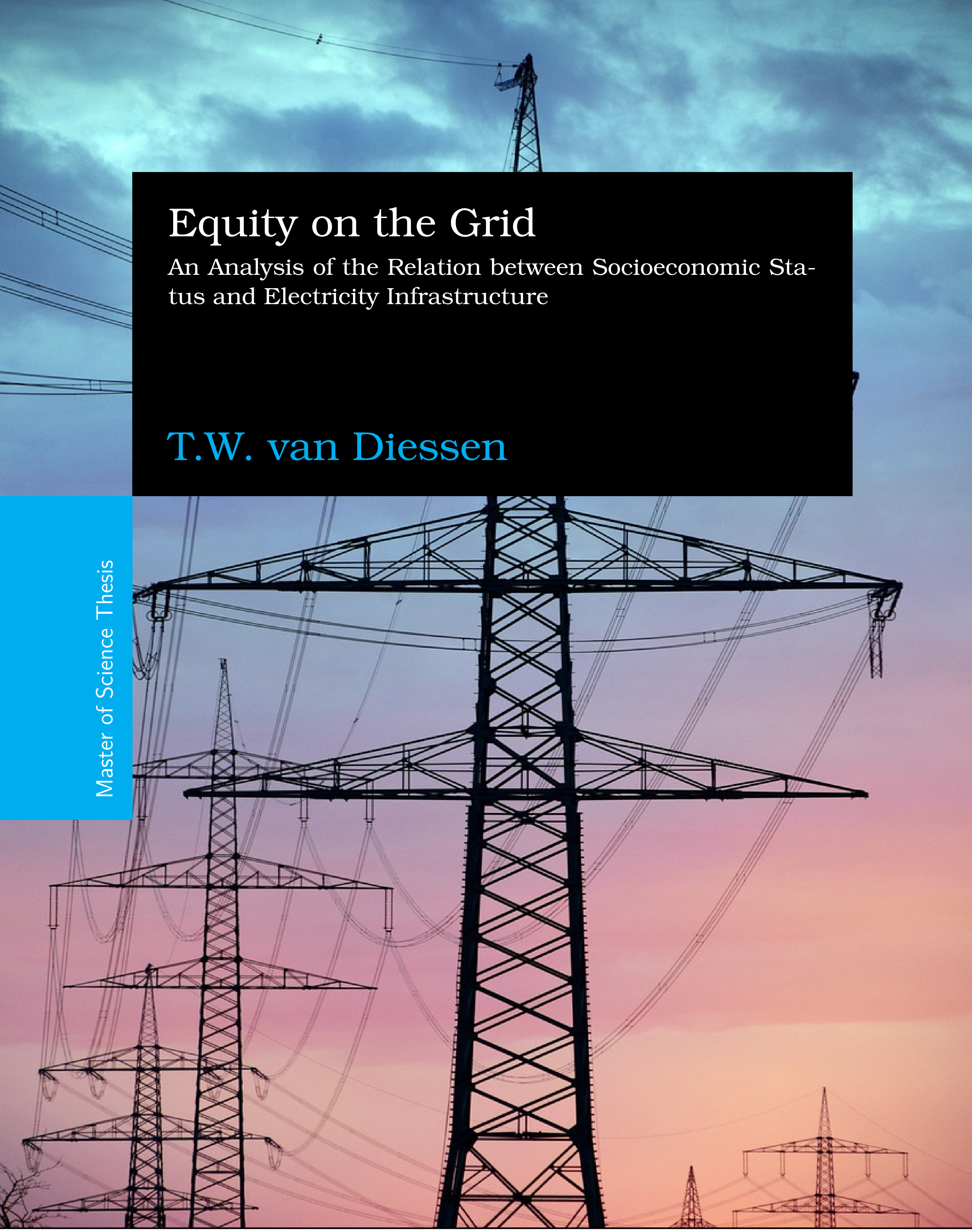

Equity on the Grid

An Analysis of the Relation between Socioeconomic Status and Electricity Infrastructure

T.W. van Diessen

Master of Science Thesis

Delft University of Technology

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Preface

The idea for this thesis started during my internship at the province of South-Holland, where I first came into contact with the subjects of electricity infrastructure and energy justice for the first time. These topics immediately sparked my interest and I was quickly set to write my thesis on this matter.
I want to deeply express my gratitude to all employees of the province of South-Holland who helped me during the process of writing my thesis. A special thanks goes out to my supervisors, Laszlo van der Wal and Ruben Huls, for giving me the opportunity to write my thesis in cooperation with the province and for their guidance during the process. Without them this research would not have been possible.

I also want to thank Nazli Aydin, who as my first supervisor provided me with feedback and guidance which was essential for the research. I further want to express my appreciation to the members of my graduation committee, Nihit Goyal and Igor Nikolic, for their feedback and advice during the process.

My gratitude also goes out to the interviewees who participated in the research as they were an essential part of the thesis who helped bind everything together.
Lastly, I want to thank my friends and family for their support during the writing of this thesis.

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Executive Summary

To advance the energy transition and prepare for the accompanying increase in electricity demand, the electrical grid of the Netherlands requires rigorous investments for expansion and maintenance. In order to solve and further prevent grid congestion, a lot of projects have to be executed and this demands collaboration of grid operators and local governments. In addition to the technical problems of the transition, there is also a growing part of the population that is suffering from energy poverty and energy injustice which prevents them from benefiting from new innovations, while wealthier households are financially profiting from these. The negative socioeconomic effects are not accounted for in the investment plans of grid operators, even though not addressing these problems will further increase inequality in the population.
In order to research how investments in the electricity grid are related to the socioeconomic status of neighbourhoods and how this affects equality in the province of South-Holland, this thesis is conducted. The study aims to answer the research question: *"To what extent can spatial relations between electricity grid infrastructure and socioeconomic characteristics be identified and quantified in the province of South-Holland and what does this relation imply for inequality?"*

To answer this question, first a literature study was conducted in order to identify socioeconomic variables related to energy poverty and energy justice to use in the research. Subsequently, data for these selected variables is collected on a neighbourhood level and the electricity infrastructure in the province of South-Holland is mapped. The research focuses on the low and middle voltage grid infrastructure as these grid levels directly influence households and their impact can be assessed on a neighbourhood level.
The collected data was then used in a correlation analysis to discover a possible relationship between the socioeconomic status of a neighbourhood and the amount of low and middle voltage stations located in it. As the electricity demand of wealthier households is higher than the demand of lower income households, it was expected that there would be a positive correlation between prosperity and electricity infrastructure. The found correlations, however, did not result in any definitive conclusions, except for the relation between the amount of inhabitants and the amount of electricity infrastructure, so another analysis was performed that focused more on the spatial correlations. In this hotspot analysis the variables with a

strong relation from the correlation analysis were used in a clustering research. This resulted in indications being found that linked areas of socioeconomic prosperity to more investments in electricity infrastructure, as was assumed. This implicates that there is an unbalanced distribution of costs and benefits on the grid as everyone pays the same for the investments, but wealthier neighbourhoods profit more.

In order to learn how this relation came to be and how it affects equality, experts on the topic were interviewed. In total five interviews were conducted with people from main stakeholders in the system, namely: grid operators, municipalities and researchers on energy justice. The interviewees were asked about their thoughts on the results of the analyses, the developments of the electricity grid, its effect on equality and the role of the province of South-Holland in the system. From these interviews it was concluded that the indicated unbalanced distribution of electricity grid investments among different socioeconomic groups in the population is not necessarily a problem for equality on the short term, although it might provide difficulties in the future. The investments follow demand and thus it is a logical consequence that neighbourhoods with a higher electricity usage require more electricity infrastructure.
The problem in the system is that there are socioeconomic groups who have no access to the energy transition and can therefore not benefit from the developments, while others are enriched by it. This unequal balance of costs and benefits causes inequality to grow in the future, so governments will have to ensure lower income households have access to energy transition innovations in order to secure a balanced and sustainable future.

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Chapter 1

Introduction

1-1 Background

As the deadline of 2050 for the climate goals set in the Paris agreement grows closer, the Dutch government together with the Dutch energy grid operators have to complete a lot of energy infrastructure projects in order to meet the desired decrease in emissions and realise the transition away from fossil fuels. These projects mostly consist of repairs to the current electricity grid and the construction or improvement of transformer stations to accommodate for the increase in electricity supply and demand. Because of the energy transition and the huge peak in electricity that comes with it, more and more areas in the Netherlands have started to suffer from grid congestion [55]. This means that no new connections can be made to the grid and problems may occur in supplying electricity to consumers. In order to reduce this congestion as much as possible, the electricity grid has to be expanded a lot in the coming years. Local governments, like municipalities and provinces, have to work together with grid operators to oversee these projects and maintain a reliable energy grid. This research will be focused on the province of South-Holland and their efforts to oversee the electricity grid expansion.
The required expansions are listed by the grid operators in their investment plans [31, 61, 74]. There are three grid operators active in South-Holland, Liander, Stedin and Westland Infra, who all have their own catchment areas in the province. The projects the grid operators defined in their plans are evaluated on their cost- and energy-efficiency, spatial fit, vision, feasibility and societal effects. The societal effects are not well evaluated in comparison to the other criteria, while it is an important indicator for a successful energy transition in which all people have to be included, no matter their social class.

An important problem that prevents people from profiting from the benefits of the energy transition is energy poverty. Energy poverty is defined by Robinson et al. (2018) [57] as when more than 10% of a households income is spent on energy costs. In the province of South-Holland 3-8% of the population has to deal with energy poverty according to research performed by TNO (2022) [69]. It should be noted that these numbers are from before the Dutch government put a cap on energy prices [53] and the current numbers might be different.

Households that suffer from energy poverty are less likely to benefit from the energy transition [68], as they often do not have the financial resources to invest in sustainable innovations. In the meantime, higher educated and wealthier households profit from the energy transition because they can afford energy saving means and they benefit from employment and innovation that comes with the energy transition [9]. This can cause the energy transition to inadvertently allow social and economic inequality to grow, while it should be beneficial for everyone according to the sustainable development goals of the United Nations [73]. To negate this possible negative effect of the energy transition, it should be thoroughly researched how the costs and benefits of the energy transition are distributed among the population.

A fair distribution of the energy transition is also being advised in a report from the Dutch Scientific Council for Government Policy [77], in which they warn that the costs and benefits of transition policies have to be divided fairly in the eyes of citizens or they might lose support for the policies. This means that legislation should not only be tested on its efficiency and lawfulness, but also on the impact on socioeconomic factors and social justice it will have.

This research topic contains a multidisciplinary approach, as it contains both technical and socioeconomic dilemmas. The report will focus on the differences between social groups and combine this with the technical aspects of electricity infrastructure. This makes it well suited for a 'Complex Systems Engineering & Management' graduation project. The problem further requires coordination between multiple groups of stakeholders, both political and commercial, which makes it a suited complex system to research.

1-2 Knowledge gap

Looking at the individual investment plans of the three grid operators in South-Holland [31, 61, 74], the socioeconomic effects of the planned electricity infrastructure projects are never mentioned. This indicates that these effects are not known, or lay outside of the main focus, and are thus not accounted for in the decision making. An explanation for this can be found in the changing role of the grid operators. Their old role consisted of operating on a 'first come, first serve' principle to comply with EU non-discrimination regulations, but this way of operating is no longer sustainable [1].
The lack of knowledge on the socioeconomic effects of the projects could prevent people from participating in the energy transition and cause inequality to grow in South-Holland. This is in conflict with the UN goals [73] and the advise of the WRR [77] and should thus be prevented.

Because of the current congestion, a long wait list of requests for new connections to the electricity grid has formed and grid operators now have to prioritise requests based on their societal impact. Due to this being a relatively new problem, the grid operators do not have regulations for this prioritising process yet. They also, as mentioned, lack a clear overview of the socioeconomic effects their projects have, which is needed to compose the new regulations. With the 'first-come, first-serve' principle, people with a lot of electricity demand are likely to be the first to apply for new connections and strengthening of their local grid. As wealthier households can afford electric vehicles (EVs), solar panels and heat pumps, which have a big impact on the electricity demand, it could be expected that most of the projects are scheduled in richer neighbourhoods. This may cause the grid in lower income neighbourhoods to lack behind, which might increase socioeconomic inequality. There is, however, not any research done that investigates this relation.

When looking at the scientific research on the topic, it is also difficult to find corresponding literature. Most research outside of the Netherlands investigates the problem of access to electricity infrastructure or clean energy [46, 60]. This is, however, not a problem in the Netherlands [15] and thus less research is done on this topic.
When specifying on research in the Netherlands, some useful literature can be found. Niet et al. (2023) [44] studied the possibilities of implementing artificial intelligence in the Dutch electricity grid. The study however mostly focuses on the electricity market and not on justice or equality. Milchram et al. (2020 and 2018) [38, 39] researched the effects of smart grid innovations on energy justice in two different papers. These studies link energy justice to the electricity grid, but only on new innovations and how these should be implemented. It is, however, not discussed how the electricity grid developed and what its relation with socioeconomic variables is.
The performed studies touch the subject of making the energy transition fair for everyone, but focus on the innovative side of the system. They do not research the development of the electricity grid itself and how this affects equality, so this has to be investigated further.

1-3 Research Questions

As discussed, it is not known if there is a relation between the location of electricity infrastructure and the socioeconomic status of the area. Because this relation is unclear, it is also unknown how this possible relation affects inequality between different regions. This information is needed in order to ensure a just decision making process in the energy transition and the battle against electricity grid congestion.
This leads to the following research question that needs to be answered:

"To what extent can spatial relations between electricity grid infrastructure and socioeconomic characteristics be identified and quantified in the province of South-Holland and what does this relation imply for inequality?"

To answer the main research question, first the socioeconomic characteristics that are relevant for the research must be identified. Then the electricity infrastructure in the province of South-Holland has to be mapped in order to look at the distribution. After this the spatial correlations between the electricity infrastructure and socioeconomic indicators can be researched. These results will then help answer how electricity infrastructure affects equality.

These steps can be translated into the following sub-questions:

- *What are key socioeconomic indicators that are relevant for a correlation analysis between socioeconomic characteristics and electricity infrastructure?*
- *How is the electricity infrastructure for the low and middle voltage grid distributed in the province of South-Holland?*
- *Can spatial correlations between socioeconomic characteristics and electricity infrastructure be identified?*
- *How does the distribution of electricity infrastructure affect equality?*

1-4 Research approach

In order to answer the sub-questions a mixture of research methods will be used.
The first question of identifying the relevant socioeconomic indicators, requires a literature review to be answered. To find socioeconomic patterns and research the effects, two key concepts are identified that cover the topic best. These concepts are: energy poverty and energy justice. By conducting a targeted literature search on articles that discuss variables related to energy poverty and energy justice, a selection of these found variables can be made and used in the research.
The literature review requires a subsequent data research to see if there is sufficient data on the selected indicators for a useful analysis. The data will be collected on a neighbourhood level, as at this level the differences in socioeconomic status between areas is most clear. The research will also only focus on the province of South-Holland, as they are supporting the research.
It is preferred that only open source data from large data banks like CBS, Databank Zuid-Holland or TNO is used. When sensitive data from, for example, the grid operators is required to give more insight into the system, permission might be asked under the signing of a non-disclosure agreement. This is, however, unlikely as organisations are very protective of their data.

The other data that must be collected for the research is the location data of the electricity infrastructure. This data is publicly available and can be downloaded from the websites of the grid operators. This data will be analysed using Geographic Information System (GIS) software. With this software the data can be read and mapped in order to study the locations of electricity infrastructure. The research will focus on the low and middle voltage grids, as these are the grids that directly impact households. The influence area of the high voltage grid is too large to pinpoint which neighbourhoods are affected by it.

To measure if there is a relation between the socioeconomic status and the amount of electricity infrastructure in a neighbourhood, a correlation analysis will be conducted. This method will allow for a lot of variables to be tested at the same time and give a clear picture of with which variables a neighbourhood is more likely to have a lot of infrastructure located in it. This way the assumption that wealthier neighbourhoods have more electricity infrastructure can be tested. It will also show which variables play an important role in the system and these variables will be further analysed in the rest of the report.
After the correlation analysis, a hotspot analysis will be conducted that will identify clusters for the socioeconomic indicators that had strong correlations in the previous analysis. This method will give a better spatial indication of the relation between socioeconomic status and electricity infrastructure, as this is missing in the correlation analysis. The variables with a strong relation identified in the correlation analysis will be used for this method. The locations of these clusters will then be compared to the areas were grid congestion is a problem and to the locations of planned investments. This will give insights in how the electricity grid will develop in the future and what types of regions are most invested in.

To help analyse the results and provide more understanding of how the system affects equality, expert interviews will be conducted. In these interviews the outcomes of the analyses and possible measures for improving equality in the energy transition will be discussed. This method was chosen as there is not much literature on the subject matter yet and interviewing experts from different backgrounds will give distinct insights in the working of the analysed system.

Based on the results of the research, an advice can be written for the province of South-Holland on how the investments in the electricity grid and socioeconomic characteristics are related and if they affect each other. This will give useful insights in how the electricity grid may be used to battle inequality, which can play a part in future decision-making concerning grid investments.

1-5 Research structure

The research report consists of 7 chapters, when not including this introduction. In chapter 2 the socioeconomic indicators with a connection to energy poverty and energy justice will be identified, answering the first sub-question. The variables selected in this chapter will be used throughout the whole research process.
Chapter 3 will describe the process of collecting the data that will be used and for the analyses. This will include mapping the electricity infrastructure in the province of South-Holland and answering the second sub-question.
After that, chapters 4 and 5 will show the performed analyses. These are the correlation and hotspot analysis respectively. In these chapters the answer to the third sub-question will be given and the relation between electricity infrastructure and socioeconomic status will be identified.
The 6th chapter will describe the expert interviews and review the insights provided by the participants. This will lead in the last two chapters in which the results of the research will first be discussed in chapter 7 and then final conclusions will be made in chapter 8.

Chapter 2

Identifying Socioeconomic Indicators

The first step in researching the correlations between socioeconomic indicators and electricity infrastructure is selecting the relevant socioeconomic factors to include in the analysis. To select the relevant indicators a literature review is conducted in which first two key concepts will be explained and then corresponding literature will be reviewed.

2-1 Key concepts

The key concepts identified are energy poverty and energy justice. The two concepts are explained below.

2-1-1 Energy Poverty

As discussed earlier, energy poverty is mainly defined as a household that spends more than 10% of its income on energy costs [57]. There are, however, other ways to measure energy poverty. In a report from TNO (2021) [68], three methods are described to define energy poverty.

The first method is the High Energy Quote (EQ). This is the most common method that defines energy poverty as the percentage of the total income spend on energy costs, with a common threshold of 10%.
The second method is the Low Income, High energy Costs (LIHC), which defines an energy poor household as a household with a low income and relatively high energy costs. In this method a low income is defined as an income among the lowest 25% of the Netherlands and high energy costs is defined as energy costs among the highest 50% of the Netherlands.
The third method is Low Income, Low Energy Label (LILLE). According to the LILLE method, a household qualifies as energy poor when it has an income among the lowest 25% of the Netherlands and lives in a house with an energy label of D or lower.
In a literature review from Siksnelyte-Butkien et al. (2021) [58], it is shown the EQ method is

the most used method to measure energy poverty in research with the LIHC method being a far second. This is because the EQ method is an easy to measure and objective indicator. It is also better usable for an international standard, as it can be communicated clearly. Some researchers also use access to clean energy to measure energy poverty [45, 26], but this is not a relevant indicator for the Netherlands as everyone has access to clean energy [15].
Despite most researchers using the EQ to define energy poverty, TNO (2021) [68] recommends using the LILLE method. This is because the EQ and LIHC methods do not measure hidden energy poverty. Hidden energy poverty is defined as a situation in which a household actively consumes less energy than needed for comfort in order to save costs, with possible negative consequences for health. By not only looking at energy costs the LILLE method also takes these households into account, giving a more complete picture of energy poverty. The downside of the LILLE method is, however, that the energy label is not clear for every house. The energy labels that are not known are estimated based on the characteristics of the neighbourhood.

Using the LILLE method, TNO concluded that energy poverty is most common in big cities and mostly occurs in houses owned by housing corporations, dated buildings and multi-family houses. As can be expected, the report also concludes energy poverty is more common among people in well-fare, social services or unemployment and people with disabilities or illness.
In other reports from TNO [65, 67, 70, 71], other characteristics of energy poor households are: low income, low education, poor quality housing, migrant background, social isolation, single parent and female. These characteristics are also mostly logical, except for female. This can, however, be explained by the fact that women are more prone to live in poverty and are over represented as single parents [11]. Numbers from TNO (2021) [67] also state that 75% of energy poor households live in homes owned by housing corporations and only 12% is a homeowner,a adding social housing to the list.
The characteristics of energy poverty show that there are often fundamental issues, like unemployment or ill health, at the base of the problems and that they are often stuck in a vicious circle of difficulties [71]. This means people in energy poverty require more structural support than just subsidies. Examples of this could be making houses more energy efficient or educating energy poor households on energy saving measures [70]. By creating measures specifically designed for the target group, energy poor households can be better helped, which will positively influence public support for the energy transition [65]. This will also help them see the energy transition as a fair development, which will further increase public support [66].

Public support is an important factor for a successful energy transition, as research indicates. Bayulgen (2020) [8] shows that towns in the United States, in which there is much public support for the energy transition, are better able to organise and realise policies that will further the transition. A report from Clingendael and Berenschot (2022) [17] also shows that public support is important. They argue that the energy transition should not be based on top-down policies, but on citizen initiatives in order to ensure public support. As this is currently not being done, research is needed on how conditions can be created in which everyone can benefit from the energy transition.

2-1-2 Energy Justice

A way to ensure public support for the energy transition is by promoting energy justice. Traditionally, energy policies were focused on how everyone should have access to energy and the main principles were: affordability, reliability and sustainability [19, 60]. With the development of the energy transition,however, the view on energy policies changed and energy justice became an important principle [20]. McCauley et al. (2013) [37] defines energy justice with three main principles:

- *Distributional justice*: a fair distribution of costs and benefits.
- *Procedural justice*: all stakeholders should be able to participate in the decision making process and be taken serious.
- *Recognition justice*: everyone must be fairly represented and no one should be excluded based on their identity.

To ensure public support and a just energy transition these three principles have to be met, but there is still a lot of work to be done before this is the case in the Netherlands.

Energy costs and benefits are currently not being divided evenly among the population. According to research from CE Delft (2021) [16], only 20% of the €750 million the Dutch government spent on climate subsidies in 2017, ended up with the half of the population with the lowest income. The other 80% was benefited from by the half of the population with the highest income. The main cause of this unbalanced distribution is the subsidy for driving EVs, but the higher income half of the population also profits more from almost all other forms of climate subsidy, such as subsidies for isolation and solar panels. The only subsidy the higher income half does not profit more from is the STEP subsidy, as this is a subsidy specifically meant for renters which are higher represented among the lower income half.

The procedural justice principle is also not met in the current situation. Especially renters and people in social housing participate significantly less in the decision making process of the energy transition, as they have little to none say about the sustainability measures taken for the home they live in according to a report from the Dutch ombudsman from 20202 [41]. The report also concludes that a lot of information about the energy transition is shared digitally and in technical language, which many people do not understand. This causes people to feel like they have no part to play in the transition.
This sentiment is further confirmed in research from Kennis Zuid-Holland (2022) [30], which states that a lot of people feel excluded from the energy transition, as they have no knowledge on the topic or feel like it is just a "party" for the rich and highly educated.

The shortcoming in recognition justice is shown by the fact that people with a migration background often feel excluded from policy making [30], as they are often badly informed and thus not aware of the possibilities they have. Other groups also have problems with recognition justice. Jenkins et al. (2016) [28], for example, states that the need for a higher base temperature for the elderly and sick are not recognised in the UK and probably many more countries.

2-2 Literature review

To identify the relevant socioeconomic variables of neighbourhoods, a literature review was preformed. In the literature review it was researched which variables have a connection with the earlier identified key concepts: energy poverty and energy justice.

A lot of literature concerning energy justice is not applicable for the research. For example, Sovacool et al. (2016) [60] defines principles for energy justice which are not easily measured (like due process, sustainability and transparency). By only focusing on measurable socioeconomic variables the selection of literature can be made a lot smaller.
Using Scopus, the following search terms were implemented: "socioeconomic variables" AND "energy justice", "characteristics" AND "energy justice" or "characteristics" AND "energy poverty". This led to wide arrange of hits (N=298), but by setting a range that excluded articles written before 2018 and by limiting the results to articles that had 'energy justice' or 'energy poverty' as a key word, the number of hits was reduced to 142. By arranging them on the number of citations, the most cited articles that included a list of socioeconomic variables for energy justice or poverty were selected. This resulted in a selection of 11 articles to be used in the research. The variables in the multiple articles from TNO, as described in the energy poverty section, will be included as the main indicators of the research.
A summarising of the variables listed in the articles can be found in the table below. Characteristics that are similar to each other have been grouped under umbrella terms in order to prevent a long list of similar factors.

Characteristic Author	Income	Wealth/poverty	Employment status	Level of education	Gender	Race/migration	Elderly	Health/ disability	Home value	Home ownership	Housing type	House construction year	Energy label house	Household size	Urbanisation	Population density	Connectedness to services	Energy consumption	Energy burden
TNO (multiple)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Popovich et al. (2024) [47]	X		X	X		X	X	X		X									
Baker et al. (2023) [6]	X																X	X	X
Min et al. (2023) [40]	X			X		X			X	X	X				X	X			
Chen et al. (2022) [24]			X	X							X	X	X	X					
Soriano et al. (2022) [59]	X																	X	X
Jenkins et al. (2021) [29]		X	X	X	X	X	X	X		X	X	X		X	X		X		X
Bao & Li (2020) [7]	X	X	X		X		X			X				X				X	
Debnath et al. (2020) [21]	X		X	X							X			X				X	
Gouveia et al. (2019) [27]	X		X	X			X			X			X						
Aristondo & Onaindia (2018) [5]			X	X	X	X		X		X	X			X		X			
Reames (2016) [52]	X	X		X		X	X			X	X	X							

Table 2-1: Overview of identified socioeconomic characteristics in the literature

In the table, it can be seen that a lot of widely used socioeconomic variables like income, level of education, age and race are included in the literature. These characteristics give a clear picture of the type of neighbourhood and will thus be included in the research. What is also noticeable, is that a lot of variables concern the housing situation of residents. The average house value and house ownership status are commonly used to determine the socioeconomic situation in a neighbourhood, but construction year and energy label are more focused on the topic of energy.

The most mentioned variables are income and level and education (mentioned in 9 of the articles) and after that employment status and house ownership (8 articles). These are all variables that are commonly associated with the financial means of a household, showing that financial status is the most important indicator for energy justice and energy poverty.
The least mentioned variable is home value (2 articles). This can be because a lot of the articles mention home ownership and home value might not be distinct enough from this to mention separately. Other less mentioned variables are energy label, urbanisation, population density and connectedness to services (all 3 articles). Energy label might be mentioned less, as it has similarities to house construction year. Urbanisation, population density and connectedness to services, also cover a lot of the same topics making them being likely to be mentioned separately less often.

Chapter 3

Data Collection

To evaluate the relation between electricity grid infrastructure and socioeconomic variables, relevant data has to be collected in order to perform a correlation research. First the process of gathering socioeconomic data is described. After that the methodology of collecting spatial data of electricity infrastructure is discussed.

3-1 Socioeconomic Data

Based on the selected socioeconomic variables in the previous chapter, accompanying data has to be gathered. This is done by collecting data from open sources and then filtering the data.

3-1-1 Data Selection

The data used in the research was selected based on the following requirements: timeliness, accuracy, completeness and accessibility. For the data to give the best representation of the current situation, it has to be timely, complete and accurate on a neighbourhood level. The data also has to be openly accessible to make it possible to repeat or check the research. To fulfill these criteria, it was decided to use data from the CBS. As the official data bank of the Netherlands, the CBS is a reliable, accurate and up-to-date source of open data. By searching for the socioeconomic variables in combination with 'neighbourhood level' on the CBS, the datasets could be found and downloaded.
First, the newest data sets (2023) were reviewed, but because of their recentness a lot of data points were missing. It was thus chosen to use data from 2022 as this was the most recent and relatively complete available, though there is still a lot of data missing (about 14%). The missing data in the CBS data sets were mostly missing due to privacy issues. For example, the income of neighbourhoods with less than 200 inhabitants is missing, to make it harder to find out the income of certain households. For neighbourhoods with less than a 100 inhabitants a lot more data (including home ownership, social benefits and level of education)

is also missing for this reason. The data from less populated neighbourhoods is also missing in older data sets, so empty data points could not be filled using these older sets.
The possibility of data imputation, a technique where missing data points are filled by taking averages of the data set [35], was also researched, but a downside of this method is that it cannot account for variation very well. Because there is a lot of variation between different neighbourhoods, even if they are adjacent, it was decided to not imputate the data so the results of the analyses would not be skewed.
A table describing the used variables and their original data set can be found in Table A-1.

3-1-2 Data Cleaning

As the selected data consisted of multiple datasets, they first had to be cleaned and standardised before they could be combined and analysed. For this process a combination of Python in Jupyter Notebook and Microsoft Excel was used.
First, only the neighbourhoods in the province of South-Holland were selected in the data sets, as this is the focus area of the research. The data was sorted per municipality, so in order to filter all neighbourhoods outside of South-Holland a list was created with all municipalities in the province. by selecting only the matching municipalities, all neighbourhoods outside the research area were filtered.

The data sets downloaded from the CBS also included a lot of variables that were not relevant for the research, like marital status, birth/death rate and car ownership, and thus had to be deleted. Some variables were presented in total numbers but had to be converted to percentages to compare neighbourhoods better. These variables were: number of male/female inhabitants, number of elderly, number of inhabitants with a migrant background, number of income receivers, number of social welfare receivers, level of education, number of businesses, number of labour participants and net electricity production. The calculated percentages of welfare receivers are not entirely accurate, as the total numbers have been rounded to the nearest ten in the CBS data. This also goes for the percentage of income receivers, as this variable is rounded to the nearest 100, making it even more inaccurate.
After this first round of cleaning, the data sets were evaluated again. This showed that a lot of the missing data came from neighbourhoods with 0 inhabitants and/or 0 households. As these neighbourhoods do not contribute to the research and their missing data influences the outcomes of the analysis, it was chosen to delete these neighbourhoods. The deleted neighbourhoods were mostly industrial areas or nature reserves, which both would have skewed the results of the analysis as they respectively use a lot of electricity and none at all.
When these neighbourhoods were deleted, there were still some variables that had a lot of missing data, namely: the average income of residents and households, which were only available for neighbourhoods with more than 2500 inhabitants, and the percentage of households connected to district heating, which only a few neighbourhoods have due to its relative novelty. Both of these variables would have been interesting to have in the analysis, but due to the lack of data they were deleted. There were also some variables with a lot of missing data that did not add much to the research, or were already (partly) included in other variables. Among these variables were the energy demand per housing type, which was deleted because the housing type differed too much per neighbourhood which made it impossible to compare. The percentage of residents among the 40% lowest and the 20% highest percentages of incomes were also deleted, as these values are also measured per household which fits better in

the research. Further there were four variables that measured the amount of households with low incomes. It was chosen to only keep percentage of households under or around the social minimum, so differences would be as clear as possible. Lastly, also the percentage of labourers per employment status (permanent, flexible, self-employed) were deleted as these variables did not add much to the research. By deleting these variables, the amount of missing data was brought back to 5.8%. If all the neighbourhoods with less than 100 inhabitants are deleted the percentage of missing data can be lowered to 1.8%. This, however, makes the research less complete because of the many excluded neighbourhoods. It was thus chosen to use the data set with 5.8% of the data missing because, while it is still a fair amount of missing data, it is acceptable for the research and it gives the most complete results.

3-1-3 Validation

In order to validate the data, the correlations between the selected socioeconomic variables are researched and it is checked if the expected outcomes are seen.
To calculate the correlations, Python in Jupyter Notebook was used. The Pearson correlations will be used throughout the research as a linear relation between two continuous variables is researched. The correlations are calculated using the following equation:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

where:

r : the correlation coefficient
n : the number of data points
x : the values of the first variable
y : the values of the second variable

The correlation matrix is shown in Table A-2. It can be seen that the logically expected correlations are accurately depicted. For example the positive and negative correlations between the level of education and income, the negative correlation between house ownership and poverty, the correlation between house construction year and energy label, and the positive correlation between the percentage of elderly and the amount of state pension receivers.
Correlations that are more relevant for the research are: higher income = higher energy demand, home ownership = higher energy demand and higher income = more self generated energy.

A problem with the data, however, is that because of the high percentage of missing data the p-values cannot be calculated correctly. This means the significance of the correlations cannot be tested and thus the correlations might be random.

With the data validated, the socioeconomic characteristics of neighbourhoods can be researched and correlations with electricity infrastructure can be identified.

3-2 Spatial Data

To analyse the correlations between electricity grid infrastructure and socioeconomic variables, the number of low and middle voltage stations in the neighbourhoods needed to be counted. To do this, spatial data from the grid operators was collected and merged with a neighbourhood map of South-Holland in ArcGIS [23].

3-2-1 Location Data

The location data from the grid operators is openly accessible from their websites in shapefile format, which is a storage format for geographic data used for spatial analysis. These shapefiles were uploaded into ArcGis and analysed.
The shapefiles included the location data of low and middle voltage stations and the location of the cabling of these grids. The cabling data was filtered out, because the cabling on the map only shows how the grid is laid and where the consumers are. This would be interesting if the research was done on a household level, but as the focus is on a neighbourhood level this is too specific and the cabling data does not add much relevance.
Stedin and Liander have a catchment area that includes more than only the province of South-Holland, so the stations outside of the research area had to be deleted. This was done by combining the location data with the data set of all neighbourhoods in South-Holland and excluding all neighbourhoods that did not match. This process resulted in the following map of low and middle voltage stations in South-Holland.

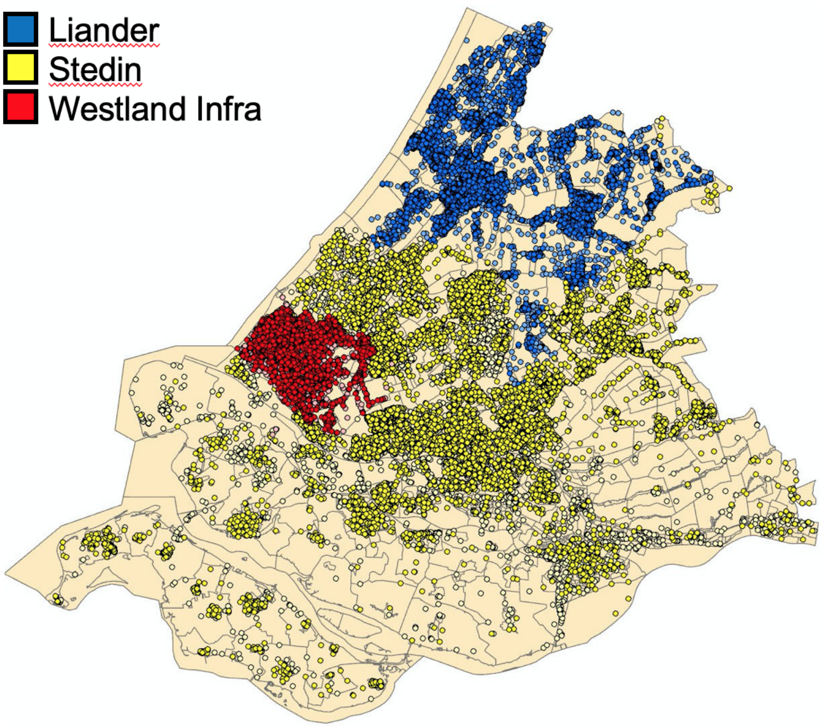

Figure 3-1: Map of all low and middle voltage stations in South-Holland

When looking at the map, a few things are instantly noticeable. There is a clear distinction

in the amount of electricity infrastructure between urban and rural areas. The Stedin areas of The Hague and Rotterdam (and everything in between) are full of stations, while the rest of the province, especially in the south and east, is much emptier. This can easily be explained by the fact that urban areas have more inhabitants and thus a larger electricity demand, which automatically results in more infrastructure being needed.
Exception to this is the Westland Infra catchment area. The whole area is full of stations, despite it not being an urban area but an agricultural area. This is also the reason why there is so much electricity infrastructure in this area. The Westland area is home to a large amount of greenhouses which produce a lot of energy. Greenhouses use gas to produce heat and light for the growth of their plants. A lot of the excess power and heat is converted to electricity and delivered back to the grid. Delivering electricity back to the grid requires a lot of infrastructure and thus electricity stations are plentiful in the area.
The number of stations was calculated by letting ArcGIS count the number of data points inside neighbourhood borders. Looking at the numbers of the stations per grid operator we can also see a lot of differences.

	Liander	Stedin	Westland Infra	**Total**
Low voltage stations	8522	10053	1835	**20413**
Middle voltage stations	3087	3501	1253	**7841**
Total stations	11609	13554	3088	**28254**
Stations per inhabitant	0.05153	0.05203	0.10449	**0.05391**
Stations per household	0.10347	0.09379	0.17172	**0.09878**

Table 3-1: Number of electricity stations per grid operator

Stedin has the most number of electricity stations in the province of South-Holland. This is because Stedin has the largest catchment area and because four of the five largest cities of the province (Dordrecht, The Hague, Rotterdam and Zoetermeer) are in this area.
Westland Infra has the smallest amount of stations, as they also have the smallest catchment area, but when looking at the number of stations per inhabitant and household they score the highest. As stated, this is because the Westland area is sparsely populated but has a large amount of greenhouses that require a lot of electricity. Another reason for the smaller amount of stations in the Westland area is the difference in capacity of the stations. For Liander and Stedin a low voltage station has a maximum voltage of 400 Volt (V) and a middle voltage station has a voltage between 400 V and 50 kilo Volt (kV). Westland Infra however, has low voltage stations with a maximum of 1 kV and middle voltage stations between 1 and 25 kV. Because the stations used by Westland Infra have a much higher capacity, less of them are needed to meet the electricity demand. The reason for the difference in capacity is the specific needs in the Westland area, where the greenhouse industry demands large amounts of energy and a robust infrastructure.
Also noticeable is that Stedin and Liander do not differ that much in the number of stations per inhabitant and household. The catchment area of both these operators consists of a combination of urban, rural and industrialised regions and thus the averages are pretty close.

With all data needed for the research collected, we can start analysing the correlations between the socioeconomic characteristics of the neighbourhoods and the amount of electricity infrastructure.

Chapter 4

Correlation Research

In order to discover if there is an identifiable relation between the identified socioeconomic variables and electricity grid infrastructure, a correlation research is conducted. For this, the correlations between the amount of electricity infrastructure in a neighbourhood and the socioeconomic characteristics of the neighbourhood are calculated, using Python in Jupyter Notebook, and evaluated. Using the created data set with socioeconomic variables combined with the number of stations per neighbourhood, the correlations between them are identified. For this, the same method as in subsection 3-1-3 is used. In the research it is assumed that the amount of electricity infrastructure is the dependent variable. Calculating the Pearson correlation gives us the correlation matrices that can be seen in Appendix B.

4-1 Overall correlations

First, we will look at the overall correlations between socioeconomic variables and electricity grid infrastructure. The results of the correlation research can be seen in section B-1. It can immediately be noticed that the correlations are pretty low overall and thus not much can be derived from them. As a lot of variables were researched, it was chosen to set a threshold for the strength of the correlations in order to only evaluate the strongest correlations. The minimum strength of 0.3 is chosen for this, as it is a common threshold in correlation research. When only selecting correlations higher than 0.3 or lower than -0.3, as they are strong enough to indicate a direct relation, we get Table 4-1 seen below.

In the table, it can be seen that all the remaining correlations barely score higher than 0.3 and all correlations are positive, meaning a higher value for the socioeconomic factor means more electricity stations. The indicators which remain are all variables that indicate the number of residents in a neighbourhood, meaning that the only thing that indicates a higher number of electricity grid stations in a neighbourhood is the amount of inhabitants. This is a logical correlation as a higher number of inhabitants means a higher electricity demand, and thus a higher number of stations to meet this demand.
Further, the middle voltage column has been deleted as all values in this column were below

	Low voltage	Total
Number of residents	0.37	0.33
Total number of households	0.38	0.34
Housing stock	0.38	0.33
Number of businesses	0.3	0.32
Number of labour participants in total population	0.37	0.33
Number of labour participants of working population	0.38	0.34

Table 4-1: Correlations (higher than 0.3 or lower than -0.3) between socioeconomic variables and the number of electricity stations on a neighbourhood level in South-Holland

0.3. In Table B-1 we can see that the correlations for the middle voltage are all very low and thus the number of middle voltage stations has no direct correlation with any of the selected socioeconomic indicators.

If the correlations would have been high enough, a direct relation could have been shown and conclusions could have been made. As the correlations for the total number of stations in a neighbourhood are too low to derive definitive conclusions from, the correlations were recalculated for the number of stations in a neighbourhood per resident and per household. By doing this, the correlations for the amount of inhabitants of a neighbourhood are less dominant and a fairer comparison between neighbourhoods can be made. These results can be seen in Table B-2.
When we filter out the values between -0.3 and 0.3 again, we end up with Table 4-2 below.

	Stations per resident	Stations per household
Median worth of individual households	0.24	0.32
Number of businesses per resident	0.59	0.66
Number of businesses per household	0.45	0.63
Percentage of employed labourers in working population	-0.34	-0.41
Average surface area of residence in neighbourhood	0.44	0.48

Table 4-2: Correlations (higher than 0.3 or lower than -0.3) between socioeconomic variables and the number of electricity stations per resident and per household on a neighbourhood level in South-Holland

The table shows completely different socioeconomic indicators than Table 4-1. The high correlations for the number of businesses per resident and household can be explained by the fact that both variables show a number of infrastructures divided by the number of inhabitants. The number of businesses and the amount of station also have a positive correlation which means the values will be close to each other and thus have a strong correlation. Therefore, these correlations do not show a direct causation and will not be further evaluated.
The other variables do show correlations that support the assumption of wealthier neighbourhoods having more electricity infrastructure. The median worth of a household and the average surface area of a residence are both variables that indicate a prosperous neighbourhood, and the positive correlations indicate they have a higher amount of electricity stations per resident/household. When looking at the negative correlations of percentage of employed labourers in the working population, one might think this contradicts the previous assumption. When we, however, revisit the correlations in Table A-2, it can be seen that the percentage of employed labourers correlates negatively with the values that indicate prosper-

ity (such as the percentage of high incomes, the median worth of a household and energy demand). this thus means that these negative correlations also support the assumption that wealthier neighbourhoods have more electricity infrastructure. It should be noted, however, that the correlations are still relatively weak and thus undisputed conclusions cannot be made yet. Further research will be required to explain the results and come to a definitive result.

4-2 Correlations per grid operator

Because the results of the overall correlations in the previous section were not conclusive and needed to be researched further, it was chosen to see if there are a lot of differences to be found in the results per grid operator. This way the differences between the three grid operators and their catchment areas can be analysed in order to identify the effect of varying types of urbanisation and land use, especially for the Westland Infra area. For this, the neighbourhoods were divided per responsible grid operator and the correlations were calculate again. These results can be seen in section B-2.
At first glance these results show a larger amount of high correlations, but also a lot of differences between the different grid operators. Liander and Stedin overall have the same direction in their correlations, although the correlations for Liander are stronger, but Westland Infra differs a lot from the other two. Explanations for this are the amount of greenhouses in the catchment area of Westland Infra and the differences in their way of operating (as explained in subsection 3-2-1).
Only looking at the strong correlations (higher than 0.3 or lower than -0.3) reveals the table as seen in Table 4-3.
A remark with these numbers is that some neighbourhoods have stations from multiple grid operators located in them. As the analyses only allows for one type of grid operator per neighbourhood, this complicates the analysis as neighbourhoods would have to be replicated for different grid operators. To make the analysis easier, it was chosen to only select one grid operator per neighbourhood. Any stations from other grid operators were added to the dominant operator. As this only concerns a small number of stations, it has little to no effect on the outcomes.

Comparing this table with Table 4-1 and Table 4-2, it can be seen there are a lot more variables with strong correlations. This can be explained by the fact that the evaluated area per grid operator is smaller, so correlations can become more apparent. This is seen in the results as Stedin has the largest catchment area in the province of South-Holland and also the weakest correlations. Because the area Stedin operates in is a mixture of both rural and urban areas, the total correlations cancel each other out resulting in weaker correlations than Liander which operates in a smaller area with less differences in urbanisation.
The strongest correlations in the table are still variables that indicate the number of inhabitants of a neighbourhood, as was the case with the overall correlations. This shows that the number of inhabitants in a neighbourhood is the best indicator for the amount of stations. These correlations are strongest for the Liander area and weakest for the Westland Infra area, with Stedin in between. This again can be explained by the population density of the catchment areas. For the variables that indicate population density and urbanisation, Westland Infra and Liander score opposite correlations. In the Westland Infra area, a higher population density and degree of urbanisation mean less stations, while these variables correlate

	Westland Total	Stedin Total	Liander Total
Number of residents	0.4	0.5	0.69
Percentage of inhabitants with a migrant background	0.05	0.22	0.38
Total number of households	0.41	0.51	0.75
Average size household	0	-0.18	-0.31
Population density	-0.26	0.1	0.37
Housing stock	0.35	0.51	0.75
Average property value	0.26	-0.08	-0.27
Percentage private owned residences	0.2	-0.19	-0.39
Percentage rented residences	-0.2	0.19	0.39
Percentage housing corporation owned residences	-0.27	0.12	0.38
Average electricity demand for all housing types	0.23	-0.16	-0.4
Electricity demand rented residence	0.3	-0.04	-0.27
Electricity demand private owned residence	0.23	-0.14	-0.37
Average gas demand for all housing types	0.21	-0.16	-0.34
Gas demand rented residence	0.31	-0.07	-0.25
Gas demand private owned residence	0.19	-0.15	-0.32
Percentage of households among the lowest 40% of national income	0.06	0.13	0.43
Percentage of households among the highest 20% of national income	0.18	-0.09	-0.39
Percentage of households under or around the social minimum income	-0.17	0.12	0.47
Median worth of individual households	0.37	-0.08	-0.27
Percentage of residents with social welfare benefits	-0.15	0.13	0.46
Number of businesses	0.78	0.5	0.59
Number of schools within 3 km road distance	-0.02	0.13	0.42
Degree of urbanisation	0.12	-0.16	-0.42
Number of labour participants in total population	0.44	0.5	0.7
Number of labour participants of working population	0.46	0.5	0.66
Percentage of employed labourers	-0.38	-0.01	0.23

Table 4-3: Correlations (higher than 0.3 or lower than -0.3) between socioeconomic variables and the number of electricity stations on a neighbourhood level in South-Holland per grid operator

positively for Liander and Stedin. This automatically indicates that a bigger population will result in lesser stations for the Westland Infra area than the other two catchment areas.
Another noticeable difference between the grid operators is the conflicting direction in correlations for electricity demand. For the Westland Infra area there is a small positive correlation for energy demand and the number of stations, while these correlations are negative for the Stedin and Liander areas. The positive correlation for Westland Infra can be explained by the fact they have a higher average energy demand (as seen in the data) because of the large amount of businesses among their clients. This is further confirmed by the higher correlation for the number of businesses.
The negative correlation for Stedin and Liander raises some questions. It would be far more logical if a higher electricity demand results in a higher amount of electricity stations, but the opposite is the case. By reviewing the correlation matrix in Table A-2, we can find an answer for this unexpected result. The fact that lower income households use less electricity and a higher population density means more low income households, indicates that densely populated areas have a lower average energy demand when compared to less densely populated regions. This means a single electricity station can provide in demand for more households in an urbanised area than in a rural area, explaining the negative direction of the correlations. A station in a rural area might also not be used to its full potential, as there are not not enough consumers to utilise it, which would mean the amount of electricity stations does not necessarily correlate with the average demand.

When we start looking at the variables that indicate welfare in neighbourhoods, there is also a lot of variance to be found between grid operators. As with the energy demand, most variables that indicate a wealthy neighbourhood correlate negatively with the number of electricity stations. For example the average property value, the percentage of private owned residences, the percentage of high income households and the median worth of a household, all correlate negatively for the Liander area, while a positive correlation would be expected based on the assumptions made in the research. Meanwhile the variables that indicate less prosperous neighbourhoods, like the percentage of migrant residents, the percentage housing corporation owned residences, percentage low income households and percentage of residents in social welfare, all correlate positively with the number of stations. Also remarkable is that these correlations are much lower for Stedin, and even opposite for Westland Infra. This means there is little connection between welfare and the number of stations in the Stedin catchment area, while in the Westland Infra region the expected correlations are confirmed.
For the explanation of these correlations, we again look at the matrix in Table A-2. As stated, lower income households often live in more densely populated areas and thus more electricity infrastructure would be needed to meet the demand of the larger numbers of inhabitants. For example, residences owned by housing corporations are mostly smaller than private owned residences and are meant for low income renters. This means that neighbourhoods with a lot of housing corporation owned residences are more densely populated and thus require more electricity infrastructure.
In the Westland region, this logic goes the other way around. Because the more densely populated living areas have a smaller energy demand than the lesser populated neighbourhoods with a lot of greenhouses. Because of this there is a negative correlation with population density. This also means the lower income, more populated, regions require less stations when compared to the greenhouse areas and this thus explains the difference in correlations between Westland Infra and Liander.

To see if looking at the number of stations per resident and household will make as much of a difference as in the previous section, these correlations were also calculated. The full matrix with these values is seen in Table B-4.
The cleaned matrix with only values higher than 0.3 or lower than -0.3 is depicted below.

In this new table, there is a positive correlation between the amount of stations per resident/household and the energy demand, which is more in line with expectations than the negative correlation from the total amount of stations. The directions of the correlations remain overall the same, but immediately noticeable are the higher correlation values, and especially the ones for Westland Infra. While the strongest correlations in Table 4-3 were mostly around 0.4, in this table Westland Infra has correlations as high as 0.83 (not counting the number of business per resident and household as explained in section 4-1). The highest correlations are, surprisingly, with the percentage of male residents and the percentage of elderly residents. When comparing the average percentage of male and elderly residents in the catchment areas, Westland Infra only scores 1 or 2% higher on both variables than the other two grid operators (52% vs 50% male; 22% vs 21% elderly), so proportionally there are not abnormally less female or younger citizens when compared to the rest of South-Holland. Looking further into the base data, an explanation for this correlation was found. There are two neighbourhoods in the Westland Infra area with a 100% elderly male residents and both these neighbourhoods happen to have a large amount of stations in them. These two values skew the curve and cause the big correlations, so therefore these correlations can be ignored.

	Westland per resident	Stedin per resident	Linader per resident		Westland per household	Stedin per household	Liander per household
Number of residents	-0.24	-0.07	-0.19		-0.33	-0.11	-0.22
Percentage of male inhabitants	0.83	0.14	-0.25		0.82	0.17	-0.07
Percentge of 65+ inhabitants	0.72	0.06	-0.17		0.67	0.06	-0.14
Total number of households	-0.23	-0.06	-0.17		-0.33	-0.1	-0.21
Population density	-0.74	-0.18	-0.19		-0.76	-0.24	-0.23
Housing stock	-0.23	-0.07	-0.17		-0.33	-0.1	-0.21
Average property value	0.53	0.18	0.05		0.58	0.23	0.08
Percentage private owned residences	0.48	0.05	-0.04		0.51	0.09	0
Percentage rented residences	-0.47	-0.05	0.04		-0.51	-0.09	0
Percentage housing corporation owned residences	-0.63	-0.2	-0.09		-0.66	-0.22	-0.2
Average electricity demand for all housing types	0.67	0.12	0.23		0.69	0.22	0.31
Electricity demand rented residence	0.72	0.08	0.31		0.79	0.17	0.34
Electricity demand private owned residence	0.62	0.19	0.16		0.63	0.29	0.28
Average gas demand for all housing types	0.63	0.15	0.19		0.63	0.22	0.26
Gas demand rented residence	0.64	0.13	0.21		0.7	0.18	0.28
Gas demand private owned residence	0.58	0.16	0.19		0.58	0.22	0.25
Percentage of income receivers	-0.41	-0.21	-0.35		-0.4	-0.3	-0.37
Percentage of households among the lowest 40% of national income	0.28	-0.03	0.29		0.02	-0.11	0.1
Percentage of households among the highest 20% of national income	0.17	0.1	-0.18		0.38	0.19	-0.02
Percentage of households under or around the social minimum income	-0.28	-0.07	0.31		-0.37	-0.11	0.18
Median worth of individual households	0.42	0.24	-0.01		0.64	0.31	0.09
Percentage of residents with retirement pension	-0.32	-0.13	-0.25		-0.34	-0.19	-0.24
Number of businesses per resident	0.96	0.56	0.78		0.94	0.63	0.89
Number of businesses per household	0.96	0.41	0.71		0.95	0.59	0.89
Average distance to general practitioner	0.37	0.13	0.14		0.44	0.16	0.18
Average distance to big supermarket	0.4	0.08	0.08		0.44	0.13	0.12
Average distance to day-care centre	0.47	0.12	0.13		0.55	0.16	0.16
Average distance to school	0.43	0.17	0.16		0.49	0.22	0.21
Number of labour participants in total population	-0.23	-0.07	-0.18		-0.33	-0.1	-0.22
Number of labour participants of working population	-0.23	-0.07	-0.19		-0.33	-0.11	-0.23
Net percentage of labour participation	0.35	0.11	-0.13		0.38	0.16	-0.02
Percentage of employed labourers in working population	-0.55	-0.38	-0.27		-0.71	-0.43	-0.36
Average surface area of residence in neighbourhood	0.46	0.47	0.31		0.53	0.52	0.32

Table 4-4: Correlations (higher than 0.3 or lower than -0.3) between socioeconomic variables and the number of electricity stations per resident and household on a neighbourhood level in South-Holland per grid operator

Without these two variables, Westland Infra has really strong positive correlations with the average property value, the percentage of privately owned residences and the energy demand, while having strong negative correlations with the population density, the percentage of rented or corporation owned residences and the percentage employed labourers in the working population. This indicates that most of the electricity infrastructure in the Westland area is located outside of densely populated areas. Mostly this will be caused by the greenhouses in the region and the increased efficiency if stations are as close as possible to the consumer. The property value and percentage of privately owned will also be higher in less populated areas and the percentage of workers will be lower, thus explaining the rest of the correlations. The correlations for Stedin are overall pretty low again. The only outliers being the negative correlation with the percentage of employed labourers in the working population and the positive correlation with the average surface area of residences. These correlations would support the assumption of there being more electricity infrastructure in wealthier neighbourhoods. This is backed up further with some lower, but also positive, correlations for the average property value, percentage of high incomes and median worth. The correlations are too low however to make any concluding remarks about this.
Liander has about the same direction in correlations as Stedin, but they are mostly a bit stronger. There are, however, not any real outliers that have not been addressed yet or are worth discussing further.

4-3 Testing other variables

The correlations found in the research give some insights in the distribution of electricity infrastructure between neighbourhoods, but as the correlations are overall pretty low and found correlations might be coincidental, it was chosen to repeat the correlation analysis with a few other socioeconomic variables. The variables are: the SES-WOA (SocioEconomic Score

- Wealth, Education and Employment) score, Energy poverty and health statistics. These variables were considered to be included in the original data set, but as there were no complete or up-to-date data for these variables, it was chosen to not use them.
Because the used data is older than 2022, the neighbourhoods were different from the original data sets. Neighbourhood names and borders are different and some municipalities have been added or combined. This is why the data had to cleaned and combined with the spatial data again. Because of the differences in neighbourhoods, it is difficult to compare the correlations of the original used data set with the new variables. Another disclaimer is that there is no historical data, so maybe there are a few stations included that did not exist when the socioeconomic data was collected.

The first of the new variables tested is the SES-WOA score [12]. This is a socioeconomic score devised by the CBS in order to give a complete picture of the the status in an area. The score combines different types of socioeconomic factors and generates a standardised output, which makes it easier to compare different regions to one another. The most recent data available for the SES-WOA score is from 2019 and the data set has a lot of missing data, with almost 30% of the cells empty. Because of this no concluding remarks can be made with the data, but an indication of a relation might be given.
The second variable is energy poverty [13], which has been introduced in subsection 2-1-1. In the data set, the energy poverty score for each different method is measured for the neighbourhoods in South-Holland. The energy poverty data is from 2020, which makes it a bit more recent than the SES-WOA score, but still not comparable to the 2022 data. The data set also has a missing data percentage of about 20% which makes it difficult to draw any conclusions from the results.
The last variable is health. As mentioned in section 2-2, bad health is one of the indicators for energy poverty and energy justice and can thus be used for the correlation research. It was considered to use the data for the main research, but as the percentage of inhabitants with disability benefits is included in the main data set and the health statistics are rather extensive, it was chosen not to include them. The data, however, is from 2022 and almost fully complete so the found correlations can be used to compare with the main findings.

For these three variables the correlations with the number of electricity stations are calculated and the resulting matrices can be seen in section B-3. These three variables all correlate highly with the degree of urbanisation. In areas with a high degree of urbanisation, people have a lower SES-WOA score, lower health statistics and suffer from energy poverty more often. These are, however, also the areas where the most electricity infrastructure is located. A positive correlation thus would have been expected, especially with the variables all having a strong connection to energy justice and energy poverty. All correlation values are between 0.3 and -0.3, which indicates there are no strong relations between the variables and electricity infrastructure.
The lack of correlation might be explained by the amount of missing data (30% for the SES-WOA score, 20% for energy poverty). This explanation, however, does not apply for the health statistics as this set had almost no missing data. The lack of correlation for this data is a bit more difficult to explain. The health statistics do heavily correlate with the selected socioeconomic indicators in the main data set, as seen in Table B-8. The explanation for this thus might be that these medical conditions are too broadly distributed in the population, making it difficult to find clear correlations as was the case with the main data set.

4-4 Correlation results

With the correlation analysis complete, there are still no clear assumptions to be made. It was notable that there were strong variations between the three grid operators active in the province, but these differences could easily be explained by analysing the composition of the individual catchment areas.
The lack of strong correlations can be explained by the large amount of neighbourhoods researched. A total of 2198 neighbourhoods were included in the research which all vary a lot in terms of size and socioeconomic status. Throwing all these neighbourhoods in one analysis might not result in definitive conclusions, but the patterns discovered do give insights in the system. It is shown that there is more infrastructure in neighbourhoods with variables that indicate prosperity and that there are big differences between rural and urban areas. The correlation analysis also helped with identifying the most relevant variables that should be included in the next analysis.

Chapter 5

Hotspot Analysis

As the correlation research did not result in definitive conclusions, another method was chosen to identify relations between socioeconomic indicators and electricity infrastructure. The selected method is the hotspot analysis, as demonstrated by Casali et al. (2024) [10]. This method was chosen as it is better suited for studying spatial factors than the correlation analysis.
In this chapter, a hotspot analysis will be performed to identify areas where certain socioeconomic indicators that have a strong correlation with the amount of electricity infrastructure are dominant and where not. The maps created in the analysis will then be compared with the congestion maps and investment plans of the grid operators, in order to see which areas overlap with each other.

5-1 Hotspots

Hotspots are areas in which the concentration of a certain value is higher than expected, given a random distribution. A hotspot analysis identifies these clusters with a high concentration of the selected spatial value within a data set [18]. An area can score low on a certain value and this is called a coldspot. The hot- and coldspots make it easy to see where certain socioeconomic are more common and where not. This gives a clear overview of the differences between areas, as you can easily compare the spots on the map and see which variables overlap or differ.
For a hot- or coldspot to be statistically significant, its neighbours should also have high (or low) values for the chosen indicator. In order to identify the hotspots the analysis makes use of spatial autocorrelations, a statistical property that indicates the degree to which spatial data points correlate, to measure how much neighbouring areas resemble each other based on the selected variables.
To measure hotspots, the Getis-Ord GI* statistic is used with the following equation [25]:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij} x_j - \bar{X} \sum_{j=1}^{n} w_{ij}}{S \sqrt{\frac{[n \sum_{j=1}^{n} w_{ij}^2 - (\sum_{j=1}^{n} w_{ij})^2]}{n-1}}}$$

where:

$$G_i^* : \text{the Getis-Ord Gi* statistic for neighbourhood i}$$
$$x_j : \text{the attribute for neighbourhood j}$$
$$w_i j : \text{the spatial weight between neighbourhood i and j}$$
$$\bar{X} : \text{the mean of the attribute values}$$
$$S : \text{the standard deviation of the attribute values}$$
$$n : \text{the number of neighbourhoods}$$

With this formula, the hot and cold clusters of selected socioeconomic variables in the province of South-Holland can be identified and the relations with the distribution of electricity grid stations can be studied.

5-2 Identifying hotspots

In the research, the optimised hotspot analysis tool in ArcGIS will be used [4]. The optimised hotspot analysis tool is chosen over the standard hotspot analysis tool, as it automatically selects the critical parameters used for the analysis and corrects the results when necessary. For example, the tool selects the optimal scale for the analysis and has a False Discovery Rate (FDR) correction. This makes it easier to perform the analysis and helps the results become more reliable.
To perform the optimised hotspot analysis in ArcGIS, the same dataset will be used as for the correlation analysis. The data is uploaded in ArcGIS and combined with the map of South-Holland and the location data of the electricity stations in order to measure the clusters for all relevant variables. For the analysis a fixed distance band was used, as the optimised hotspot analysis tool deemed this the best scale for the analysis. With a fixed distance band, the analysis ensures that each neighbourhood has at least one neighbour and that the distance between different neighbourhoods does not matter.
The optimised hotspot analysis could only be performed for one variable at a time, so unfortunately no hotspots with multiple socioeconomic characteristics can be identified in the analysis. The different maps with the resulting hot- and coldspots can be seen in section C-1.

When analysing the maps, the most evident differences in hot- and coldspots can be seen between rural and urban areas. The areas around the big cities in South-Holland (The Hague, Leiden and Rotterdam) are hot- or coldspots for almost every variable, while the more rural areas in the province are often the opposite colour. This is most evident in the maps showing variables related to the number of inhabitants (Figure C-1, Figure C-2, Figure C-3, Figure C-4, Figure C-15, Figure C-16), but can, for example, also be seen in the maps shwowing the percentages of private owned, rented or corporation owned residences (Figure C-6, Figure C-7, Figure C-8). On these maps it can be seen that the big cities are hotspots for the percentage of rented and corporation owned properties and coldspots for the percentage of private owned residences. These hot- and coldspots are reversed for the more rural areas in the east and south of the province.
Some of the resulting maps are not so useful for the analysis. The map for the percentage of

inhabitants with social benefits (Figure C-14) show only a few small hotspots in neighbourhoods while showing no coldspots. These hotspots are in the lower income neighbourhoods of Dordrecht, The Hague and Rotterdam, and also in Nissewaard, which is also known as a lower income area. The map showing the number of low and middle voltage stations per resident (Figure C-25) is also not useful for the analysis. As can be seen, there is only one hotspot, which is the Maasvlakte. This is the industrialised area of the Port of Rotterdam and thus has a huge electricity demand, while having very little inhabitants. This skews the analysis, making it the only hotspot.

When looking at the hotspots of socioeconomic variables, we can see that the big cities are often hotspots for indicators associated with a lower socioeconomic status. This can most clearly be seen in the SES-WOA score map (Figure C-19). This is because there are more low income households in big cities, as can be seen in the correlations between low-income and population density. On the SES-WOA it is also notable that the catchment area of Liander has only hotspots for this variable. This shows that there are a lot more well-off neighbourhoods in this area than in the Stedin and Westland Infra regions.

5-3 Congestion maps

To analyse the relations between the hotspots and the investments in the electricity grid, the hotspot maps will be compared with the congestion maps published by the grid operators [33, 63]. The congested areas were chosen for the analysis, as these are the regions were the amount of electricity infrastructure is insufficient. By looking at which variables are dominant in these areas, it can be researched what the socioeconomic status in the neighbourhoods with a lack of infrastructure is.

5-3-1 Analysing congestion maps

Only Liander and Stedin have published maps showing the congestion on the grid and these can be seen in section C-2. Westland Infra has not published a map of their electricity grid congestion, but states they do not experience congestion for the consumption and only have problems with the feed-in of electricity on the grid [75]. They explain the absence of congestion on the consumption side is because they invested heavily in their grid since a shortage about 15 years ago. Since then, Westland Infra has created a high-quality grid that has not suffered from congestion yet.

When looking at the congestion maps of Stedin, it can be seen that the province of South-Holland has relatively little congestion when compared with the rest of their catchment area. Especially for the feed-in congestion, shown in Figure C-27, South-Holland has little issues while the whole province of Utrecht is in the red and also a large part of the province Zeeland has trouble with congestion. According to interviews with employees of Stedin, the reason why South-Holland has relatively less congestion is because the province is a 'consumer' region as it has a large amount of inhabitants and a high degree of urbanisation with little available space. Because of this, it is very hard to find suitable locations for wind and solar energy parks. In contrast to South-Holland, the provinces of Utrecht and Zeeland have more available space which can be used for the production of sustainable energy. These wind and solar parks, however, are a huge burden for the electricity grid and because the generated electricity often has to be transported to other areas, it results in a lot of strain on the network. In the province of South-Holland, the produced energy is often directly used in close proximity to the source. Especially in cities, the generated electricity from, for example, solar panels is used in the city and this causes less stress for the grid. This is why there is more congestion in other provinces when compared to South-Holland.

Combining the congestion maps of Liander and Stedin results in a better overview of the congestion areas in South-Holland. The combined maps are shown below.

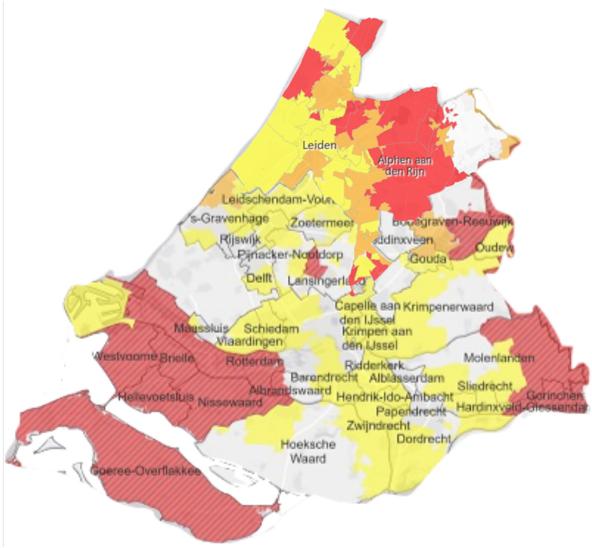

Figure 5-1: Congestion map for electricity consumption in South-Holland

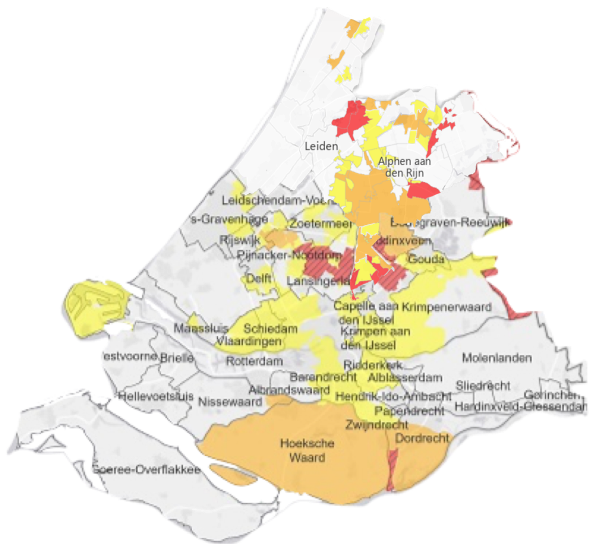

Figure 5-2: Congestion map for electricity feed-in in South-Holland

The combined figures show that South-Holland mostly has problems with the consumption. Notable is that the consumption congestion is mostly outside of the urban areas. This is caused by the larger amount of industry and agricultural businesses located outside of densely

populated areas and their larger energy consumption and production.
As mentioned a little earlier, South-Holland is a 'consumption' region, which results in the generated electricity being mostly self-consumed by the producer and thus having a lot of free capacity. Only in the areas where solar and wind parks are located further away from densely populated areas, you can see some yellow and orange areas with red areas being rare.

5-3-2 Relation congestion and hotspots

When the maps are compared to the maps from the hotspot analysis in section C-1, some relations can be identified. The consumption map shows that most of the congestion is in sparsely populated, non-urban, areas with a high electricity demand and high amounts of self produced electricity. When looking more at the socioeconomic side, notable similarities can be seen with hotspots for a high percentage of private owned residences, high average property values and a high median worth of households. In line with those indicators, more congestion can be seen in areas with less housing corporation owned residences and low-income households. Also the hotspots for the SES-WOA score match relatively well with the areas where there is more congestion. Especially the financial and employment scores have their hotspots in congested regions. The SES-WOA spread score further shows that congested areas are very homogeneous, meaning there are little differences in socioeconomic status of inhabitants of the neighbourhoods with a high SES-WOA score. The SES-WOA score map also shows that most high scoring areas are in the Liander catchment area in the north of the province. This is also the most congested area, further showing the relation between consumption congestion and socioeconomic prosperity. The same goes for energy poverty (Figure C-23. In the Liander area there are coldspots for energy poverty in the most congested districts. For Stedin however, this relation is not shown as there are no hot- or coldspots in their red areas.
In the Stedin region, there are also interesting differences in the Voorne-Putte territory which is heavily congested. The west of the region, around Westvoorne, is a hotspot for indicators that imply prosperity, while the east of the congested area, around Nissewaard, is a coldspot for these variables. Both areas are in the highly congested zone, but are opposites of each other based on their socioeconomic status. This can be explained by the fact that the congestion happens on the higher grid levels, which affects the entire region and thus differences inside the region are less apparent.
Looking at the feed-in congestion map, many of the same matches with hotspots can be found. The feed-in congested regions are also areas with coldspots for the degree of urbanisation and population density, while having a high energy demand and more self produced energy. There is also the same connection with high income neighbourhoods, high percentage of private owned residences, high property values and the SES-WOA score. Differences are that the feed-in map also shows that feed-in congestion is most common in areas with hotspots with a high labour participation and a large number of total stations, while having no match with the total number of inhabitants and households.

Although the areas on the maps often do not match one on one, it is still noteworthy that a lot of hotspots for socioeconomic variables that indicate prosperity are in the most congested regions. This suggests there might be a relation between socioeconomic welfare and electricity grid congestion. This relation may be caused by the fact that congestion mostly appears outside of the bigger cities. As discussed in the previous chapter, the percentage of lower

income households tends to be higher in densely populated regions and are thus affected less by the congestion. That the congestion happens more in wealthier areas can further be explained by their higher electricity demand and higher percentage of self produced electricity. When looking at the hotspot maps for these variables (Figure C-9, Figure C-18) we can see that these maps heavily match with both congestion maps. As wealthier households use and produce more electricity, it is a logical effect that congestion is a bigger problem in more prosperous areas.
A problem with the congestion maps, however, is that industrial consumers and producers are included in them. As the maps are produced by the grid operators to show the congestion on their full grid, these consumers could be filtered out. In the maps from the hotspot analysis, the industrial consumers and producers are filtered out. It can be seen on the maps that the most congested areas are in region with a lot of industry, like the Port of Rotterdam along the Meuse, and it can be assumed the congestion is mainly caused by these actors.

5-4 Investment plans

In order to further analyse socioeconomic status of the areas in which grid operators will invest, the maps showing the planned investments will be compared with the hotspot maps. The future investments show how the electricity grid will develop in the near future and what type of areas will benefit the most from the developments.

5-4-1 Analysing planned investments

The maps with planned investments from Liander and Stedin are shown below [34, 64]. Westland Infra has not produced a map with an overview of their planned investments so their catchment area will not be considered in the analysis.
On the maps there are a number of blocks in different colours and different sizes. White blocks indicate existing stations that do not require change, blue blocks are stations scheduled for expansion or replacement and yellow blocks are new to build stations. The three different sizes indicate: 150 kV stations (big blocks), 50 kV stations (small blocks) and 20-10 kV stations (small cylinders). The coloured lines on the map indicate the different electricity cables of the high voltage grid. In the report the focus has been on the low and middle voltage grid so far, but as grid operators can not share information about investments on the low voltage grid we will have to look at the higher voltages. The high voltage stations (big blocks) will not be considered, but the middle voltage stations, represented by the smallest blocks, are analysed.

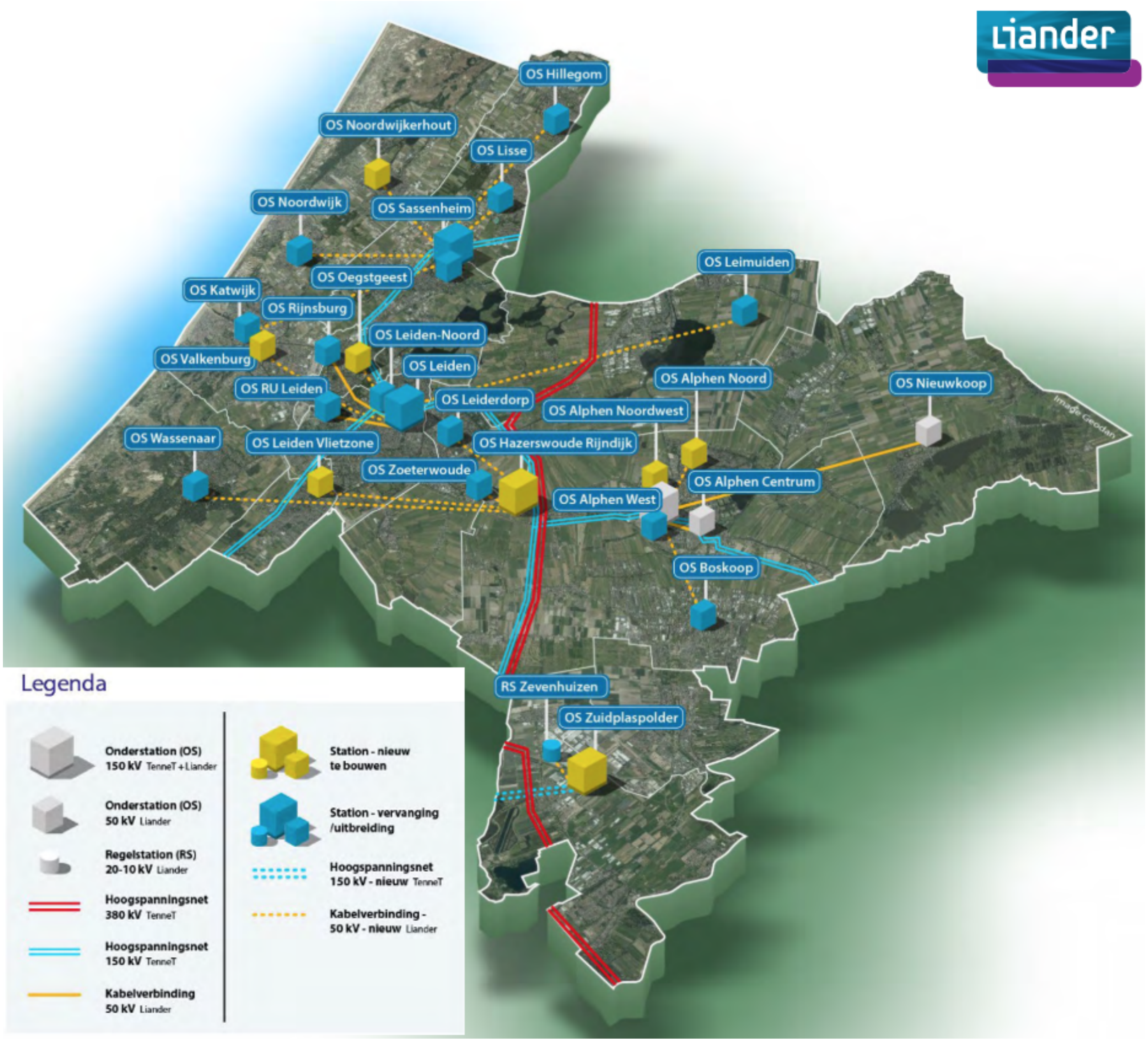

Figure 5-3: Planned investments of Liander in South-Holland

In the Liander catchment area, we can see that most planned investments involve the expansion of existing infrastructure. Especially in the area around the city of Leiden and in the north-east of the province, a lot of stations require replacement or expansion. When comparing this to the congestion maps from section 5-3, this can be explained by the consumption congestion in the area. We can also see that are some investments around Alphen aan den Rijn and more to the South in the Zuidplaspolder, which are also areas with a lot of consumption congestion.
Looking at the feed-in congestion map, there are a lot less investments in feed-in congested areas than in consumption congestion areas. This is a result of consumption congestion being higher on the agenda than feed-in congestion. When an area experiences feed-in congestion the only negative effect is that no new solar panels or wind turbines can be attached to the grid or people can not use their solar panels to their full potential, while with consumption congestion no new connections can be made to the grid. This means that newly constructed homes or businesses cannot get electricity.

Further noticeable is that most investments involve the bigger stations. There is only one expansion planned for a middle voltage station at Zevenhuizen. This is because a lot of the congestion is caused by congestion on the higher grid levels. By tackling these issues, congestion on the lower grids can be prevented.

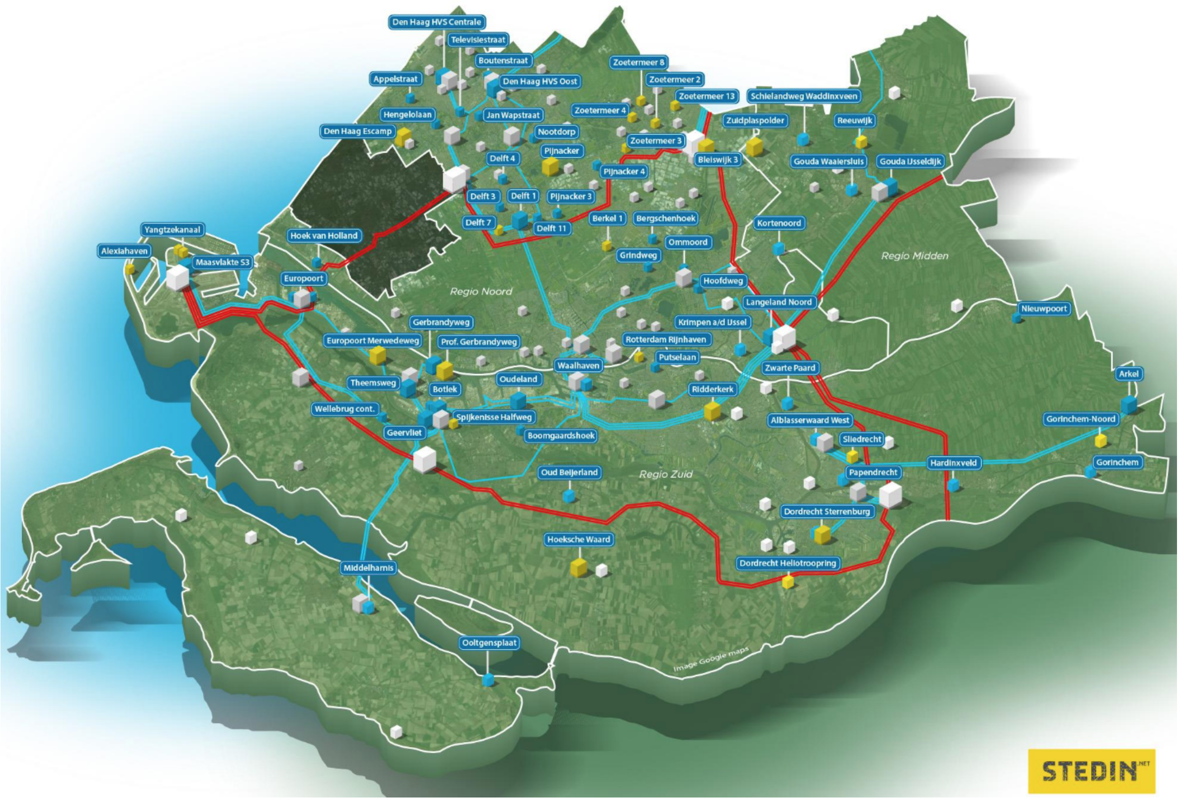

Figure 5-4: Planned investments of Stedin in South-Holland

The planned investments of Stedin look a lot different than those of Liander. Where the investments of Liander are mostly in congested areas, the planned investments from Stedin are not. In the south-west of the province, the most congested area, there are only a few planned investments. Only in the far east corner are a lot of investments in a completely congested area. In the areas with feed-in congestion, there are more investments planned. Especially in the south of the province and, for example, the highly congested area south of Zoetermeer have a lot of expansions or replacements planned in order to solve the congestion in the region.

Interesting is the difference between the two biggest cities in the province. There are a lot of investments planned in the region of The Hague, but only a few in Rotterdam. Notable is also the amount of new to be constructed stations in the proximity of Zoetermeer. This is because there are a lot of new residential neighbourhoods being built in this area, with even a whole new village that is to be constructed [49]. Further there are a lot of investments in the Port of Rotterdam area along the Meuse river, as this is an area that requires a lot of electricity in order to, for example, help with the production of hydrogen fuels.

5-4-2 Relation investments and hotspots

When putting the investment maps next to the hotspots from section C-1, we can look at how the locations of the investments match with the selected socioeconomic variables.
In the Liander catchment area, there are a lot of planned projects on a smaller domain than for Stedin. This results in the Liander projects having a clearer overlap with hotspots. Because the region in which Liander operates also has a lot more hotspots for socioeconomic welfare, there are a lot of connections found between prosperous areas and the planned projects. It can be seen that there are more projects planned in hotspots for a high median worth of households, high income, high percentage of private owned residences and high property values. Also the SES-WOA score and energy poverty indicate that there are more investments in well-off neighbourhoods.
Further notable is that there are more investments planned in areas with a high gas demand and lower electricity demand. This can be explained by the fact that all Dutch homes have to be transferred from using gas to using electricity in 2050 [54]. To facilitate this transition, significant investments are needed in the electricity grid of regions that still heavily rely on gas, ensuring that all households can eventually switch to electricity. This clarifies why there are a lot of newly planned stations constructed in those hotspots. It is also interesting to see that most of these newly planned stations are in hotspots with a high percentage of private owned residences. This is caused by a lot of newly build homes, which are often more expensive [14], that need to be connected to the electricity grid. The planned projects are also mostly located in coldspots for the population density, housing stock and the amount of inhabitants and households. This is because the investments depicted are mostly for the high voltage grid. These investments require a lot of space (30.000-45.000 m^2 for the 150 kV stations; 2.000-5.000 m^2 for the 50 kV stations [62]) and can thus often not be constructed in densely populated areas. The stations that require expansion or replacement are more often located in the denser populated areas where a lot of stations already are constructed. These regions already have a high electricity demand because they have more inhabitants, but now the stations have to be updated in order to make them future proof.
A clear distinction can be seen between the city of Leiden and the rest of the Liander catchment area. As the biggest city in this area, Leiden has a lot of different characteristics than the rest of the region. In contrast to the rest of the area, Leiden is a hotspot for population density, lower incomes and percentage of rented residences. Most of the investments shown on the map are in the proximity of Leiden. These are almost all expansion or replacement plans, indicating there is already a lot of existing electricity grid infrastructure near the city. This difference shows that the best indication for the amount of electricity grid investments in an area is still the number of inhabitants.

This is also apparent when we evaluate the investment map of Stedin. Despite it being the most congested area, there are almost no investments in the southern and eastern parts of the province as these are also the least densely populated. Most investments are in the hotspots for population density, thus in the cities. The bigger difference between urban and rural regions in the Stedin catchment area makes it more difficult to find a clear relation between the investments and the hotspots. The investments are spread out over a bigger surface, thus making it difficult to really pinpoint certain notable correlations. For example, in the cities of Dordrecht, The Hague and Rotterdam there are a lot of planned investments and these cities are hotspots for lower income households. But around the city of Zoetermeer a lot of newly

to be constructed stations are planned, while this a higher income area. The region around Zoetermeer is a hotspot for most variables that indicate prosperity, like electricity demand, private owned residences, property value and SES-WOA score, while being a coldspot for the percentage of housing corporation owned residences and energy poverty.
The clearest indicators for investments in the Stedin catchment area are the degree of urbanisation and population density. The difference in investments between rural and urban areas is really clear in the Stedin investment map and is further confirmed with the hotspot analysis. This relation is a logical consequence of the investments following demand. As there is a lot more total electricity demand in urban areas, a lot more infrastructure is needed to meet this demand.

5-5 Congestion and investments

Comparing the found hotspots to the congestion areas and investment locations gave some clearer insights into the relations between electricity grid infrastructure and the socioeconomic status in South-Holland than the correlation analysis. Looking at the congested areas in the province showed that congestion is most common in regions with hotspots for socioeconomic variables that indicate prosperity. Especially in the Liander catchment area, a lot of the congestion problems are in better off neighbourhoods. The biggest differences are, however, between the rural and urban regions, both in congestion and socioeconomic status.
The planned investment maps show a little more spread in the socioeconomic variables, but also indicate a big difference between areas based on their degree of urbanisation. This goes hand in hand with a higher number of residents, households and businesses which explains a lot of the correlation. Noteworthy, however, is that the rural areas which are heavily congested and where a lot of investments are planned, are often the more prosperous areas. It can also be seen that most newly to be constructed stations are located in areas with higher scores for the socioeconomic variables.
The downside of the analysis is that the depicted hotspots cover very broad areas, in which a lot of differences between neighbourhoods might still exist. This way it cannot be said for sure how clear the found relations are. The analysed hotspots also do not match precisely with the congested regions and locations of planned investments, so some estimation errors might have been be made. Further, there is no publicly available data about the reach of electricity stations, so we cannot tell which exact neighbourhoods will experience benefits from the investments. Despite this, it can be expected that regions in closer proximity to an investment will benefit from the expansion and thus estimations can be made of the influence area.

Chapter 6

Expert interviews

Because no definitive conclusions could be derived from the correlation and hotspot analyses, it was chosen to interview experts on the topic in order to find out why there no clear relations were discovered, learn more about the workings of investments in the electricity grid and think of possible just investment strategies.
This chapter first discusses the set-up of the interview. It will be described how interviewees were selected and the interview questions will be deliberated. After that the results of the interviews will be evaluated per interview topic.

6-1 Interview set-up

To set up the interviews, the guidelines of Mathers et al. (2000) [36] will be followed. In line with these guidelines, first the interview methodology will be discussed, then the selection process for interview candidates is explained and lastly the interview protocol is described.

6-1-1 Interview methodology

In the interview methodology, it is thought out what the interviews will look like. It is chosen to use a semi-structured interview method with open-ended questions. As the interviews seek to answer exploratory questions, it would not be advisable to use a closed interview set-up. This would not give the interviewees the opportunity to state their full opinion and set out their line of thought on the subject matter. Using open-ended questions, a lot more information can be derived from the interviews and unexpected answers are more easily given, broadening the understanding of the system and preventing tunnel vision. Having a freer interview also creates the possibility for the interviewees to give their criticism on the research, which can than be used to improved the report.
The semi-structured approach is best fitting for the interviews, as there has to be some structure to the questions that are being asked. It is beneficial that an open dialogue is created, in which there is also the possibility to ask follow-up questions based on the given

answers, but the interview has to explain certain phenomena and explore the chosen topics in order to be valuable for the study. If the interviews are conducted in an unstructured manner, the risk occurs that the answers will wander away from the subject matter. This would probably result in an interesting discussion, but it would not be of much addition for answering the research questions.

For the research, individual interviews will be conducted. This provides a safer environment for the interviewees to speak their mind and not let their answers be influenced by other participants. As the topic of an unjust distribution of investments could be a touchy subject for people working in the sector, the individual approach might enable the participants to talk about sensitive subjects more freely and provide the most unbiased results.
The interviews will be held via video-calls, as this is the most flexible way of administering them. Video-calls provide most of the benefits of a face-to-face talk, while also giving more flexibility for the location and time of the interview. This flexibility is necessary, as the interviews will have to be conducted in a relatively short time and the participants will probably have a busy schedule. A video-call also enables the recording of the interviews, when given permission by the interviewee, so the interviews can be revisited and analysed. This way it will not be necessary to try and document everything that is being said during the interview and the focus can be fully on the conversation.

6-1-2 Selecting interview candidates

As the interviews for the research will be qualitative, only a select number of experts will be needed, as a lot of interviews would take up too much time for the research.
The research topic covers a lot of different subjects and includes many different stakeholders. In order to give a full overview of the system, experts from different main stakeholders need to be interviewed. The interviewed stakeholders are: the grid operators, the province of South-Holland, municipalities in the province and researchers on the topic of energy justice and energy poverty. These different views on the system will all provide a new perspective on the problems and give distinct insights in the possible solutions. This will help with identifying the effect of unbalanced investments in the electricity grid on inequality.

Participants for the interviews will be recruited by approaching people from the mentioned organisations directly. Using the networks provided by the province of South-Holland and the TU Delft, experts will be invited to take part in the research via e-mail. This is an accessible way to establish contact with possible participants, as it does not obligate the intended partakers to anything. They can answer to the e-mail on their own convenience and easily turn the offer down if they are not interested or do not have time to be involved in the study. When this is the case, it will be asked if they know other people from their organisation that might be willing to participate and these suggested individuals will be approached. This snowballing technique will be used until experts from all organisations have been interviewed.

In the research, a minimum number of five in-depth interviews will have to be conducted in order to provide a serious contribution to the research. Five interviews would also be the minimum number needed to speak to a member of each of the important stakeholders. Preferably, interviews with both Liander and Stedin will be conducted, in order to give more insights in the workings of the grid operators. Westland Infra is the least interesting grid operator to interview, as they have an abnormal catchment area. For the municipalities, it would be preferred to interview employees from the bigger cities in South-Holland (The Hague or Rotterdam) as these are the most interesting areas to dive in deeper because of the big differences between neighbourhoods within the municipality and their power to influence the investment strategies of grid operators. Due to the limited time available for the study, the aim is to have between five and ten interviews.

6-1-3 Interview protocol

As the interviews will be conducted in a semi-structured manner, an interview protocol will be made to have some guidance during the conversation. The protocol lines out the interview and includes possible questions per topic. These topics will differ a bit in content based on the background of each interviewee, but are overall the same.
The interviews are structured the following way. First a short introduction will be held, explaining the motivation and goals of the research, and the ethics guidelines and consent form will be shortly talked through. Then, the results of the correlation and hotspot analyses will be presented and questions will be asked about the outcomes. After this the planned investments and possible methods to solve congestion on the electricity grid are discussed and lastly the role for the province of South-Holland in the issues is explored. After this initial set-up, the interviewee will be given the possibility to talk about topics that were not mentioned or provide any final thoughts. The interview protocols per different interviewed organisation can be found in Appendix D.
Fitting to the semi-structured approach, the questions can vary in order and composition based on the course of the interview. The structure and questions are also not binding, thus there is enough possibility to ask follow-up questions and diverge from the set-up.

6-2 Interview results

In the interview process, five interviews were conducted with people from the different organisations involved in the system. These included public servants, employees of grid operators and researchers. A list of the interviewees is shown below. In order to protect the identity of the participants, each is given a letter and only their profession is shown.

	Profession
Interviewee A	Employee of grid operator
Interviewee B	Employee of grid operator
Interviewee C	Researcher connected to grid operator
Interviewee D	Researcher on energy justice
Interviewee E	Employee of a municipality in South-Holland

Table 6-1: List of interview participants

The outcomes of the interviews will be discussed per topic mentioned in the interview protocol, namely: reflection on results of the analyses, solving congestion and the role of the province.

6-2-1 Results of analyses

After presenting the results of the research, the interviewees were asked to give their opinion on the outcomes of both analyses. The reactions differed a lot when asked if they had expected the lack of strong correlations. Interviewees connected to the grid operators were skeptical about possible correlations and mentioned that if they were found, they would probably be coincidental. The researcher on energy justice was surprised by the lack of found relations between the electricity infrastructure and socioeconomic, as a broad spectrum of variables was used and it would be reasonable to assume that areas with more electricity consumption would have a more extensive grid.
A recurring reasoning for the lack of correlations is that the difference in electricity demand between households is a recent phenomenon, as devices with a high electricity demand (such as EV's, solar panels and heat pumps) have only recently become accessible. It might happen that correlations will become more apparent in the coming years, as expansion of the electricity grid will target congested areas first and according to the hotspot analysis from subsection 5-3-2, these regions have a high concentration of prosperous households. If this occurs, it does not mean that the way of investing is unjust. As grid operators state, the investments in the electricity grid follow the demand, so it is a logical effect that there will be more investments in areas that use more electricity. It would be illogical to invest in areas where there is less demand and no congestion.
This line of reasoning is sound, yet at the same time exposes a problem when considering energy justice according to interviewee D. The fact that the investments in the electricity grid follow demand and might thus be unevenly distributed in the population is not necessarily a problem, but the underlying issue of poorer households having trouble with joining the energy transition is. By only focusing on expanding the grid for those who need it, while simultaneously ignoring the need of others to participate in the energy transition, will only delay fulfilling the set climate agreements. This problem has to be tackled by governmental institutions in order for the energy transition to be successful, as stated by the WRR [77]. On the short term, the unevenly distributed investments are thus not a problem, but the bigger picture has to be addressed in order to reach the long term goals of being fossil free in 2050.

The experts further concluded that correlations between households and congestion are difficult to indicate. According to the employees of grid operators, congestion mainly is a problem on the higher grid levels and especially the high voltage grid. On the middle voltage grid congestion mostly affects industrial consumers, because of their large demand, and the electricity demand of households on this level is negligible compared to industry.
The lack of congestion on the low voltage grid is further explained by interviewees C and E, who state that grid operators tend to service capacity on this level the best as it influences the most people. Grid operators are assessed on the amount of people that suffer black outs [42] and when there are problems with the low voltage grid, a lot of household are affected. This is also an explanation for the difference in the amount of investments between urban and rural areas. In urban areas a lot more people are affected when problems on the grid occur, so the grid operators prioritise these areas.

Another point of critique on the research method is that there is not necessarily a connection between the location of an investment and the area it influences. A station can be constructed in one neighbourhood to relieve congestion in another neighbourhood. It is, however, preferred to construct stations as close to the user as possible in order to minimise transport loss

and increase reliability [32].
There is also a difference in requests for new connections and investments in the grid. Especially on the low voltage grid, investments are planned based on forecasts made by the grid operators and requests for new connections are not directly taken into account for this, while the investment decisions have been made multiple years in advance. The requests will, however, be included in the forecast of the next investments. Despite this, it is fair to assume that the areas that currently suffer from congestion will be the first to receive expansions if possible.

Something that would be helpful for the research, is the historical data of the electricity grid. If the historical development of the grid can be analysed, patterns in the locations of investments might be better identified. Data with construction and maintenance years of electricity stations is, unfortunately, not publicly available. It would be interesting to research the timeline of electricity grid investments, but this should be initialised by the grid operators as they have all the relevant data.

6-2-2 Solving congestion

In order to try and solve congestion, the ACM has released guidelines that prioritise new connections to the grid [1]. When asked about these regulations, the interviewees responded that they were happy the guidelines were created, as it means that there is attention for the issues, but most were skeptical about the impact they would have. Prioritising does not create more capacity on the grid and it will only be applicable in rare occasions. It was stated by the grid operators that the investments have been planned years in advance and prioritising certain consumers will not influence them. To solve problems of inequality on the grid, the grid operators could change their forecasts to include socioeconomic variables, but this would go against the non-discriminatory principle.

As mentioned, grid operators base their investments in the electricity grid on forecast models. These forecasts analyse the potential increase of demand in the catchment areas and predict where investments will be most necessary. In these models a lot of variables are included, like the current grid load, voltage quality and scenario predictions for demand [62]. Socioeconomic variables are not included in the models as this would be discriminatory, but predictions of how certain neighbourhoods will develop their demand are. This way predictions about increased use of solar panels, heat pumps or EV's are taken into account. This analysis is done for all neighbourhoods and when grid operators spot potential problems, they will try to mitigate these issues. According to the grid operators this way of operating is non-discriminatory, as all investments made are necessary according to their predictions and thus only follow demand.
A problem with the current low voltage grid is that the older stations lack the technology to properly measure the amount of electricity passing through them, which complicates the forecast of demand. Updating or replacing older stations takes up a lot of workforce for the grid operators, but is necessary to make the electricity grid future proof. This creates opportunities for modular building, as mentioned by interviewee E. Modular building consists of standardising construction elements of electricity infrastructure in order to make the process cheaper, faster and more efficient [3]. The grid operators are already working on the possibilities of modular building, but this requires cooperation of all local operators and

Tennet, the high voltage grid operator, which might prove difficult as they all have different existing infrastructure. Governmental bodies might assist in this process by helping to create guidelines for standardisation.

Despite the investing methods being non-discriminatory and blind to socioeconomic differences, all interviewees agree that the distribution of costs and benefits of the investments are unbalanced. A household that consumes and produces more electricity (often wealthier households) benefits way more from expansion of the local grid than a household that keeps its consumption to a minimum (often lower income households), even though every household pays the same fee for their grid connection. These network tariffs are set by the ACM for each grid operator and only differ based on connection capacities [2]. Since these capacities are the same for almost all households, there is no price differentiation based on the level of stress a household places on the grid.
This might be solved by introducing a region based tariff, in which a household pays a higher connection tariff when the grid operator has invested more in their region, or by basing the tariff on the amount of consumed and produced electricity. The region based tariff is a very difficult process, as it is very difficult to tell who benefits from investments in the region. If, for example, a solar park is constructed in a region, it requires investments in the infrastructure to transport the produced electricity. The investments will be done in the region of the solar park and thus get an increased tariff, while the produced electricity might be consumed by an industrial consumer in another region. This could be solved by increasing the tariff based on usage of the electricity grid, you also do not want to discourage people from using electrical innovations that replace gas, in order to save electricity costs.

Besides investing, the grid operators are also working on congestion management [43]. Congestion management started out as an emergency measure to ask large consumers and producers of electricity to spread their demand and output over the day more evenly. This technique, also called 'peak shaving', reduces stress on the electricity grid by flattening outliers in peak demand and production periods. While congestion management started out as a measure mostly targeted at industrial consumers and producers, households are now also being asked to participate in the peak shaving due to the congestion problems. Despite the influence of households on congestion being minimal, it can help if people do not activate their solar panels and heat pumps or charge their EV's during peak hours.
Often there is a financial compensation involved for congestion management, for example cheaper electricity outside peak hours. This might further increase inequality between households, as prosperous households that can afford electricity-consuming innovations will be compensated for their flexibility. This will allow them to earn back their investments faster, while less well-off households cannot profit from this.

The goal of making the Netherlands gas free by 2050 [54] also heavily influences the way investments are being done. The phasing out of gas as a fuel greatly increases the electricity demand and puts even more stress on the grid. To try and reduce this, district heating is introduced in the bigger cities. By using district heating, households do not require heat pumps which saves a lot of electricity. District heating is only viable if a lot of people are connected to them. This is why district heating is mostly implemented in the bigger cities [50].
According to the municipality employee, the implementation of district heating is often targeted at housing corporations, as this directly secures a lot of connections to the infrastructure and you do not have to come to an agreement with every individual home owner. The costs

of district heating, however, are much higher than a gas connection and often require a financial contribution of the connected household [72]. Households in housing corporation owned residences often have a lower income and are less willing to pay for the district heating, but despite this they often have little say in the decision process of the housing corporation as they are victims of procedural injustice (subsection 2-1-2). The wishes of residents thus has to be considered when implementing district heating to ensure a just process.
Opposed to neighbourhoods that are being connected to district heating, there are neighbourhoods that will become all-electric, which means that a neighbourhood will have no more gas connections and everything will be powered by electricity [22]. In order for a house to become all-electric, it will need to have a high energy label, solar panels and a heat pump. Houses selected to become all-electric are often located in wealthier neighbourhoods as they are better isolated and able to afford the installation of the demanded innovations. Houses that become all electric require a heavier connection to the electricity grid and thus put more stress on the grid. The poorer neighbourhoods thus have to implement a measure that might be less beneficial for them in order to make room on the electricity grid for more well-off households.

6-2-3 Role of the province

When asked what the grid operators needed from governmental bodies, the answer was clear: transparency and a fast permit granting process. The grid operators need to know the development plans from local governments to use in their forecasts. When this communication is not clear, grid operators will be lagging behind and not plan the most efficient investments. Initiatives as the pMIEK [48] are a good example of governmental bodies working together with grid operators and help them create clarity for their investments plans. Important here is that the grid operators are given the freedom to invest according to their own forecasts and local government do not try to decide where they should invest. However, it is a positive development that governments are getting more involved with the issues on the electricity grid, as stated by the researchers. Grid operators typically solely focus on the technical aspects of the system, so it is beneficial that administrators are now overseeing them more closely and the socioeconomic aspects of the issues are also considered.
The cooperation between municipalities and grid operators is currently going well as municipalities mostly help with finding suitable locations for investments and spatial planning, while leaving the investing strategies to the grid operators. This proves difficult, as electricity infrastructure takes up a lot of space [62] and this is scarce in a densely populated province like South-Holland. An example of this is that there has to be build an electricity station the size of a football field in the city center of The Hague. Municipalities and grid operators have regular contact in order to keep communication clear and the processes smooth. The province can jump in when it sees fit, but does not really get involved with investments in the low voltage grid. They only come into play when bigger investments on the middle voltage grid and high voltage grid are being planned.

Another thing that would help grid operators is a faster process for getting permits. The electricity grid congestion got out of hand in the Netherlands because the ACM evaluated grid operators based on their efficiency, even though they received reports that this would take away the incentive for grid operators to make future proof investments [51]. Despite early warnings from grid operators and experts, like the WRR [76], who foresaw that more rigorous investments were needed to prepare the electricity grid for the coming energy transition, the

evaluation methods were not changed and thus lead to underinvesting.
This problem has been relatively well addressed by now, as the grid operators state that they have gotten more financial freedom to invest as they see fit. The current problem is that the investments are going too fast for local governments to keep up with the permit granting process. The interviewed municipality employee stated that smaller municipalities have even more trouble with the permit granting than bigger municipalities, as they lack labour force, which would help explain the difference in investments between urban and rural areas. Although this claim is in line with a report from the Dutch Council for Living Environment and Infrastructure (Rli) [56], in which it is stated that rural areas are structurally disadvantaged, there is no direct supporting research for this claim. It would still be beneficial for the province to look into the differences between rural and urban areas, as the analyses also showed big differences on this variable.
The implementation of modular building could also help with speeding up the permit granting process [3]. If procedures are standardised, a lot less time will have to be spent in evaluating each investment and grid operators can start construction faster. The province can help grid operators and municipalities with setting up guidelines for this method of building.

6-3 Interpretation

The interviews gave some useful insights in the workings of the grid operators, the developments on the electricity grid and the possible strategies to tackle grid congestion. Although the investments of the grid operators are planned in a non-discriminatory manner, they can result in an uneven balanced investment strategy as investments follow demand and it would be illogical to invest in areas were there is no need for it yet. This can result in congestion problems for underdeveloped regions in the future, but for now this is not a problem. The problem is that less prosperous households are not able to afford a higher electricity consumption and are thus also not able to acquire any innovations, which will save them money on the long term. This prevents people from profiting from the energy transition will only increase the financial gap between households.

While this problem is only increasing, governmental bodies are mainly focused on reducing grid congestion in order to reach the energy transition goals. With measures like district heating, emissions can be reduced by a lot and it will relieve the electricity grid. The socioeconomic effects are however not well considered, as district heating is mainly targeted at less wealthy households, while it is more costly for those households than their current energy provision. In trying to solve one problem, another problem is thus neglected, thus a trade-off will have to be made between reducing congestion and reducing inequality.

Chapter 7

Discussion

With the research completed, the results of the different analyses will be evaluated and their implications will be discussed. Then, the limitations of the research are deliberated and recommendations for future research are made.

7-1 Results

The analyses in the research aim to identify a possible relation between the location of electricity grid infrastructure and socioeconomic variables connected to energy poverty and energy justice. Although it was expected there would be stronger correlations, this was not the case. The main problem with the results is that they lacks strong evidence to back up the conclusions that can be derived from them. Both the correlation and hotspot analysis imply that there is relation between socioeconomic prosperity in a neighbourhood and the amount of investments in its electricity infrastructure, but both analyses lack any decisive evidence to make such a strong claim. It is logical to assume that these findings are just the result of supply and demand in a regulated market, without indicating any bias towards socioeconomic status.

First it was tried to prove the relation by calculating the correlations between the number of low and middle voltage stations in a neighbourhood and its socioeconomic status. The correlation analysis did not result in any definitive conclusions, as the found correlations were overall too low (between 0.3 and -0.3). This result implies that investments in the electricity grid are blind to differences in socioeconomic status between neighbourhoods, but this is given the fact that there is no grid congestion. As grid congestion is a recent phenomenon and prioritisation will have to be applied to the investments for the first time, it can result in a different distribution of investments in the near future. It will be interesting to evaluate this development and see how the electricity grid evolves in the coming decade.
In retrospect the correlation analysis was not the best method to identify the relation, as the spatial factor was missing in it. However, the correlation research was a useful tool to discover which socioeconomic variables had the most impact on the system and this was very

useful for the hotspot analysis performed afterwards. As in the hotspot analysis only a single variable at a time could be mapped, it was very helpful that most of the variables could be filtered out with the results of the correlations.

Comparing the identified hotspots to congested areas and the locations of investments in the electricity grid showed evidence supporting the relation between socioeconomic prosperity and electricity infrastructure. Although it is hard to draw undisputed conclusions from the analysis, as the hotspots are often not exactly on the same location as the congestion and investments, the patterns found give a clear indication that verify the assumption. Especially the connection found between stations planned for construction and newly built homes is interesting, as newer homes are often more expensive than older homes and thus for higher income households. It is logical that newly constructed homes have to be connected to the electricity grid, but it is interesting to see what will happen if this prevents already constructed areas from getting the grid expansion they require.

The claims made in the interviews are valuable for the explanation of the system and found relations between electricity infrastructure and socioeconomic status, but as some things were only brought up by one participant, they could not be taken for absolute truths. The content of the interviews were checked for supporting literature, but for some statements this was unfortunately not possible. Some things said in the interviews were speculative and, despite having a logical reasoning behind them, might not be 100% accurate. Especially predictions made about the coming years might be flawed as no one can foresee the future.

The results thus indicate that problems of inequality on the electricity grid might arise in the near future. This is mainly caused by the grid congestion and the unbalanced access to the energy transition. A trade-off has to be made here, as helping every household in joining the transition will only increase the electricity demand and worsen the grid congestion. Governmental bodies will have to make a decision on how to prioritise these two issues.

7-2 Scientific contribution

The main objective of this research was to identify a spatial relation between socioeconomic characteristics and electricity grid infrastructure, as this relation has not been considered enough in research and governmental decision making. Most of the research done in the field of energy justice and energy poverty is about how the energy transition can be made inclusive for everyone in the future, with the focus on adaptation of new innovations. This ignores the bigger picture of how these problems were created on if maybe the base of the system is unfair. By identifying a positive relation between the amount of electricity infrastructure and socioeconomic prosperity, this research this contributed some insights in this problem.
The identified relation shows that households in less prosperous neighbourhoods will have more problems with connections to the grid in the future, if the current way of operating is not changed. This is a useful policy insight for the grid operators and governmental bodies, who should consider the possibility that some areas might be neglected in the investment process.

The research further provided insights in which socioeconomic variables have the most correlation with electricity infrastructure. This provides insights for governments and grid operators on which factors they can focus on in future decision making. The report also gave advice on how the cooperation in decision between governments and grid operators might be improved and which possible strategies might be implemented to keep the electricity grid accessible for everyone.

7-3 Limitations and future research

The performed research has some limitations that could be improved in future research. The main shortcoming in the analyses is the lack of complete data sets. The data collected from the CBS had a lot of missing values and even after cleaning the data there was still a little less than 6% of the data missing. The missing data made it difficult to draw any definitive conclusions, as the significance of the found correlations could not be calculated due to the incomplete dataset. This meant it was not possible to check whether the correlations were coincidental or that they indicated a relation between variables. With a complete dataset, a more definitive analysis could have been performed and the results of the research would be substantiated stronger.
A recommendation for future research is to involve the grid operators better, as they have a lot of data concerning the electricity grid that is not publicly available. If, for example, the catchment area of each station can be used int the analysis instead of the neighbourhood borders, more could be said about the impact of stations on households. The investment plans for the low voltage grid would also have been a good addition to the hotspot analysis, as this would have given a clearer indication on how much is invested on a neighbourhood level.
Another interesting study that could be performed, is to look at the construction or maintenance years of each station and see how investments affect different types of neighbourhoods over time. This would have better shown if investments follow demand or if electricity demand rises if the infrastructure is available. Based on this predictions can be made on how to make the electricity grid future proof.

Further limitations are that district heating is not included in the research. As mentioned in the interviews (subsection 6-2-2), district heating plays an important part in the transition strategy of larger cities and is a key solution for lowering grid congestion. Analysing the socioeconomic variables of neighbourhoods marked for district heating, would give valuable insights in how different areas are treated in the phasing out of fossil fuels and how this affects energy justice. This also shows the bigger picture of the energy transition and the many possibilities that come with it, instead of only focusing on electricity.

More interviews would also have provided a better understanding of the researched system. As only five interviews were conducted some claims made were hard to validate as only one interviewee brought it up. There was also no opportunity for interviewees to react to the answers of other participants, what could have resulted in an interesting conversation. It is recommended for future research to bring the multiple parties involved in the system to the table in order to facilitate a panel discussion and compare the different views on problems.

Chapter 8

Conclusion

In this final chapter, the conclusions that can be drawn from the performed research will be presented. The study aimed to find an answer to the question: *"To what extent can spatial relations between electricity grid infrastructure and socioeconomic characteristics be identified and quantified in the province of South-Holland and what does this relation imply for inequality?"*
By first identifying which socioeconomic variables should be included in the research and mapping the electricity infrastructure in the province, multiple analyses could be performed in order to identify the possible relation between the socioeconomic status of a neighbourhood and the amount of electricity stations located in it. After this, it was evaluated how this relation affects equality and a balanced division of costs and benefits in the energy transition so an advise can be given on how to future proof the electricity grid while realising an inclusive energy transition.

In the identification process of the relevant socioeconomic indicators for the research, the variables were selected based on their connection to energy poverty and energy justice. This resulted in a set of variables that were mostly demographic, but also included factors as home ownership, urbanisation and energy demand and production. From this data it became apparent that the expected relations between energy demand and wealth were true and higher income households thus used more electricity. This was the first step in indicating a relation between socioeconomic prosperity and electricity infrastructure, as it is reasonable to assume the amount of infrastructure would be in line with demand.

To find evidence that further confirms this theory, a correlation analysis was performed. While the analysis showed indications of a positive correlation between high income neighbourhoods, the only concluding remark was that there is a strong relation between the amount of electricity infrastructure and the number of inhabitants, which is unsurprising as a larger population requires a more extensive grid.
The subsequent performed hotspot analysis showed more support for the assumption that electricity grid investments are more frequent in prosperous areas. The analysis revealed that regions where grid congestion is a problem are mostly wealthier neighbourhoods and also when looking at the planned investments of the Liander and Stedin, it can be seen that these

are mostly located in higher income areas. The biggest difference that can observed in the analysis is between urban and rural areas. In urban areas, a lot more investments are planned while the congestion is mostly in rural regions. This shows that grid operators prioritise areas with a lot of inhabitants so investments affect more households. As grid operators are evaluated on their efficiency, this is a logical way of operating, but it may unbalance access to the grid in the future.

In order to validate the results of the analyses and learn more about how the system connects to equality, experts interviews were conducted. From these interviews it could be concluded that the problem of inequality is not in the location of investments per se, as these just follow demand, but in the unbalanced distribution of electricity demand and the financial barriers that prevent people from participating in and profiting from the energy transition. When these problems are tackled, however, it will cause the electricity demand to further increase and grid congestion will worsen. A trade-off thus has to made between reducing grid congestion and reducing inequality.
The province, municipalities and grid operators have to coordinate efforts in order to solve the congestion problems and keep the electricity accessible for everyone. This can be done with clear communication about investment plans and transparency on future developments. A more rigorous policy would be to increase net tariffs based on the usage of a household. This would mean that a household pays a higher fee for their connection to the electricity grid if they put more stress on it. A negative effect of this, however, is that you discourage people from implementing electrical innovations.

Although little evidence of inequality on the electricity grid could be found in the research, indications were shown that this problem might develop in the near future. It is a good sign that the province and local governments are aware of this problem and try to mitigate the negative socioeconomic effects of the energy transition. For the sake of equality, governmental bodies have to address the issues of energy injustice and ensure an inclusive energy transition. If these problems are considered adequately in the decision making process, it will result in maintaining equal access to the electricity grid for all users while securing a more sustainable future.

Appendix A

Data Collection

A-1 Overview of the selected variables

Attribute	Description	Unit	Level of measurement	Source
a_inw	Number of residents	#	Ratio	CBS
p_man	Percentage of male inhabitants	%	Interval	CBS
p_elderly	Percentge of 65+ inhabitants	%	Interval	CBS
p_migrant	Percentage of inhabitants with a migrant background	%	Interval	CBS
a_hh	Total number of households	#	Ratio	CBS
g_hhgro	Average size household	#	Ratio	CBS
bev_dich	Population density	#/km2	Ratio	CBS
a_woning	Housing stock	#	Ratio	CBS
g_wozbag	Average property value	€ x 1000	Ratio	CBS
p_koopw	Percentage private owned residences	%	Interval	CBS
p_huurw	Percentage rented residences	%	Interval	CBS
p_wcorpw	Percentage housing corporation owned residences	%	Interval	CBS
p_bjj2k	Percentage constructed before 2000	%	Interval	CBS
p_bjo2k	Percentage constructed after 2000	%	Interval	CBS
g_ele	Average electricity demand for all housing types	kWh	Ratio	CBS
g_ele_hu	Electricity demand rented residence	kWh	Ratio	CBS
g_ele_ko	Electricity demand private owned residence	kWh	Ratio	CBS
g_gas	Average gas demand for all housing types	m3	Ratio	CBS
g_gas_hu	Gas demand rented residence	m3	Ratio	CBS
g_gas_ko	Gas demand private owned residence	m3	Ratio	CBS
p_inkont	Percentage of income receivers	%	Interval	CBS
p_hh_li	Percentage of households among the lowest 40% of national income	%	Interval	CBS
p_hh_hi	Percentage of households among the highest 20% of national income	%	Interval	CBS
p_hh_osm	Percentage of households under or around the social minimum income	%	Interval	CBS
m_hh_ver	Median worth of individual households	€ x 1000	Ratio	CBS
p_soz_wb	Percentage of residents with social welfare benefits	%	Interval	CBS
p_soz_ao	Percentage of residents with disability benefits	%	Interval	CBS
p_soz_ww	Percentage of residents with unemployment benefits	%	Interval	CBS
p_soz_ow	Percentage of residents with retirement pension	%	Interval	CBS
a_bedv	Number of businesses	#	Ratio	CBS
a_bedv_inw	Number of businesses per resident	#	Interval	CBS
a_bedv_hh	Number of businesses per houshold	#	Interval	CBS
g_afs_hp	Average distance to general practitioner	Km	Ratio	CBS
g_afs_gs	Average distance to big supermarket	Km	Ratio	CBS
g_afs_kv	Average distance to day-care centre	Km	Ratio	CBS
g_afs_sc	Average distance to school	Km	Ratio	CBS
g_3km_sc	Number of schools within 3 km road distance	#	Ratio	CBS
ste_mvs	Degree of urbanisation	#	Ordinal	CBS
p_Opl_Laag	Percentage of residents with low education level	%	Interval	CBS
p_Opl_Middelbaar	Percentage of residents with middle education level	%	Interval	CBS
p_Opl_Hoog	Percentage of residents with high education level	%	Interval	CBS
Beroeps- en niet-beroepsbevolking (aantal)	Number of labour participants in total population	#	Ratio	CBS
Werkzame beroepsbevolking (aantal)	Number of labour participants of working population	#	Ratio	CBS
Netto arbeidsparticipatie (%)	Net percentage of labour participation	%	Interval	CBS
Werknemer (% van de werkzame bevolking)	Percentage of employed labourers	%	Interval	CBS
oppervlakte	Average surface of residence in neighbourhood	km2	Ratio	CBS
energieklasse	Median of energy label class in neighbourhood	#	Ordinal	RVO
Leveringsrichting	Percentage of electricity delivered. When not 100, property delivered electricity to the grid with solar panels	%	Interval	CBS

Table A-1: Table with the selected socioeconomic indicators.

A-2 Data validation

	a_inw	p_man	p_elderly	p_migrant	a_hh	g_hhgro	bev_dich	a_woning	g_wozbag	p_koopw	p_huurw	p_wcorpw	p_bjj2k	p_bjo2k	g_ele	g_ele_hu	g_ele_ko	g_gas	g_gas_hu	g_gas_ko	p_inkont	p_hh_li	p_hh_hi	p_hh_osm	m_hh_ver	p_soz_wb	p_soz_ao	p_soz_ww	p_soz_ow	a_bedv	a_bedv_inw	a_bedv_hh	g_afs_hp	g_afs_gs	g_afs_kv	g_afs_sc	g_3km_sc	ste_mvs	p_Opl_Laag	p_Opl_Middelbaar	p_Opl_Hoog	Beroeps- en niet-beroepsbevolking (aantal)	Werkzame beroepsbevolking (aantal)	Netto arbeidsparticipatie (%)	Werknemer (% van de werkzame bevolking)	oppervlakte	energieklasse	Leveringsrichting
a_inw	1	-0.1	-0.12	0.45	0.99	-0.17	0.47	0.99	-0.24	-0.31	0.31	0.27	0.02	-0.02	-0.37	-0.26	-0.35	-0.34	-0.27	-0.33	0.12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
p_man	-0.1	1	-0.09	0.03	-0.09	0.02	-0.21	-0.1	0.14	0.18	-0.18	-0.31	-0.09	0.09	0.21	0.27	0.18	0.14	0.17	0.13	-0.17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
p_elderly	-0.12	-0.09	1	-0.22	-0.1	-0.31	-0.11	-0.09	0.02	-0.06	0.06	0.09	0.18	-0.18	-0.1	-0.11	-0.06	0.06	0.03	0.1	0.05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
p_migrant	0.45	0.03	-0.22	1	0.47	-0.39	0.58	0.46	-0.41	-0.67	0.67	0.54	0	0	-0.5	-0.28	-0.45	-0.46	-0.33	-0.43	0.03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
a_hh	0.99	-0.09	-0.1	0.47	1	-0.24	0.5	1	-0.26	-0.36	0.36	0.28	0.06	-0.06	-0.39	-0.27	-0.38	-0.34	-0.26	-0.32	0.12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
g_hhgro	-0.17	0.02	-0.31	-0.39	-0.24	1	-0.37	-0.24	0.45	0.65	-0.64	-0.42	-0.28	0.28	0.64	0.44	0.58	0.37	0.29	0.3	-0.13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
bev_dich	0.47	-0.21	-0.11	0.58	0.5	-0.37	1	0.48	-0.52	-0.5	0.5	0.46	0.14	-0.14	-0.66	-0.48	-0.68	-0.55	-0.43	-0.53	0.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
a_woning	0.99	-0.1	-0.09	0.46	1	-0.24	0.48	1	-0.26	-0.35	0.35	0.29	0.06	-0.06	-0.4	-0.28	-0.38	-0.34	-0.27	-0.32	0.13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
g_wozbag	-0.24	0.14	0.02	-0.41	-0.26	0.45	-0.52	-0.26	1	0.59	-0.59	-0.58	-0.22	0.22	0.77	0.58	0.73	0.65	0.54	0.6	0.06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
p_koopw	-0.31	0.18	-0.06	-0.67	-0.36	0.65	-0.5	-0.35	0.59	1	-1	-0.81	-0.11	0.11	0.7	0.44	0.54	0.52	0.41	0.41	0.11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
p_huurw	0.31	-0.18	0.06	0.67	0.36	-0.64	0.5	0.35	-0.59	-1	1	0.81	0.11	-0.11	-0.69	-0.44	-0.54	-0.52	-0.41	-0.41	-0.11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
p_wcorpw	0.27	-0.31	0.09	0.54	0.28	-0.42	0.46	0.29	-0.58	-0.81	0.81	1	0.13	-0.13	-0.62	-0.45	-0.48	-0.5	-0.43	-0.41	-0.05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
p_bjj2k	0.02	-0.09	0.18	0	0.06	-0.28	0.14	0.06	-0.22	-0.11	0.11	0.13	1		-0.2	-0.12	-0.22	0.27	0.24	0.3	0.12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
p_bjo2k	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
g_ele	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
g_ele_hu	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
g_ele_ko	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
g_gas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.13	0.04	0.08	-0.34	-0.35	0.19	-0.65	0.32	-0.33	-0.18
g_gas_hu	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.06	0.01	0.04	-0.26	-0.27	0.15	-0.61	0.36	-0.36	-0.07
g_gas_ko	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.12	0.01	0.08	-0.33	-0.34	0.11	-0.61	0.29	-0.31	-0.15
p_inkont	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.13	0.06	0.05	0.13	0.13	-0.05	0	-0.3	-0.06	0.07
p_hh_li	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.44	-0.05	-0.29	0.23	0.18	-0.68	0.27	-0.16	-0.15	0.53
p_hh_hi	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.49	-0.19	0.47	-0.19	-0.15	0.59	-0.46	0.26	0.22	-0.52
p_hh_osm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.51	-0.12	-0.3	0.35	0.28	-0.69	0.14	-0.15	-0.1	0.47
m_hh_ver	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.38	-0.2	0.39	-0.24	-0.22	0.32	-0.64	0.31	0.01	-0.3
p_soz_wb	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.48	-0.06	-0.33	0.38	0.33	-0.62	0.27	-0.18	-0.06	0.38
p_soz_ao	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.43	-0.07	-0.28	0.09	0.08	-0.39	0.24	-0.14	0.07	0.18
p_soz_ww	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.07	-0.06	-0.01	0.28	0.28	-0.19	0.25	-0.23	0.03	0.2
p_soz_ow	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.09	0.01	-0.07	-0.05	-0.07	-0.45	-0.12	-0.21	-0.05	0.1
a_bedv	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.01	-0.22	0.16	0.89	0.89	-0.11	-0.05	-0.08	0.02	0.24
a_bedv_inw	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.06	0.05	0	-0.11	-0.12	0.17	-0.46	0.33	0.11	0.03
a_bedv_hh	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.06	0.07	0	-0.14	-0.14	0.24	-0.59	0.3	0.15	0
g_afs_hp	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.03	0.12	-0.06	-0.27	-0.27	0.25	-0.44	0.21	-0.07	-0.26
g_afs_gs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.08	0.09	0	-0.28	-0.28	0.27	-0.49	0.19	-0.07	-0.29
g_afs_kv	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.06	0.12	-0.04	-0.3	-0.3	0.24	-0.56	0.22	-0.08	-0.27
g_afs_sc	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.08	0.05	0.03	-0.29	-0.29	0.25	-0.55	0.28	-0.03	-0.24
g_3km_sc	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.06	-0.31	0.17	0.46	0.44	-0.34	0.14	-0.12	-0.06	0.42
ste_mvs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.04	0.27	-0.16	-0.37	-0.36	0.41	-0.45	0.22	0.01	-0.45
p_Opl_Laag	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	-0.07	-0.72	0.08	0.05	-0.39	0.15	-0.01	-0.01	0.18
p_Opl_Middelbaar	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.07	1	-0.64	-0.14	-0.14	0.17	0.13	0.04	-0.05	-0.16
p_Opl_Hoog	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.72	-0.64	1	0.04	0.06	0.18	-0.19	-0.02	0.04	-0.03
Beroeps- en niet-beroepsbevolking (aantal)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.08	-0.14	0.04	1	0.99	-0.18	0.12	-0.18	0	0.22
Werkzame beroepsbevolking (aantal)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.05	-0.14	0.06	0.99	1	-0.1	0.13	-0.18	0.02	0.19
Netto arbeidsparticipatie (%)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.39	0.17	0.18	-0.18	-0.1	1	-0.16	0.17	0.16	-0.51
Werknemer (% van de werkzame bevolking)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.15	0.13	-0.19	0.12	0.13	-0.16	1	-0.39	0.12	0.09
oppervlakte	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.01	0.04	-0.02	-0.18	-0.18	0.17	-0.39	1	0.09	-0.11
energieklasse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.01	-0.05	0.04	0	0.02	0.16	0.12	0.09	1	-0.24
Leveringsrichting	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.18	-0.16	-0.03	0.22	0.19	-0.51	0.09	-0.11	-0.24	1

Table A-2: Correlation matrix of selected socioeconomic variables

Appendix B

Correlation research

B-1 Overall correlation results

	Low voltage	Middle voltage	Total
Number of residents	0.37	0.08	0.33
Percentage of male inhabitants	-0.07	0.09	-0.02
Percentge of 65+ inhabitants	-0.01	-0.04	-0.02
Percentage of inhabitants with a migrant background	0.13	0.01	0.11
Total number of households	0.38	0.09	0.34
Average size household	-0.18	-0.07	-0.17
Population density	0.2	-0.17	0.1
Housing stock	0.38	0.08	0.33
Average property value	-0.09	0.17	-0.02
Percentage private owned residences	-0.18	0.01	-0.14
Percentage rented residences	0.18	-0.01	0.14
Percentage housing corporation owned residences	0.17	-0.12	0.09
Percentage constructed before 2000	0.1	-0.07	0.06
Percentage constructed after 2000	-0.1	0.07	-0.06
Average electricity demand for all housing types	-0.23	0.12	-0.14
Electricity demand rented residence	-0.15	0.2	-0.05
Electricity demand private owned residence	-0.22	0.13	-0.13
Average gas demand for all housing types	-0.19	0.09	-0.12
Gas demand rented residence	-0.13	0.18	-0.04
Gas demand private owned residence	-0.17	0.09	-0.11
Percentage of income receivers	0.12	0	0.09
Percentage of households among the lowest 40% of national income	0.16	0	0.13
Percentage of households among the highest 20% of national income	-0.14	0.1	-0.08
Percentage of households under or around the social minimum income	0.09	-0.07	0.05
Median worth of individual households	-0.09	0.18	0
Percentage of residents with social welfare benefits	0.16	-0.08	0.1
Percentage of residents with disability benefits	0.04	-0.06	0.01
Percentage of residents with unemployment benefits	0.14	-0.06	0.09
Percentage of residents with retirement pension	0.05	-0.06	0.02
Number of businesses	0.3	0.23	0.32
Number of businesses per resident	-0.05	0.21	0.04
Number of businesses per houshold	-0.06	0.2	0.02
Average distance to general practitioner	-0.18	0.07	-0.12
Average distance to big supermarket	-0.18	0.06	-0.12
Average distance to day-care centre	-0.18	0.1	-0.11
Average distance to school	-0.17	0.14	-0.09
Number of schools within 3 km road distance	0.13	-0.02	0.1
Degree of urbanisation	-0.23	0.11	-0.15
Percentage of residents with low education level	0	-0.05	-0.01
Percentage of residents with middle education level	-0.07	-0.04	-0.07
Percentage of residents with high education level	0.04	0.07	0.06
Number of labour participants in total population	0.37	0.09	0.33
Number of labour participants of working population	0.38	0.1	0.34
Net percentage of labour participation	-0.04	0.14	0.02
Percentage of employed labourers in working population	0.11	-0.27	0
Average surface area of residence in neighbourhood	-0.08	0.28	0.04
Median of energy label class in neighbourhood	-0.02	0.11	0.03
Percentage of electricity delivered. When not 100. property delivered electricity to the grid with solar panels	0.08	-0.05	0.05

Table B-1: Correlations between socioeconomic variables and the number of electricity stations on a neighbourhood level in South-Holland

	Stations per resident	Stations per household
Number of residents	-0.08	-0.12
Percentage of male inhabitants	0.13	0.16
Percentge of 65+ inhabitants	0.07	0.06
Percentage of inhabitants with a migrant background	0.05	0
Total number of households	-0.07	-0.11
Average size household	-0.08	-0.03
Population density	-0.19	-0.25
Housing stock	-0.07	-0.11
Average property value	0.2	0.25
Percentage private owned residences	0.08	0.11
Percentage rented residences	-0.08	-0.11
Percentage housing corporation owned residences	-0.21	-0.24
Percentage constructed before 2000	0.02	0
Percentage constructed after 2000	-0.02	0
Average electricity demand for all housing types	0.14	0.24
Electricity demand rented residence	0.1	0.19
Electricity demand private owned residence	0.2	0.3
Average gas demand for all housing types	0.16	0.23
Gas demand rented residence	0.13	0.2
Gas demand private owned residence	0.18	0.24
Percentage of income receivers	-0.22	-0.31
Percentage of households among the lowest 40% of national income	0.01	-0.09
Percentage of households among the highest 20% of national income	0.09	0.18
Percentage of households under or around the social minimum income	-0.1	-0.15
Median worth of individual households	0.24	0.32
Percentage of residents with social welfare benefits	-0.07	-0.11
Percentage of residents with disability benefits	-0.08	-0.1
Percentage of residents with unemployment benefits	-0.1	-0.15
Percentage of residents with retirement pension	-0.14	-0.2
Number of businesses	-0.02	-0.04
Number of businesses per resident	0.59	0.66
Number of businesses per houshold	0.45	0.63
Average distance to general practitioner	0.13	0.17
Average distance to big supermarket	0.09	0.13
Average distance to day-care centre	0.12	0.17
Average distance to school	0.17	0.22
Number of schools within 3 km road distance	-0.06	-0.09
Degree of urbanisation	0.09	0.13
Percentage of residents with low education level	0	-0.01
Percentage of residents with middle education level	0.05	0.06
Percentage of residents with high education level	-0.03	-0.04
Number of labour participants in total population	-0.08	-0.12
Number of labour participants of working population	-0.08	-0.12
Net percentage of labour participation	0.17	0.21
Percentage of employed labourers in working population	-0.34	-0.41
Average surface area of residence in neighbourhood	0.44	0.48
Median of energy label class in neighbourhood	0.08	0.11
Percentage of electricity delivered. When not 100. property delivered electricity to the grid with solar panels	0.01	-0.02

Table B-2: Correlations between socioeconomic variables and the number of electricity stations per resident and household on a neighbourhood level in South-Holland

B-2 Correlation results per grid operator

	Westland Low	Stedin Low	Liander Low	Westland Middle	Stedin Middle	Liander Middle	Westland Total	Stedin Total	Liander Total
Number of residents	0.61	0.54	0.68	0.18	0.13	0.28	0.4	0.5	0.69
Percentage of male inhabitants	-0.12	-0.06	-0.09	0.03	0.14	0.06	-0.04	0.01	-0.07
Percentge of 65+ inhabitants	-0.19	-0.01	-0.01	-0.12	-0.05	-0.04	-0.16	-0.03	-0.02
Percentage of inhabitants with a migrant background	0.13	0.2	0.41	-0.02	0.13	0.01	0.05	0.22	0.38
Total number of households	0.62	0.54	0.73	0.19	0.14	0.3	0.41	0.51	0.75
Average size household	-0.02	-0.17	-0.31	0.02	-0.11	-0.07	0	-0.18	-0.31
Population density	-0.1	0.19	0.44	-0.37	-0.16	-0.18	-0.26	0.1	0.37
Housing stock	0.57	0.54	0.73	0.13	0.14	0.28	0.35	0.51	0.75
Average property value	0.13	-0.13	-0.3	0.35	0.1	0.05	0.26	-0.08	-0.27
Percentage private owned residences	0.14	-0.18	-0.41	0.24	-0.09	-0.03	0.2	-0.19	-0.39
Percentage rented residences	-0.14	0.18	0.41	-0.24	0.09	0.03	-0.2	0.19	0.39
Percentage housing corporation owned residences	-0.16	0.17	0.43	-0.34	-0.08	-0.07	-0.27	0.12	0.38
Percentage constructed before 2000	-0.02	0.13	0.16	0.03	-0.08	-0.09	0	0.08	0.13
Percentage constructed after 2000	0.02	-0.13	-0.16	-0.03	0.08	0.09	0	-0.08	-0.13
Average electricity demand for all housing types	0.06	-0.22	-0.45	0.36	0.08	0.11	0.23	-0.16	-0.4
Electricity demand rented residence	0.09	-0.12	-0.32	0.44	0.17	0.15	0.3	-0.04	-0.27
Electricity demand private owned residence	0.06	-0.21	-0.42	0.35	0.1	0.11	0.23	-0.14	-0.37
Average gas demand for all housing types	0.03	-0.2	-0.37	0.34	0.02	0.04	0.21	-0.16	-0.34
Gas demand rented residence	0.1	-0.13	-0.29	0.45	0.1	0.1	0.31	-0.07	-0.25
Gas demand private owned residence	0.02	-0.18	-0.35	0.31	0.01	0.04	0.19	-0.15	-0.32
Percentage of income receivers	0.22	0.11	0.14	0.14	-0.09	0.09	0.18	0.05	0.15
Percentage of households among the lowest 40% of national income	0.06	0.13	0.44	0.05	0.05	0.07	0.06	0.13	0.43
Percentage of households among the highest 20% of national income	0.12	-0.12	-0.43	0.21	0.04	0.04	0.18	-0.09	-0.39
Percentage of households under or around the social minimum income	-0.15	0.12	0.5	-0.18	0.03	0.02	-0.17	0.12	0.47
Median worth of individual households	0.23	-0.11	-0.3	0.44	0.06	0.07	0.37	-0.08	-0.27
Percentage of residents with social welfare benefits	-0.05	0.18	0.5	-0.22	-0.04	0	-0.15	0.13	0.46
Percentage of residents with disability benefits	-0.12	0.06	0.07	-0.11	-0.05	-0.04	-0.12	0.03	0.06
Percentage of residents with unemployment benefits	0.23	0.16	0.26	0.08	-0.07	0.01	0.16	0.1	0.24
Percentage of residents with retirement pension	0.06	0.05	0.06	-0.05	-0.13	0.02	0	-0.01	0.06
Number of businesses	0.87	0.45	0.49	0.62	0.3	0.59	0.78	0.5	0.59
Number of businesses per resident	-0.11	-0.03	-0.1	-0.01	0.37	0.18	-0.06	0.13	-0.05
Number of businesses per household	-0.13	-0.04	-0.11	-0.01	0.34	0.19	-0.07	0.1	-0.06
Average distance to general practitioner	-0.02	-0.15	-0.3	0.26	0.08	0.09	0.14	-0.09	-0.26
Average distance to big supermarket	0.01	-0.16	-0.31	0.26	0.05	0.05	0.15	-0.12	-0.28
Average distance to day-care centre	0.04	-0.17	-0.32	0.32	0.09	0.12	0.2	-0.11	-0.27
Average distance to school	-0.07	-0.17	-0.27	0.24	0.16	0.13	0.1	-0.08	-0.23
Number of schools within 3 km road distance	0.04	0.12	0.46	-0.07	0.07	-0.04	-0.02	0.13	0.42
Degree of urbanisation	-0.03	-0.23	-0.48	0.23	0.07	0.11	0.12	-0.16	-0.42
Percentage of residents with low education level	-0.03	0.02	0.1	0.01	-0.06	-0.04	-0.01	-0.01	0.08
Percentage of residents with middle education level	-0.05	-0.08	-0.05	-0.04	-0.08	-0.01	-0.04	-0.09	-0.05
Percentage of residents with high education level	0.09	0.04	-0.03	0.03	0.1	0.03	0.06	0.07	-0.02
Number of labour participants in total population	0.64	0.54	0.68	0.22	0.13	0.3	0.44	0.5	0.7
Number of labour participants of working population	0.65	0.54	0.64	0.24	0.13	0.3	0.46	0.5	0.66
Net percentage of labour participation	0.18	-0.09	-0.28	0.26	0.02	0.05	0.24	-0.07	-0.25
Percentage of employed labourers in working population	-0.19	0.08	0.31	-0.5	-0.22	-0.3	-0.38	-0.01	0.23
Average surface area of residence in neighbourhood	-0.02	-0.08	-0.19	0.21	0.41	0.07	0.11	0.11	-0.16
Median of energy label class in neighbourhood	0.07	-0.02	-0.06	-0.06	0.16	0.1	0	0.05	-0.04
Percentage of electricity delivered	-0.17	0.13	0.23	-0.2	0.03	0.09	-0.2	0.12	0.23

Table B-3: Correlations between socioeconomic variables and the number of electricity stations for each grid operator in South-Holland

	Westland per resident	Stedin per resident	Linader per resident	Westland per household	Stedin per household	Liander per household
Number of residents	-0.24	-0.07	-0.19	-0.33	-0.11	-0.22
Percentage of male inhabitants	0.83	0.14	-0.25	0.82	0.17	-0.07
Percentge of 65+ inhabitants	0.72	0.06	-0.17	0.67	0.06	-0.14
Percentage of inhabitants with a migrant background	-0.24	0.07	-0.14	-0.29	0.02	-0.11
Total number of households	-0.23	-0.06	-0.17	-0.33	-0.1	-0.21
Average size household	-0.21	-0.08	-0.06	-0.17	-0.03	0
Population density	-0.74	-0.18	-0.19	-0.76	-0.24	-0.23
Housing stock	-0.23	-0.07	-0.17	-0.33	-0.1	-0.21
Average property value	0.53	0.18	0.05	0.58	0.23	0.08
Percentage private owned residences	0.48	0.05	-0.04	0.51	0.09	0
Percentage rented residences	-0.47	-0.05	0.04	-0.51	-0.09	0
Percentage housing corporation owned residences	-0.63	-0.2	-0.09	-0.66	-0.22	-0.2
Percentage constructed before 2000	0.15	0.03	0	0.11	0.01	-0.02
Percentage constructed after 2000	-0.15	-0.03	0	-0.11	-0.01	0.02
Average electricity demand for all housing types	0.67	0.12	0.23	0.69	0.22	0.31
Electricity demand rented residence	0.72	0.08	0.31	0.79	0.17	0.34
Electricity demand private owned residence	0.62	0.19	0.16	0.63	0.29	0.28
Average gas demand for all housing types	0.63	0.15	0.19	0.63	0.22	0.26
Gas demand rented residence	0.64	0.13	0.21	0.7	0.18	0.28
Gas demand private owned residence	0.58	0.16	0.19	0.58	0.22	0.25
Percentage of income receivers	-0.41	-0.21	-0.35	-0.4	-0.3	-0.37
Percentage of households among the lowest 40% of national income	0.28	-0.03	0.29	0.02	-0.11	0.1
Percentage of households among the highest 20% of national income	0.17	0.1	-0.18	0.38	0.19	-0.02
Percentage of households under or around the social minimum income	-0.28	-0.07	0.31	-0.37	-0.11	0.18
Median worth of individual households	0.42	0.24	-0.01	0.64	0.31	0.09
Percentage of residents with social welfare benefits	-0.18	-0.07	-0.08	-0.27	-0.11	-0.1
Percentage of residents with disability benefits	-0.12	-0.09	-0.09	-0.14	-0.12	-0.05
Percentage of residents with unemployment benefits	-0.14	-0.09	-0.16	-0.22	-0.14	-0.2
Percentage of residents with retirement pension	-0.32	-0.13	-0.25	-0.34	-0.19	-0.24
Number of businesses	-0.08	-0.02	-0.04	-0.1	-0.03	-0.04
Number of businesses per resident	0.96	0.56	0.78	0.94	0.63	0.89
Number of businesses per household	0.96	0.41	0.71	0.95	0.59	0.89
Average distance to general practitioner	0.37	0.13	0.14	0.44	0.16	0.18
Average distance to big supermarket	0.4	0.08	0.08	0.44	0.13	0.12
Average distance to day-care centre	0.47	0.12	0.13	0.55	0.16	0.16
Average distance to school	0.43	0.17	0.16	0.49	0.22	0.21
Number of schools within 3 km road distance	-0.2	-0.06	-0.05	-0.22	-0.09	-0.07
Degree of urbanisation	0.16	0.09	0.06	0.26	0.13	0.11
Percentage of residents with low education level	0.22	-0.05	0.19	0.12	-0.05	0.17
Percentage of residents with middle education level	-0.12	0.05	0.13	-0.07	0.05	0.17
Percentage of residents with high education level	-0.13	0	-0.21	-0.06	0	-0.22
Number of labour participants in total population	-0.23	-0.07	-0.18	-0.33	-0.1	-0.22
Number of labour participants of working population	-0.23	-0.07	-0.19	-0.33	-0.11	-0.23
Net percentage of labour participation	0.35	0.11	-0.13	0.38	0.16	-0.02
Percentage of employed labourers in working population	-0.55	-0.38	-0.27	-0.71	-0.43	-0.36
Average surface area of residence in neighbourhood	0.46	0.47	0.31	0.53	0.52	0.32
Median of energy label class in neighbourhood	0.12	0.08	0.08	0.1	0.12	0.08
Percentage of electricity delivered	-0.19	0	0.13	-0.2	-0.02	0.09

Table B-4: Correlations between socioeconomic variables and the number of electricity stations per resident and household for each grid operator in South-Holland

B-3 Correlation results for other variables

	Low voltage	Middle voltage	Total	Stations per resident
SES-WOA/Total score	-0.11	0.07	-0.06	0.08
SES-WOA/Wealth score	-0.13	0.06	-0.08	0.08
SES-WOA/Education score	-0.05	0.09	-0.01	0.05
SES-WOA/Employment score	-0.1	0.07	-0.05	0.1

Table B-5: Correlations between SES-WOA score and the number of electricity stations in South-Holland

	Low voltage	Middle voltage	Total	Stations per resident
HEq (High Energy quote) (%)	-0.07	0.24	0.03	0.1
LIHE (Low Income, High Energy cost) (%)	-0.01	-0.07	-0.04	-0.04
LILEK (Low Income, Low Energy Class) (%)	0.01	-0.11	-0.03	-0.06
LEKWI (Low Energy Class, Little Investmentpotential) (%)	0.01	-0.08	-0.02	-0.06
LIHE and/or LILEK (%)	0.03	-0.11	-0.01	-0.06
Average standardised residual income	-0.05	0.17	0.02	0.08
Average energy quote (%)	-0.08	0.06	-0.04	0.02

Table B-6: Correlations between energy poverty and the number of electricity stations in South-Holland

	Low voltage	Middle voltage	Total	Stations per resident
Experienced health (good/really good) (%)	-0.13	0.12	-0.06	0.02
Excercise/Meets exercise norm (%)	0.17	0.26	0.23	0.03
Excercise/Weakly excercisers (%)	0.09	0.23	0.16	0.01
Weight/Underweight (%)	0.11	0.12	0.13	0.14
Weight/Normal weight (%)	0.07	0.24	0.14	0.07
Weight/Overweight (%)	-0.07	-0.23	-0.14	-0.06
Weight/Heavily overweight (%)	0.01	-0.21	-0.07	-0.05
Smoker (%)	0.13	0.03	0.11	0.08
Alcohol usage/Meets alcohol guidelines (%)	-0.03	-0.22	-0.1	-0.01
Alcohol usage/Drinker (%)	-0.06	0.16	0.01	0.03
Alcohol usage/Heavy drinker (%)	0.13	0.21	0.18	0.01
Alcohol usage/Excesive drinker (%)	0.1	0.19	0.15	-0.01
Physical health/One or more long term illments (%)	0.11	-0.18	0.02	-0.06
Physical health/Limited by health (%)	0.1	-0.16	0.03	-0.06
Physcial health/Severly limited by health (%)	0.12	-0.13	0.05	-0.05
Physical health/Long term illness and limitations (%)	0.09	-0.17	0.01	-0.06
Psychological illments (%)	0.17	-0.02	0.12	0.03
Resilience/(Very) low resilience (%)	0.15	-0.09	0.09	-0.02
Resilience/(Very) high resilience (%)	-0.15	0.07	-0.09	0.01
High risk for anxiety or depression (%)	0.16	-0.03	0.12	0.02
Loneliness/Lonely (%)	0.16	-0.01	0.12	0.09
Loneliness/Severe loneliness (%)	0.15	-0.01	0.12	0.05
Loneliness/Emotional loneliness (%)	0.17	0.02	0.14	0.08
Loneliness/Social loneliness (%)	0.13	-0.01	0.11	0.08
Difficulty making ends meet (%)	0.17	-0.02	0.13	0.03

Table B-7: Correlations between health statistics and the number of electricity stations in South-Holland

	Experienced health (good/really good) (%)	Exercise/Meets exercise norm (%)	Exercise/Weekly exerciser (%)	Weight/Underweight (%)	Weight/Normal weight (%)	Weight/Overweight (%)	Weight/Heavily overweight (%)	Smoker (%)	Alcohol usage/Meets alcohol guidelines (%)	Alcohol usage/Drinker (%)	Alcohol usage/Heavy drinker (%)	Alcohol usage/Excessive drinker (%)	Physical health/One or more long term illnesses (%)
Number of residents	-0.33	0	-0.06	0.2	-0.08	0.06	0.18	0.32	0.25	-0.35	-0.05	-0.2	0.21
Percentage of male inhabitants	0.18	0.18	0.16	0.09	0.14	-0.14	-0.14	0.09	-0.2	0.16	0.22	0.12	-0.25
Percentage of 65+ inhabitants	-0.21	-0.33	-0.3	-0.24	-0.21	0.22	0.12	-0.29	0.16	-0.02	-0.34	0.08	0.5
Percentage of inhabitants with a migrant background	-0.66	-0.03	-0.19	0.5	-0.18	0.12	0.35	0.71	0.55	-0.72	-0.14	-0.37	0.38
Total number of households	-0.36	0.02	-0.06	0.26	-0.05	0.02	0.16	0.36	0.23	-0.35	0	-0.14	0.23
Average size household	0.57	0.04	0.13	-0.34	0.14	-0.09	-0.26	-0.53	-0.16	0.27	-0.06	-0.15	-0.58
Population density	-0.55	-0.01	-0.14	0.33	-0.19	0.14	0.34	0.52	0.35	-0.49	-0.01	-0.18	0.41
Housing stock	-0.36	0	-0.07	0.24	-0.07	0.04	0.18	0.35	0.24	-0.35	-0.03	-0.16	0.24
Average property value	0.71	0.48	0.58	-0.16	0.6	-0.56	-0.71	-0.65	-0.56	0.61	0.17	0.37	-0.57
Percentage private owned residences	0.81	0.21	0.42	-0.5	0.29	-0.23	-0.5	-0.76	-0.52	0.68	0	0.14	-0.6
Percentage rented residences	-0.81	-0.21	-0.42	0.5	-0.29	0.23	0.5	0.76	0.53	-0.68	0	-0.15	0.6
Percentage housing corporation owned residences	-0.83	-0.39	-0.56	0.22	-0.53	0.48	0.67	0.62	0.67	-0.76	-0.22	-0.32	0.7
Percentage constructed before 2000	-0.24	-0.06	-0.25	0.11	-0.16	0.14	0.19	0.18	0.11	-0.12	0.04	0.16	0.3
Percentage constructed after 2000	0.24	0.06	0.25	-0.11	0.16	-0.14	-0.19	-0.18	-0.11	0.12	-0.04	-0.16	-0.3
Average electricity demand for all housing types	0.68	0.2	0.29	-0.27	0.33	-0.28	-0.49	-0.58	-0.41	0.52	0.12	0.21	-0.6
Electricity demand rented residence	0.45	0.17	0.19	-0.14	0.25	-0.21	-0.33	-0.33	-0.28	0.33	0.12	0.17	-0.44
Electricity demand private owned residence	0.59	0.14	0.23	-0.25	0.28	-0.24	-0.42	-0.52	-0.33	0.43	0.08	0.17	-0.53
Average gas demand for all housing types	0.5	0.2	0.17	-0.16	0.31	-0.27	-0.43	-0.45	-0.35	0.43	0.15	0.35	-0.4
Gas demand rented residence	0.38	0.18	0.13	-0.1	0.24	-0.21	-0.32	-0.29	-0.27	0.32	0.15	0.28	-0.34
Gas demand private owned residence	0.46	0.2	0.16	-0.11	0.32	-0.29	-0.42	-0.41	-0.33	0.4	0.15	0.35	-0.36
Percentage of income receivers	-0.08	-0.02	-0.02	0.01	-0.05	0.04	0.06	0	0.03	-0.04	-0.03	0	0.13
Percentage of households among the lowest 40% of national income	-0.82	-0.22	-0.5	0.57	-0.25	0.18	0.44	0.77	0.51	-0.65	0.09	-0.02	0.63
Percentage of households among the highest 20% of national income	0.82	0.36	0.63	-0.37	0.48	-0.42	-0.62	-0.76	-0.55	0.64	0.02	0.1	-0.69
Percentage of households under or around the social minimum income	-0.84	-0.23	-0.51	0.45	-0.33	0.27	0.5	0.74	0.65	-0.81	-0.09	-0.24	0.63
Median worth of individual households	0.68	0.36	0.52	-0.3	0.45	-0.4	-0.6	-0.72	-0.5	0.58	0.02	0.27	-0.49
Percentage of residents with social welfare benefits	-0.8	-0.25	-0.45	0.3	-0.41	0.36	0.58	0.67	0.64	-0.79	-0.17	-0.33	0.59
Percentage of residents with disability benefits	-0.38	-0.18	-0.24	0.05	-0.28	0.27	0.35	0.31	0.28	-0.33	-0.11	-0.15	0.33
Percentage of residents with unemployment benefits	-0.35	-0.06	-0.09	0.11	-0.22	0.19	0.3	0.37	0.23	-0.3	-0.09	-0.17	0.29
Percentage of residents with retirement pension	-0.24	-0.32	-0.28	-0.23	-0.22	0.22	0.15	-0.24	0.19	-0.07	-0.34	0.02	0.51
Number of businesses	-0.21	0.14	0.08	0.3	0.1	-0.13	0	0.32	0.09	-0.21	0.08	-0.07	0.07
Number of businesses per resident	0.08	0.05	0.05	0.11	0.09	-0.08	-0.1	0.05	-0.07	0.09	0.05	0.05	-0.12
Number of businesses per houshold	0.11	0.04	0.05	0.11	0.1	-0.1	-0.12	0.01	-0.08	0.1	0.04	0.04	-0.16
Average distance to general practitioner	0.37	-0.01	-0.01	-0.21	0.11	-0.07	-0.2	-0.3	-0.21	0.27	0.11	0.17	-0.35
Average distance to big supermarket	0.42	0.05	0.04	-0.19	0.19	-0.16	-0.28	-0.35	-0.25	0.31	0.13	0.19	-0.4
Average distance to day-care centre	0.41	0.05	0.02	-0.18	0.18	-0.15	-0.28	-0.33	-0.26	0.32	0.15	0.23	-0.38
Average distance to school	0.39	0.09	0.08	-0.13	0.22	-0.19	-0.3	-0.29	-0.28	0.31	0.17	0.23	-0.38
Number of schools within 3 km road distance	-0.45	0.16	0	0.49	0.02	-0.08	0.12	0.53	0.25	-0.41	0.04	-0.12	0.3
Degree of urbanisation	0.53	-0.05	0.02	-0.4	0.1	-0.04	-0.25	-0.48	-0.31	0.42	0.1	0.19	-0.48
Percentage of residents with low education level	-0.57	-0.47	-0.62	-0.1	-0.6	0.58	0.62	0.4	0.58	-0.59	-0.29	-0.34	0.48
Percentage of residents with middle education level	-0.04	-0.34	-0.35	-0.27	-0.39	0.41	0.32	0.04	0.12	-0.04	-0.04	-0.09	0.02
Percentage of residents with high education level	0.47	0.6	0.72	0.26	0.73	-0.73	-0.69	-0.33	-0.53	0.48	0.25	0.32	-0.38
Number of labour participants in total population	-0.33	0.02	-0.04	0.22	-0.06	0.03	0.16	0.34	0.23	-0.34	-0.02	-0.18	0.19
Number of labour participants of working population	-0.28	0.04	0	0.2	-0.04	0.01	0.13	0.31	0.18	-0.29	0	-0.17	0.15
Net percentage of labour participation	0.74	0.25	0.5	-0.31	0.35	-0.29	-0.45	-0.43	-0.58	0.61	0.27	0.09	-0.79
Percentage of employed labourers in working population	-0.38	-0.23	-0.23	0.07	-0.35	0.33	0.44	0.35	0.29	-0.29	-0.13	-0.29	0.34
Average surface area of residence in neighbourhood	0.12	0.07	0.07	0.03	0.1	-0.09	-0.12	-0.02	-0.12	0.13	0.06	0.07	-0.14
Median of energy label class in neighbourhood	0.09	0.02	0.12	-0.06	0.03	-0.03	-0.05	-0.06	-0.03	0.03	-0.05	-0.11	-0.11
Percentage of electricity delivered	-0.39	-0.01	-0.14	0.36	-0.06	0.02	0.16	0.41	0.22	-0.3	0.02	0	0.31

	Physical health/Limited by health (%)	Physical health/Severely limited by health (%)	Physical health/Long term illness and limitations (%)	Psychological illnesses (%)	Resilience/(Very) low resilience (%)	Resilience/(Very) high resilience (%)	High risk for anxiety or depression (%)	Loneliness/Lonely (%)	Loneliness/Severe loneliness (%)	Loneliness/Emotional loneliness (%)	Loneliness/Social loneliness (%)	Difficulty making ends meet (%)
Number of residents	0.22	0.31	0.19	0.39	0.39	-0.39	0.4	0.36	0.38	0.37	0.37	0.39
Percentage of male inhabitants	-0.24	-0.17	-0.24	-0.02	-0.1	0.07	-0.01	-0.04	-0.01	-0.01	-0.02	-0.04
Percentage of 65+ inhabitants	0.47	0.21	0.48	-0.2	-0.08	0.19	-0.24	0	-0.11	-0.09	-0.01	-0.19
Percentage of inhabitants with a migrant background	0.42	0.61	0.35	0.84	0.79	-0.76	0.84	0.81	0.85	0.83	0.83	0.82
Total number of households	0.24	0.33	0.21	0.44	0.42	-0.42	0.44	0.4	0.43	0.42	0.41	0.43
Average size household	-0.57	-0.52	-0.53	-0.56	-0.5	0.48	-0.51	-0.65	-0.6	-0.63	-0.61	-0.52
Population density	0.41	0.5	0.36	0.63	0.61	-0.63	0.62	0.57	0.59	0.59	0.54	0.6
Housing stock	0.25	0.34	0.22	0.42	0.42	-0.41	0.42	0.4	0.42	0.41	0.4	0.42
Average property value	-0.62	-0.64	-0.61	-0.65	-0.69	0.75	-0.63	-0.65	-0.63	-0.62	-0.62	-0.65
Percentage private owned residences	-0.69	-0.79	-0.64	-0.84	-0.84	0.82	-0.82	-0.84	-0.84	-0.85	-0.81	-0.85
Percentage rented residences	0.69	0.79	0.64	0.84	0.84	-0.82	0.82	0.84	0.84	0.85	0.81	0.85
Percentage housing corporation owned residences	0.77	0.83	0.74	0.72	0.81	-0.74	0.72	0.71	0.72	0.69	0.71	0.77
Percentage constructed before 2000	0.29	0.23	0.29	0.15	0.17	-0.16	0.14	0.18	0.15	0.15	0.18	0.17
Percentage constructed after 2000	-0.29	-0.23	-0.29	-0.15	-0.17	0.16	-0.14	-0.18	-0.15	-0.15	-0.18	-0.17
Average electricity demand for all housing types	-0.61	-0.63	-0.57	-0.66	-0.67	0.7	-0.63	-0.68	-0.65	-0.67	-0.62	-0.64
Electricity demand rented residence	-0.42	-0.42	-0.4	-0.41	-0.43	0.45	-0.39	-0.42	-0.4	-0.42	-0.38	-0.38
Electricity demand private owned residence	-0.52	-0.54	-0.49	-0.59	-0.58	0.63	-0.57	-0.61	-0.58	-0.61	-0.55	-0.56
Average gas demand for all housing types	-0.4	-0.44	-0.37	-0.53	-0.53	0.57	-0.51	-0.51	-0.51	-0.52	-0.47	-0.5
Gas demand rented residence	-0.32	-0.34	-0.3	-0.38	-0.39	0.42	-0.36	-0.38	-0.37	-0.38	-0.34	-0.35
Gas demand private owned residence	-0.35	-0.39	-0.32	-0.48	-0.48	0.52	-0.47	-0.46	-0.46	-0.46	-0.43	-0.45
Percentage of income receivers	0.1	0.06	0.09	0.03	0.05	-0.06	0.03	0.04	0.02	0.02	0.03	0.03
Percentage of households among the lowest 40% of national income	0.73	0.81	0.68	0.83	0.82	-0.82	0.8	0.86	0.84	0.86	0.82	0.83
Percentage of households among the highest 20% of national income	-0.76	-0.77	-0.73	-0.76	-0.78	0.8	-0.73	-0.81	-0.76	-0.78	-0.77	-0.77
Percentage of households under or around the social minimum income	0.71	0.87	0.67	0.85	0.89	-0.82	0.86	0.83	0.87	0.84	0.86	0.87
Median worth of individual households	-0.56	-0.62	-0.53	-0.71	-0.71	0.78	-0.68	-0.69	-0.67	-0.68	-0.65	-0.7
Percentage of residents with social welfare benefits	0.66	0.78	0.62	0.78	0.84	-0.76	0.8	0.73	0.77	0.73	0.75	0.82
Percentage of residents with disability benefits	0.35	0.37	0.34	0.32	0.37	-0.34	0.34	0.31	0.32	0.3	0.31	0.35
Percentage of residents with unemployment benefits	0.26	0.31	0.24	0.4	0.38	-0.38	0.39	0.38	0.38	0.38	0.37	0.38
Percentage of residents with retirement pension	0.47	0.24	0.48	-0.14	-0.02	0.12	-0.17	0.03	-0.06	-0.05	0.01	-0.13
Number of businesses	0.08	0.19	0.05	0.36	0.3	-0.32	0.35	0.32	0.35	0.36	0.33	0.34
Number of businesses per resident	-0.11	-0.09	-0.11	-0.01	-0.06	0.06	-0.02	0.03	0.03	0.04	0.04	-0.02
Number of businesses per houshold	-0.14	-0.13	-0.14	-0.05	-0.09	0.09	-0.05	-0.01	-0.01	0	0	-0.05
Average distance to general practitioner	-0.31	-0.34	-0.28	-0.4	-0.37	0.38	-0.38	-0.39	-0.39	-0.41	-0.35	-0.36
Average distance to big supermarket	-0.37	-0.38	-0.33	-0.43	-0.41	0.42	-0.41	-0.44	-0.43	-0.45	-0.4	-0.4
Average distance to day-care centre	-0.33	-0.36	-0.3	-0.43	-0.41	0.42	-0.42	-0.42	-0.42	-0.43	-0.38	-0.4
Average distance to school	-0.34	-0.34	-0.31	-0.38	-0.38	0.39	-0.37	-0.38	-0.38	-0.39	-0.34	-0.36
Number of schools within 3 km road distance	0.29	0.43	0.24	0.62	0.54	-0.54	0.61	0.57	0.6	0.61	0.57	0.57
Degree of urbanisation	-0.41	-0.48	-0.36	-0.63	-0.55	0.56	-0.6	-0.61	-0.6	-0.62	-0.56	-0.54
Percentage of residents with low education level	0.56	0.56	0.56	0.38	0.52	-0.43	0.41	0.41	0.41	0.36	0.45	0.46
Percentage of residents with middle education level	0.07	0	0.1	-0.1	0	-0.01	-0.07	-0.1	-0.11	-0.14	-0.09	-0.04
Percentage of residents with high education level	-0.47	-0.43	-0.5	-0.23	-0.39	0.34	-0.26	-0.25	-0.23	-0.18	-0.28	-0.32
Number of labour participants in total population	0.2	0.3	0.18	0.41	0.4	-0.4	0.41	0.37	0.39	0.39	0.38	0.41
Number of labour participants of working population	0.16	0.25	0.13	0.37	0.35	-0.36	0.37	0.33	0.35	0.35	0.33	0.36
Net percentage of labour participation	-0.78	-0.75	-0.74	-0.58	-0.63	0.53	-0.56	-0.69	-0.64	-0.63	-0.69	-0.59
Percentage of employed labourers in working population	0.32	0.32	0.31	0.38	0.38	-0.46	0.37	0.38	0.35	0.36	0.32	0.36
Average surface area of residence in neighbourhood	-0.12	-0.11	-0.12	-0.07	-0.11	0.1	-0.08	-0.04	-0.05	-0.04	-0.04	-0.08
Median of energy label class in neighbourhood	-0.12	-0.1	-0.12	-0.05	-0.06	0.06	-0.05	-0.05	-0.04	-0.04	-0.05	-0.06
Percentage of electricity delivered	0.31	0.35	0.28	0.46	0.41	-0.41	0.44	0.48	0.46	0.48	0.46	0.43

Table B-8: Correlations between health statistics and the selected socioeconomic indicators

Appendix C

Hotspot analysis

C-1 Hotspot maps

Shown below are the resulting maps from the hotspot analysis. Red areas are hotspots and blue areas are coldspots (unless mentioned otherwise in the title of the map). A white background indicates areas that are neither hot- nor coldspots and a yellowish background means that there was not enough data available to analyse the neighbourhood.

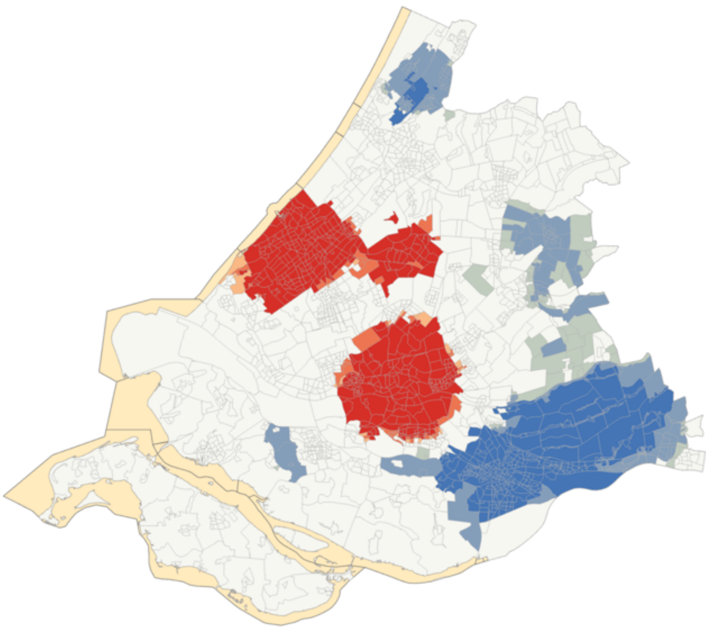

Figure C-1: Hot- and coldspot map for the number of inhabitants in the province of South-Holland

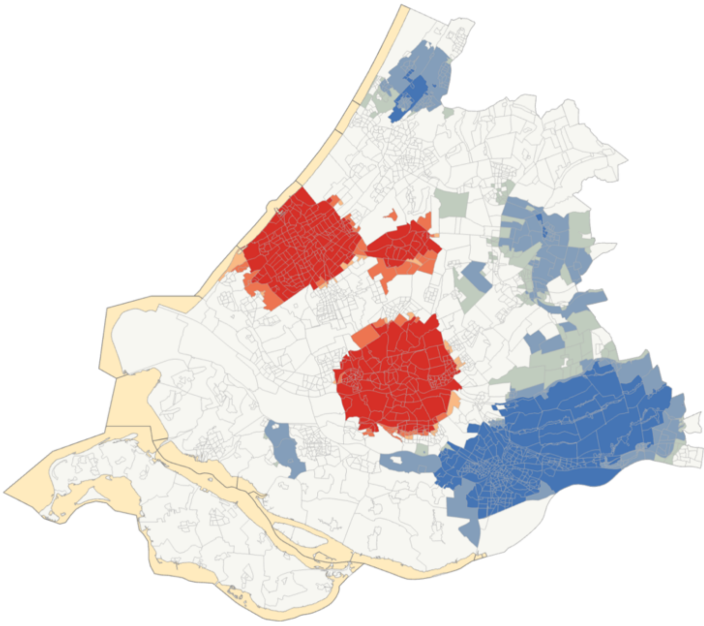

Figure C-2: Hot- and coldspot map for the number of households in the province of South-Holland

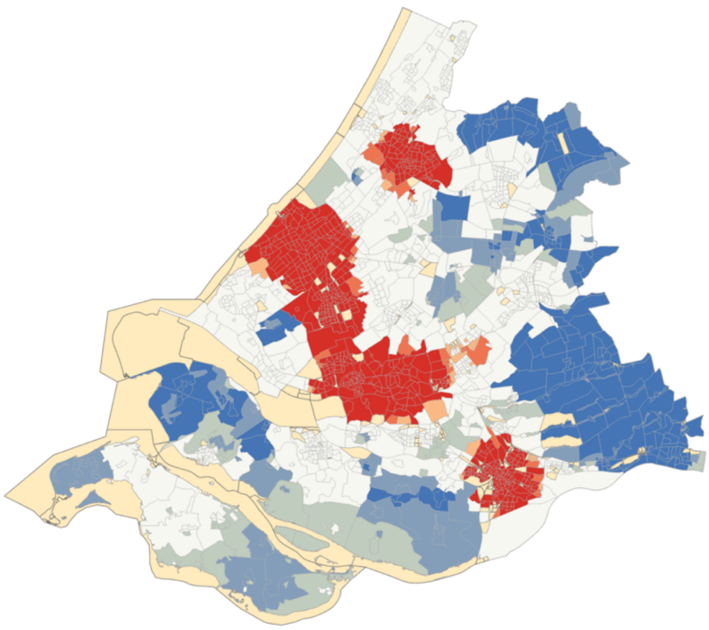

Figure C-3: Hot- and coldspot map for population density in the province of South-Holland

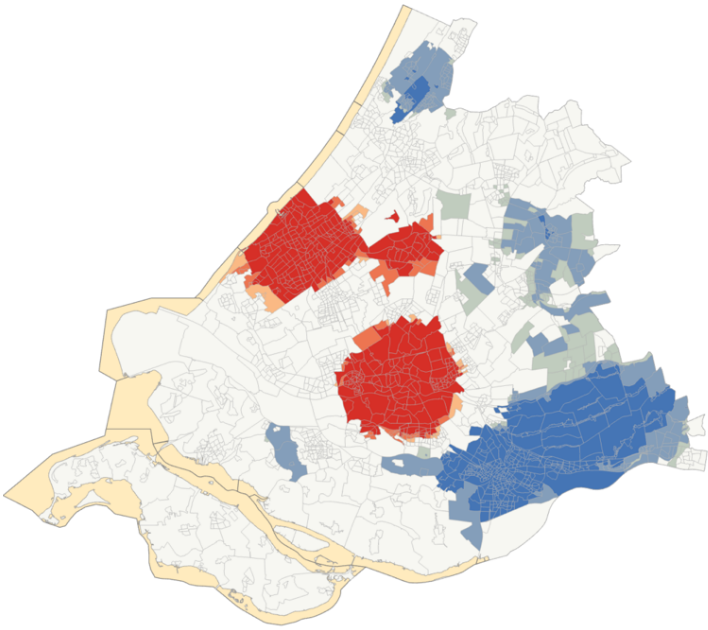

Figure C-4: Hot- and coldspot map for the housing stock in the province of South-Holland

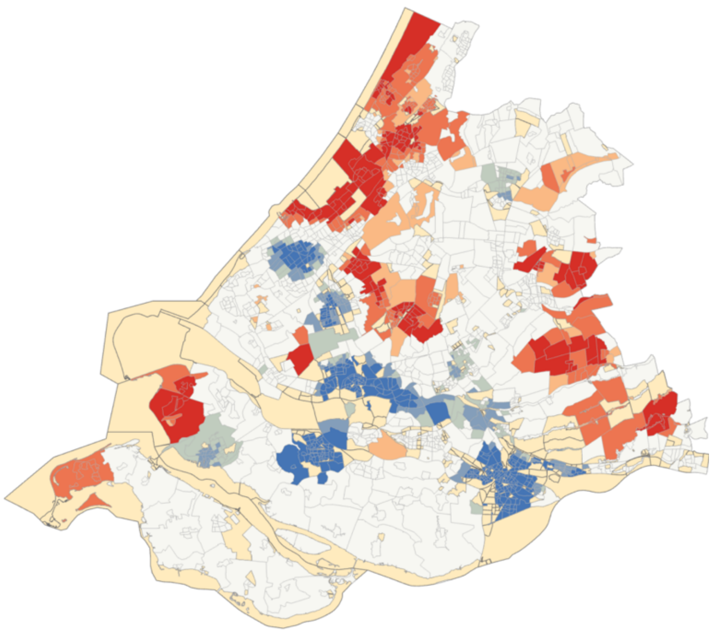

Figure C-5: Hot- and coldspot map for the average property value in the province of South-Holland

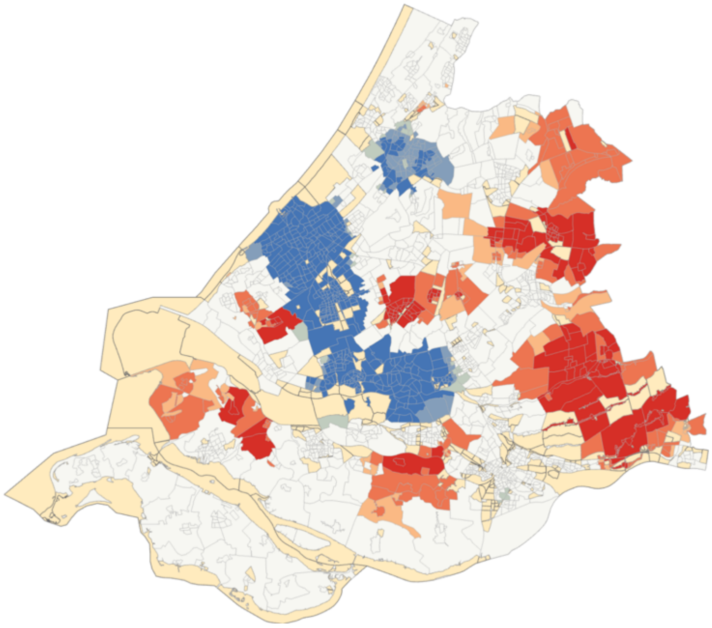

Figure C-6: Hot- and coldspot map for the percentage of private owned residences in the province of South-Holland

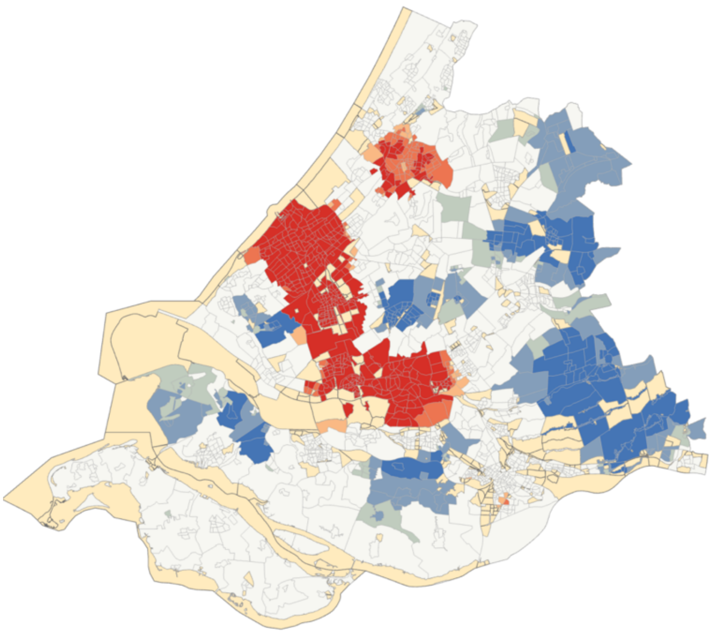

Figure C-7: Hot- and coldspot map for the percentage of rented residences in the province of South-Holland

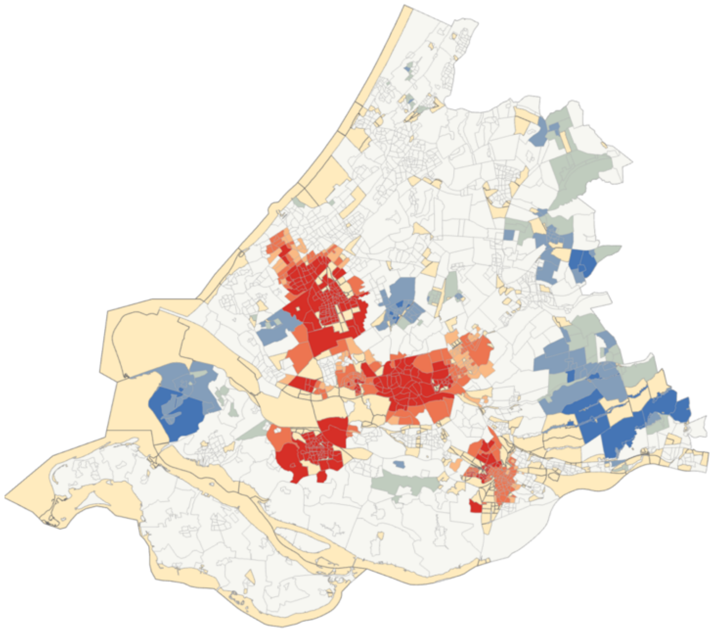

Figure C-8: Hot- and coldspot map for the percentage of housing corporation owned residences in the province of South-Holland

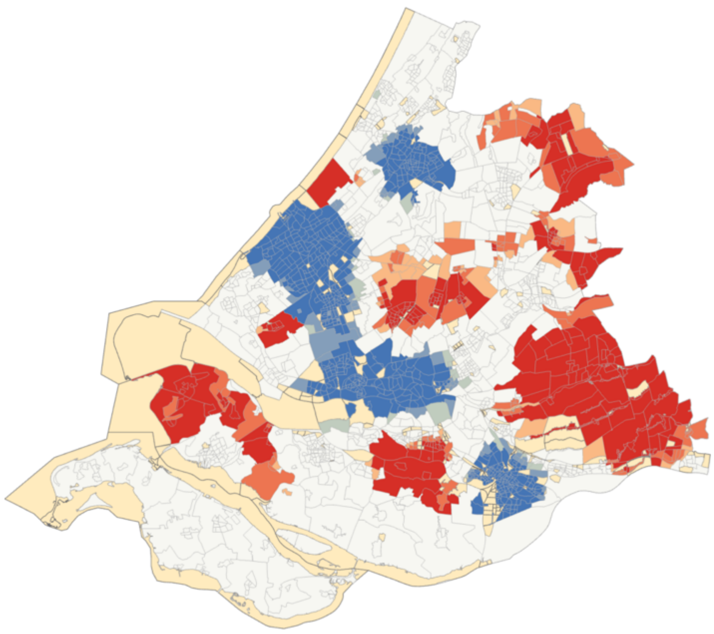

Figure C-9: Hot- and coldspot map for the electricity demand in the province of South-Holland

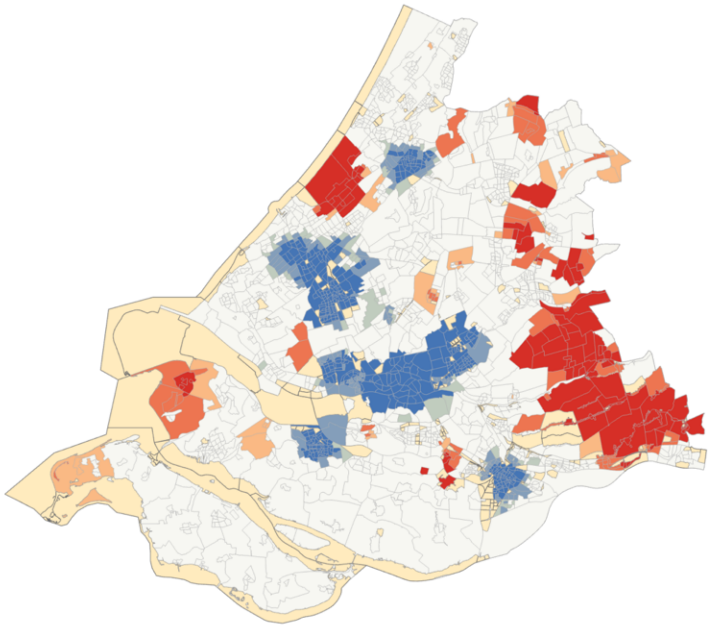

Figure C-10: Hot- and coldspot map for the gas demand in the province of South-Holland

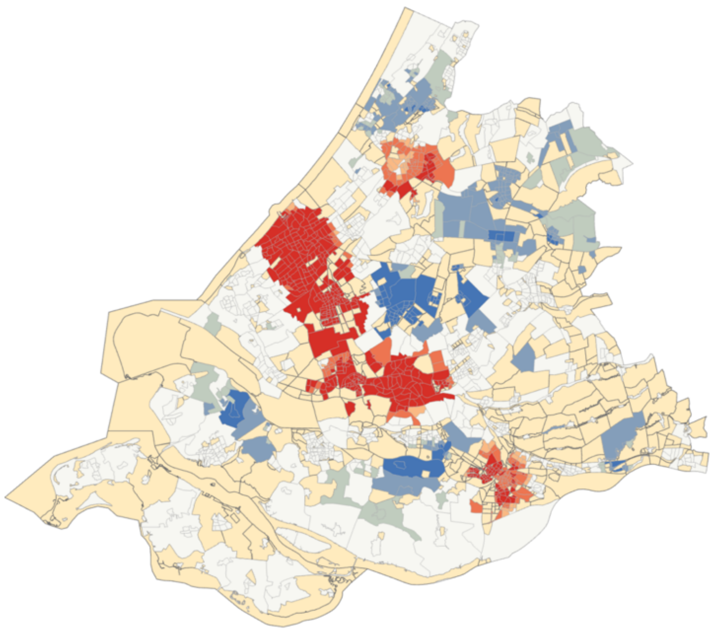

Figure C-11: Hot- and coldspot map for the percentage of low-income household in the province of South-Holland

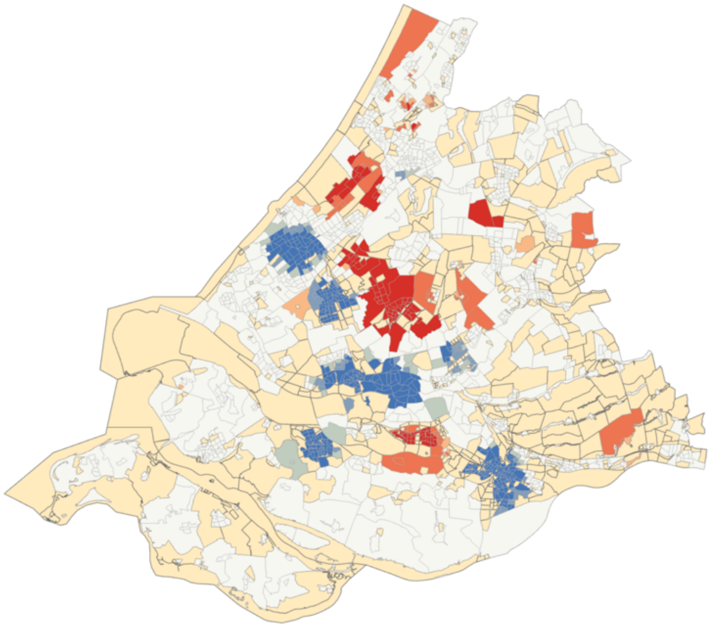

Figure C-12: Hot- and coldspot map for the percentage of high-income households in the province of South-Holland

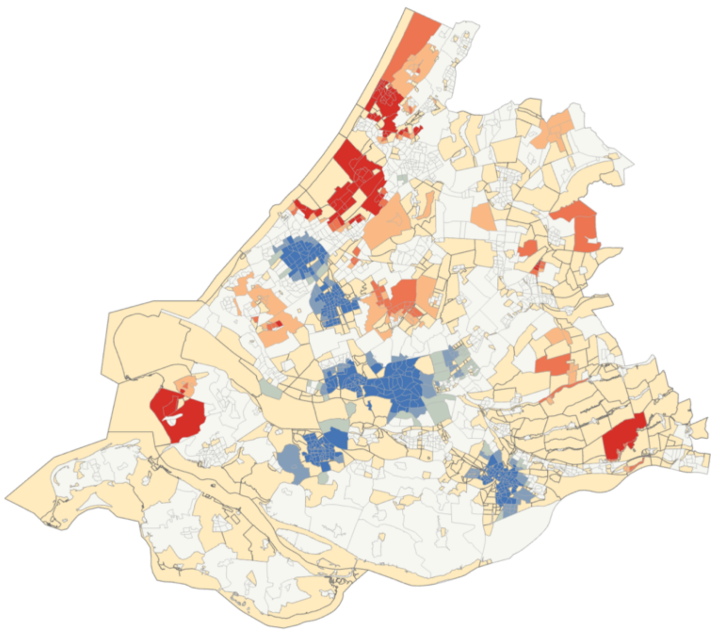

Figure C-13: Hot- and coldspot map for the median worth of individual households in the province of South-Holland

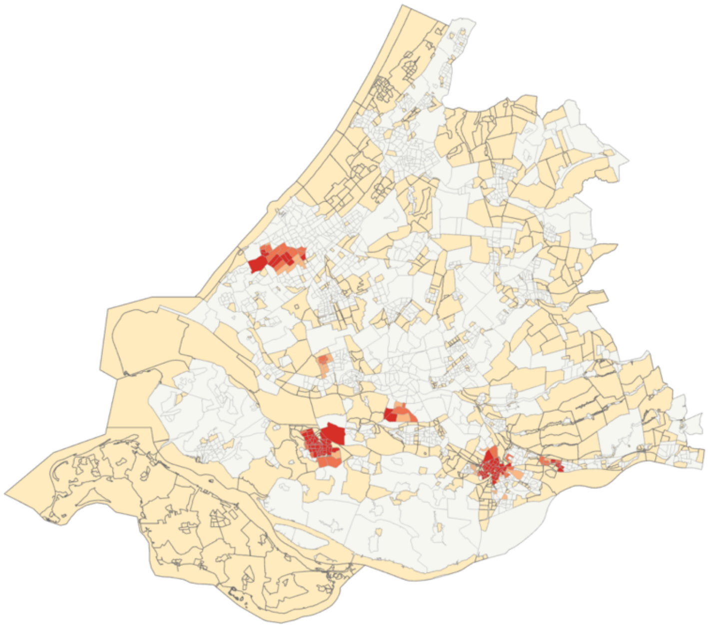

Figure C-14: Hot- and coldspot map for the percentage of inhabitants with social welfare benefits in the province of South-Holland

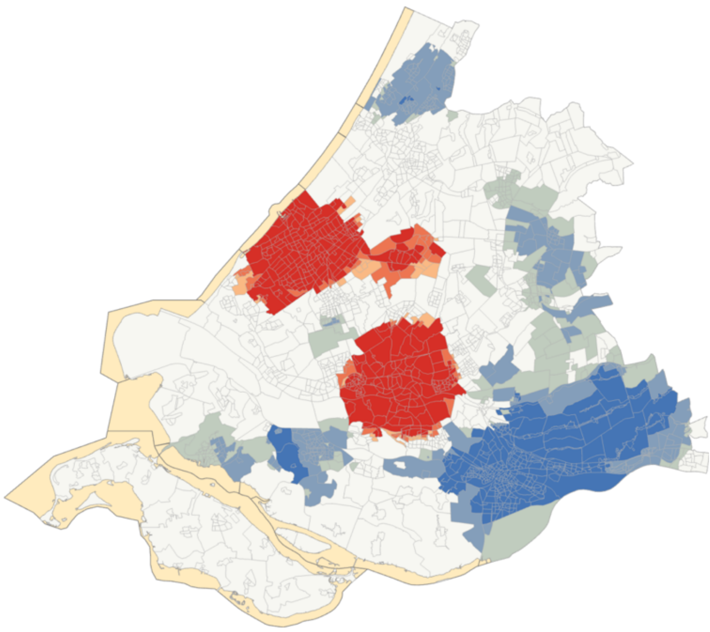

Figure C-15: Hot- and coldspot map for the number of businesses in the province of South-Holland

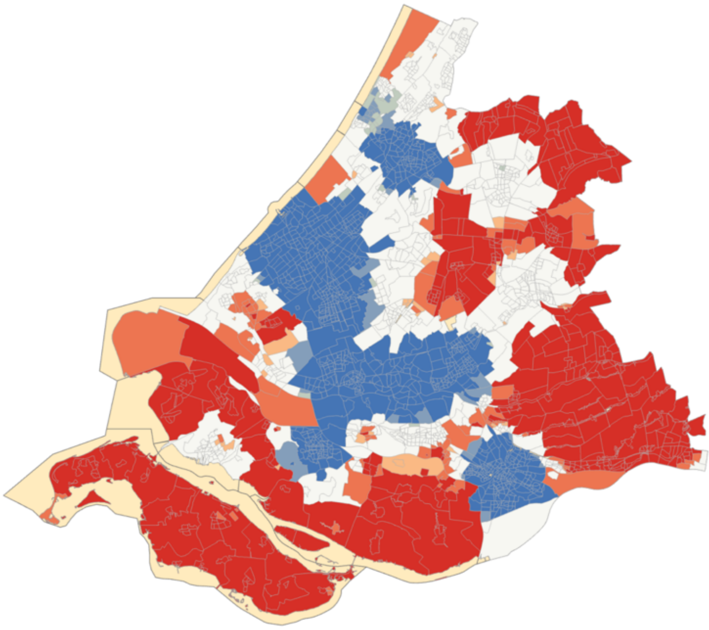

Figure C-16: Hot- and coldspot map for the degree of urbanisation in the province of South-Holland (Blue is hotspot; Red is coldspot)

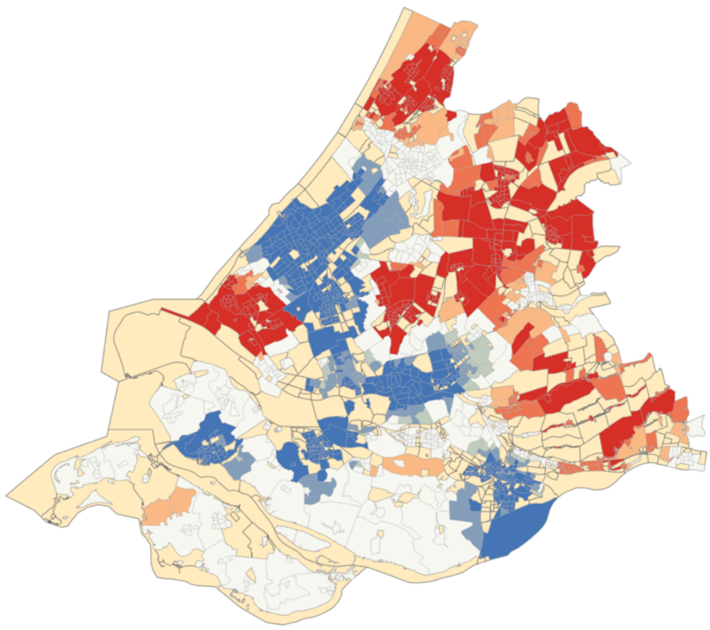

Figure C-17: Hot- and coldspot map for the percentage of labour participants in the province of South-Holland

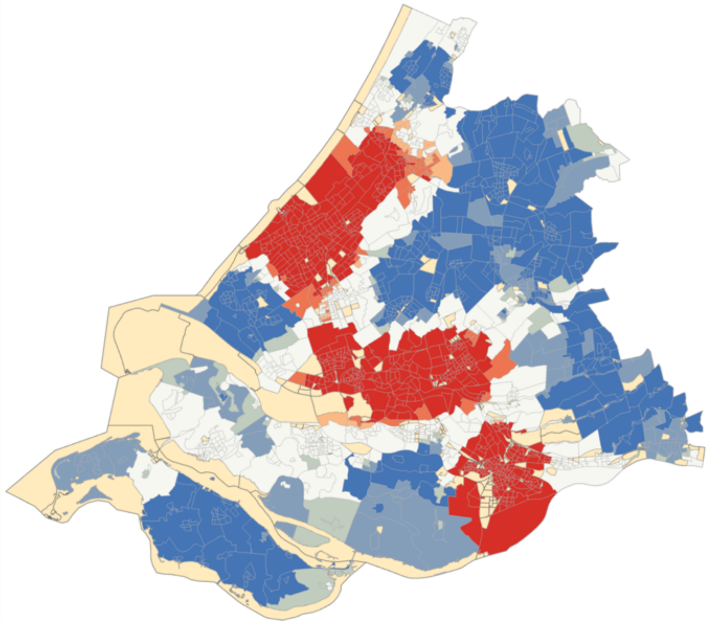

Figure C-18: Hot- and coldspot map for the amount of self-produced electricity in the province of South-Holland (Blue is hotspot; Red is coldspot)

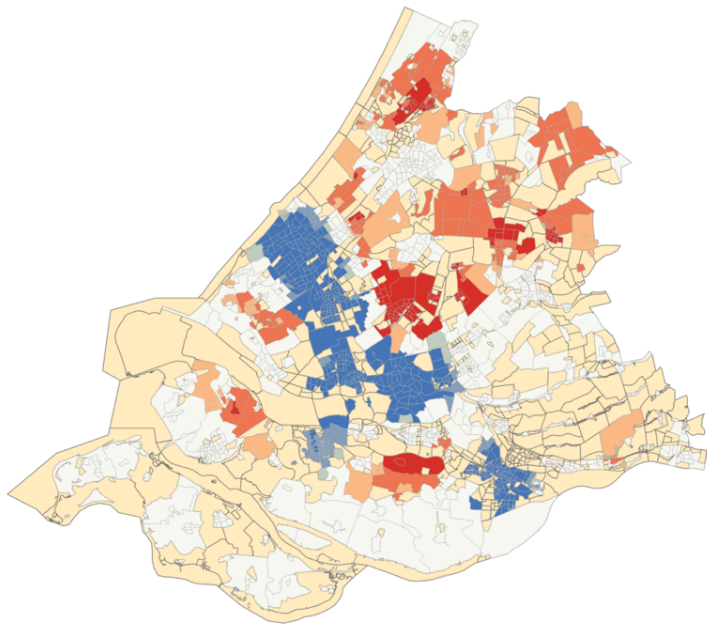

Figure C-19: Hot- and coldspot map for the SES-WOA score in the province of South-Holland

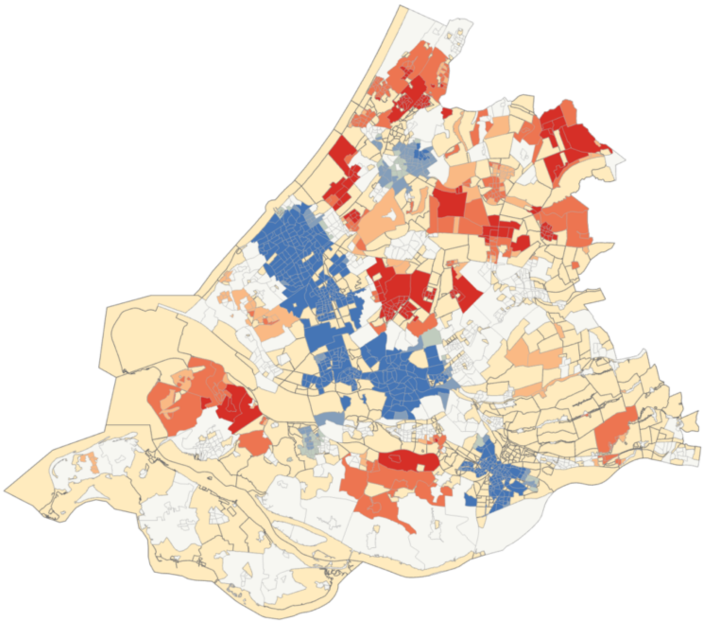

Figure C-20: Hot- and coldspot map for the financial SES-WOA score in the province of South-Holland

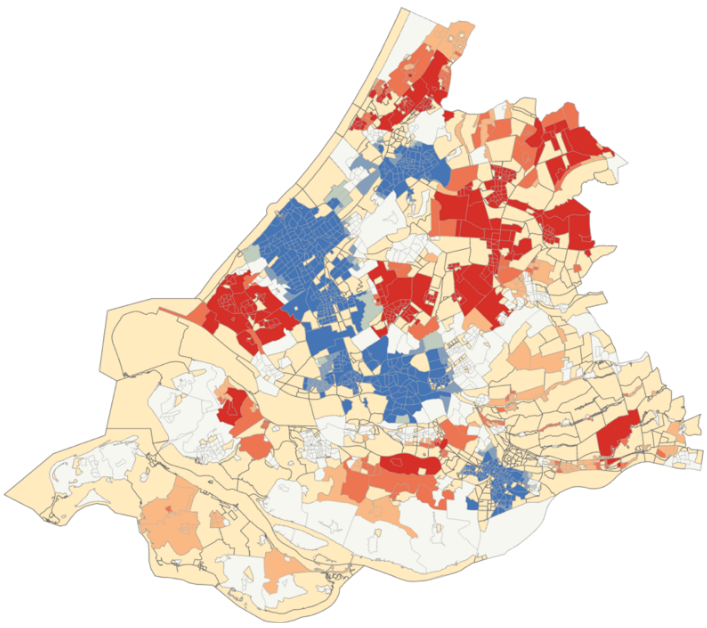

Figure C-21: Hot- and coldspot map for the employment SES-WOA score in the province of South-Holland

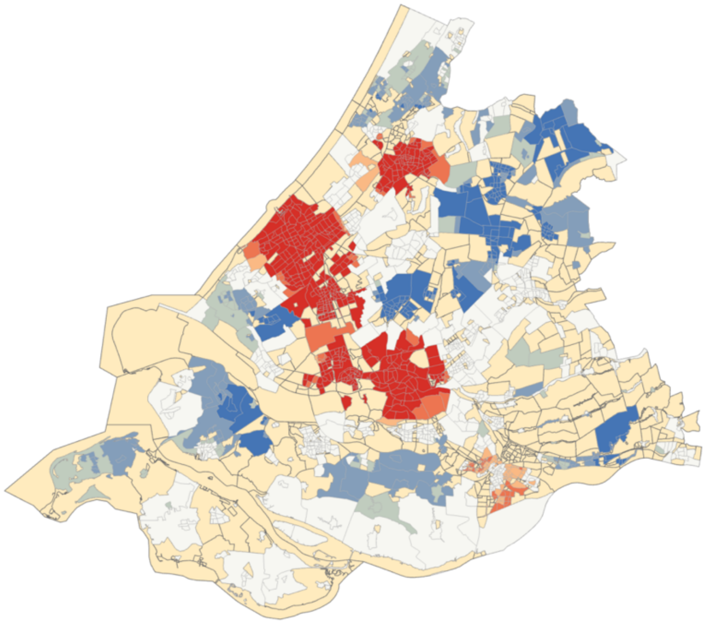

Figure C-22: Hot- and coldspot map for the spread of SES-WOA score in the province of South-Holland

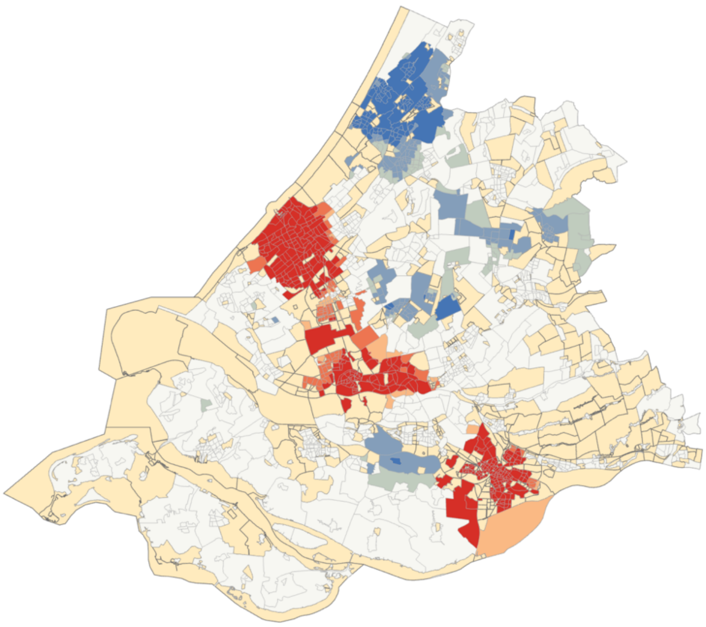

Figure C-23: Hot- and coldspot map for energy poverty according to the LIHC and/or LILLE method in the province of South-Holland

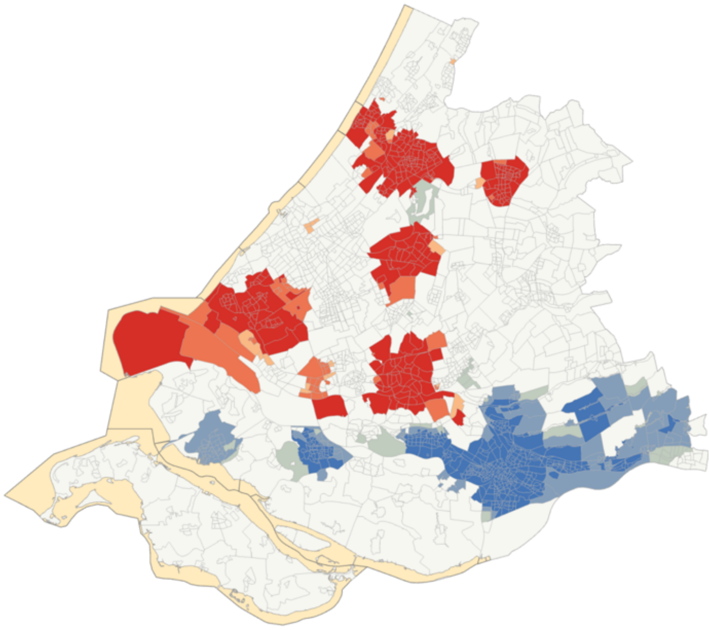

Figure C-24: Hot- and coldspot map for the total number of low- and middle voltage stations in the province of South-Holland

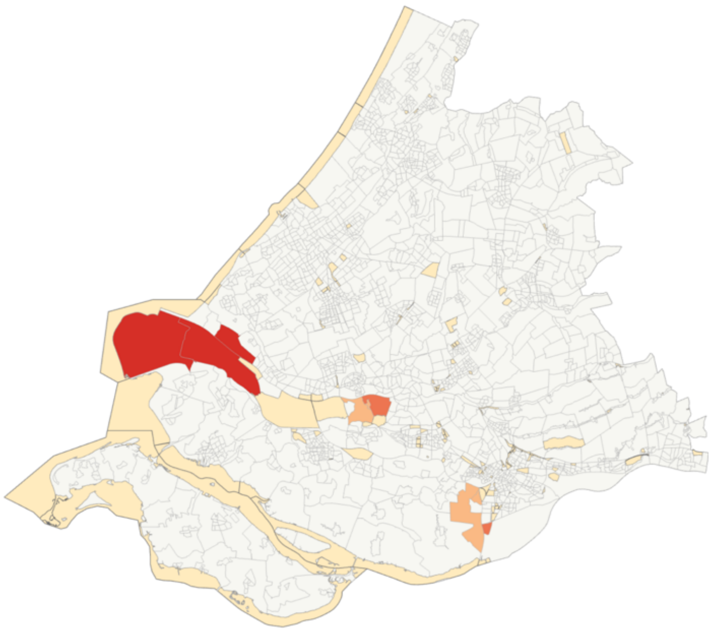

Figure C-25: Hot- and coldspot map for the number of low and middle voltage stations per resident in the province of South-Holland

C-2 Congestion maps

Below, the maps showing the electricity congestion for Liander and Stedin can be seen. White areas do not have any congestion. In the yellow areas the transport capacity is scarce. Orange areas are region where no new connections can be made until congestion management has been researched. Red areas are areas where no new connections can be made and congestion management is not an option.

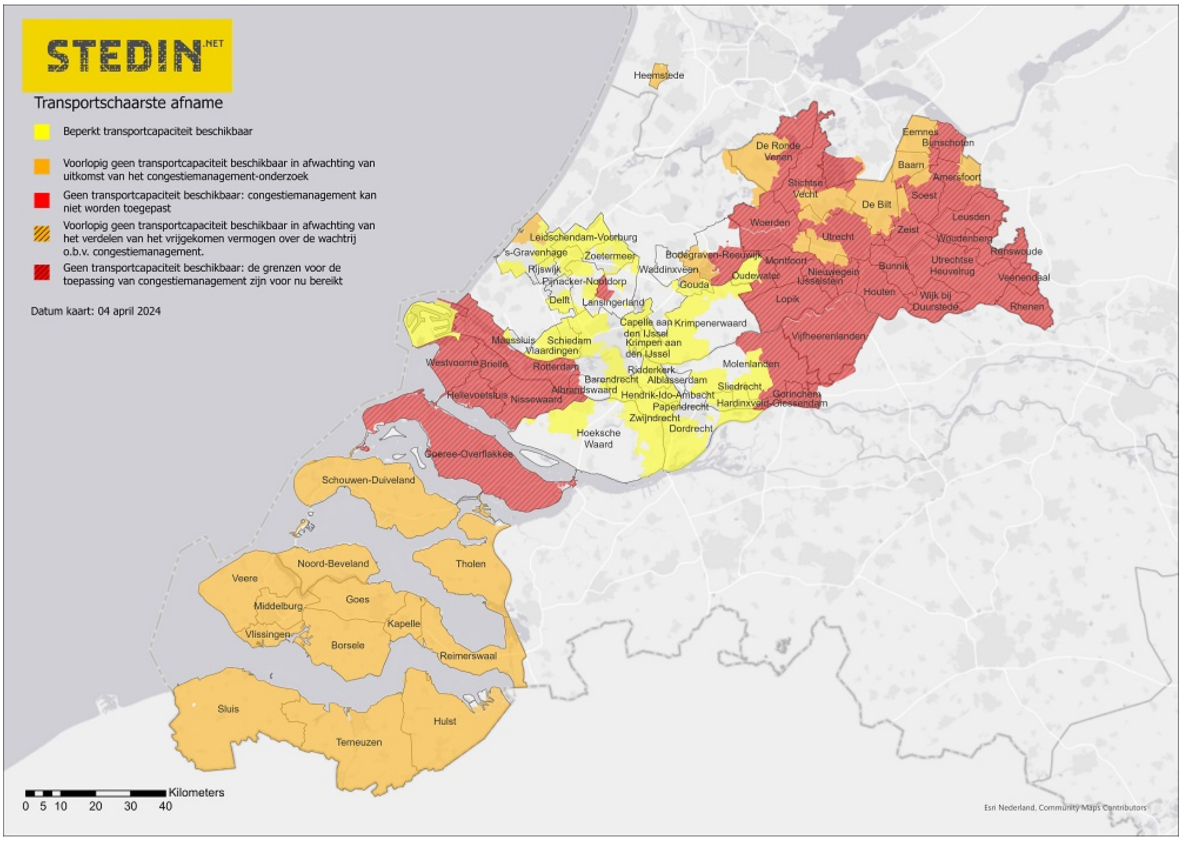

Figure C-26: Map of the congestion for electricity consumption in the catchment area of Stedin

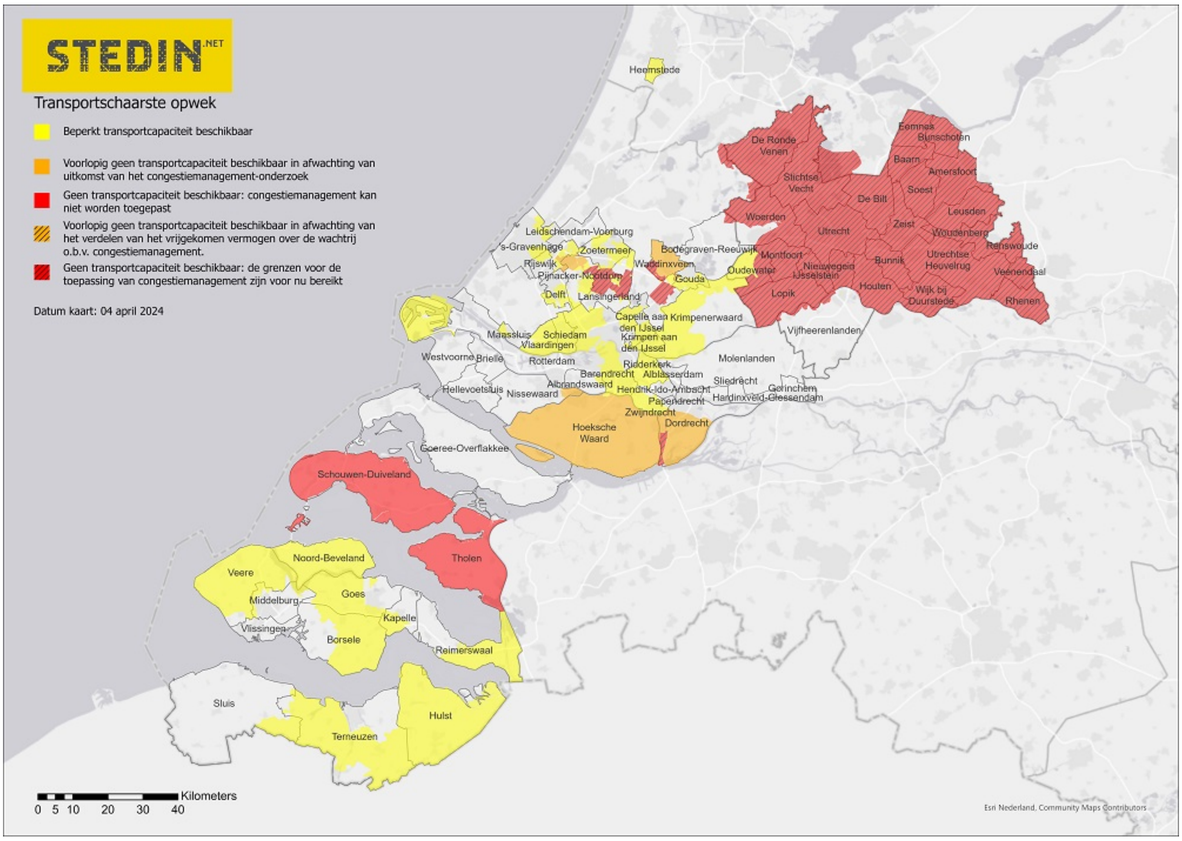

Figure C-27: Map of the congestion for electricity feed-in for the catchment area of Stedin

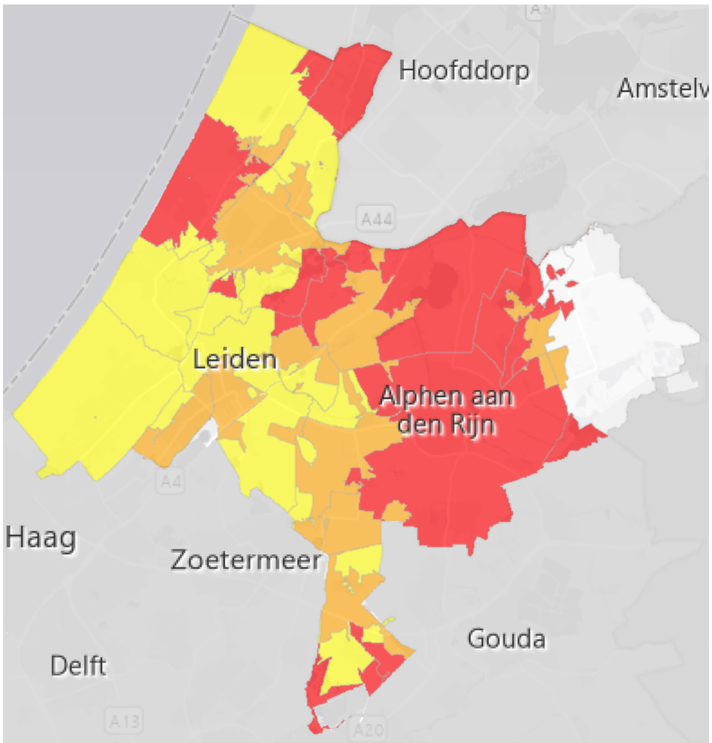

Figure C-28: Map of the congestion for electricity consumption in the catchment area of Liander in South-Holland

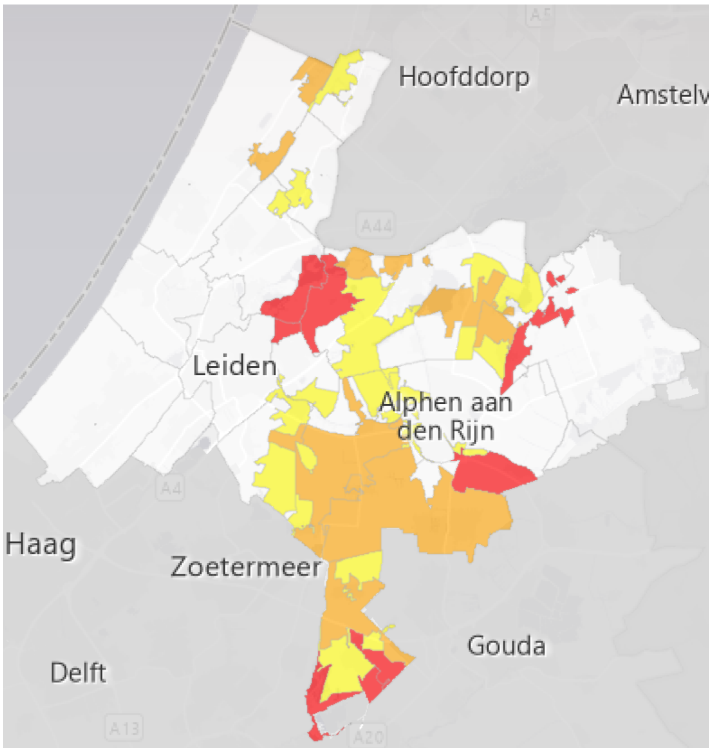

Figure C-29: Map of the congestion for electricity feed-in for the catchment area of Liander in South-Holland

Appendix D

Interviews

D-1 Interview protocol grid operators

Introduction (5 min)
Introduction of interviewee (Name, position, relationship to the research)

Explanation of research:

- a. Motivation for research
- b. Knowledge gap
- c. Goal of the research

Discussion results of the analysis
Discussion of interview expectations

Brief discussion of ethical guidelines and review of consent form (answers will be anonymised to prevent identification, given answers can be withdrawn if desired)

Research results (30 min)
How would you explain the few correlations between the chosen socioeconomic characteristics and the location of electricity infrastructure? Did you expect this outcome?

Are there socioeconomic indicators or other factors missing that you think should be included in the analysis? What are those factors?

Do you think a different scale in the analysis would make a difference (e.g., postal code 6 or individual households)? How would redrawing neighbourhood boundaries (e.g. by considering the influence areas of stations) influence the results?

Net congestion is a relatively new problem, and choices have only been made on the network for a few years. Does this lead to a different distribution of investments than the first come first serve principle?

Currently, clear correlations cannot be found, but could they arise due to current shortages in executive force? If the relationships are re-examined in x years, how would the results change?

The results show that there is a lot of difference between the various grid operators. For WestlandInfra this is logical, but how would you explain the differences between Liander and Stedin?

There is a significant difference between correlations on the low and medium voltage grid in the analysis. How do investments in the medium voltage grid affect low voltage and vice versa?

Future investments (20 min)
The analysis shows that wealthier neighbourhoods consume more energy. Could this lead to these neighbourhoods being prioritized for grid reinforcement/expansion? Does this inadvertently result in less attention being given to other neighbourhoods? How do you ensure equal access to the grid for everyone?

Are there areas where grid expansion is more difficult (e.g., due to lack of space)? How are these areas addressed? What are other technical/spatial limitations that play a role?

"Grid operators currently have insufficient insight into the (future) load of the low voltage grids to accurately determine where and how much the grid needs to be reinforced and where the need is highest. This is partly due to limited monitoring of the low voltage grid loads, the unpredictable autonomous growth of solar PV, heat pumps, and EVs, and limited insight into municipal plans for heat transition, electric transportation, and housing construction." How are you attempting to mitigate this problem?

The ACM (Authority for Consumers & Markets) will soon introduce a new guideline to prioritize applications for the power grid. Are you aware of this? (Brief explanation if no) Are these measures sufficient? To what extent does this alleviate the pressure on grid operators? What are the areas for improvement?

Grid operators have submitted a request to the ACM to implement time-based tariffs. To what extent is this a solution for grid congestion? Is this a temporary solution, or can it reduce the demand for new infrastructure/reinforcement?

The price of your grid fee is currently determined by the capacity of the type of connection. So, no distinction is made between households with the same connection for the level of network usage. Is it an option to adjust the grid fee based on usage, or are the differences in usage of the same connections too small? To what extent can this make a difference?

Role of the province (10 min)
Which role does the province have in this process? Is the low-voltage grid more in the scope of municipalities?

How can the province help grid operators or municipalities in the process? How is the current collaboration with all parties going?

Conclusion (5 min)
Are there any other points you want to address? Are there any aspects that you think are missing in the research?

Do you believe the research could add value for future investment plans in the electricity grid?

Are there any responses you would like to revisit or prefer not to be included in the final report?

D-2 Interview protocol municipalities

Introduction (5 min)
Introduction of interviewee (Name, position, relationship to the research)

Explanation of research:

- a. Motivation for research
- b. Knowledge gap
- c. Goal of the research

Discussion results of the analysis
Discussion of interview expectations

Brief discussion of ethical guidelines and review of consent form (answers will be anonymised to prevent identification, given answers can be withdrawn if desired)

Research results (30 min)
How would you explain the few correlations between the chosen socioeconomic characteristics and the location of electricity infrastructure? Did you expect this outcome?

Are there socioeconomic indicators or other factors missing that you think should be included in the analysis? What are those factors?

Do you think a different scale in the analysis would make a difference (e.g., postal code 6 or individual households)? How would redrawing neighbourhood boundaries (e.g. by considering the influence areas of stations) influence the results?

Net congestion is a relatively new problem, and choices have only been made on the network for a few years. Does this lead to a different distribution of investments than the first come first serve principle?

Currently, clear correlations cannot be found, but could they arise due to current shortages in executive force? If the relationships are re-examined in x years, how would the results change?

Future investments (20 min)
How are municipalities addressing grid congestion? What is their role in the problem and what measures can they take?

How are energy justice and energy poverty included in the decision making process?

The research indicates that people living in housing corporation owned residences experience more injustice due to their limited input in the decision-making. What role do housing corporations play in this issue?

Is there any insight into the group for who investments in efficient usage (e.g., neighbourhood batteries) are not an option? What problems might this group face in the future if there is currently less focus on them?

"Grid operators currently have insufficient insight into the (future) load of the low voltage grids to accurately determine where and how much the grid needs to be reinforced and where the need is highest. This is partly due to limited monitoring of the low voltage grid loads, the unpredictable autonomous growth of solar PV, heat pumps, and EVs, and limited insight into municipal plans for heat transition, electric transportation, and housing construction." How is the communication between grid operators and municipalities? Do you have insights in each others development plans?

The ACM (Authority for Consumers & Markets) will soon introduce a new guideline to prioritize applications for the power grid. Are you aware of this? (Brief explanation if no) Are these measures sufficient? To what extent does this alleviate the pressure on grid operators? What are the areas for improvement?

The analysis shows that wealthier neighbourhoods consume more energy. Could this lead to these neighbourhoods being prioritized for grid reinforcement/expansion? Does this inadvertently result in less attention being given to other neighbourhoods? How do you ensure equal access to the grid for everyone?

Role of the province (10 min)
Which role does the province have in this process? Is the low-voltage grid more in the scope of municipalities?

What do municipalities need from the province? How is the current collaboration with all parties going?

Grid operators indicated that they benefit from clarity in the plans of the municipalities and a fast process for permits. How is this currently going?

Conclusion (5 min)
Are there any other points you want to address? Are there any aspects that you think are missing in the research?

Do you believe the research could add value for future investment plans in the electricity grid?

Are there any responses you would like to revisit or prefer not to be included in the final report?

D-3 Interview protocol researchers

Introduction (5 min)
Introduction of interviewee (Name, position, relationship to the research)

Explanation of research:

- a. Motivation for research
- b. Knowledge gap
- c. Goal of the research

Discussion results of the analysis
Discussion of interview expectations

Brief discussion of ethical guidelines and review of consent form (answers will be anonymised to prevent identification, given answers can be withdrawn if desired)

Research results (30 min)
How would you explain the few correlations between the chosen socioeconomic characteristics and the location of electricity infrastructure? Did you expect this outcome?

Are there socioeconomic indicators or other factors missing that you think should be included in the analysis? What are those factors?

Do you think a different scale in the analysis would make a difference (e.g., postal code 6 or individual households)? How would redrawing neighbourhood boundaries (e.g. by considering the influence areas of stations) influence the results?

Currently, clear correlations cannot be found, but could they arise due to current shortages in executive force? If the relationships are re-examined in x years, how would the results change?

Future investments (20 min)
The analysis shows that wealthier neighbourhoods consume more energy. Could this lead to these neighbourhoods being prioritized for grid reinforcement/expansion? Does this inadvertently result in less attention being given to other neighbourhoods? How do you ensure equal access to the grid for everyone?

According to the WRR a balanced distribution of costs and benefits among the population is crucial for a successful energy transition. Is this currently being achieved? Is this being monitored properly?

The research indicates that people living in housing corporation owned residences experience more injustice due to their limited input in the decision-making. What role do housing corporations play in this issue?

Is there any insight into the group for who investments in efficient usage (e.g., neighbourhood batteries) are not an option? What problems might this group face in the future if there is currently less focus on them?

The ACM (Authority for Consumers & Markets) will soon introduce a new guideline to prioritize applications for the power grid. Are you aware of this? (Brief explanation if no) Are these measures sufficient? To what extent does this alleviate the pressure on grid operators? What are the areas for improvement?

Role of the province (10 min)
Which role does the province have in this process? Is the low-voltage grid more in the scope of municipalities?

How can the province better account for energy justice in their decision making?

How can governmental bodies and grid operators best work together to keep the electricity grid evenly accessible for everyone?

Conclusion (5 min)
Are there any other points you want to address? Are there any aspects that you think are missing in the research?

Do you believe the research could add value for future investment plans in the electricity grid?

Are there any responses you would like to revisit or prefer not to be included in the final report?

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