The influence of geodata and regional economics on energy modelling

Internship Draft

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Abstract

To shift energy supply from centralized fossil fuel-based of today to decentralized, environmentally friendly, renewable energy-based an energy transition is required. One of the issues that needs to be addressed to enable this transition is to make accurate and reliable information available to consumers and producers, containing both detailed models as well as detailed data. The aim of this study is to investigate the influence of the use of geodata and the neighbourhood scale on the accuracy of energy modelling (modelling of the energy potential, economic evaluation and CO_2-reduction potential) compared to individual household-scale modelling using average data, for the case study Amsterdam Nieuw-West in the Netherlands.

Firstly, the energy potential for the case study has been modelled for three scenarios; first using only national averages, second using geodata, and third using both geodata and the neighbourhood approach. Secondly, an economic analysis has been done for all three scenarios. Finally, the avoided CO_2-emissions that is expected after implementing the renewable energy solutions has been modelled for all three scenarios.

A significant difference between the three scenarios can be observed. By comparing scenario 1 and 2 it can be concluded that the use of geographic data has a significant influence of the results of energy potential, economic and emission models. For instance, the insulation potential in scenario 2 is 33% less than in scenario 1. Furthermore, the neighbourhood approach also has a similar impact on these models, as can be concluded from comparing scenario 2 and 3. For instance, the photovoltaic potential in scenario 3 is 70% more than in scenario 3. Yet, which of these three scenarios is the most accurate can only be determined by researching the actual energy potential in the case study.

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List of Abbreviations

BAG	Basisregistratie Adressen en Gebouwen (basic administration buildings and addresses)
GJ/PJ	GigaJoule/PetaJoule
IRR	Internal Rate of Return
kWh	kiloWatt hour
LCA	Life Cycle Analysis
O&M	Operation and Maintenance
NPV	Net Present Value
PBP	PayBack Period

1. Introduction

The annual energy consumption of the Netherlands is approximately 3496 PJ, of which 1083 PJ (~ 30%) is consumption by the built environment (Ministerie van EZ, 2011). Only 4% of the total Dutch energy consumption is generated by renewable energy resources (such as wind, water, biomass, etc.) (CBS, 2012). Most energy is produced using fossil resources, which are damaging to the environment. This is due to for instance greenhouse gas emissions causing global warming or by an increase in the emission of particulate matter. Additionally, using fossil fuels is increasingly associated with decreasing energy security, both through the dwindling reserves as well as through the dependency on other countries with unstable governments. To provide more environmentally friendly and secure energy, an energy transition is required (Calvert, et al., 2013).

Traditionally, in Western countries energy is produced mainly on a national scale (or macro scale). However, with the increase in energy production using renewable energy sources, decentralized energy production on the micro scale increases (Ramachandra & Shruthi, 2007). At this scale, each individual household applies energy saving measures or renewable energy techniques. However, to be able to utilize larger renewable energy producers, such as geothermal or wind turbines, inhancing the 'green economy' and increasing the number of 'green jobs', a third scale, the meso scale or regional approach, has to be considered (McCauley & Stephens, 2012; IEA, 2011). This scale can be described by regional economics. Regional economics describes how units (generally firms) that are located close together can share benefits, such as infrastructure, advantages of scale and others that can decrease costs of production (Hoover & Giarratani, 1984).

Energy production by renewable energy techniques applied at the micro and meso scale differs per location depending on both the geographic constraints (such as wind speed and solar irradiation) as well as financial circumstances and political boundaries (Calvert, et al., 2013). For instance, the solar intensity and number of solar hours has a strong influence on the energy potential. Furthermore, policy regarding the proximity of wind turbines to residential areas can inhibit the placement of a wind turbine at certain locations. Using datasets that are linked to a specific location, geodata, the geographic influence can be taken into account in modelling the energy potential, as well as modelling CO_2-emissions and the economic consequences. Therefore, when taking the average properties of households rather than geographically specific data, a less accurate representation of the potential of a household is obtained. For instance, assuming an average available roof surface area results in a less accurate estimate of the potential energy production compared to using the exact surface area of the rooftops of households, which can be deduced from geographical data.

Integrating the meso scale and geodata is one of the goals of the PICO (Project Interactive Communication and Design tool) project (PICO, 2013). "PICO is developing an energy transition support system that offers an extensive up-to-date and transparent data collection (from different disciplines), which can be visualized in its geographical context on different platforms. These data are used as input for both energy models and financial models at the meso scale that can be used to calculate investment potentials and potentials for energy saving and renewable energy generation for any region in The Netherlands. Furthermore, impacts of energy-reducing measures can be modelled, using for example cost-benefit analyses and CO_2 emission models" (Fruijtier et al., 2014, p. 5).

In this study it is aimed to investigate the influence of using geodata and the meso scale on the accuracy of energy modelling compared to micro scale modelling using average data for a case study in the Netherlands. Similar to the PICO project the energy potential, economic evaluation and GHG-

emissions are modelled in this study. The case study is a cluster of approximately 25,000 houses in the city district Nieuw-West in Amsterdam. This city district has a highly variable household type, and the DRO (Spatial Planning Service) has collected data for this area on for instance income, house type, building age, etc. (DRO, 2013). Data availability in the city of Amsterdam is a major consideration in selecting this area as a case study.
When geodata and regional economics have a positive influence on the accuracy energy models, which is assumed in the PICO project, this can increase public acceptance of renewable energy technology, because the public has access to more approachable and accurate data (PICO, 2013). The hypothesis in this study is that using geodata and the meso scale results in more accurate energy modelling results. This likely overcomes one of the barriers of energy transition, which concerns the lack of trust from the general public in the results of the energy potential models, as well as the economic analysis, because each model displays a large uncertainty. Furthermore, more accurate energy modelling can create more thorough insight into the locations at which it is optimal to integrate a renewable energy solution or decide which solution is most suitable at a specific location, supporting an optimal investment decision. The main research question of this study is:

What are the effects of the use of geodata and regional economics on results obtained from energy modelling in Amsterdam Nieuw-West, the Netherlands?

Subquestions are:

- *How does the use of geodata and the use of both geodata and regional economics influence the modelled renewable energy potential in a cluster of households?*
- *How does the use of geodata and the use of both geodata and regional economics influence the modelled economic analysis of renewable energy solutions in a cluster of households?*
- *How does the use of geodata and the use of both geodata and regional economics influence the modelled potential for avoiding GHG-emissions in a cluster of households?*

2. Literature review

The design of the energy transition can be described by the *trias energetica* (Vandevyvere & Stremke, 2012; IEA, 2011; Lysen, 1996; Stremke, et al., 2011). Recently, an additional step is added, referring to this new method as 'New Step Strategy', which consists of the following steps (Vandevyvere & Stremke, 2012; IEA, 2011):

1. Reducing energy consumption (by change in e.g. behaviour, insulation, urban morphology)
2. Use waste energy streams
3. Replace fossil resources by renewable energy technologies
4. Use fossil resources as clean and efficient as possible

The original *trias energetica* is represented by step 1, 3 and 4. Using waste heat streams is one of the new techniques that is introduced to reduce energy consumption and to tailor energy consumption to the end user.

In current energy modelling mainly average data (on country level) is used. Using more detailed geographic information (geodata) likely results in more accurate energy modelling (Calvert, et al., 2013). Furthermore, using geodata supports the cooperation of different stakeholders, because it provides more insight into different aspects of the energy system and a recognisable map in which households can find their own house, with information specific to their house (Calvert, et al., 2013). Additionally, a geographic approach provides more thorough insight into the opportunities to enable the energy transition in a cluster of households and its vicinity (McCauley & Stephens, 2012; Späth & Rohracher, 2010; Truffer, 2008). Also Horner et al. (2011) indicate that to accurately model the energy transition and stimulate environmental improvement, Geographic Information Systems (GIS) can be used, which can benefit both GIS and the energy science research. In bioenergy it is more common to apply geodata to for instance plan the shortest transportation distance, using geographic components (such as van der Hilst & Faaij (2012), (Velazquez-Marti & Annevelink (2009) and many others). Furthermore, renewable energy potential (for photovoltaics (PV), hydro energy, wind energy and biomass) for specific regions has been mapped by for instance Ramachandra & Shruthi (2007) for India and McCauley & Stephens (2012) for the US. In the Netherlands, models have been made that display the solar PV potential (Huld, et al., 2014) and the geothermal potential (van Wees, et al., 2010).

Besides that no studies have been carried out to model the energy potential in the Netherlands using geodata, no studies on energy transition technologies on the meso scale have been carried out in the Netherlands. McCauley & Stephens (2012) have carried out a study mapping the added value of renewable energy production at the meso scale for the US. They mention that similarities can be found between the meso scale and regional economics (McCauley & Stephens, 2012). For instance when certain resources are location specific and are difficult to transport (such as solar irradiation or geothermal potential) it is useful to use them on a local scale. Furthermore, aggregation in a small region can have significant advantages, because the demand for resources (in this case energy) can be joined, justifying larger, more economically feasible energy installations. Furthermore, besides demands also the capital can be joined in an agglomeration, such that more expensive energy installations can be afforded. Furthermore, when applying a new measure to an agglomeration of households (for instance solar panels to many households), economies of scale can apply, decreasing the investment price per panel. Yet, up until now, no true connection has been made between regional economics and energy modelling. Studies regarding regional economics mainly discuss different types of firms in different urban settings (Hoover & Giarratani, 1984; Feldman, 1999). These studies all combine three stages of regional economics: economies of scale, localisation economics (advantages of working with other firms) and urbanization economics (advantages of using the urban infrastructure) (Hoover & Giarratani, 1984). Yet, the advantages of using regional economics to model renewable energy potential have not yet been studied.

3. Case study

The case study area is the city district Nieuw-West in Amsterdam, the capital of the Netherlands (Figure 1). This city district consists of 17 neighbourhoods. The city district has mainly been built in the 1950's and 1960's, with an expansion in the 1990's. The building style is very open, allowing for a lot of green areas between the buildings. The building types are very diverse as well, with …% apartment buildings, …% detached houses, …% semi-detached houses, …% corner houses and …% terraced houses. Also several parks are located in the city district, such as Rembrandtpark, Westgaarde and Gerbrandypark. Furthermore, there are two lakes located in the centre (Sloterplas) and at the border (Nieuwe meer) of the city district (Gemeente Amsterdam, 2014).

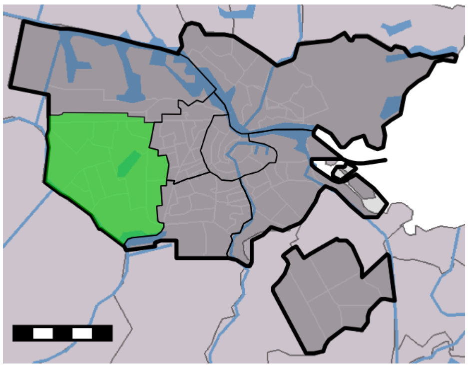

Figure 1: Map showing the city of Amsterdam. Amsterdam Nieuw-West is indicated in green.

The city district had 141,852 inhabitants in 2013, of which 50.5% are non-Western immigrants (DRO, 2013). The average electricity consumption is 2931 kWh and the average gas consumption is 1214 m^3 according to Alliander. The average housing value is €194,000, of which 29% is privately owned (DRO, 2013). The average disposable income (income after taxes) is €29,600, while 26.5% are considered to have a low income (<€17,900 per year) (DRO, 2013). In this case study, 25.000 households are considered, due to data availability.

4. Method

4.1 Scenarios

To evaluate the influence of geodata and regional economics on the accuracy and outcomes of energy modelling, three scenarios for the case study are distinguished. For all scenarios the potential for renewable energy production and energy saving is modelled (in kWh), a costs evaluation is made (in investment costs in €, economic payback period (PBP) and internal rate of return (IRR)) and the avoided GHG-emissions are modelled (in kg CO_2-eq/kWh) (see sections 4.2-4.5).

The first scenario, the base scenario, does not make use of geodata and regional economics, and operates at the micro scale. Average data for the Netherlands is used as input for the energy models. Currently, this type of data is commonly used in energy modelling. Because this scenario models only at the micro scale, only renewable energy technologies and energy saving methods that are economically viable at the household scale are considered. In this study, these technologies are photovoltaics and insulation. Other technologies, such as rooftop mounted wind turbines and solar water heaters are not considered in this study, because these technologies are not economically viable, or too experimental.

The second scenario operates at the micro scale as well, yet it utilizes geodata as input for energy models. The main part of the household data used is collected specifically for the case study area, and therefore spatially specific. However, not all data required has yet been gathered for this specific case study. For the missing data estimations are made based on averages (see section 4.2-4.5).

The third scenario operates at the meso scale, where an entire cluster of houses is treated as one entity that has to undergo the energy transition, rather than each household within the cluster individually. This principle is based on regional economics and utilizes geodata as main inputs, just as in the second scenario. This approach allows for additional energy producing and storage technologies to be considered, due to the increase in energy demand, as well as the larger investment opportunity that occurs due to the pooling of resources (Fujita & Thisse, 1996). In this study, the additional technologies that are considered besides the ones considered in the previous scenarios, are wind turbines, residual heat from commercial buildings in the case study and geothermal heat production. How regional economics is specifically applied in this study and how the energy potential, costs and avoided GHG-emissions for these technologies are modelled in this specific case study are described in the next sections.

4.2 Energy potential

The aim of calculating the energy potential is to match the current annual energy use of all buildings in the case study, both natural gas and electricity use, that is generated with centralized energy sources with decentralized renewable energy sources. The energy potential is determined differently in the three different scenario's. In scenario 1 only PV and insulation are discussed. For scenario 2, the same technologies are considered, but with geospatial data input. Finally, for scenario 3 wind turbines, residual heat and geothermal energy are considered in addition to PV and insulation, using geospatial data as inputs.

4.2.1 Scenario 1

In scenario 1 the energy potential is based on the average gas and electricity use of a Dutch household (Nibud, 2014). The insulation potential is modelled as the improvement of the current insulation to a specific insulation value. The energy saved is the decreased gas use caused by the increased insulation value. The goal of insulation in this study is to improve the insulation value up to 2.5 m^2K/W. This is not the maximum insulation value that can be achieved (which is 5.0 m^2K/W, a heat neutral house) but according to PBL (2014) it is the highest cost effective insulation value that can be achieved. For scenario 1 the insulation measures suggested by Milieucentraal (2014) are used (without implementing the solar water heater) that are shown in Table 1. In this study, the insulation potential is the difference between the current average insulation value and the aspired insulation value of 2.5 m^2K/W.

The solar potential is modelled using the PV model from TNO (2011), assuming a fixed roof area, fixed level of irradiation and a fixed angle of incidence. The total energy potential is calculated by multiplying the number of households with the output of the PV model.

Table 1: Average annual energy consumption and potential in scenario 1.

Variable	Value	Source
PV-potential per household	1235 kWh	(TNO, 2011)
Average Dutch annual electricity use	3340 kWh	(Nibud, 2014)
Average Dutch gas use	1440 m^3	(Nibud, 2014)
Gas saved per household with insulation	1000 m^3	(Milieucentraal, 2014)
Roof area	12.36 m^2	(TNO, 2011)
Irradiation	1000 W/m^2	(TNO, 2011)
Angle of Incidence	30°	(TNO, 2011)

4.2.2 Scenario 2

In scenario 2 the geospatial aspect is introduced. The first geospatial component is the energy use. In scenario 2 the energy use is based on data obtained from Alliander, which is the grid operator in the case study area. The household data (the yearly average energy use) is aggregated to ensure the privacy of the households. Anomalies in the data set, such as very high or very low values, are not included in the analysis. To assure valid results for households, the electricity use for an individual household in 2013 has to be between 100 kWh (to assure that the electricity use is truly of households, not buildings with other functions) and 10,000 kWh, which is approximately triple the average Dutch electricity use in a detached house (Nibud, 2014). For the gas use, the lower limit is set at 400 m^3, which is approximately the boundary for gas use for cooking and heating water (van Gulik, 2014) (see Figure 2). The upper limit of 5000 m^3, which is approximately double the average of a six person household (Nibud, 2014). Furthermore, all households that have a supplement to the house number have been rejected as part of the case study, for these houses could not be matched with the data obtained from Alliander. All households in the case study are shown in Figure 3a and all households in the analysis are shown in Figure 3b. The area of the case study that is used to present the results is shown in Figure 3c.

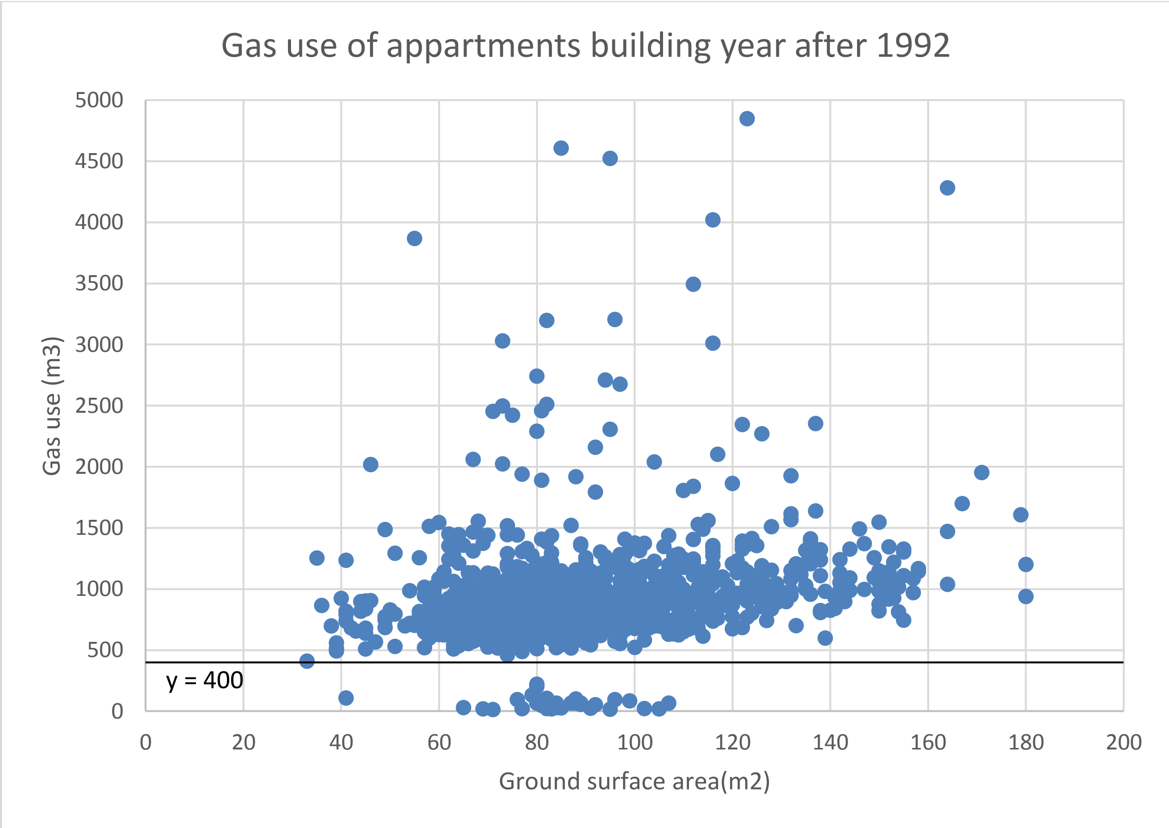

Figure 2: Graph showing the clear distinction between gas use for heating and gas use for household warming. The values under the 400 m^3 line are from households that are already connected to a district heating network (van Gulik, 2014).

Figure 3: a) All households present in the case study area b) households in the case study area that are considered in this study c) in blue are shown the households that are used to present the results of this study.

The insulation model in scenario 2 is based on data from AgentschapNL (2011a), which has calculated for several example households (different house types of different building years) the required energy saving measures to achieve an insulation level of 2.5 m^2K/W and the energy and costs savings accordingly. These data can be found in Appendix A. These measures and savings are linked to the specific house types with different building years in the case study area. The house types in Nieuw-West are determined based on an geometric analysis of the BAG (Basisregistratie Adressen en Gebouwen, or basic administration buildings and addresses), a dataset that shows all buildings and addresses in the Netherlands and their associated properties (Ellenkamp & Maessen, 2009). The building year of a building is an attribute of the BAG. Only insulation methods with a PBP of less than 25 years are considered in this study.

The PV potential in scenario 2 depends on the amount of electricity that can be extracted from solar irradiation in a certain area (the cumulative electricity potential). Furthermore, it depends on the building properties roof orientation, roof angle and available roof area. In this study it is assumed that roofs can have 2 angles: flat and an optimal roof angle of 30 degrees. Apartment buildings have a flat roof and all other houses have a roof with an optimal roof angle of 30 degrees. The cumulative electricity potential from PV systems for these two roof shapes is taken from Huld et al., (2014), who provide data for flat roofs and optimally inclined roofs. The orientation of the roof is determined by first establishing the longest line segment of a house geometry. Second, the coordinates in accordance with this line segment provide the coordinates of the house. Finally, using the arctangent and adding 90°, the orientation is determined. Only houses that have a roof facet oriented towards south, south-west or south-east are considered feasible for PV. Inclined roof facets with other orientations have limited energy potential (Hachem, et al., 2011; Carrilho da Graça, et al., 2012) and are therefore not considered in this study. Because the apartment buildings have flat roofs, all roof area is available for PV, and the orientation is inconsequential. The roof area of inclined roofs is defined as half the floor area of the building. This assumption is made because only half the roof area is suitable for PV cells due to orientation, and not all roof area is available, but approximately only 80% (TNO, 2011), so the roof area is calculated using Equation 1:

$$A_{available} = A_{floor} \times \frac{1}{2} \times 80\% \quad (1)$$

$A_{available}$	Available roof area for PV panels	m^2
A_{floor}	Floor area of a building	m^2

The floor area of a building is obtained from the BAG (Ellenkamp & Maessen, 2009). For apartment buildings the available roof area is equal to the floor, which is also obtained from the BAG (Ellenkamp & Maessen, 2009).

4.2.3 Scenario 3

Scenario 3 introduces, besides the geospatial component, the neighbourhood approach, as is described in section 4.1. Consequently, besides the PV and insulation technologies with a geospatial approach (as described for scenario 2), also wind turbines, geothermal energy and residual heat are considered.

Regarding wind energy, in this study only the technical potential is calculated, combined with a suitability map based on rules that are applied to wind turbines in the province of Noord-Holland, which can be found in Appendix B. This suitability map indicates at which locations wind turbines can be legally placed based on the legislation of the province of Noord-Holland (Provincie Noord-Holland, 2014). The electricity that can be produced by wind turbines is calculated using Equation 2:

$$E_{wind} = \frac{1}{2} \times \rho_{air} \times C_p \times A_{turbine} \times \sum_t \boldsymbol{v_{wind}}^3 \quad (2)$$

E_{wind}	Electricity produced by the wind turbines	Wh
ρ_{air}	Density of air	kg/m^3
C_p	Power coeficient	(-)
$A_{turbine}$	Surface area covered by turbine blades	m^2
v_{wind}	Velocity of wind at 100 m (hub height)	m/s
t	time	year

The wind velocity at 100m (v_{wind}) is taken from SenterNovem (2005), which shows an annual average of the wind velocity at 100 m at every location in the Netherlands at. These data have a geographic component, a resolution of 10x10 km^2 and has differentiates the wind velocity with a resolution of 0.1 m/s.

The surface area of the turbine blades ($A_{turbine}$) is calculated using Equation 3:

$$A_{Turbine} = \frac{1}{4} \times \pi \times D_{rotor}{}^2 \quad (3)$$

D_{rotor}	Diameter of the rotor blades	m

The input for the wind energy potential model is taken from Twidell & Weir (2006) and TNO (2011) and can be found in Table 2. The suitability map is created using data as listed in Appendix B. No wind turbines can be built in areas that are restricted or in a buffer around restricted areas (see Appendix B. This study does not take into account the resistance citizens might have against living in the vicinity of wind turbines, or the Not In My Back Yard (NIMBY) effect (Baxter, et al., 2013).

Table 2: Input data for the wind model.

Variable	Value
ρ_{air}	1,225 kg/m^3
C_p	0.45
$T_{operation}$	8760 hours
D_{rotor}	100 m

The residual heat potential is based on the excess heat production from companies in the case study. This can be for instance different types of industries, such as steel manufacturers or waste incinerators (TNO, 2011). The data is obtained from Gemeente Amsterdam (2014).
The potential for geothermal energy is calculated using a model from TNO (2011) for Enhanced Geothermal Systems (EGS). The geothermal potential depends mainly on the heat flow in the soil. The systems under consideration are those located at 2-5 km depth (van Wees, et al., 2010). In 2012, six installations have been placed in the Netherlands, together producing 495 TJ of heat (equivalent to 12 million m^3 natural gas), which is equivalent to the heat use of approximately 8000 households (CBS, 2014; Nibud, 2014). No EGS has yet been constructed in the Amsterdam Nieuw-West.

4.3 Cost evaluation

In this study two cost evaluations have been performed: calculation of the PBP and IRR. The PBP is calculated because this value is well understood by most citizens, which is important for involving stakeholders and creating commitment. The PBP is described in Equation 4:

$$PBP = \frac{Costs_{lifetime}}{Energy\ production \times Energy\ price} \tag{4}$$

PBP	Payback period	years
Costs$_{lifetime}$	Investment and Operation & Maintainance (O&M) costs per lifetime	€
Energy production	Annual energy production with new technology	GJ/year
Energy costs	Costs of the energy from the Dutch energy mix	€/GJ

The IRR is calculated to provide more scientific information on the costs, that is valued by the companies that can invest in renewable technologies. The IRR is the interest rate that makes the Net Present Value (NPV) zero. The IRR is described in Equation 5:

$$NPV = I + \sum \frac{(Energy\ production \times Energy\ price) - Costs_{annual}}{(1+IRR)^t} \tag{5}$$

NPV	Net Present Value	€
I	Investement costs	€
Costs$_{annual}$	Investment costs, annual O&M costs per year	€/year
Energy production	Annual energy production with new technology	GJ/year
Energy costs	Costs of the energy from the Dutch energy mix	€/GJ
IRR	Internal rate of return	%
t	Lifetime of the investment	years

The benefits for all scenarios are calculated based on the difference between the actual energy consumption of households in the old situation, and the new energy consumption in the new situation where the renewable energy solutions are in place. This difference is then multiplied with the current energy costs (€0.21/kWh for electricity and €0.65/m^3 for gas (Nibud, 2014)). However, the electricity cost for PV is analysed both at the current rate (€0.21/kWh) but also at €0.07/kWh, due to uncertainty in the government policy. The Dutch government is namely considering to stop the ability for Dutch households to apply "salderen", or in English net metering. Net metering is a Dutch word that literally means "to balance". In this study it refers to "an arrangement a consumers has with an electricity company where electricity that is returned to the electricity grid by the consumer is balanced with the electricity bill the consumer has with the electricity producer" (Longman, 2014). The actual cost of production of energy in the Netherlands is between €0.07 and €0.09, the remainder of the €0.21 is network costs and energy taxes. When net metering is no longer permitted, the compensation for electricity from PV systems is approximately €0.07, which is therefore considered as a second scenario in this study. The actual energy consumption of households is obtained from Alliander. The same limits have been set for the economic analysis as for the energy potential (section 4.2). Values used in the scenarios for the different technologies are listed in table 3.

Table 3: Investment costs associated with the technologies discussed in all three scenarios. If a scenario is not mentioned, the cost is an assumption for all three scenarios.

Variable	Investment costs	Source
Insulation		
scenario 1	9000 €	(Milieucentraal, 2014)
scenario 2&3	See Appendix A	(AgentschapNL, 2011a)
PV panels	265 €/m^2	(van Sark, et al., 2013)
Residual heating	2,000,000	(AgentschapNL, 2011)

4.4 CO_2-emissions

The current Dutch energy mix causes the emission of CO_2. One of the reasons to enhance the energy transition towards renewable energy sources is to reduce the CO_2-emissions. The energy that is produced by renewable technologies does not have to be produced by the energy mix anymore and therefore these emissions are avoided. Furthermore, the energy use that is avoided by insulation also no longer causes CO_2-emissions. The CO_2-emissions that are avoided by the implementation of renewable energy technologies or energy saving measures is calculated based on the Dutch energy mix and the average emissions made of each energy generation technique in the Dutch energy mix (CBS, 2014) and can be found in Table 4. This has an average of 400 g CO_2/kWh.

Table 4: Market share and emission factor of different contributors to the Dutch electricity mix.

Energy source	Market share (%)	Emission factor (g CO_2/kWh)	Source
Coal	19.10	1000	(IPCC, 2006; CBS, 2014)
Natural Gas	65.70	450	(IPCC, 2006; CBS, 2014)
Nuclear	3.40	10	(IPCC, 2006; CBS, 2014)
Renewable	3.50	0	(IPCC, 2006; CBS, 2014)
Waste/biomass	7.30	0	(IPCC, 2006; CBS, 2014)
Other	1	25	(IPCC, 2006; CBS, 2014)

5. Results

5.1 Energy potential

5.1.1 Scenario 1

The potential gas saved by additional insulation is 25,000,000 m^3 (approximately 70% of the total gas consumption), which is on average 1000 m^3 per household in the case study area. The potential electricity replaced by PV electricity is 30,875,000 kWh (37% of total electricity consumption), which is on average 1235 kWh per household.

5.1.2 Scenario 2

For scenario 2, the building type and building year of each household is taken into account when modelling the insulation potential of households. The total potential for gas savings are 8,227,760 m^3, which is approximately 30% of the total gas use of the case study. The average potential gas saved per household is 575 m^3, but there is a large variation, as can be seen in Figure 4.

The potential for electricity production through PV systems in the case study is 27,486,966 kWh, which is 37.5% of the total energy consumption; this is on average 1097 kWh per household. However, for some households, the potential electricity production of the PV systems is higher than the electricity consumption of the individual household. Because in scenario 2 each household is considered individually, it is assumed that the electricity production is not allowed to exceed the electricity consumption and therefore, some households are assigned less surface area for PV systems than available on the roof. To ensure privacy, no map is shown displaying the variation in PV potential, considering data from Alliander has been used.

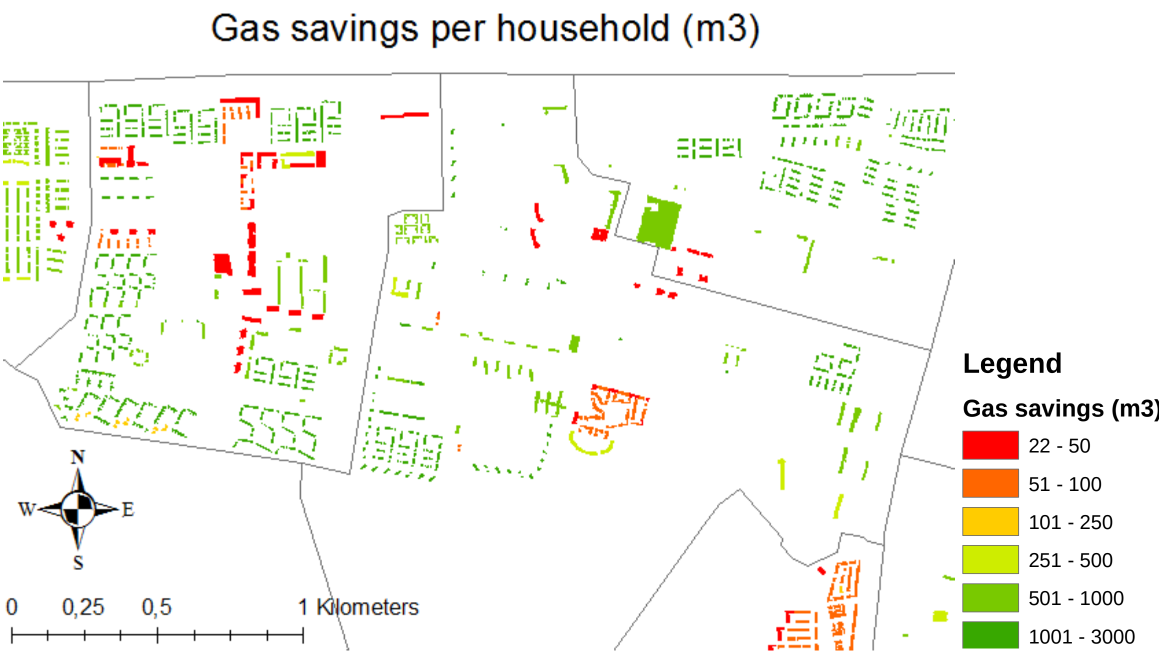

Figure 4: Gas savings that can be achieved in individual households by insulation based on the example households.

5.1.3 Scenario 3

In scenario 3, the potential gas savings through insulation are equal to the savings described for scenario 2 (see 5.1.2) and are shown in Figure 4.

The PV potential is calculated in a similar way as described for scenario 2 (see 5.1.2). However, because the neighbourhood approach is adopted in scenario 3, the remaining potential, the electricity potential that exceeds the actual electricity consumption of a household, of the PV systems that is not employed in scenario 2 is considered in scenario 3. Therefore, the data from Alliander is not used. This results in a higher electricity potential through PV systems compared to scenario 2: 38,603,994 kWh, which is 52.5% of the total electricity consumption in the case study, and on average 2770 kWh per household. The potential per household is shown in Figure 5.

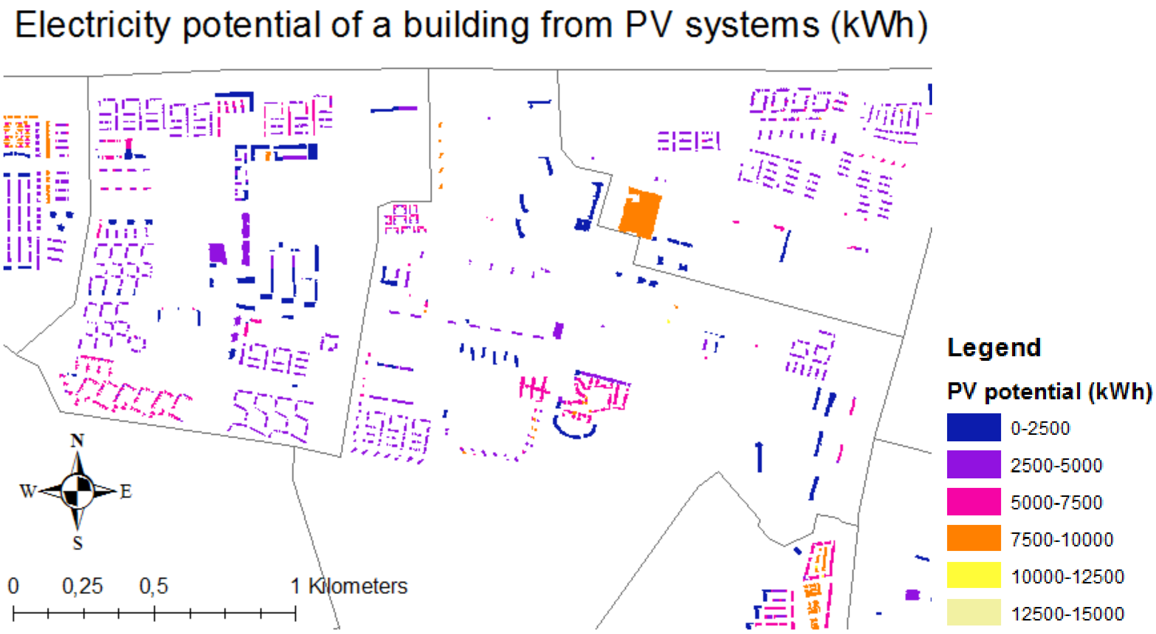

Figure 5: Electricity potential for PV systems in the case study (kWh.

The wind energy potential depends on two factors: the energy potential and the legal suitability (whether it is permitted by law to place a wind turbine in a specific location). Figure 6 shows a wind energy potential map for the Netherlands, calculated using Equations 2 and 3. This image shows that the energy potential in the Amsterdam region is relatively low compared to other parts of the Netherlands, yet the potential is still significant. However, the suitability map shown in Figure 7 shows that in this region there is no location that is defined as suitable for energy production by wind turbines (Provincie Noord-Holland, 2014).

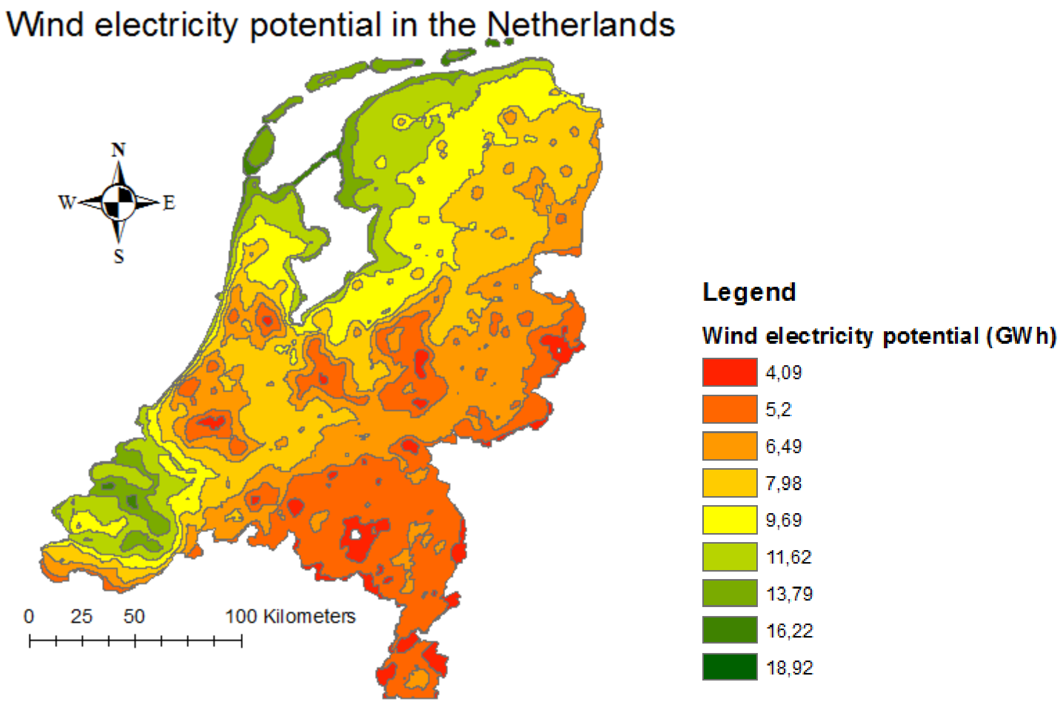

Figure 6: Electricity potential from wind turbines in the Netherlands (in GWh).

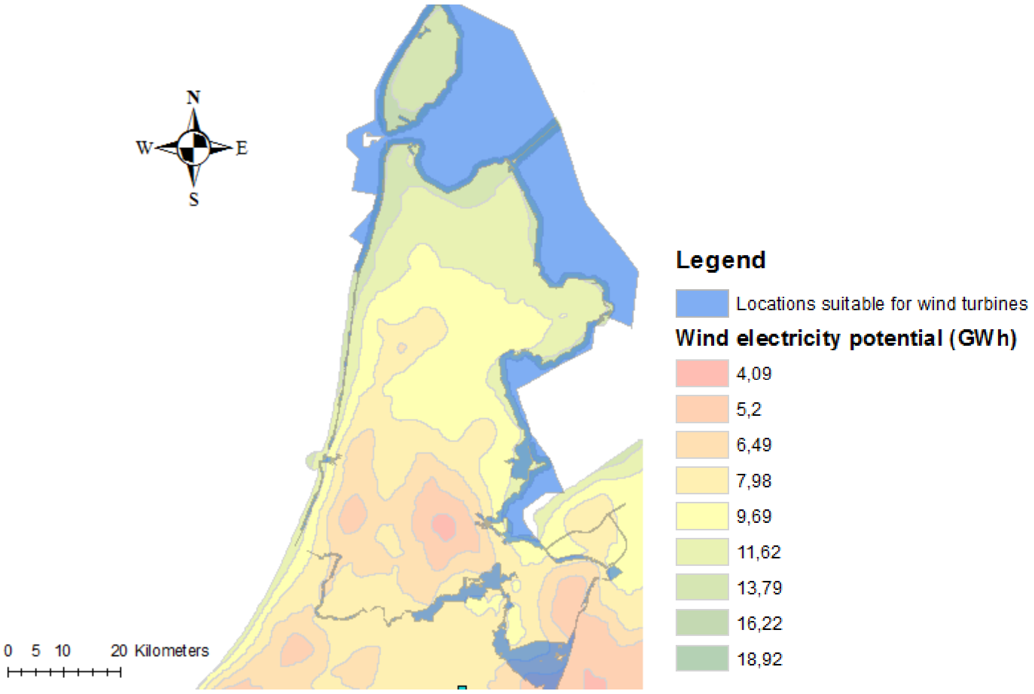

Figure 7: Map showing whether or not a wind turbine can be placed in a specific location. When a location is suitable, a wind turbine can be legally placed in that location.

The residual heat potential in the region is shown in Figure 8. The total potential is approximately 1.4 PJ, which can replace approximately 40,000,000 m^3 gas (Gemeente Amsterdam, 2014). After the insulation methods are in place, this is well over 100% of the gas consumption of the case study.

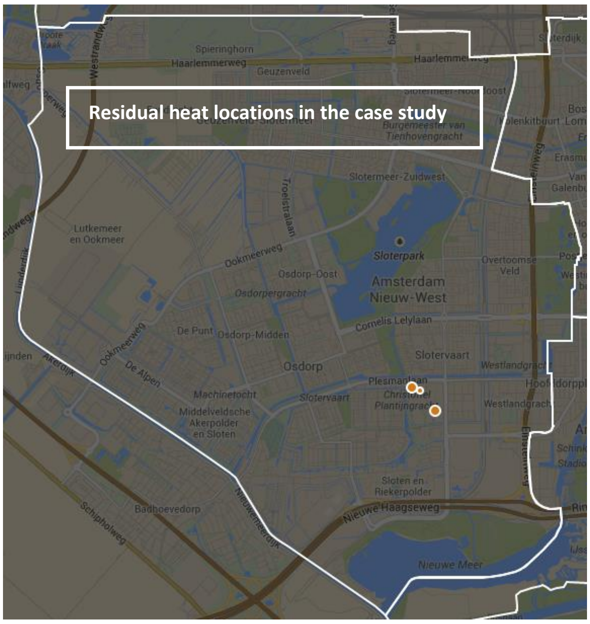

Figure 8: Residual heat potential in the case study. The orange dots are companies that could supply heat, and do not do so yet. The total potential of these three companies is approximately 1.4 PJ, or 40.000.000 m^3 of gas (Gemeente Amsterdam, 2014).

The geothermal heat potential for the Netherlands is shown in Figure 9. As can be observed, the energy potential in the Amsterdam region is significantly less than in other parts of the Netherlands. In fact, according to van Wees, et al (2010) the energy potential for this case study area is too low to allow for a feasible geothermal energy production. Therefore geothermal energy is not considered in further analysis this study.

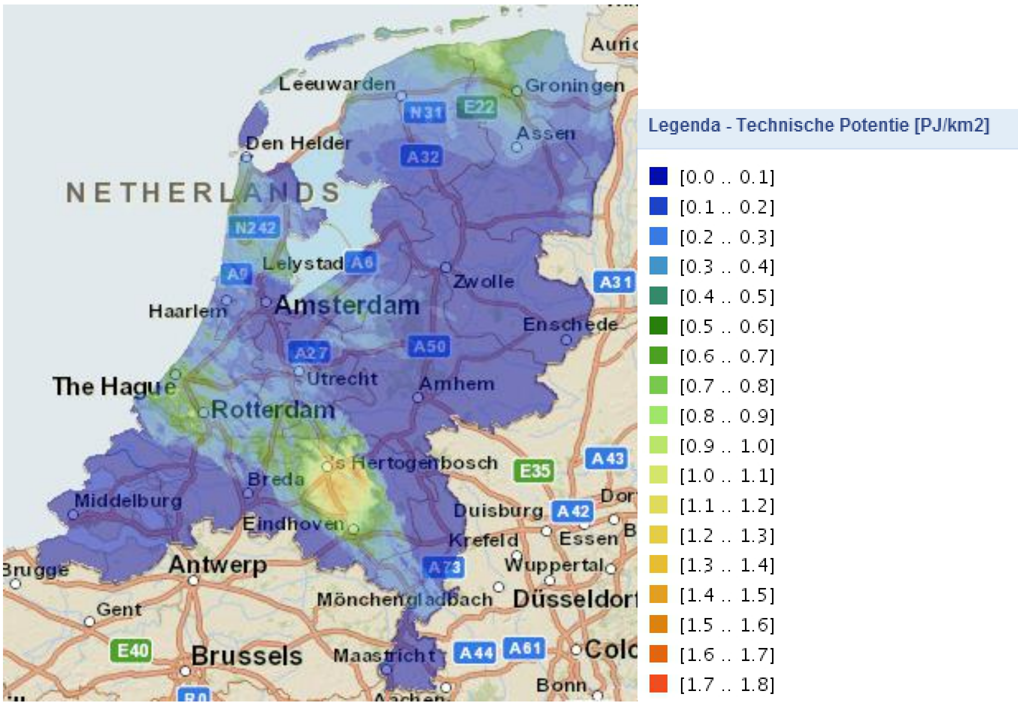

Figure 9: Geothermal potential in the Netherlands, with the legend showing the technical potential in PJ/km2 (van Wees, et al., 2010)

5.2 Economic analysis

5.2.1 Scenario 1

The costs associated with the energy measures installed are calculated similar to the energy potential. This results in a total investment costs of €225,000,000 for insulation, which corresponds to a PBP of approximately 14 years and an IRR of approximately 5%. For PV systems, the total investment costs are €65,236,080. The PBP and IRR for a price of electricity of €0.21 are 10 years or 9%. The PBP and IRR for a price of electricity of €0.07 are 30 years and a negative IRR. The economic analysis of scenario 1 is summarized in Table 5.

Table 5: The investment costs, PBP and IRR for insulation and PV systems in scenario 1. The PV system has been evaluated for a price of electricity of €0.21 and €0.07.

	Investment costs (million €)	PBP (year)	IRR (%)	Fraction of consumption (%)
Insulation	225	14	5	70
PV system (€0.21)	65.3	10	9	37
PV system (€0.07)	65.3	30	<0	37

5.2.2 Scenario 2

The total investment costs associated with the insulation of the entire case study are €36,439,740. All investments with a PBP of more than 25 years are ignored and therefore, the average PBP is 10 years, with a spread between 4.9 years and 20.8 years, as is shown in Figure 10. The IRR is approximately 5%.

The total investment costs associated with the PV systems of the entire case study are € 35,008,676. The PBP and IRR for a price of electricity of €0.21 (with net metering) are approximately 3.5 years or 16%. The PBP and IRR for a price of electricity of €0.07 (without net metering) are 10 years or 2,5%. The economic analysis of scenario 2 is summarized in Table 6.

Table 6: The investment costs, PBP and IRR for insulation and PV systems in scenario 2. The PV system has been evaluated for a price of electricity of €0.21 and €0.07.

	Investment costs (million)	PBP (year)	IRR (%)	Fraction of consumption (%)
Insulation	36.5	10	5	30
PV system (€0.21)	35	3.5	16	37.5
PV system (€0.07)	35	10	2.5	37.5

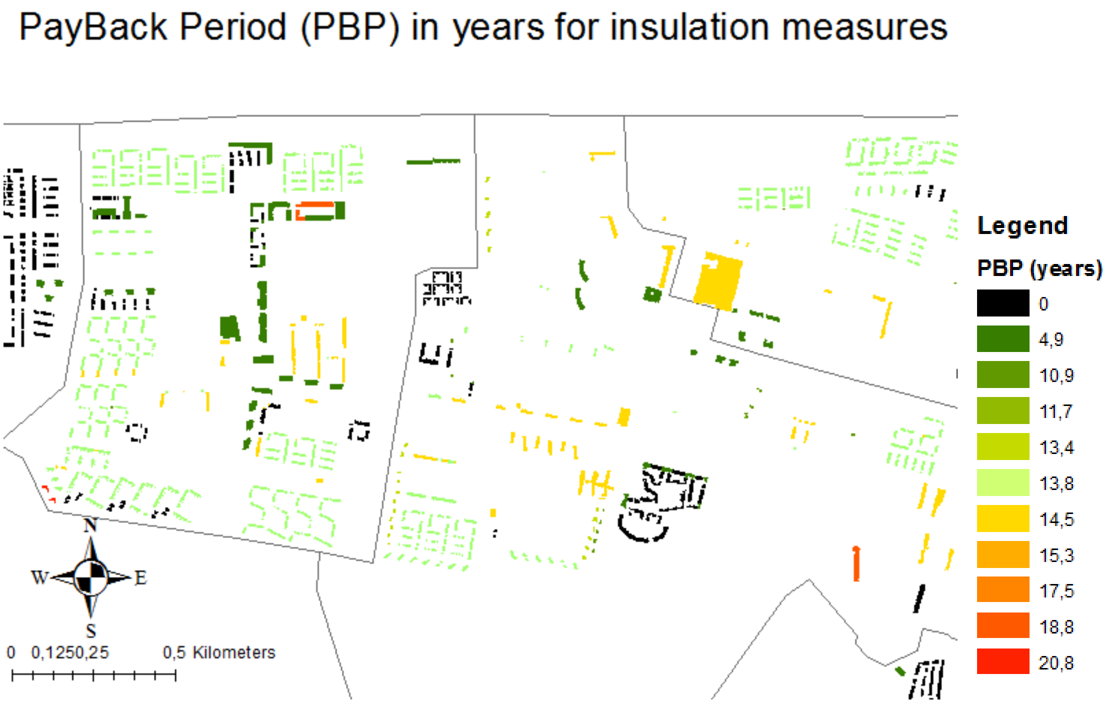

Figure 10: Map showing the PBP of the insulation measurements in years. These data are all based on the example households (AgentschapNL, 2011a).

5.2.3 Scenario 3

The costs associated with insulation are equal to those in scenario 2 and can be found in section 5.2.2. The total investment costs associated with the PV systems of the entire case study are € 48,888,382. The PBP and IRR for a price of electricity of €0.21 are approximately 3.5 years or 16%. The PBP and IRR for a price of electricity of €0.07 are 10 years or 2,5%. These values are almost equal to the values obtained in scenario 2. The variance is too small to be significant.
The investment costs associated with the residual heat system are approximately €20,000,000, which is an approximation from the GEN model (AgentschapNL, 2011). The PBP is approximately 11 years, with an IRR of 9%. The economic analysis of scenario 3 is summarized in Table 7.

Table 7: The investment costs, PBP and IRR for insulation and PV systems and residual heat in scenario 3. The PV system has been evaluated for a price of electricity of €0.21 and €0.07.

	Investment costs (million €)	PBP (year)	IRR (%)	Fraction of consumption (%)
Insulation	36.5	10	5	30
PV system (€0.21)	48.8	3.5	16	52.5
PV system (€0.07)	48.8	10	2.5	52.5
Residual heat	20	11	9	70

5.3 CO_2-emissions

The avoided CO_2-emissions are shown per scenario per renewable energy technology is shown in Table 8.

Table 8: Avoided emissions of different renewable energy technologies in the three scenarios in tonne CO_2 per year.

	Insulation (tonne CO_2)	PV system (tonne CO_2)	Residual heat (tonne CO_2)
Scenario 1	400000	55000	0
Scenario 2	130000	48000	0
Scenario 3	130000	68000	304000

6. Discussion

In this study, the renewable energy potential, the economic analysis, and the potential of avoiding CO_2-emissions for the case study Amsterdam Nieuw-West has been determined. This has been done for three different scenarios: the current state of affair, using national averages in scenario 1, in scenario 2 using as much geographical data as is available and in scenario 3 include a neighbourhood approach. To demonstrate the influence of geographic data on energy modelling, scenario 1 is compared to scenario 2. To demonstrate the influence of the neighbourhood approach, scenario 2 is compared to scenario 3.

The potential to replace the heat consumption (currently from gas) due to insulation in scenario 1 is 70% of the total heat consumption in the entire case study. However, the use of location-specific geodata in scenario 2 has a different energy saving potential of only 30% of the total gas use, or 33% less than in scenario 1. In scenario 3 the gas use that can be saved or replaced is 100%, due to the introduction of residual heating (the insulation potential is equal to scenario 2). This indicates that the case study area can become completely heat demand neutral, which means that the case study area could be completely disconnected from the gas grid. Another heat supply technology considered in this study (geothermal energy), which is not required to make the case study area heat demand neutral, is determined to be unfeasible, because the heat potential in the case study area is too low, while generally in the Netherlands the potential is sufficient. This shows an additional added value of using geographic data. However, the geographic data used in this study have large uncertainty, because the example houses from AgentschapNL (2011a), used to model the insulation potential, are still based on average houses. In addition to the fact that geothermal energy is not considered for the case study area, experimental technology and economically unfeasible technologies, such as solar water heaters, are not considered. Including such technologies could even increase the calculated energy potential in the area.

The potential to produce decentralized electricity with PV systems for scenario 1 is 37% of the total electricity consumption for the case study area. In scenario 2, this PV system potential is still approximately 37% of the total consumption, while the average production per household has decreased with approximately 15%. This can be explained by the electricity consumption estimated in scenario 1 that is significantly different than the actual measured electricity use from Alliander. In scenario 3, the PV potential is 52.5% of the total electricity consumption, or an average of 2770 kWh per household. This is more than double the average potential per household in scenario 1 and 70% more than in scenario 2. This is because the total potential is assumed, including the fraction that exceeds the individual demand. In addition, the case study area shows a significant technical potential for electricity from wind turbines. Yet, due to legislation it is not permitted to locate wind turbines in or near the case study area, which results in no actual potential. The renewable electricity potential in this case study cannot match the annual electricity consumption in none of the scenarios, the highest percentage possible is 52.5%. Furthermore, not only throughout the year the consumption surpasses the demand, also during the day there is a discrepancy, because the electricity use occurs mainly in late afternoon and early evening, while the production is during the day. Furthermore, an uncertainty in the PV model is the efficiency of the panels. When the efficiency decreases, the electricity production can decrease linearly. Another uncertainty in the results is the data modelled regarding the roof orientation, angle and surface area.

In this study, a feasibility study has been done regarding the costs and benefits of the different technologies in the scenarios, not an exact economic evaluation, so the values are indicative. In scenario 1 the insulation has a PBP of 14 years and an IRR of 5%. For scenario 2 and 3 the IRR is similar to scenario 1, while the PBP is only 10 years. This can be explained by the fact that the investment costs are approximately six times higher in scenario 1. The uncertainties described for the energy potential are propagated in the economic analysis.

For the PV systems, two economics analyses have been made, one with and one without net metering. In scenario 1, with net metering, the PBP is 10 years, and the IRR 9%, while without net metering, the PBP 30 years and the IRR is negative. Net metering in this scenario makes the difference between an economically feasible and unfeasible situation. For scenario 2 and 3, the economic analysis is more favourable, with a PBP for both scenario of approximately 4 years with net metering and 10 years without. The IRR with net metering is approximately 16% and without only 2.5%. The differences in PBP and IRR for scenario 2 and 3 exist, but are insignificant. Even in scenario 2 and 3 the economic feasibility without net metering is fragile.

In scenario 3 the economic feasibility of residual heat is considered. Based on the data from GEN (AgentschapNL, 2011), the PBP is approximately 11 years and an IRR of 9%. However, this is uncertain due to the instability of the policy of the national government. This also influences the economic feasibility of the PV systems (as mentioned with the issue of net metering) and wind turbines.

The CO_2-emissions can be decreased significantly in scenario 1 with approximately 455,000 tonnes per year. For scenario 2, where the data use is more accurate, this is only 178,000 tonnes. This difference is mainly due to the insulation (scenario 2 has only 32% of the CO_2-emission decrease of scenario 1) and only very little due to the PV systems. For scenario 3, the total decrease in CO_2-emissions is 502,000 tonnes per year. The residual heat system is the main contributor to these decreased emissions. The avoided emissions for the PV systems are largest in scenario 3, approximately 25% more than in the other scenarios. It has to be noted that this analysis is not based on lifecycle analyses (LCAs).

As can be observed from the comparison between scenario 1 and 2, geographic data can have a significant impact in the results of energy models. Additionally, from the comparison between scenario 2 and 3 also the neighbourhood approach has a significant influence on energy models, such as for instance the heat potential.

For future research it would be interesting to include a temporal component to the technical analyses of for instance the wind potential and the solar PV potential, to not only estimate the energy neutrality over a year, but to see how grid independent households can become. Furthermore, it is interesting to refine the energy models, being the energy potential models, the economic models and the CO_2-models, as well as the data analysis models, such as the rooftop properties. Additionally, it would be interesting to include LCA analyses for all technologies. Finally, it would be very interesting to determine the actual energy potential in the case study area, such that it can be determined which scenario most accurately represents the actual energy potential. This could be researched by placing experimental PV systems in the case study area and monitoring their electricity production. Or by monitoring the gas use of households before and after insulation measures are installed.

7. Conclusion

The aim of this study has been to research the influence of use of geodata and the meso scale on the accuracy of energy modelling compared to micro scale modelling using average data for a case study in the Netherlands. Firstly, the energy potential for the case study has been modelled for three scenarios; first using only national averages, second using geodata, and third using both geodata and the neighbourhood approach. Secondly, an economic analysis has been done for all three scenarios. Finally, the avoided CO_2-emissions that are expected after implementing the renewable energy solutions have been modelled for all three scenarios.

As can be concluded from the comparison between scenario 1 and 2, the use of geographic data can have a significant impact in the results of energy models. This is well illustrated by the fact that in scenario 2 only 33 % of the potential insulation from scenario 1 is modelled. It can furthermore be concluded from the comparison between scenario 2 and 3 also the neighbourhood approach has a significant influence on energy models, such as for instance the heat potential. This is illustrated by the fact that the total heat potential in scenario 2 is 37% of the total heat consumption, while in scenario 3 this exceeds the total heat consumption. Similar trends are observed in the economic analyses and the CO_2-emission decrease. Yet, which of these three scenarios is the most accurate can only be determined by researching the actual energy potential in the case study.

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Appendix A: Data used for the insulation model for scenario 2 and 3

Building type and year	Total investment (€)	Gas savings (m^3)	Gas savings (€)	PBP (year)
Detached house				
until 1964	15515	3235	1427	11
1965-1974	16871	2508	1106	15
1975-1991	16500	1035	457	36
1992-2014	2570	180	79	33
Semi-Detached house				
until 1964	13395	2259	996	13
1965-1974	13981	1813	800	17
1975-1991	14239	681	300	47
21992-22014	3678	201	89	41
Corner house				
until 1945	12764	2480	1094	12
1946-1964	9253	1517	669	14
1965-1974	10464	1141	503	21
1975-1991	9722	596	263	37
1992-2014	994	58	26	38
Terraced house				
until 1945	11483	2231	984	12
1946-1964	7885	1293	570	14
1965-1974	8984	980	432	21
1975-1991	8240	505	223	37
1992-2014	994	58	26	38
Apartment				
until 1964	3831	615	264	15
1965-1974	4152	500	221	19
1975-1991	3498	252	104	34
1992-2014	49	22	10	5

Appendix B: Data suitability map wind turbines

Description	Legislation	Source
***Basisregistraties Adressen en Gebouwen*. All buildings in a specified area.**	Buildings per hectare: ≤2 buffer 50 meters >2 buffer 400 meters	(Ellenkamp & Maessen, 2009; Provincie Noord-Holland, 2014)
Provincial monuments	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Geological monuments	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Geological interesting areas	Additional research required	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
National important landscapes	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Areas where the sound level has to below 40 decibel	Additional research required	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Landscapes on the UNESCO heritage list	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Monumental dike: *Noorderijdijk*	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Monumental dike: *Zuiderijdijk*	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Flood defense system	Not allowed	(AgentschapNL, 2013; Provincie Noord-Holland, 2014a)
Monumental dike: *Westfriese Omringdijk*	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Protected area: *Stelling Den Helder*	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Monumental dike: *Wierdijk*	Not allowed	(Provincie Noord-

		Holland, 2014; Provincie Noord-Holland, 2014a)
Recreational areas close to the *IJsselmeer*	Buffer 50 meters	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Recreational areas *Stelling van Amsterdam*	Not allowed within and buffer 50 meters around	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Recreational areas with fortresses of the *Stelling van Amsterdam*	Buffer 50 meters	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Large recreational areas intended to limit development and to preserve green areas	Not allowed within and buffer 50 meters around	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Recreational area	Buffer 50 meters	(Provincie Noord-Holland, 2014)
Large recreational area between Utrecht and Amsterdam	Not allowed within and buffer 50 meters around	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Natural areas for meadow birds	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Natural areas	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
National park	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Natural areas	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Natural areas	Not allowed	(Provincie Noord-Holland, 2014; Provincie Noord-Holland, 2014a)
Fly zone international airport *Schiphol*	Not allowed	(AgentschapNL, 2013; Provincie Noord-Holland, 2014a)
Important waterways	Buffer 50 meters	(AgentschapNL, 2013; Provincie Noord-Holland, 2014a)

Important waterways	Buffer 50 meters	(AgentschapNL, 2013; Provincie Noord-Holland, 2014a)
Water bodies on land	Not allowed	(AgentschapNL, 2013; Provincie Noord-Holland, 2014a)
National highways	Buffer 50 meters	(AgentschapNL, 2013; Provincie Noord-Holland, 2014a)
National railroads	Buffer 57.85 meters	(AgentschapNL, 2013; Provincie Noord-Holland, 2014a)

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Programme Energy Sciences
Programme Water Science and Management

Statement of Originality

Student's name: Sanne Hettinga

Student's ID: 3922332

Title report / thesis: The influence of geodata and regional economics on energy modelling

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