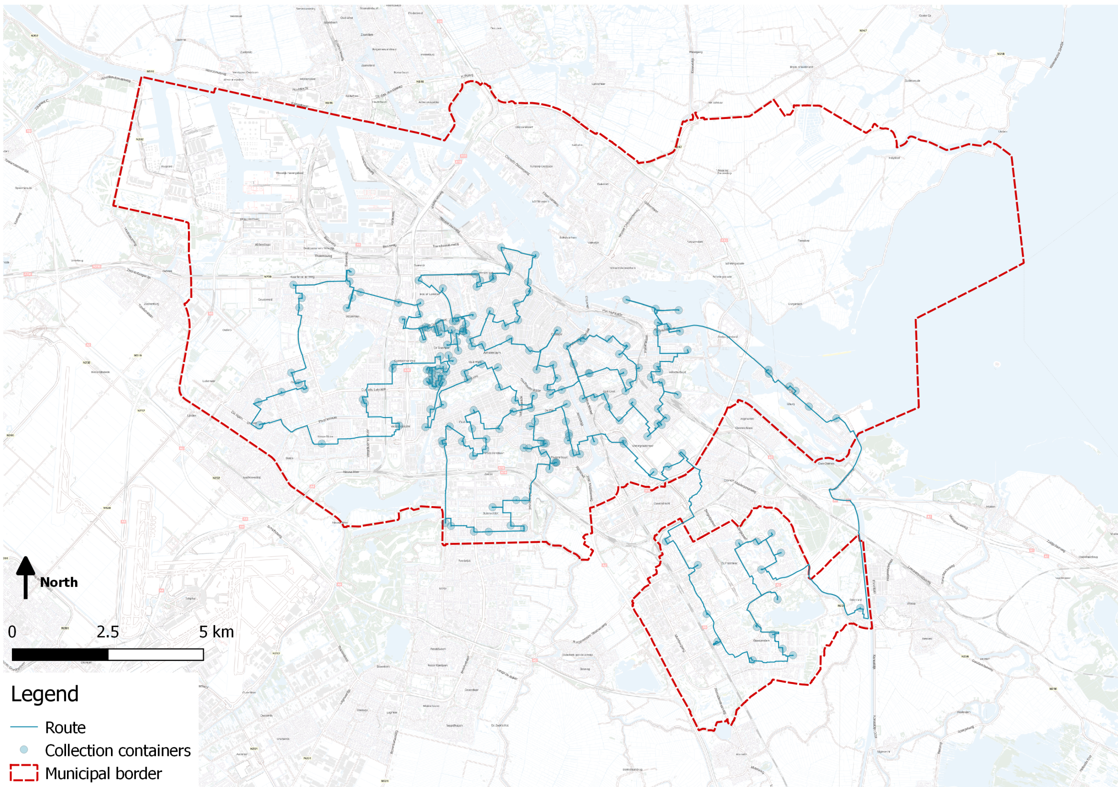
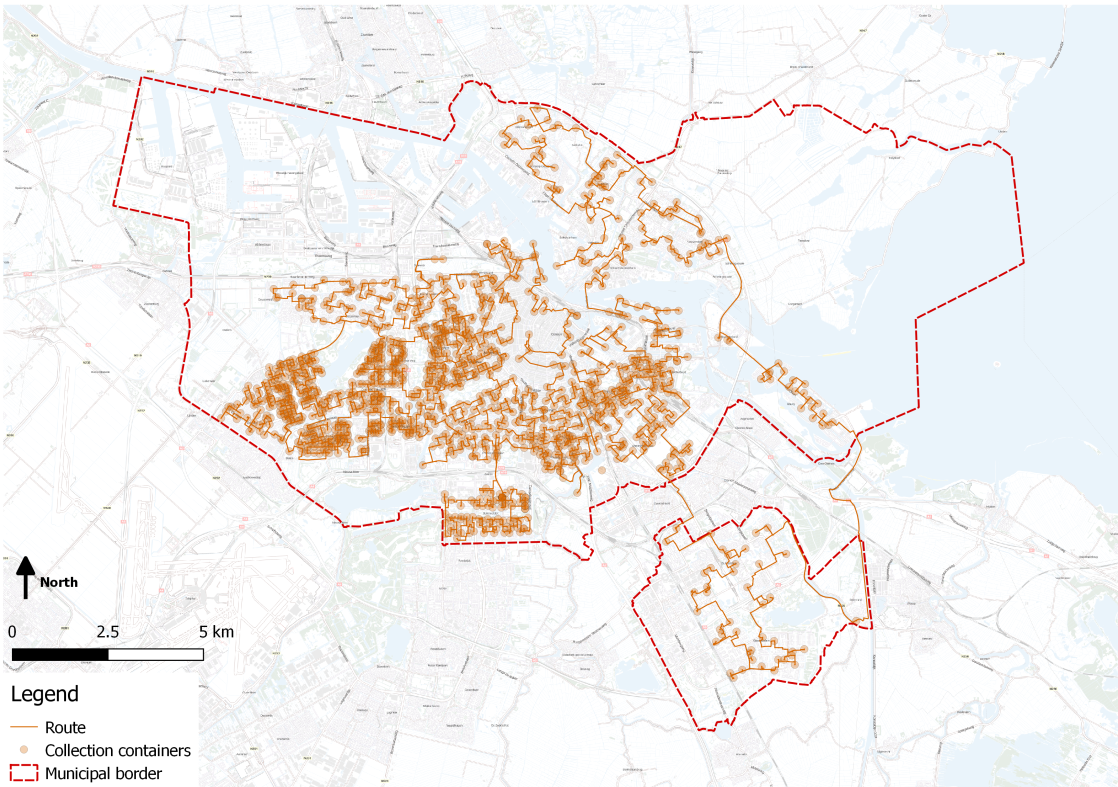


Figure 14: Waste collection system scenario C: decentralized, few routes and high collection frequency



Next to GRASS GIS, experiments were done in pgRouting, a database analysis tool in pgAdmin. However, this tool does not incorporate the road network between points: it uses euclidean distances to calculate the sequence of cities to visit. Since the goal was to make routes, this tool was not of use.

Composing the Schedules After having composed the routes, the schedule were manually added in the QGIS attribute table of each. The choices made are presented in table 4 below.

Table 4: Collection schedule per scenario

Scenario	Frequency	Day of week	Starting time
Scenario A	Every two weeks	Each route on a different weekday	11:00 AM
Scenario B	Twice a week	Monday and Thursday	08:00 AM
Scenario C	Twice a week	Monday and Thursday	08:00 AM

5.3. Impacts, Objectives and Indicators

Impacts The impacts to spatially model are divided into nuisance impacts and sustainability impacts. Nuisance impacts are chosen to be: the impact of noise produced by collecting vehicles on neighboring inhabitants; the impact of odor produced by the waste gathered at collection points on neighboring inhabitants; the impact of congestion aggravation caused by collecting vehicles on other vehicles. Sustainability impacts are chosen to be: the impact of CO_2 emitted by collecting vehicles on the environment; the impact of the extent to which the system is used resulting from the location of collection points to the environment. The impacts were chosen based on work by Taelman et al. (2017).

Ministère de l'Écologie du Développement Durable et de l'Énergie: Inspection des Installations Classées describes that noise and odor from waste management facilities causes dissatisfaction among local populations: after noise, odor is the second cause for complaints.

Objectives and Indicators To be able to model these impacts, choices have to be made regarding what exactly to model. The subject to model can span multiple dimensions, such as economy, society and environment. For each dimension, an objective can be defined (Miller et al., 2013). An *objective* can be defined as a variable with a direction of preference (Ferretti and Montibeller, 2016). To an objective, multiple *indicators* can be defined, operationalized using an attribute, for example contaminating particle per ton of soil. An indicator value can be defined by measuring variables Also, an indicator can be assigned a weight and should be normalized (Ferretti and Montibeller, 2016). For this research, objectives and indicators were chosen based on experiences and expectations.

The relationship between objectives, impacts and indicators is presented in the table 5, together with their desired direction of development.

Assigning Weights to Indicators Miller et al. (2013) describes the process of assigning weights to indicator, normalizing them and aggregating them. Weights define the relative importance and are scale-free. Another method to define weights is to choose them such that the monetary value of each indicator is expressed, which is often meaningful to decision makers and public involved. However, for social and environmental dimensions in particular, this approach

Table 5: Impacts to model

Objective	Impact	Indicator	Desired direction	Influenced by
Nuisance reduction	Noise	length of exposure	minimize	duration of event
		proximity of source	minimize	route: location
		intensity of sound	minimize	route: characteristics
		level of irritation	minimize	schedule: moment
	Odor	proximity of source	minimize	collection: location
		time before handling	minimize	collection: capacity; schedule: frequency
	Congestion	aggravation of congestion	minimize	route: location; schedule: moment
Sustainable development	CO_2 emission	vehicle efficiency	maximize	duration of event
		driving time	minimize	route: location
		length of route	minimize	route: characteristics
	Organic Waste Collection	amount of organic waste collected	maximize	schedule: frequency; collection: capacity
		proximity of collection points	maximize	collection: location

can be misleading. Methods for assigning weights are *analytical hierarchy process* (Saaty, 1990), decomposing a multi criteria problem to sub criteria level. Decision makers are then asked to conduct pairwise comparisons between sets of sub criteria. Afterwards, a judgment matrix is composed expressing the relative weights of all sub criteria. Another method is described by Sakamoto and Fukui (2004): *fuzzy structure modeling* allowing for modeling of ambiguous relationships in the calculation of indicator weights. This method is useful when one indicator reflects multiple objectives or when one objective reflects multiple dimensions.

For this research, no stakeholders will be involved in the process of assigning weights to indicators. The weight assignment will be simulated based on literature and own experiences.

Normalizing Indicator Values As far as normalization of indicator values is concerned, Miller et al. (2013) mentions three methods: Z-score transformations, linear normalization and distance from the best and worst performer. Normalization often requires definition of a reference point, reflecting judgment about ideal performance. The reference point should be able to reflect a sense of progress from bad to desired performance and should be realistic and meaningful (Miller et al., 2013).

Based on literature, the choice for one of these three methods will be made.

Relationships Between Scenario, Context and Impact A key element of the project is defined by the relationship between the different components of the spatial planning scenarios, their context and the different impacts. Many relationships can be found. A visualization of this is included in appendix B.

5.4. Noise and Odor Modeling

Noise Modeling Numerous researches into spatial modeling of noise are described in literature. Some of them seem usable for use in this research project. In table 6 an overview is given. Until now, no relevant studies have been found on modeling noise from moving sources.

Table 6: Summary table of spatial noise modelling researches

Name	Usability	References
CNOSSOS-EU Noise Modelling	Maybe partly	Kephalopoulos et al. (2014)
CoRTN Road Traffic Noise Calculation	No	Department of Transport Welsh Office (1988)
Noise Effect Quality and Efficiency	Yes	Kluijver and Stoter (2003)
Noise Prediction for Skåne Region (Sweden)	Maybe partly	Farcaş (2008); Farcaş and Sivertun
TRANEX Noise Exposure Calculation	Maybe partly	Gulliver et al. (2015)

Odor Modeling Also for spatial modeling of odor various researches are available. Table 7 provides an overview.

FIDOL Principle for Impact of Odor Freeman and Cudmore (2002) describe five factors influencing the impact of an odor, collectively known as *FIDOL*: *frequency*, *intensity*, *duration*, *offensiveness* and *location*. In their report, further explanation to these factors is provided, together with an extensive overview of theory, categories, usage and more. Nicell (2009) uses the FIDOL principle as a starting point for an odor impact assessment method. Although the

Table 7: Summary table of spatial odor modeling researches

Name	Usability	References
Empirical Odor Modeling	Yes	Schauberger et al. (2012a,b)
Gaussian Plume Model	Partly	Smith (1995, 1993)
Impact Pathway for Organic Waste Odor	Maybe partly	Marchand et al. (2013)

factors include *Location*, both researches take geographical variation only to very limited and theoretical extent into account. However, Nicell (2009) does take into account time by using average values per time interval.

6. Time Planning

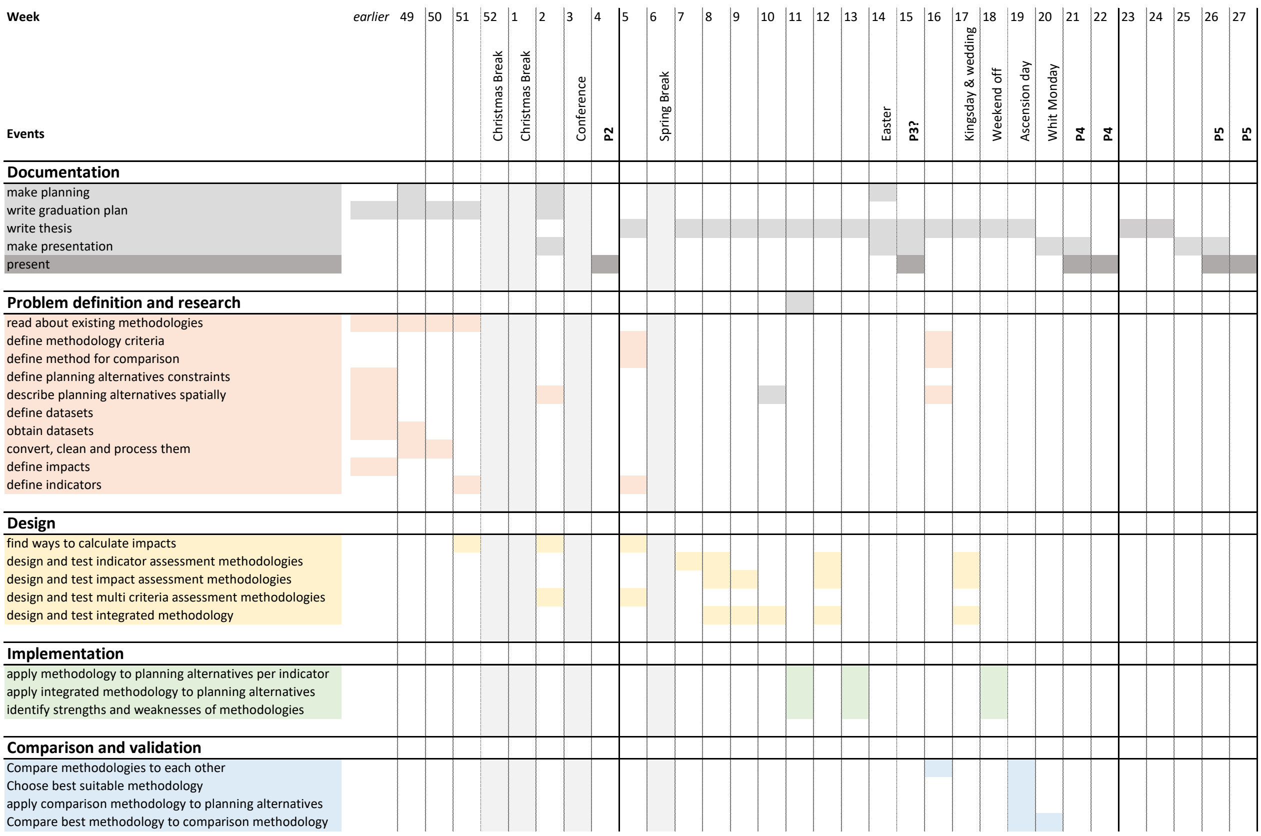
In figure 15 an overview of the project planning is given. The tasks are divided into four phases, similar to the phases defined in the methodology. Each phase has its own color. A fifth task is documentation of the project in both documents and presentations, which will run continuously throughout the project.

The GANTT chart starts in week 49 of the year 2017, the week in which it was established. Before that, exploration of the topic and research choices were already running. Important presentation dates set by the Faculty are:

1. P1 - 2017, October 13th
2. P2 - 2018, January 23rd
3. P3 - 2018, around week 15 (yet to be decided)
4. P4 - 2018, week 21 or 22
5. P5 - 2018, week 26 or 27

During the project, weekly meetings will be held with the first supervisor Rusné Šileryté. Second supervisor Jorge Gil will join these meetings when his agenda allows.

Figure 15: GANTT Chart of project time planning



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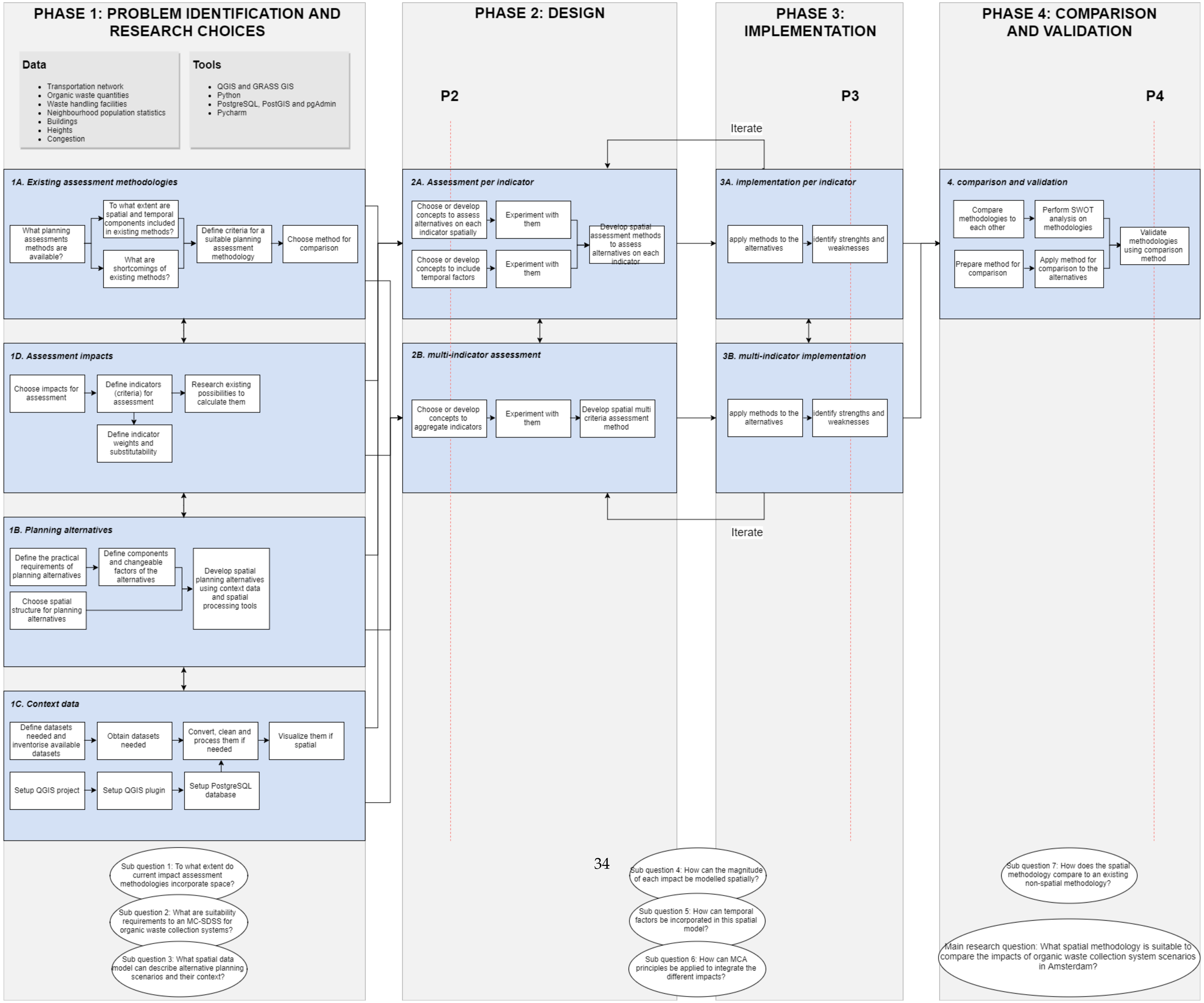
Appendices

A. Appendix A

Figure 16: Full methodology overview



B. Appendix B

Figure 17: Relationship between scenarios, receptors and impacts