THE IMPACT OF SHALE GAS EXTRACTION IN THE NETHERLANDS

Assessing the possible impact of shale gas extraction on commercial property values in the Netherlands, using data from the province of Groningen as a study.

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Abstract

The Dutch government has expressed its interest in shale gas extraction in particular regions, because the Groningen gas field will be fully exhausted in the near future. In the United States, shale gas extraction is successful and a viable business case with relatively low costs. However, this seemingly interesting business has some downsides. Worldwide there are examples of earthquakes occurring near shale gas extraction and problems with the surrounding environment.

This study assesses the impacts of shale gas extraction on commercial real estate values in the Netherlands, using a dataset of commercial property values in Groningen. Koster and van Ommeren (2015) show that house prices in Groningen depreciate due to induced earthquakes caused by natural gas extraction. They did not address the depreciation of rental prices of commercial property and by applying a hedonic price analysis on commercial real estate, that depreciation of that real estate is established in this study. The goal of this study is to estimate the depreciation of rental price of commercial property in Groningen and extrapolate this to a possible shale gas region in the Netherlands, to find the impacts of extraction there. Direct extrapolation of impacts in Groningen to another region in the Netherlands is not possible. This thesis will therefore make use of different scenarios and this result in ranges of the possible impacts.

This research estimated an 8.6 percent depreciation of commercial real estate rents in Groningen due to induced earthquakes in the baseline scenario, using a hedonic price method. Shale gas extraction could, geologically seen, take place in the Peel area. The economic viability depends upon the natural gas price, the costs and the technological possibilities. Without commercial property depreciation, shale gas extraction would only result in a positive net present value with medium and high prices and low costs. When the analysis includes commercial property depreciation, even the most optimistic scenario results in negative net present values. The most optimistic scenario only results in positive net present values when the natural gas price is above 0.5 euro per m^3, which is not very likely to occur. Therefore, shale gas extraction in the Netherlands is not a viable business case yet and this will depend on the costs and technological development of the industry.

Contents

1. Introduction

The Dutch economy is largely dependent upon the availability of natural gas; Dutch heating systems use natural gas as combustion fuel. However, as with all natural resources, natural gas is an exhaustible resource. Using shale gas as replacement for natural gas is possible, but extraction of shale gas is controversial because of the production techniques. These techniques can cause earthquakes and it is both for the government and inhabitants of the shale gas regions important to know what the impacts of shale gas extraction could be.

Apart from the revenues the state gets from natural gas, the extraction of it produces earthquakes. These earthquakes cause damage to buildings and therefore property prices decrease. The Dutch Petroleum Company (NAM), a joint venture of Shell and Esso, compensates for damage costs, but nonetheless the house prices depreciate. This indicates that there must be other causes of this depreciation (Koster & van Ommeren, 2015). Compared to house prices, less knowledge is available about the effects on commercial real estate. House prices and rents are highly linked because rents reflect the investment in the building and one needs to gain its investment back. If house prices depreciate, what is the effect of earthquakes on commercial property and therefore on the rental prices? In addition, if shale gas extraction takes place, what are the costs in both the private and commercial property sector and would the costs be smaller than the benefits? This complements to the cost-benefit analysis for decision makers about the allowance of shale gas extraction. The main objective of this thesis is to assess what impact natural gas extraction could have on commercial property values in Groningen due to the existence of induced earthquakes. These results are extrapolated to regions with shale gas presence. This research will therefore assess the influence of induced earthquakes on commercial property values in the province of Groningen, Friesland and Drenthe, and apply this to the Dutch shale gas regions. This section will introduce the topic and will describe the research question.

1.1 Shale gas

Currently, there is a popular trend towards using shale gas, which in the United States has already resulted in large-scale extraction. The gas price relates to the crude oil Brent[1] price and that price has decreased from close to $100 in November 2014 to $35 per barrel in February 2016. Price decreases of oil hardly influence the production of conventional oil and gas, because the costs of production in most important parts of the world are relatively low. Shale gas extraction has very high production costs and a relatively low production period, which means that revenues from the gas should be relatively high for the production to be profitable. Even with the oil prices going down, the United States produce an average of 1.2 billion cubic meters shale gas per day (U.S. Energy Information Administration, 2015). In the Netherlands, there has not been any exploratory drilling or production of shale gas yet. The government commissioned research about the implications of shale gas production (for example by from Witteveen & Bos et al. (2013)) but will only decide at the end of 2015 whether shale gas extraction is a valuable option for energy production (Rijksoverheid, 2015). Most municipalities have recently spoken out against shale gas extraction, but the government does not rule out the possibility of exploratory drilling (Rijksoverheid, 2015). There is a high probability of shale gas present in the southern part of the Netherlands. However, the impacts on the environment when shale gas extraction takes place could be much bigger than for example in the United States. A possible indicator of effects on the environment could be the comparison of population density in the extraction area between a shale gas producer in the United States and in North-Brabant. The

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[1] Brent crude oil price is an international trading price for oil based on the properties from the Brent field (in the North Sea)

population density of Texas is 40.8 persons per km^2 compared to 490 persons per km^2 in North-Brabant, which would mean that production would take place closer to more densely populated areas and its effects would reach inhabitants faster (U.S. Energy Information Administration, 2015).

Studies on the effects of shale gas extraction on soil subsidence and additional earthquakes are not elaborately present yet, due to the relatively new production technologies. Current research about shale gas extraction is focused on the effects of pollution, the injection water with high rates of chemicals and the environmental effects from that and the regional impact on air quality due to fracking or fraccing (llewellyn, et al., 2015; Kiviat, 2013; Vinciguerra et al., 2015). Very recently, an increasing amount of earthquakes in an area (United States) where extraction of shale gas takes place has put people on alert (Walsh, 2015). Induced earthquakes have a time lag, which makes it more difficult to connect the action of gas extraction to earthquakes. As in Groningen, increased seismic activity happened years after the first extraction of natural gas (KNMI, 2015).

1.2 Natural gas in Groningen

NAM discovered a large natural gas reserve near Slochteren in 1959. This natural gas field turned out to be the biggest natural gas field in Western Europe with an initially recoverable stock of 2.800 billion cubic meters of gas (NAM, 2015). The production of natural gas started in 1963 and showed initially no signs of soil subsidence or earthquakes. The Royal Netherlands Meteorological Institute (KNMI) recorded the first induced earthquake in Groningen in 1986, and up until September 2015, there have been 1192 earthquakes recorded, most of which have a magnitude that humans cannot feel (KNMI, 2015). With an increasing amount of earthquakes, interest in the relationship between natural gas production and induced earthquakes also increased. Sgeall, Grasso and Mossop (1994) describe this relationship and Haak and de Crook (1994) do this for the specifics of the Groningen gasfield.

Compared to the earthquakes worldwide, the earthquakes in the Netherlands are relatively small. A recent earthquake in Nepal on April 25 with a magnitude of 8.1 on the scale of Richter (M_L), had a peak ground velocity (PGV) of approximately 1 meter per second, which means that the ground moves 1 meter horizontally (USGS, 2015). In Spain, May 11th 2011, an earthquake with a magnitude of 5.1 M_L occurred and thereby a peak ground velocity between 16 and 60 centimeters per second. The earthquake with the highest magnitude that occurred in the Netherlands was 3.6 M_L in Huizinge on the 16th of August 2012. This corresponds with a peak ground velocity of only 5 centimeters per second (KNMI, 2015). Relatively seen, the earthquakes in the Netherlands are rather small.

1.3 Commercial real estate prices

Even though earthquakes in the Netherlands are relatively small in comparison to earthquakes abroad, they do cause damages to properties. House owners get compensated for damage in Groningen, so the monetary costs of the earthquakes are compensated. Koster and Ommeren (2015) show in their article that house owners suffer from a depreciation of their house prices as estimated by non-monetary costs, this can be seen as for example the declining willingness to live in Groningen.

This thesis assesses the influence of earthquakes on commercial real estate, using the same method as used by Koster en van Ommeren (2015). Why would the effects on commercial real estate be different from those on private property, since the prices and rents are highly linked? The expected cash flows over the years measures the value of the rent. Discounting these cash flows is necessary since the general belief is that one values money that comes in now higher than money that comes in next year. This will result in the Net Present Value (NPV) of the investment. A positive NPV indicates that the projected revenues will exceed the costs and this generally this will result in a profitable investment. This study hypothesizes the effects of an earthquake on commercial real estate to be different because tenants do not suffer directly from damage to a building. It affects tenants when their business suffers from the damage. As the NAM compensates damage on buildings, some kind of other cost is involved here. For example, the willingness to move a shop when damage is being repaired. It is not convenient to move the contents of a store to another location, where the target audience is not present. These are non-monetary costs; tenants will never suffer directly from the monetary costs since they do not own the building. This must have an influence on the rental prices since building owners do not want their property to be empty. To get a tenant in the building, rental prices must be lower to compensate for the declining willingness to settle there. Therefore, the expectation is that the influence depreciates the rents. In order to obtain the results of the commercial property values, this study applies a hedonic price analysis. With a hedonic price model, one can examine the determinants of house prices with respect to individual characteristics of houses such as property, socio-economic, spatial and neighborhood characteristics. This study examines the effect of earthquakes on commercial property and therefore includes several variables, which relate to earthquakes, such as the impact of the earthquake (peak ground velocity). The decline in commercial property values that will be obtained in this study, will result in the total commercial property depreciation of Groningen. The estimated results will be applied to the region where shale gas is present and an indication of the possible economic impacts of shale gas extraction in that region can be given.

1.4 Research question

This study contributes to the debates within the Dutch society about changing energy sources and can assess how shale gas extraction will affect the regions with shale gas stocks. There have not been any studies about the influence of shale gas extraction and its subsequent earthquakes on private and commercial property prices before. The increased interest in shale gas extraction in the Netherlands and the probability of induced earthquakes, combined with knowledge of the earthquakes in Groningen, makes this a relevant topic. With this knowledge in mind, this paper examines the following research question:

What are the possible impacts of shale gas extraction on commercial property values in the Netherlands?

Sub questions that will contribute to answer the research question are:

The geological part:

- What are the properties of Groningen natural gas and how is this different from shale gas?
- What is the difference between natural gas and shale gas in ways of extraction?
- What are the expected impacts of extraction in terms of frequency, magnitude and distribution of the earthquakes induced by shale gas extraction and how do they differ from earthquakes induced at the Groningen gas field?
- In what parts in the Netherlands is it possible to extract shale gas with the economic viability aspects taken into account?
- Is it possible to extrapolate the earthquakes and its impacts of Groningen to another area in the Netherlands?

The economical/empirical part:

- Following the method of Koster en van Ommeren (2015), what is the commercial real estate property depreciation as induced by the earthquakes in Groningen?
- What is the influence of possible shale gas extraction on the commercial property values in the Peel area?

- What is the value of the stock of real estate in the Peel area?
- What are the costs of the shale gas extraction, using the results of the property depreciation applied to the economically viable parts for shale gas extraction?
- Is shale gas extraction worth the investment, based on the costs as calculated and the revenues? What price is necessary to make the investment worthwhile?

This thesis proceeds as follows. Chapter 2 contains the literature review and the context of the problem. Chapter 3 will give an outline of the data and Chapter 4 will discuss the used methods. Chapter 5 and 6 contain the results, first the geological results will be discussed where answers on the sub questions are given. Chapter 6 will discuss the economical results and Chapter 7 contains the discussion and conclusion. This thesis will end with the references and appendices.

2. Literature review

A lot of research already exists on the influence of natural factors on house prices. This study focuses on the influence of earthquakes, induced by humans, on the rental prices of commercial property. This chapter will give an overview of the existing literature about both the relationship between earthquakes and natural gas production and the relationship between natural factors influencing house and rental prices.

2.1 Relationship between earthquakes and natural gas production

Before one can calculate what the impact of an earthquake is on the environment, one needs to know what this earthquake causes. The difference between a natural earthquake and an induced earthquake must be clear because the impacts are possibly different in ways of causation and impacts. The prediction of a natural earthquake is very uncertain, the tension that builds up during the period before the earthquake is probably very high and the impacts are therefore much greater. However, with the extraction of hydrocarbons, there is knowledge of the rock layers and the volume of hydrocarbons. With this knowledge, making a prediction of the soil subsidence and compaction is possible. Both these processes happen at a relatively fast rate and the earthquakes that occur from this have a lower magnitude than natural earthquakes. In order to know whether there is a relationship between natural gas production and earthquakes, this next section will seek in the literature for proof.

An article of the Dutch State Supervision of the Mines (Pöttgens & Brouwer, 1991) discusses the predicted and real soil subsidence due to natural gas extraction and its effects. Remarkable is the fact that it does not touch the subject of earthquakes due to soil subsidence, but focuses on damage to buildings and changes in hydrological environment. The specific Dutch case where the natural gas production induced earthquakes was first described in 1993. This study showed the relationship between natural gas production and the induced earthquakes with the help of models (Haak et al., 1993). The models showed the movement of faults in the subsurface and when the faults are already tensioned, the natural gas production can trigger the fault. According to the model, the maximum magnitude that can be expected is 3.3 M_L. They also note that even in 'unfavourable conditions' damage to buildings is not expected. This can be rejected with today's knowledge, since damage to buildings did happen and the maximum occurred magnitude was 3.6 M_L (NAM, 2013).

In 2006 van Eck et al. conducted a study based upon long term monitoring of seismicity. They recalculated the maximum magnitude that would likely occur in Groningen, based on long term seismicity and found a maximum magnitude of 3.9 M_L. This is a higher maximum magnitude than calculated by the model of Haak et al. (1993) but more reliable since it is based on measurements during a longer period. Van Eijs et al. (2006) found a correlation between Groningen reservoir characetristics and induced seismicity. Pressure drop in the reservoir, fault density and a stiffness ratio[2] between reservoir and seal rock are all correlated to the induced seismicity in Groningen.

Not only in the Netherlands the relationship between hydrocarbon production and induced earthquakes have been found. Pennington et al. (1986) conducted a study to the fault planes in oil and gas fields in South Texas and found that reduced fluid pressure in the pores of the reservoir, results in a strengtening fault which will eventually slip and cause an earthquake.

Segall, Grasso and Mossop (1994) show that the relationship between average reservoir pressure drop and soil subsidence in a gasfield in France is linear. This means that when hydrocarbons are extracted from the reservoir, the pressure in the pores declines. The burden of the overlying layers remains the

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[2] The stiffness ratio is defined as the differences in layer stiffness of the seal over reservoir.

same and will subsequently result in soil subsidence on the surface. This soil subsidence leads to more pressure on the layers, when the layers slips it causes an earthquake.

To show how many studies have been conducted about the relationship between hydrocarbon production and induced earthquakes, Suckale (2009) summarizes the published articles about seismicity induced by human activities. In this article, 70 cases have been studied in order to make the current knowledge accesible and try to get a better understanding of the processes which underlie the induced seismicity. Induced seismicity due to hydraulic fracking is not adressed in this article because this kind of seismicity is intentionally induced, this shall be explained in the next section. Two important observations were made by Suckale. Firstly, induced seismicity is mostly regionally concentrated and this has most elaborately been studied in Groningen and Texas. Secondly, induced earthquakes tend to happen where preexisting faults are reactivated by the production of hydrocarbons (Suckale, 2009). This last observation is in line with the correlations that were made by Van Eijs et al. (2006).

2.2 Relationship between earthquakes and hydraulic fracking

Now that the above paragraph examined the relationship between natural gas extraction and earthquakes, the next step in this research is to examine the relation between hydraulic fracking and earthquakes. The section below will explain the relationship between earthquakes and hydraulic fracking and its harmfulness for the environment.

2.2.1 Hydraulic fracking

Hydraulic fracking is a method to obtain unconventional resources from reservoirs with a low permeability. Unconventional refers to the recoverability of the resources that are only possible using special techniques, such as hydraulic fracking, because it would not produce resources cost-effectifely otherwise (United States Environmental Protection Agency, 2015). Due to this low permeability, it is not possible for hydrocarbons to move freely through the reservoir. With hydraulic fracking, millions liters of water, proppants (sands to keep the pores open) and chemicals are pumped into the rock to create fissures. The permeability of the reservoir rock therefore increases and it is possible to recover hydrocarbons at an economically viable rate (Cuadrilla, 2015). With this technique, shale gas, coal bed methane and tight sands are recoverable. The injected production water will flow back to the surface through the fissures and will most likely be stored in an underground injection water well. The differences between recovering natural gas and shale gas will be more elaborately described in Chapter 5.2.

According to Muntendam-Bos (2015) from State Supervision on the Mines in the Netherlands, hydraulic fracking itself normally only causes micro seismicity (magnitudes of 0 or lower). Even if a higher magnitude occurs, it will only be one earthquake when the rock fractures (Muntendam-Bos, 2015). There are however some case studies available where the practice of hydraulic fracking possibly caused a series of induced seismicity. Near Blackpool (United Kingdom) Cuadrilla started hydraulic fracking for the recovery of shale gas and within 10 hours after fracking, seismicity with magnitudes up to 2.3 M_L were measured (de Pater & Baisch, 2011). According to the report the events happened not immediately after the hydraulic fracking started and it is therefore not completely sure that there is a strong correlation between the two.

In Oklahoma, US, increased seismicity has been recorded where hydraulic fracking started. With the calculations in a pore pressure diffusion model, spatial and temporal correlations can be seen from hydraulic fracking and seismic activity. This has been calculated with a simple model and quite a number of uncertainties, but it strongly suggests a relationship (Holland, 2011).

Only three examples exist of felt induced earthquakes due to hydraulic fracking. Most of the seismicity will be microseismicity and can not be felt (Davies et al., 2013). Davies et al. (2013) propose three mechanisms that can cause seismicity based on the three known examples. The three mechanisms all connect to reactivation of a fault. Firstly, the fracking fluid enters the fault directly. Secondly, through the newly made fractures the pressure pulse may transmit to the preexisting fault. Lastly, there may be a connection with preexisting fractures. Davies te al. (2013) conclude that if hydraulic fracking itself causes induced seismicity, one of the three above mechanisms should be present.

2.2.2 Wastewater injection

Knowing all causes of earthquakes is necessary in order to make any statements about the occurrence of induced earthquakes through shale gas production. Another cause of induced earthquakes can be the injection of wastewater. Wastewater is a consequence of hydraulic fracking and even though the hydraulic fracking has a relatively small amount of induced earthquakes; wastewater injection causes a higher amount of induced earthquakes. The underlying mechanisms of the induced earthquakes due to waste water injection is associated with increased pore pressure along preexisting faults (Kim, 2013). Rocks break when the tension in pore pressure exeeds the strength of the rock (Elssworth, 2013; Segall, et al., 1994; Weingarten et al., 2015).

To get rid of the wastewater, it can be send to a cleaning facility or is more likely stored in an underground water well. This storage happens at different rates of injection and it is more likely that a high-rate injection well will cause an induced earthquake (Weingarten, et al., 2015). This article adressed 18,757 injection water wells in the United States which had injection rates between 100 barrels per month up to 2 million barrels per month. High rate injection is identified as more than 300,000 barrels per month, and the correlation with earthquakes is statistical significant at almost 99%.

Next to the influence of induced earthquakes due to wastewater injection on housing prices, there is also the risk of environmental pollution. Llewelln et al. (2015) estimate the risk of groundwater contamination due to chemicals in injection water and Muehlenbachs et al. (2013) show that this risk causes a depriciation of 24% in housing values. The same authors show that the effects stay negative over time if a shale gas well is in the neighbourhood, especially when homes are dependend upon groundwater from that region (Muehlenbachs, et al., 2014).

Currently, in the Netherlands the injection of wastewater in water bearing layers is not allowed (Muntendam-Bos, 2015). So if shale gas extraction will be enhanced in the future, wastewater should either be brought to a cleaning facility or the Dutch laws have to be revised. The possibility of earthquakes due to shale gas extraction in the Netherlands is therefore currently reduced to the induced seismitity of fracking itself.

2.3 Relationship between natural factors and commercial real estate

There have been several studies to estimate the effect of earthquakes on housing prices. The effect of natural factors on commercial property rents is less widely available but the studies that are available will be discussed here.

Naoi et al. (2009) used a hedonic price analysis in their research and found that both rental and housing prices in Japan suffer from a discount when an earthquake has occurred in the recent past. Prices do not suffer from a discount pre-earthquake, of which can be concluded that households do not assess the risk of an earthquake very high when the earthquake was further in the past. For this study they used a dataset that was available for the whole country, so differences between earthquake-prone regions and others can be seen. This paper focuses on the prices before and after a huge event and did not mention any compensation for damage. What they did include was the notion that buildings which were built after the introduction of a new building law, were discounted less than buildings from before the law. As in the paper of Naoi et al. (2009), the paper of Beron et al. (1997) analyzes the differences in housing prices before and after an earthquake with a focus on how consumers estimate the risk of an earthquake. The earthquake of Loma Prieta, San Fransisco, is studied and they found that consumers initially estimate the risk of an earthquake high. Even after the earthquake, the specific earthquake variables have a negative impact on the house prices, but their influence is less. Which means that consumers initally estimate the risk of damage due to earthquakes too high (Beron, et al., 1997). These papers contradict each other, this might be due to difference in culture or socio-economic conditions. None of these papers includes the compensation of damage repairs.

Another study in Japan focuses on the risk of an earthquake happening and its effect on land prices, using a hazard map. The regression shows that land prices in the area with the lowest risk do not differ significantly, but land prices that lie in the highest risk zones, suffer from a 8% loss of price (Nakagawa, Saito, & Yamaga, 2008).

Even more relevant for this study is the research of the same author in 2007. Nakagawa, Saito and Yamaga (2007) find differences in housing rents in risky earthquake areas. As explanatory variables they use various building characterisics as well as demographic and spatial charasteristics. They also add construction materials because in Japan there has been a change in construction law in 1981 which made stronger constructions obliged. Buildings in risky areas have a higher discount on the rents when they have been built before the new law. After the implementation of the new law, buildings in the highest risk zones still suffer from a discount on rents.

The housing market in Istanbul also shows a negative correlation with respect to earthquakes. The risk of earthquakes here was included as a location variable and showed that when the amount of damaged building rises with 1%, there is a substantial decrease in housing prices (Keskin, 2008).

For the province of Groningen, a few studies about the influence of the induced earthquakes on the housing prices have been done. A research issued by the Dutch minister of Economic affairs was done and found that no significant decreasing property values were found after the earthquake in Huizinge (Francke & Lee, 2013). This report did not take into account the amount of properties that suffered from damage. Another report was conduced in 2014; it found that properties with damage had a significant longer selling period, but it did not have influence on the property values (Francke & Lee, 2014).

In contrast to the above mentioned reports, the paper of Koster and van Ommeren (2015) did find an influence of earthquakes on houseprices. Since households are compensated for damage, the depreciation of house prices must have other reasons. This can be the willingness to live in a region and the discomfort by living with uncertainties associated with earthquakes (Koster & van Ommeren, 2015).

Koster and van Ommeren (2015) use peak ground velocity (PGV) as a measure of the earthquake intensity per property and calculate the number of earthquakes that are noticable. Their regression results show that areas which had noticable earthquakes suffered from a price discount between 1.2-2.2 percent. The average non-monetary costs of earthquakes on a household are €2,200 (Koster & van Ommeren, 2015).

3. Data

Buildings are heterogeneous goods; the value of such goods is therefore depending upon many characteristics. This chapter will describe and present the data used in this study to identify those characterizations.

3.1 Commercial property data

This study uses data of the rental prices in the provinces Groningen, Friesland and Drenthe for the analysis. The company Strabo provided the dataset. This dataset is, according to their own website, the most complete dataset on commercial real estate in the Netherlands (Strabo, 2015). For every property, there is information about the use of the building, the amount of square meters available and rent per square meters. Furthermore, the data provides information about its location and makes linking to other demographic features possible. This research focuses on commercial property and only uses the observations where rents were available. The total dataset had 6,168 observations but this included some observations with selling prices. This leaves the dataset on 4,339 observations, which have rents. A lack of both coordinates and complete addresses makes another 33 observations unusable because spatially linking is not possible; this leaves 4306 observations available for this research. The dataset is a repeated cross-section with 4306 observations, observed in the period from 1986 to 2015. A rough 60% of the observations resides with at least one other observation in the same building, so this results in 2505 individual locations. This can be shopping malls where multiple shops are located in the same location. This does not generate double counting since the rents only cover the amount of rented square meters.

The different type of tenants can influence the rents, so to see the differences in influence a dummy is created for every sort of tenant (offices, commercial buildings, shops, mixed property and remaining uses).

3.2 Other variables

Besides the physical attributes of the observations, the analysis includes some spatial and demographic variables. Land use could be of influence of the rents because stores tend to prefer to locate near houses in the city center, so in build-up areas. Offices or commercial buildings tend to prefer a spot near a highway entry or exit, which would typically lay in the more open spaces. The extraction of the land uses use the topographical map of the Netherlands (Kadaster, 2015). Land use makes a deviation between build-up areas, water, agriculture and forested areas. Figure 1A shows the land use in the northern provinces. The distance to railway stations and highway ramps is included as variable in the regression because different uses of buildings tend to prefer to be close to highways, this might be for example a distribution center (commercial building). Figure 1B shows the infrastructure in the northern provinces.

Other variables that are used are the occurred earthquakes, in figure 2A and 2B the earthquakes can be seen and the occurrence of the natural gas fields (KNMI, 2015).

Construction year could be of influence on the rental price because an old city center may be more attractive for stores to locate than a new industrial terrain. Therefore, adding dummy variables with different construction years based on the spatial information of the observations captures this influence. Parking lot information was included in the dataset but very incomplete; therefore, this data will not be included in the analysis.

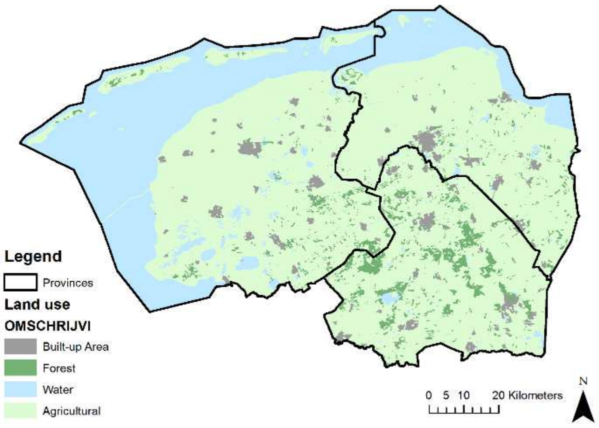

Figure 1A, Land use in Groningen (own figure, based on data of Kadaster (2015))

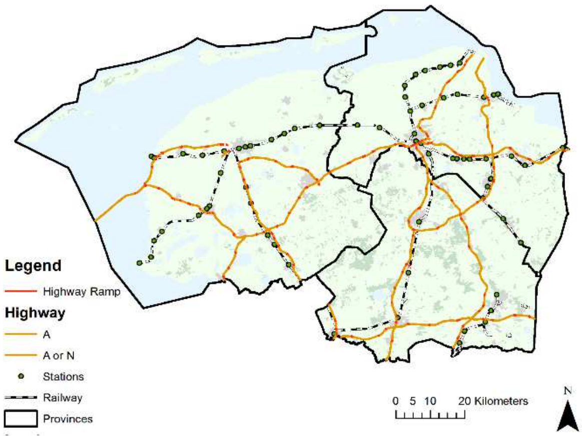

Figure 1B, Infrastructure in Groningen (own figure, based on data of Kadaster (2015))

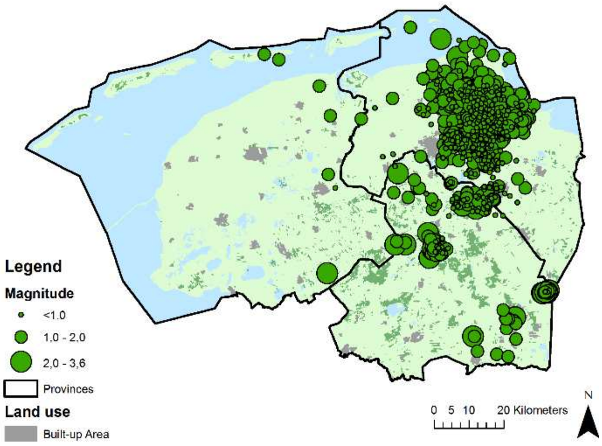

Figure 2A, distribution of earthquakes (own figure, based on data of KNMI (2015))

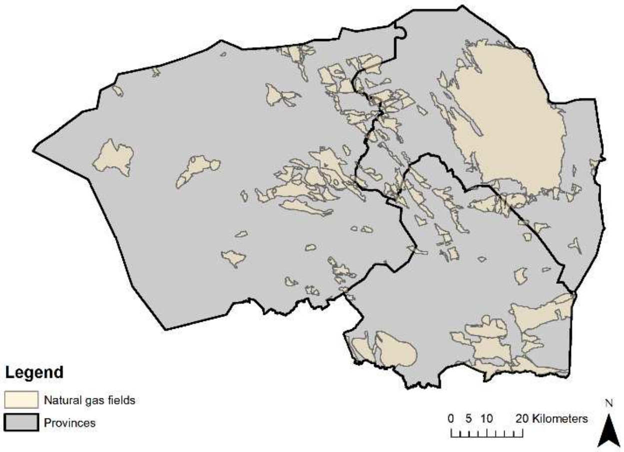

Figure 2B, occurrence of natural gas fields (own figure, based on data of KNMI (2015))

Neighborhood data is added to the regression as published by the Statistics Netherlands (CBS). Neighborhood level was not available so the next most detailed information is used, which was municipality level. The most recent data available was the year 2012. It provides information such as, population density per municipality, share of young people, share of old people and share of foreigners in the population (CBS, 2015).

Similar to the study by Koster & Ommeren (2015), the PGV is used to find a value for the severity of each earthquake per observation. Based in the earthquake dataset, an intensity variable is included and the amount of low magnitude and high magnitude earthquakes. The dataset includes all earthquakes with a magnitude above 0.5 M_L between December 1986 and August 2015. It includes 1014 earthquakes in the provinces of Groningen, Friesland and Drenthe. Average magnitude is 1.27 M_L and average depth of the earthquakes is 2.95 kilometers.

It is likely that shops are concentrated in the center of a city. Therefore a dummy variable is created with information about the location of the observation (in the city center or not).

3.3 Descriptive statistics

Table 1 summarizes the statistics of the variables. The average rental price per square meter of commercial property is €135. No knowledge is present about the duration of the rents, if the rent is set for a certain period or if the rent fluctuates. Hence, the study works with the assumption that the rents are set for the whole rental period. Distance to highway ramps and railway stations are expressed in meters and are on average 2.4 and 2.1 kilometers away from the observations, which is lower than the national average of 5 kilometers. Shops have the highest share of the observations, followed by office buildings. Age is the difference between de building year and the year the rents were set. The cities Groningen, Leeuwarden and Assen, which are the largest cities in the analyzed provinces, contain 58% of the observations. This means that these three cities lift the average population density because population density is higher in these cities. The other 42% of the observations have population densities below 630 people per square kilometer. The share of foreigners is relatively low with 16% in the northern provinces, compared to the 21% national average. Land use has the highest share in agriculture; about 70% of the provinces is agricultural use. On average 22% of a municipality is build-up. The last set of dummy variables are 1 if the observation lies within the city center and 0 if it does not lie within a city center. Groningen has most of its observations within the city center; this is not surprising, because the bulk of observations situates in Groningen. The number of noticeable earthquakes (PGV05) that observations have experienced are relatively low, with 6 as a maximum and an average of 0.3. The PGVs with other values are also included, the higher the PGV value, the lower the amount of earthquakes that generated high PGVs that observations experience.

Table 1

Variables		Mean	Std. Dev.	Min	Max
Rent price	€ per m^2	135.096	119.516	7.931	1649.484
Distance to highway ramp	m	2445.930	3878.996	61	22248
Distance to railway station	m	2135.588	2236.267	56	27313
Size of property	m^2	704.376	1187.980	22	24600
Building type – Commercial		0.172	0.378	0	1
Building type – Office		0.321	0.467	0	1
Building type – Shop		0.482	0.500	0	1
Building type - Mixed		0.019	0.139	0	1
Building type - Remainder		0.005	0.070	0	1
Age		38.373	48.781	0	721
Population density		1306.686	1049.415	60	2559
Share young people (<15 year)		0.149	0.023	0.123	0.200
Share elderly people (>65 year)		0.165	0.042	0.119	0.268
Share foreigners		0.162	0.059	0.036	0.226
Land use – Build up		0.219	0.148	0	0.390
Land use - Forest		0.044	0.022	0	0.258
Land use - Water		0.042	0.091	0	0.930
Land use - Agriculture		0.696	0.140	0.0618	0.995
Groningen city center		0.140	0.347	0	1
Leeuwarden city center		0.208	0.406	0	1
Assen city center		0.240	0.427	0	1
Weak Earthquakes within 1 km	$1 < M_L =< 1.5$	24.882	27.137	0	244
Number of strong earthquakes	PGV > 0.75 cm/s	0.041	0.237	0	3
Number of weak earthquakes	PGV > 0.25 cm/s	1.442	1.796	0	17
Number of earthquakes (PGV01)	PGV > 0.1 cm/s	6.771	5.812	0	36
Number of earthquakes (PGV02)	PGV > 0.2 cm/s	2.021	2.239	0	19
Number of earthquakes (PGV03)	PGV > 0.3 cm/s	0.873	1.347	0	11
Number of earthquakes (PGV04)	PGV > 0.4 cm/s	0.200	0.671	0	8
Number of earthquakes (PGV05)	PGV > 0.5 cm/s	0.305	0.771	0	6
Number of earthquakes (PGV06)	PGV > 0.6 cm/s	0.061	0.301	0	5
Number of earthquakes (PGV07)	PGV > 0.7 cm/s	0.046	0.253	0	3
Number of earthquakes (PGV08)	PGV > 0.8 cm/s	0.039	0.233	0	3
Number of earthquakes (PGV09)	PGV > 0.9 cm/s	0.035	0.212	0	3
Number of earthquakes (PGV1)	PGV > 1 cm/s	0.029	0.181	0	3

Note: M_L refers to the magnitude on the Richter scale. The variable Weak Earthquakes within 1 km of the observations is the count of earthquakes that have magnitudes between 1 and 1.5 this can be translated in PGVs but that is not the value as is used in the analyses, therefore it is expressed in M_L.

Table 2

	Weak Earthquakes	**Earthquakes05075**	**Earthquakes02505**	**PGV01**	**PGV02**	**PGV025**	**PGV03**	**PGV04**	**PGV05**	**PGV06**	**PGV07**	**PGV075**	**PGV08**	**PGV09**	**PGV1**
Weak Earthquakes	1														
Earthquakes05075	0.160152	1													
Earthquakes02505	0.506241	0.366750	1												
PGV01	0.685097	0.278576	0.843927	1											
PGV02	0.539524	0.550396	0.917607	0.865718	1										
PGV025	0.445478	0.529555	0.957498	0.783031	0.938150	1									
PGV03	0.365382	0.620184	0.852231	0.660394	0.891831	0.924956	1								
PGV04	0.161346	0.752230	0.596690	0.401966	0.700129	0.742971	0.80310	1							
PGV05	0.134925	0.898120	0.443818	0.295966	0.612413	0.630387	0.700015	0.848123	1						
PGV06	0.114572	0.777572	0.474228	0.292513	0.616751	0.637213	0.691931	0.802225	0.914748	1					
PGV07	0.103601	0.648440	0.465596	0.273666	0.585891	0.623721	0.65730	0.791887	0.876653	0.910108	1				
PGV075	0.067679	0.579257	0.448797	0.249056	0.544724	0.610946	0.642538	0.764713	0.848683	0.870671	0.957828	1			
PGV08	0.065504	0.582577	0.449215	0.246274	0.537443	0.612141	0.642576	0.766770	0.845005	0.859301	0.946620	0.987590	1		
PGV09	0.042307	0.556508	0.423420	0.227341	0.505735	0.584238	0.613866	0.728475	0.814762	0.814653	0.893324	0.951227	0.962620	1	
PGV1	0.009435	0.400153	0.429944	0.201663	0.461520	0.554905	0.584816	0.607263	0.653064	0.720451	0.796226	0.852209	0.866672	0.907817	1

Note: Correlation matrix of earthquake variables

Table 2 shows the correlation matrix of all the earthquake variables. Highlighted in red are the correlations which are higher than 0.5. The correlation between all the PGV01-1 are expected because they contain the number of earthquakes that generated a PGV of above that specific number, so lower PGVs have all the higher ones included. Variable Weak Earthquakes is expected to have a high correlation with low PGVs since that variable contains earthquakes of magnitude 1-1.5, which generates low PGVs. Apart from PGV01 and PGV02 it is possible to include both the Weak Earthquakes variable and the PGV variables in a regression. Furthermore, a high correlation exists between population density and build-up areas, which is as expected but results in the exclusion of population density in the regressions.

4. Methodology

This study consists of literature review, interpretation of geological data and an empirical study. The geological part of this study will contain descriptions of the current geological situation in the Netherlands. The second part of the study will contain the empirical analysis on the data of the commercial real estate. The empirical analysis will be a hedonic price analysis, which is a revealed preference method of the value. It is a revealed preference because the prices or rents that the regression uses are prices that one actually pays for the object. The hedonic pricing method measures the relative importance of explanatory variables, like in this case the influence of earthquakes on commercial property prices.

A regression analysis is conducted to find the impact of earthquakes on rental prices. Housing and rental prices can be modelled using hedonic price functions. A hedonic price analysis has the underlying assumption that the price of every house or building can be explained by it individual characteristics (Rosen, 1974). These characteristics exist of structural, neighborhood and spatial characteristics. It depends on the research what kind of characteristics should be added to the analysis to find the influence on the housing or rental prices. The technique used is a statistical analysis where the price of the unit is the dependent variable and all possible explaining variables are the independent ones. Each independent variable has its own implicit price, which is the hedonic price, and every independent variable will have its own importance to the overall rent of the property (Dunse & Jones, 1998).

Section 4.1 will start with the description of the variable construction. Section 4.2 will explain the empirical framework that this study uses for the hedonic analysis.

4.1 Variable construction

The variables consists of three different categories: structural, neighborhood and spatial characteristics of the observations. The variables are constructed by using a geographical information system; ArcGIS 10.1.

Structural characteristics are variables such as the price, size and construction year of a building. The year of construction is extracted from the Basic administration Addresses and Buildings (BAG) of the Netherlands and was added to the observations based on spatial information (Kadaster, 2015). This information provides the basis for the variable age, and this research uses it to see whether age has an influence on the rents.

Neighborhood characteristics are variables that describe the environment of the region. It provides information such as population density per municipality, share of young people, share of old people and share of foreigners in the population. It gives information per observation as a percentage of the total population.

Spatial characteristics include variables such as distance to railway stations, highway exits and natural gas fields. The most detailed map of the topography of the Netherlands is used to extract these characteristics (Kadaster, 2015). These distances have been calculated making use of the tool 'Generate Near Table'. Furthermore, every observation gets a variable with the share of every land use per municipality by relating the observations to the topographic map of the Netherlands (Kadaster, 2015).

In order to find an effect of earthquakes on commercial rental values, the PGV that determines the intensity of each earthquake is constructed. The calculation of the PGV per property uses an attenuation function. PGV shows a correlation between earthquake intensity and damages to houses, so this research uses the PGV to measure earthquake intensity (Wu et al., 2004; Koster & van

Ommeren, 2015). The PGV is depending upon spatial factors and therefore the Dutch Meteorological Institute has constructed an attenuation function that is applicable to Groningen (Dost, Van Eck, & Haak, 2004; Dost & Haak, 2002; Koster & van Ommeren, 2015). The next function represents the PGV (attenuation function):

$$\log_{10} v_{it} = -1.53 + 0.74 M_{Ljt} - 1.33 \log_{10} r_{ijt} - 0.00139\, r_{ijt} \tag{1}$$

$$r_{ijt} = \sqrt{d_{ijt}^2 + s_{ijt}^2} \tag{2}$$

Where $\log_{10} v_{it}$ is the PGV in cm/s per observation in time, M_{Ljt} is the magnitude on the scale of Richter per earthquake in time *t*. r_{ijt} is the hypocentrical distance between an earthquake occurring at location *j* and the observation at location *i*. The second formula calculates r_{ijt}, where d^2_{ijt} is the distance between the earthquake and each observation and s^2_{ijt} is the depth of the earthquake. The depth is set at 2 kilometers as is done in the paper of Koster & van Ommeren (2015) due to a lack of detailed information (NAM, 2015). According to a research of the NAM, this is an appropriate assumption (NAM, 2015).

Earthquakes are noticeable to humans when $M_L > 2$, so as seen in an earlier study by Koster & van Ommeren (2015) this paper first focuses on the effect of these earthquakes, this corresponds to a PGV of 0.5 cm/s. A peak ground velocity of above half a cm/s corresponds to a 5% probability of damage (Van Kanten-Roos, Dost, Vrouwenvelder, & Van Eck, 2011; Koster & van Ommeren, 2015). The analysis uses the cumulative amount of earthquakes that generated a PGV of above 0.5 cm/s for each observation. The next function represents that cumulative amount of earthquakes:

$$e_{it} = \sum_{t=1986}^{t} 1(v_{it} > 0.5) \tag{3}$$

Where e_{it} is the amount of noticeable earthquakes per observation in year *t*.

Koster & van Ommeren (2015) have a PGV of 0.5 cm/s when an earthquake of magnitude 2.2 occurs and the house is exactly located above the epicenter. This dataset did not include an observation that was located above an epicenter so validation of the exact PGV was not possible in that way. To see whether the constructed PGVs are correct, a graph with distance between observations and PGV has been constructed. Appendix A contains the results.

4.2 Empirical framework

To find whether a relationship between the rental prices and induced earthquakes exists, a regression analysis is conducted. Since property owners get compensation for any monetary costs they have from damage, the regression will identify non-monetary costs. The regression is based upon historical data with different magnitudes of earthquakes and has the assumption that tenants will be influenced in their decision-making by the information about past earthquakes. The regression uses the following hedonic price function to estimate the factors affecting rental prices:

$$\log p_{it} = \alpha e_{it} + \beta H_{it} + \gamma N_t + \delta S_t + \epsilon_t \tag{4}$$

Where $\log p_{it}$ is the logarithmical transformation of the rental price per square meter, e_{it} are the PGVs of noticeable earthquakes, H_{it} are the property characteristics, N_t are the neighborhood characteristics, S_t are the spatial characteristics, ϵ_t is the error term. α, β, γ, δ are parameters to be estimated.

The regression uses robust standard errors, which improves the regression in such a way, that it corrects for heteroscedasticity in the errors terms.

The data covers multiple years, so it might suffer from annual price changes. To control for these annual price effects, year fixed effects are added to the equation. Locational fixed effects are also included because it corrects for the changes that occur within a certain spatial boundary. For example, the price of an attractive neighborhood might be higher, so the observed price trend in that neighborhood is higher. The included variables might not cover all the variation within the data; therefore, the regression includes fixed effects. Locational fixed effects are based on postal code 4 areas, which covers areas of about 1 to 8 km^2. The data did not allow for the inclusion of a more detailed postal code area. This results in the following equation:

$$\log p_{it} = \alpha e_{it} + \beta H_{it} + \gamma N_t + \delta S_t + \theta_t + \vartheta_i + \epsilon_{it} \qquad (5)$$

Where θ_t are the time fixed effects, ϑ_i are the postal code fixed effects and $\epsilon_{it}$the independent error term.

A last addition to the model is the inclusion of weak earthquakes. This variable is included because chances are that earthquakes occur non-random over space. Koster & van Ommeren (2015) have tested this hypothesis and found that earthquakes with PGVs above 0.5 cm/s are indeed more concentrated than would be the case if they occur randomly in space. However, since strong earthquakes are rare, it is possible that these earthquakes, depending on the amount of weak earthquakes, do occur randomly over space. The inclusion of weak earthquakes within 1 km of the observation with $1 < M_L <= 1.5$ therefore lowers the possibility of correlation between unobserved price trends and earthquakes.

Spatial autocorrelation

When working with spatial data, it is possible that near observations have a correlation with each other because they are close to each other. A house or commercial property, which has a high rent per square meter, is likely to have a neighbor, which also has a high rent. When this is the case, a normal ordinary leas square (OLS) analysis should be adapted to compensate for this. To see whether the use of an OLS model is correct, a model should tests for spatial autocorrelation. When one of the tests is significant, a reconsideration of the regression form is appropriate. Moran's I is one of the spatial dependence tests. If there is spatial dependency, one of the following models is appropriate to use; a spatial lag model is based upon the distance between observations and the model corrects for the dependency. A spatial error model corrects for the dependency of the error terms of the observations (Dekkers & Koomen, 2008).

A row standardized spatial weight matrix is made, based on the distance from every observation to every other observation. Based on this spatial weight matrix the Moran's I can be calculated. The formal notation of this spatial error model is:

$$p = \alpha + \rho W p + \beta H_t + \gamma N_t + \delta S_t + \varepsilon \qquad (6)$$

$$\varepsilon = \lambda W \varepsilon + u \qquad (7)$$

Where p is the rent price, W the spatial weight matrix, and ε is the independent error term. ρ and λ are econometric coefficients that describe the importance of the spatial lag and spatial error terms (Dekkers & Koomen, 2008).

5. Geology

In order to understand whether it is possible to extrapolate the results from Groningen to another area in the Netherlands, this paragraph provides a brief introduction in geology. This chapter answers the main question:

'Is it possible to extrapolate the earthquakes and its impacts of Groningen to another area in the Netherlands?'

This section will start with a general outline of necessary conditions to form and trap natural gas and will present an overview of the differences between Groningen and the shale gas regions.

To understand the occurrence of hydrocarbons, this section provides an explanation of the concept of petroleum systems. A petroleum system is a system where all the elements are at the same time in place to form hydrocarbons. The existence of a source rock, reservoir rock, seal and trap is necessary. Source rocks exist out of organic-rich sediments which deposition can occur in different environments. The source rock type depends upon the type of basin and most abundant organic material. Due to increasing burial and temperature, the source rock starts to mature and the organic material breaks down into smaller hydrocarbon molecules, named kerogen. The kerogen that is included in the organic-rich sediments expels from the source rock and forms the hydrocarbons (Jager, 2015). Depending on the pressure and temperature, oil or gas or possibly both will form. It then migrates upwards due to buoyancy[3] into porous rocks. When a rock is largely porous, it can be a reservoir rock and contains the hydrocarbons in its pore space. Depending upon the presence of a seal, the rock can be a successful reservoir. The last thing that is necessary to capture hydrocarbons is a trap, a geological structure that can trap hydrocarbons. This can for example be an anticline (see figure below) or a trap due to faulting (Fjaer et al., 2008). If there is no trap, the hydrocarbons move to the surface. When all these factors are in place, there is a prospective of a gas field to be developed. Figure 3 shows a simplified version of a conceptual petroleum system.

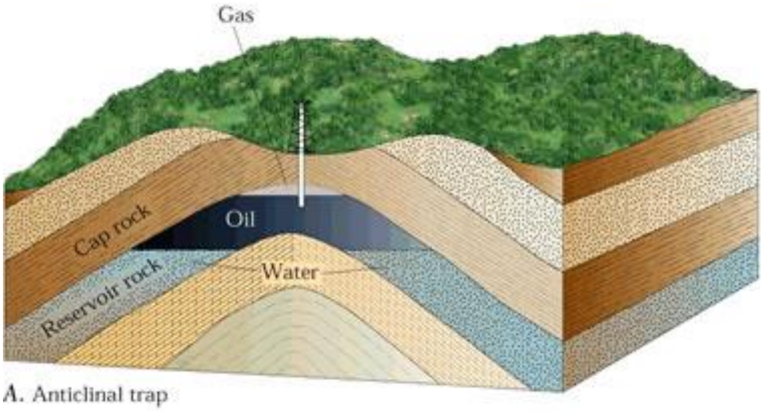

Figure 3, petroleum system (Jager, 2015)

5.1 Properties of Groningen natural gas and shale gas regions

The Dutch heating system is mainly built upon the composition of the natural gas as found in Groningen. This might make it difficult for the government to use other gas when the Groningen gas reservoir is depleted in the future. This section will answer the question:

What are the properties of Groningen natural gas and how is this different from shale gas?

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[3] Buoyancy is the upward force that a fluid exerts on an object with less density then itself.

To know what the composition of the natural gas in Groningen is, one needs a more detailed underlying geological understanding. The next section will start by explaining the geological features of the Groningen field.

5.1.1 Geological background Groningen

The Groningen gas field lies within the Southern Permian Basin gas province, which is an extensive east-west oriented sedimentary basin (figure 4A). The basin goes as far from central Poland to the Southern North Sea area. Even though the complete basin exists out of different source rocks, the source rocks in Groningen are terrestrial rocks, which are mostly associated with natural gas production (Amin, 2014; Bergen et al., 2013). The Groningen gas field has emerged above the sediments of the Carboniferous[4] and the development of the field started at the end of this geological timeframe (Amin, 2014). Groningen natural gas started to develop in the Westphalian coal layers of the Carboniferous, where it escaped and migrated towards the above lying Rotliegend reservoir. The reservoir layer exists of sand and claystone with a high porosity and has formed in the Permian[5] age (NLOG, 2015). The natural gas situates in the Slochteren formation (Glennie & Provan, 1990). In Groningen, the Zechstein formation is the sealing salt layer from the Permian age. It is a perfectly sealing layer, which consist of 500 to 1,500 meters salt (Amin, 2014).

The Zechstein salt highs form the traps; they are fault-bounded (Nicholson, 1999). During the Late Cretaceous and Tertiary, uplift of the Rotliegend reservoir caused some structural closures into which gas has migrated (Glennie & Provan, 1990). This also caused the extensive region of faults, which one can see in the geology today. This faulted structure has a single reservoir-seal pair, which makes it a very robust structure (Jager, 2015).

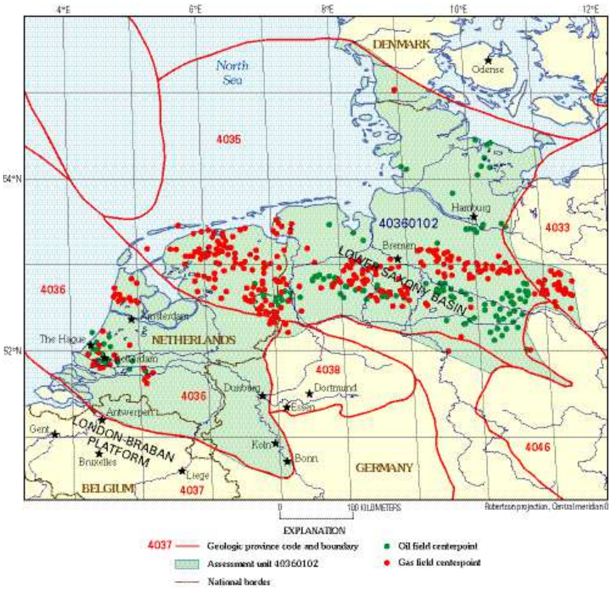

Figure 4A, Southern Permian Basin-Europ (Gautier, 2005)

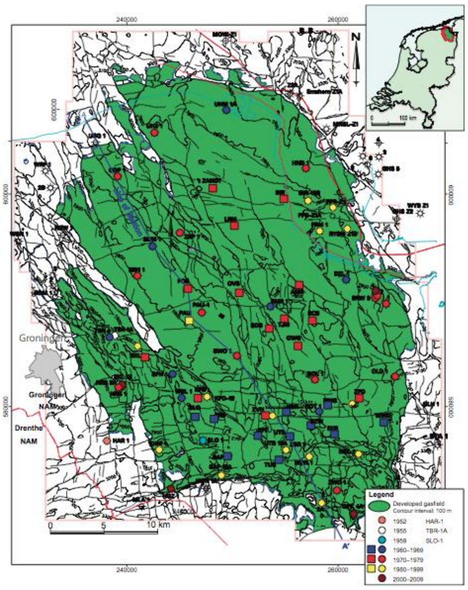

Figure 4B, faulted structure Groningen (Amin, 2014)

Groningen gas field lies at an average depth of 2,750 meters and its thickness varies from 70-240 meter. The gas extraction occurs at approximately 3 kilometers depth (Witteveen en Bos et al., 2013). As stated in the introduction, the volume of recoverable natural gas in Groningen is about 2.800 billion m^3. Average porosity is 17%, which means that 17% of the volume of the rock is void space and water or hydrocarbons can accumulate (N.V. Nederlandse Gasunie, 1980). Porosity is important because a higher porous rock will have higher potential to compaction and therefore a

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[4] The Carboniferous period started approximately 359 Ma (millions of years ago) and ended 299 Ma.

[5] The Permian age started approximately 299 Ma until 252 Ma.

higher potential to cause land subsidence and subsequent earthquakes. This is a relatively high porosity (Amin, 2014). The Slochteren formation is most important layer in Groningen because extraction of the natural gas is from that layer. A survey taken by the NAM confirmed that earthquakes take place at a depth of 2 kilometers, as stated by Dost et al. (2004).

5.1.2 Properties Groningen gas

There is a rough deviation in the properties of Dutch natural gas compared to gas in other regions of the world. The production in Groningen contains low calorific gas; this means that the energy value is relatively low[6]. Low calorific gas (L-gas) has energy values between 9.5 and 10.7 kWh/m^3, where high calorific gas (H-gas) has values between 10.8 and 12.8 kWh/m^3 (RVO, 2015). In the Netherlands, all heating systems use low calorific gas. L-gas has a relatively higher percentage of nitrogen and lower methane content. Measurements of the methane content range from 81 to 86% (Nicholson, 1999; Dijkema 2012; N.V. Nederlandse Gasunie, 1980). These measurements are still well in the range of 80-87% for L-gas. When H-gas is used, nitrogen is added to let the systems work properly (RVO, 2015).

5.1.3 Geological background shale gas regions

Shale gas forms in the same way as natural gas but the main difference between the two is the storage. Conventional gas migrates towards above lying layers and into permeable layers and structural or stratigraphic traps bound the gas (Herber, 2011). Unconventional gas is not bounded by structural or stratigraphic traps. Unconventional resources also lack a clear hydrocarbon-water contact because shales that occur are not sufficiently permeable to carry water. Shale gas appears in shales, which both serves as source rock and reservoir. Due to the low permeability, gas cannot migrate freely to the above lying layers, so it is trapped in its own source rock (Herber & Jager, 2010). The seal is a capillary pressure seal, which means that the gas is bounded by a water block. Due to the gas pressure, water is expelled and little water remains in the pores. According to Herber & Jager (2010), shale gas plays should fulfill five requirements before a shale gas play can be commercial viable. As first requirement they mention the total organic content (TOC) of the source rock, should exceed 2 or 3%. Second, shales should be at least 30 metres thick, this is required to drill horizontal development wells. Third, source rocks should be mature with a vitrinite reflectance of at least 1.2 Ro[7]. Fourth, geologically a mineral composition which supports the development of fractures is necessary. Both silica and carbonate structures are suitable for this. Fifth, a late uplift of the layers which brings the layers closer to the surface and therefore a higher recoverability (Herber & Jager, 2010). They also add a favourable porosity of 3-8%. The next subsections will first discuss what potential shale gas possibilities are available in the Netherlands. It wil then continue to the expected properties of shale gas.

The word potential is used here because there have not been any exploratory drillings yet, and it is therefore difficult to determine the exact properties and contents of the gas. Potential extraction sites in the Netherlands are the Posidonia and Geverik shale (Bergen et al., 2013; Herber & Jager, 2010; Witteveen en Bos et al., 2013).

Posidonia

The Posidonia shale originated in the Jurassic Age[8] and is found in the western- and central part of the Netherlands. This formation lies between 830 and 3,055 meters and is shale gas bearing between depths of 1,500-2,500 meters (Bergen et al., 2013). It has a relatively uniform character and thickness. The thickness is mostly around 30-60 meters and net thickness is 15-35 meters (Herber, 2011). This

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[6] Energy value is measured as the amount of energy needed to heat 1 kilogram water of 14.5 C° with one degree at atmospheric pressure.

[7] Ro represents the maturity of natural gas in the gas window.

[8] The Jurassic Age started 200 Ma and ended 145 Ma.

shale formation exists out of darkgrey to brownish-black bituminous and fissile clay stones and is probably brittle, which is favorable for fracking activities (Herber & Jager, 2010). The majority of measurements show a marine type II source rock and this indicates gas preservation potential (Bergen et al., 2013). According to Bergen et al. (2013), average TOC is about 6%. However, due to a relatively high maturity, it is argued that original TOC must have been higher. Maturity was not directly measurable but calculations showed that only the western part of the basin has reached maturity for gas generation. They conclude that gas generation therefore restricts to the deeper lying layers of the basin, but log wells indicate that gas is present in the immature areas. Average porosity lies between 7-10%, which is relatively high for shales. They estimated 0.26–0.46 billion cubic meters (bcm) as gas-in-place values, which is relatively low compared to the US Marcellus shale (Bergen et al., 2013).

Geverik

The Geverik shale stems from the Carboniferous period and is part of the Epen formation; it is located on both the eastern and southern borders of the Netherlands. The Geverik member is a locally found black bituminous, calcareous shale at the base of the Epen formation. Because of its bituminous character, both the government and private partners consider it as a possible shale gas location. The Geverik shale lies on top of carbonate rock and this is considered the lower boundary. Carbonates as lower boundary could be an important factor for success of shale gas recovery because this type of rock is not vulnerable to fracking, which limits the possibility of escaping gas. Gas potential would occur on depths >1,700 meters and the shale is approximately 50-70 meters thick with a net thickness of 10-30 meters (TNO&EBN 2009; Bergen et al., 2013; Herber, 2011).

The Geverik shale has a TOC of 5% of marine Type II kerogen and maturity increases from top to base of the formation (2 to 3% Ro). This maturity indicates that the southeastern part of the country may have too high maturity but the upper part of the formation may still be in the right maturity phase. No calculations of conclusive gas content exist due to limited data (Bergen, et al., 2013). Porosity is 3% and estimated volume in place is 200-600 bcm with an ultimate recovery estimation of 10-30 bcm (Herber, 2011). The Geverik member has a late uplift in the Peel area, which is favorable for the extraction procedures.

The table below represents the prerequisites and characteristics of both Posidonia and Geverik layers.

Table 3

Characteristic		Requirement	Posidonia	Geverik
Total Organic Carbon	%	>2-3	6	5
Thickness	Meter	>30	15-35	10-30
Vitrine Reflectance	Ro	>1.2	0.55-1.3	2-3
Porosity	%	3-8	7-10	3
Geological composition		Silica or carbonate	Carbonate	Carbonate
Uplift	Stage	Late	Relatively late	Late

Note: Requirement refers to the minimum conditions that are required for a geological layer to be successful for shale gas extraction.

5.1.4 Properties of shale gas

This subsection will answer the question on how the chemical properties in shale gas are different from conventional natural gas.

Examples of the United States show that different shale plays result in different compositions of the natural gasses (Gue, 2010). The shale gas plays in the United States occur in significant distance from each other and it is therefore likely that different sedimentary environments were at stake. Therefore, source rocks and chemical content, are different in the United States. In the Netherlands, such measurements are not available because exploratory drillings have not taken place yet. Therefore, making an assumption about the composition of natural shale gas in the Netherlands is necessary. Witteveen en Bos et al. (2013), mention that no significant difference between the composition of conventional and unconventional natural gas in the Netherlands occurs. However, low-calorific gas as produced in Groningen is only existent in Groningen. Therefore, gas from other regions must have higher nitrogen values (N.V. Nederlandse Gasunie, 1980). EBN (2014) confirms this argument; it states that there is a high probability of a higher calorific natural gas in the shales.

5.1.5 Conclusion

This section answers the question '*What are the properties of Groningen natural gas and how is this different from shale gas?'.* The main difference between shale and natural gas is the way it originated. The shales do not have a proper seal but the gas situates in the source rock itself and a capillary pressure seal traps the gas. Natural gas in Groningen has a proper source rock, reservoir and seal pair. Groningen extracts its gas on approximately 3 km depth and the reservoir has an average porosity of 17%. Earthquakes occur at approximately 2 km depth (NAM, 2015). The Geverik member with gas potential would be situated at a depth of at least 1700 meters. This is much shallower than in Groningen, paragraph 5.4 describes the implications of this. Porosity is about 3%, which is lower than in Groningen. Although real properties of shale gas are unknown in the Netherlands, there is a high probability of H-gas since L-gas is only found in Groningen.

5.2 Extraction

This chapter will elaborate on the different ways of extraction and the impacts on the spatial and social environment. The ways of extraction might be of influence on the different impacts it has on the physical and social environment. Therefore, it is important to understand the differences. This chapter will give answer to the sub-question as formulated below.

'What is the difference between natural gas and shale gas in ways of extraction?'

5.2.1 Extraction of Groningen natural gas

The Rotliegend reservoir in Groningen has a high permeability, which means that fluid can easily access and move through the layers. Natural gas in Groningen is produced at a depth of 3 kilometers. Drilling happens vertically and due to high pressures, high permeability and porosity, natural gas flows automatically towards the vertical producing drill hole.

Fracking is normal in shale gas extractions, but unknown to the wider public is the fact that it is also applicable to conventional gas reserves. This technique is applied more than 200 times in the Netherlands to increase the amount of natural gas that can be extracted (Witteveen en Bos et al., 2013). Most of these applications resides in the fact that gas pressure declines in time and natural gas flows at declining rates to the surface.

Possible damage and nuisance

Apart from induced earthquakes, there are some minor risks at the production of conventional gas. In the case of conventional gas production the chances are that, a blowout occurs. A blowout is an uncontrollable escape of natural gas through the layer to the surface. In the Netherlands, risk mitigation and several law- and rule enforcements make this risk very limited (Rijksoverheid, 2015). In the nearby environment, citizens might suffer from noise pollution, but this is not likely to reach further than 50 meters from the production site. Some horizon pollution at the places of production sites might also exist. These damage and nuisance factors are not very abundant and are not likely to cause severe problems for residents.

5.2.2 Extraction of shale gas the Netherlands

Shales are very tight reservoir rocks and therefore natural gas will not flow automatically to a drilling hole. Therefore, horizontal drilling and fracking is applied. Fracking is the creation of fissures in the layer (Jager, 2015). Through these fissures, gas can migrate towards the drilling hole. Fracking makes use of water and chemical ‘proppants’ which are injected at a high rate to create and keep the fissures open. The same as with conventional gas, due to the high-pressure differences, the gas will flow automatically towards the borehole. Because permeability is low in shales, development and recovery of shale gas requires a large number of wells to produce efficiently.

Possible damage and nuisance.

According to Witteveen en Bos et al. (2013) the spatial impact of unconventional gas production is higher than of conventional gas. This is because more boreholes are necessary and the construction of such holes takes longer. Fracking itself needs more activities on location and the construction needs more supplies to work properly. Most nuisance will happen during the drilling itself; noise will spread in the surrounding area. After fracking, the spatial pressure and noise are largely gone. However, chances on a blowout are much smaller because natural gas cannot migrate by itself to above lying layers (Witteveen en Bos et al., 2013). Due to the lack of exploratory drilling to shale gas developments in the Netherlands, it is not possible to give an estimated chance.

Water use is substantially higher when unconventional gas is produced. For fracking 7,000-30,000 m^3 water is needed per well. Conventional drilling needs 900-2,400 m^3. This water partially runs back to the surface as wastewater and can be reused. After drilling and within the production process there is still 95 m^3 of water used per day. This water has different components than sewage water and cannot be disposed in the sewage system. This water has to be drained and processed on different locations (Witteveen en Bos et al., 2013). Some of the chemicals used for fracking can be dangerous to people and the environment, when high concentrations are expelled. The risk of environmental damage due to spilled chemicals might also be a cause of depreciation of housing values in addition to the earthquakes. As stated in Chapter 2, worldwide there are several cases where shale gas development caused severe damage to the surrounding environment (llewellyn, et al., 2015; Kiviat, 2013; Vinciguerra et al., 2015).

5.2.3 Conclusion

To answer the question as stated in the beginning of this paragraph; it is important in shale gas development that the gas-bearing layer is sufficiently thick because horizontal fracking would otherwise not be possible. The main differences of both extractions lies in the fact that conventional gas migrates by itself towards the surface due to sufficient permeability and in shales this permeability is very low. Therefore, possible nuisance and damage is higher at the production of unconventional natural gas.

5.3 Location shale gas extraction

The last section discusses the geological characteristics and ways of extraction of the shales located in the Netherlands. There are more limitations then geological and technical ones, the Netherlands is a densely populated country and social and geographical limitations exist as well. This paragraph will answer the question:

‘In what parts in the Netherlands is it possible to extract shale gas with the economic viability aspects taken into account?’

As the analysis considers the above-mentioned geological requirements, shale gas potential exists both in the Posidonia and Geverik shales. However, there might be potential to both shales, Herber & de

Jager (2010) state that extraction for now would only be possible from Geverik shale in the Peel area. This area has a high uplift and is therefore most easily reachable and this would benefit the production costs (TNO & EBN, 2009). This source rock does have a high TOC of 8% but net total thickness is only 15-35 meters. This might cause problems with horizontal drilling, since this is at the very minimum of the thickness that is required (Herber & Jager, 2010). The potential recoverable volume would lie between 10-30 bcm for the whole Geverik member and Herber & Jager (2010) do not expect it to exceed this value. Compared to the Marcellus shale (113 bcm per year) in the US, this value is sufficiently low (U.S. Energy Information Administration, 2015). Figure 5 shows the location of the potential reachable shale gas.

Figure 5, locations of Posidonia and Geverik shale with the prospect area (own figure, based on data of KNMI (2015)).

5.3.1 Peel area

The amount of reachable gas is not only limited to the geological requirements, but also to social and environmental requirements. Figure 12 in appendix B shows the land use and areas where extraction cannot take place like urban areas and protected regions (Rijksoverheid, 2015). The selected area covers 1,500 km^2. Estimates of the Geverik potential are between 0.23-0.7 bcm/km^2 (Herber, 2011). Which results in 345 bcm of Gas initially in Place (GIIP) for the Peel area. When we assume a buffer between wells and protected or urban areas of 1 km, the amount of potential recoverable shale gas is more limited. The recoverable volume of shale gas needs adjustment to the different scenarios of technological requirements. Technologically it is possible to drill horizontally at a distance of 500-1,500 meters; this indicates that it is not possible to reach all the gas. This generates three possible scenarios of the amount of recoverable gas volume (TNO & EBN, 2009). Table 4 shows the outcomes of the spatial analysis. Appendix C shows the detailed spatial analysis and map of the buffer areas. The technologically feasible amount that can be extracted is the Producible Gas In Place (PGIP) and represents the GIIP volume corrected by the estimated recovery factor and porosity of the shale. The recovery factor of the Netherlands is rather low and would lie in a range between 5-20%, TNO & EBN (2009) use a recovery factor of 10% since this is calculated for the Netherlands in the case of basin centered gas extraction. The porosity is estimated at 3 percent (Herber, 2011).

Table 4

Horizontal drilling in m	km^2 reachable	bcm recoverable in Peel area (GIIP)	PGIP
500	1100	253	0.76
1000	1300	299	0.9
1500	1400	322	0.97

Note: bcm stands for billion cubic meters, GIIP stands for Gas Initially In Place and PGIP stands for Producible Gas In Place.

5.4 Impacts

In order to find whether extrapolation of the results from the empirical analysis is possible, one needs knowledge about the reaction of the subsurface on earthquakes. This part will try to find an answer to the question:

'What are the expected impacts of extraction in terms of frequency, magnitude and distribution of the earthquakes induced by shale gas extraction and how do they differ from earthquakes induced at the Groningen gas field?'

An indication of the impact is given by making comparisons between Groningen and the Peel area. Because real impacts are hard to estimate, this chapter will result in different scenarios about the impacts of earthquakes.

5.4.1 Subsurface

For conventional gas production, the correlation between induced earthquakes and hydrocarbon production has been established empirically (van Eijs et al., 2006). This correlation is not directly applicable to unconventional gasses because the pressure drop of the field is not as abundant as in conventional fields. In addition to this, the stiffness contrast between seal and reservoir is non-existent because it occurs in the same layer. The only element that remains is the reservoir fault density, which can be of influence since shale gasses occur in highly faulted regions. Based on observations worldwide, induced earthquakes do occur where unconventional gasses are extracted with hydraulic fracking (Davies, et al., 2013, Holland, 2011, de Pater & Baisch, 2011). All of this induced seismicity takes place where preexisting faults are activated again (Davies, Foulger, Bindley, & Styles, 2013). Since the Peel area lies in the Roer Valley Graben, where a substantial amount of faults is present, chances of reactivation of faults are present.

From the assumption of reactivation of faults, an estimation of the impact on the surface is necessary. This relies on the characteristics of the subsurface where the 20-30 meters below the surface are most important (Witteveen en Bos et al., 2013; TNO, 2003). Appendix D shows the subsurface of Groningen and the Peel area. Layers that alternate between sand and clay, even within the same formations, characterize both these areas. Three major factors influence the damage that occurs on buildings.

First, the attenuation matters, this is the degree of mutation of the earthquake when it is moving from the hypocenter[9] to the surface (TNO, 2003). The attenuation function for the Netherlands is based upon measurements of Groningen, but these are the only relevant measurements of induced earthquakes in the Netherlands (Dost, Van Eck, & Haak, 2004). According to their research, applying

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[9] Location of the earthquake in the subsurface, the exact location on the surface is the epicenter.

this attenuation function in the rest of the Netherlands is possible. So an assumption of the same attenuation function is made here.

Secondly, the shallow layers influence the magnitude and amplitude of earthquakes, which is called the site response (TNO, 2003). Clay and peat in the shallow layers will create a bigger amplitude and acceleration than sand (TNO, 2003 & Berendsen, 2004). The Dutch subsurface is non-uniform and differs between very small areas. This makes interpretations of the subsurface very uncertain. In order to give an answer to the question of this section, some assumptions are necessary. First, both regions are characterized by different formations so even though they both contain clay and sand, the specific details of the formations differs. Looking at the sections in appendix D, to the first 50 meters, one can see that Groningen contains large amounts of clay and in the Peel area the bigger clay layers only occur at deeper sections (>50m) with some minor occurrences at the surface. This indicates that amplitudes at the surface will be lower and therefore the impact on the surface will be lower in the Peel area.

Lastly, the nature of the construction of buildings and its response to movements influence the damage that occurs on buildings (TNO, 2003). This is highly dependent upon the construction year and construction materials. No statements can be made about this.

According to Witteveen en Bos et al. (2013) there is no change of soil subsidence because the compaction in shales is very limited. Due to the low porosity, the expectation is that soil subsidence remains small in shales. Fracking itself will not cause earthquakes but the reactivation of faults can cause induced earthquakes. This will be up to a magnitude of 3 M_L (TNO & EBN, 2009). Fracking itself will have minor earthquakes (M_L<1) which cannot be felt on the surface. Distribution of earthquakes depends upon the drilling locations and on the reactivation of faults. The area is highly faulted and this indicates a higher possibility of earthquakes.

To conclude this section, the determination of impacts is highly uncertain. To overcome the problem of uncertainty, different scenarios are made to work with in the empirical analysis.

1. Assume only one earthquake occurs due to fracking which causes damage and some micro-seismicity which cannot be felt and does not create damage.
    - With similar subsurface conditions as in Groningen.
    - Where the subsurface is less flexible and the impacts on the subsurface are lower (calculated with lower PGVs since this had the best correlation with damage (Wu et al., 2004; Koster & van Ommeren, 2015).
2. Assume earthquakes occur over the whole production period.
    - With similar subsurface conditions as in Groningen.
    - Where the subsurface is less flexible and the impacts on the subsurface are lower (calculated with lower PGVs since this had the best correlation with damage (Wu et al., 2004; Koster & van Ommeren, 2015).
3. Assume earthquakes caused by fracking cause micro-seismicity and cannot be felt at the surface, so there is no influence on the commercial real estate in the Peel area.

5.6 Extrapolation

This chapter answered the following question: ‘Is it possible to extrapolate the earthquakes and its impacts of Groningen to another area in the Netherlands?’

It is not directly possible to extrapolate the impacts of Groningen to another region, due to the differences between both the deeper and shallower subsurface. In the deeper subsurface the compaction due to extraction differs in such a way that shale gas extraction does not cause soil subsidence in the Netherlands due to a low porosity of the shale. In the shallower subsurface are some differences that reflect the movements of the surface and therefore differ in damage. To account for these differences and to make it possible to give an estimate of the possible impact of shale gas extraction in the Netherlands, the choice was made to use scenarios. These scenarios are based upon the same different levels of impact compared to what happens in Groningen. The next chapter will start with the empirical analysis of the rental depreciation of commercial property in Groningen and will end with the extrapolation with use of scenarios.

6. Empirical results

This chapter will present the results of the empirical analysis regarding the commercial rent prices in Groningen. Paragraph 6.1 will present the empirical analysis and paragraph 6.2 contains the estimated impacts on the Peel area, using the empirically found outcomes of the first paragraph.

6.1 Commercial real estate property depreciation

To find an effect of the earthquakes on the commercial property rental prices, this study uses an empirical analysis. This chapter will answer the question:

‘*What is the commercial real estate property depreciation as induced by the earthquakes in Groningen?’*

Appendix E contains the results of the spatial autocorrelation and indicates that the use of an OLS regression is sufficient and there is no spatial autocorrelation detected with the different tests. A test for outliers resulted in one observation with a large outlier. Because OLS is very sensitive for outliers, this observation was removed of the dataset.

6.1.1 Baseline estimates

Table 5 shows the main results of the regressions. Model 1 indicates the regression of the logarithmic transformation of the rent prices on the number of noticeable earthquakes and year fixed effects. This indicates that the rent price per square meter is 7.8 percent lower in areas that experienced earthquakes that caused PGVs higher than 0.5 cm/s and is statistically significant. Model 2 includes the postal code fixed effects, to account for the locational effects of where the earthquakes occur and where the objects are situated. The effect seems to get twice as high as in Model 1. Model 3 includes the Weak Earthquakes variable, which controls for activity on the surface related to drilling. With this variable, the model takes into account that given the weak earthquakes, the heavy earthquakes occur random over space. It therefore corrects for any unobserved price trend. It does not change the coefficient of PGV05 much and stays statistically significant with a negative price discount of 15.6 percent.

Model 4 includes the building characteristics and this lowers the effect of noticeable earthquakes to a 6.7 percent decrease of the rents. Leaving building type ‘remainder’ out of the regression, shows that shops tend to have a positive influence on the rental price, as compared to ‘remainder’ buildings. This might have to do with the location of shops but sensitivity tests on the next page will clarify this finding. The type of building is of significant influence. The inclusion of the number of weak earthquakes ($1 > M_L < 1.5$) within 1 kilometer from the observation causes very small changes within the model (model 5).

Model 6 includes the neighborhood and spatial variables. The coefficient of PGV05 decreases slightly to a 6.5 percent decrease of the rental prices. Neighborhood and spatial variables seem to have a very high coefficient and standard errors. This is the case because the neighborhood characteristics are based upon municipal data and due to the largely small towns in the provinces; this has a high correspondence with the postal code areas. To account for this, model 7 runs without postal code fixed effects and without weak earthquakes. In model 6, PGV05 has a 6.5 percent negative influence, while the exclusion of the postal code fixed effects and weak earthquakes lowers this to 5 percent. The regression does not include the variable ‘water’ from land-use, so observations in municipalities with a high share of build-up or agricultural areas have a statistically significant positive influence on the rental price. This has the expected signs. Interesting to notice is the fact that distances to railway stations do not have significance influence on the rental price of buildings. Distances to highway ramps are significant but have a negative correlation. Which indicates that a bigger distance to the highway lowers the price of the property. The spatial and neighborhood variables have an expected influence on the rental prices. Municipalities with a high share of young people tend to have a positive influence.

Table 5

	Dependent variable: the logarithm of rental price per m²							
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PGV05	-0.0786*** (0.0221)	-0.157*** (0.0340)	-0.156*** (0.0339)	-0.0672** (0.0304)	-0.0658** (0.0303)	-0.0645** (0.0306)	-0.0498*** (0.0173)	-0.0856*** (0.0263)
Log size				-0.214*** (0.00907)	-0.215*** (0.00904)	-0.217*** (0.00900)	-0.216*** (0.00905)	
Building commercial				-0.842*** (0.112)	-0.841*** (0.112)	-0.827*** (0.110)	-0.920*** (0.132)	-0.935*** (0.145)
Building office				-0.228** (0.109)	-0.230** (0.108)	-0.237** (0.107)	-0.144 (0.131)	-0.246* (0.142)
Building shop				0.0638 (0.109)	0.0647 (0.109)	0.0614 (0.108)	0.200 (0.132)	0.182 (0.142)
Building mixed				-0.655*** (0.116)	-0.652*** (0.116)	-0.634*** (0.115)	-0.730*** (0.136)	-0.773*** (0.148)
Age				-0.00155*** (0.000450)	-0.00154*** (0.000449)	-0.00161*** (0.000455)	-0.000388 (0.000361)	-0.000926** (0.000442)
Age squared				3.89e-06** (1.84e-06)	3.82e-06** (1.83e-06)	3.90e-06** (1.87e-06)	2.41e-06 (1.62e-06)	2.79e-06* (1.69e-06)
Share Young people						187.3*** (42.59)	1.918*** (0.639)	
Share elderly people						229.5*** (63.66)	0.310 (0.515)	
Share foreigner people						-21.85 (15.54)	1.456*** (0.444)	
Land use buildup						139.9*** (41.98)	0.925*** (0.211)	
Land use forest						129.3*** (35.86)	0.416 (0.327)	
Land use agriculture						-24.19*** (5.621)	0.366*** (0.0865)	
Log distance highway						-0.0301 (0.0214)	-0.0448*** (0.00794)	
Log distance railway						-0.0184 (0.0211)	-0.00310 (0.00979)	
Weak Earthquakes			-0.00255 (0.00259)		-0.00411** (0.00178)	-0.0133*** (0.00239)		-0.00337** (0.00154)
Constant	4.331*** (0.145)	4.255*** (0.0989)	4.319*** (0.119)	5.905*** (0.152)	6.011*** (0.158)	-61.27*** (17.34)	5.146*** (0.276)	4.593*** (0.170)
Observations	4,306	4,306	4,306	4,306	4,306	4,306	4,306	4,306
R-squared	0.017	0.498	0.498	0.694	0.694	0.697	0.621	0.639
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Postal code FE	NO	YES	YES	YES	YES	YES	NO	YES

*Note: Standard errors are robust standard errors. Coefficients with * are significant at the 10% level, with ** to the 5% level and with *** to the 1% level, all-in bold.*

It is possible that the included variables from model 7 do not account for all the price trends, it is preferred to use a model where the postal code fixed effects are included and where the weak earthquakes are included. Therefore, model 8 excludes the spatial and neighborhood variables. It also excludes the size of the building since this had a high correlation with the type of building. The last column is considered as the best specification to find the effect of earthquakes on rental prices because of the above-mentioned considerations. Because the dataset consists of rental prices of a certain point in time, the rental prices decreases with 8.6 percent when noticeable earthquakes occurred in the past.

The preferred model 8 gives a rent decrease of 8.6 percent due to noticeable earthquakes. As stated before is a peak ground velocity of 0.5 cm/s noticeable but to see whether lower and higher PGVs have a significant influence on the rental price, a sensitivity analysis is carried out (Van Kanten-Roos et al., 2011).

6.1.2 Sensitivity analysis

Table 6 reports the last specification of table 5, model 8 but with different PGVs. Interesting to see is the fact that the PGVs are all statistically significant up until PGV08 and increase when intensity of the earthquake increases. A peak ground velocity of 0.1 cm/s only accounts for a decrease of 1.9 percent in rental prices. This is expected since the probability of damage from these earthquakes is expected to be non-existent and the earthquake is not noticeable to residents. This specification did not include weak earthquakes since there is a high correlation between low PGVs and weak earthquakes. The amount of observations that suffered higher PGVs decreases once the intensity of PGVs increases, for example; 2999 observations experienced PGVs of 0.1 cm/s but only 116 observations experienced PGV of 1 cm/s so this influences the standard errors. PGV06 shows the strongest effect, with a decrease of 18.8 percent. Higher PGVs generate lower decreases; this might be because fewer observations suffer from these earthquakes. Once the weaker and stronger earthquakes are included in the analysis, the results are not significant and only significant for PGVs between 0.25 and 5 cm/s (model 11).

Where Koster & van Ommeren (2015) find an effect of 3% on house prices at PGVs above 0.5 cm/s, commercial property suffers from a substantially higher rental decrease. This might indicate that the rental price decrease of commercial property contains both monetary and non-monetary costs. House owners get compensation for any monetary costs they have (damage). The commercial property might also get a compensation for the damage but what lacks are any compensation for the costs the tenants make due to any inoperability of their business. This might be an explanation for the higher price discounts on the rents.

Table 7 describes some more checks against which the baseline specification is tested. Since one can expect that historical buildings (constructed before 1945) might suffer from a more severe impact when an earthquake happens, model 1 represents the baseline regression with only historical buildings included. The regression excludes age squared because this model only includes old buildings. Therefore, the effect of older buildings creating a small negative price effects is not applicable in this model. The effect is not statistically significant.

Model 2 displays the baseline analysis with only observations in the province of Groningen. Even though the smaller amount of observations, there is a negative price trend but it is not significant. One would expect that shops are more vulnerable to earthquakes since they cannot just move their businesses, and are therefore spatially dependent. The prices should suffer from a bigger influence when earthquakes appear, which is exactly what model 3 shows. A 20 percent price decrease when shops suffer a PGV of 0.5 cm/s. It furthermore matters if shops are located in the city center of Groningen or Leeuwarden, which tends to influence the rental price positively.

6.1.3 Conclusion

The commercial rental prices in the three northern provinces are affected by the earthquakes within the range of 3.6 to 18.8 percent price decrease. Where 3.6 percent represents a PGV of 0.3 cm/s and 18.8 a PGV of 0.6 cm/s. All the earthquakes taken from the point that they are noticeable and the considered baseline specification (PGV 0.5 cm/s), generate an 8.6 percent price decrease. The robustness checks are somewhat different from the baseline estimates, but do not show unexpected outcomes.

Table 6

	Dependent variable: the logarithm of rental price per m^2										
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
PGV01	**-0.0185***** **(0.00383)**										
PGV02		**-0.0309***** **(0.00691)**									
PGV03			**-0.0357***** **(0.00998)**								
PGV04				**-0.0810***** **(0.0195)**							
PGV05					**-0.0856***** **(0.0263)**						
PGV06						**-0.188***** **(0.0383)**					
PGV07							**-0.153***** **(0.0412)**				
PGV08								**-0.129***** **(0.0433)**			
PGV09									**-0.127***** **(0.0461)**		
PGV1										-0.105* (0.0540)	
PGV075											-0.000736 (0.0509)
Earthquakes05075											-0.0570 (0.0384)
Earthquakes02505											**-0.0440***** **(0.0115)**
WeakEarthquakes			-0.00221 (0.00161)	-0.00319** (0.00152)	-0.00337** (0.00154)	-0.00335** (0.00154)	-0.00337** (0.00154)	-0.00336** (0.00153)	-0.00332** (0.00153)	-0.00336** (0.00154)	-0.00199 (0.00161)
Constant	**4.623***** **(0.166)**	**4.560***** **(0.165)**	**4.585***** **(0.170)**	**4.595***** **(0.170)**	**4.593***** **(0.170)**	**4.593***** **(0.170)**	**4.591***** **(0.170)**	**4.591***** **(0.170)**	**4.590***** **(0.170)**	**4.590***** **(0.170)**	**4.617***** **(0.170)**
Observations	4,306	4,306	4,306	4,306	4,306	4,306	4,306	4,306	4,306	4,306	4,306
R-squared	0.640	0.639	0.639	0.639	0.639	0.639	0.639	0.638	0.638	0.638	0.640
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Postal code FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Building	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Age	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

*Note: Standard errors are robust standard errors. Coefficients with * are significant at the 10% level, with ** to the 5% level and with *** to the 1% level, all-in bold*.

Table 7

	Dependent variable: the logarithm of rental price per m^2		
VARIABLES	(1) Only historic buildings	(2) Only Groningen	(3) Only shops
PGV05	-0.0444 (0.0428)	-0.0335 (0.0435)	**-0.201***** **(0.0596)**
Weak Earthquakes	**0.00267***** **(0.000932)**	-0.00359** (0.00161)	-0.00747 (0.00720)
Building commercial	**-1.310***** **(0.350)**	**-1.050***** **(0.145)**	
Building office	-0.322 (0.319)	**-0.347**** **(0.140)**	
Building_shop	0.352 (0.320)	0.112 (0.142)	
Building_mixed	-0.844** (0.330)	**-0.934***** **(0.150)**	
Age	**0.00148***** **(0.000422)**	-0.00129** (0.000600)	3.32e-05 (0.000521)
Age squared		3.09e-06 (1.89e-06)	1.11e-07 (1.35e-06)
Groningen center			**0.768***** **(0.0726)**
Leeuwarden center			**0.718***** **(0.117)**
Assen center			0.0833 (0.136)
Constant	**4.488***** **(0.395)**	**5.088***** **(0.203)**	**4.267***** **(0.197)**
Observations	1,122	2,248	2,076
R-squared	0.291	0.602	0.414
Year FE	YES	YES	YES
Postal code FE	YES	YES	YES

*Note: Standard errors are robust standard errors. Coefficients with * are significant at the 10% level, with ** to the 5% level and with *** to the 1% level, all-in bold.*

6.2 Influence of shale gas extraction in the Peel area

Now that the empirical analysis shows a relationship between earthquakes in Groningen and commercial property, an assessment of the effect in the Peel area is possible. It is hard to predict what scenario would occur when shale gas extraction takes place, so the following analysis uses both scenarios. First, the influence of a single earthquake will be estimated, with both the same impacts as in Groningen (the 8.6 percent influence) and the lower impacts (3.6 percent). Second, this study shows an estimation of the influence of repeating earthquakes in both the same and lower impact as in Groningen. An extension for the single and continuing earthquake scenarios includes the addition of a high impact variable (the 18.8 percent influence). Note that that both scenarios base their outcomes on the analysis of the Groningen data, so the outcomes are a supposed ceiling because it is very unlikely that shale gas extraction would generate the same amount and magnitudes of earthquakes as in Groningen (Witteveen en Bos et al., 2013; Walsh, 2015; TNO & EBN, 2009). This section will answer the next question:

'What is the influence of possible shale gas extraction on the commercial property values in the Peel area?'

To answer this, it is important to find the value of the commercial property. It is thereby important to apply the depreciation rates of Groningen to the Peel area to find the total depreciation. Third, there will be a valuation about the possibility of investing in shale gas and find the price where the investment would be worthwhile.

6.2.1 Scenario 1

In this scenario, there is only one noticeable earthquake, which relates to a once occurring decline in rental revenues. Based on this temporary depreciation is the underlying assumption of a price decrease of 8.6 percent as baseline and same impact as in Groningen. Furthermore, 3.6 and 18.8 percent depreciation is used as lower and upper boundary for weaker and stronger influence of earthquakes.

Based on the annual rents per property, the total rents can be calculated for the whole of the northern provinces and Peel area. For Groningen, this results in 270 million euros per year and for the Peel area this accounts for 244 million euros per year. A larger area than just the Peel area feels earthquakes that occur in that region, so the analysis uses data of the rents of the whole of Limburg; just earthquakes occurring in Groningen also have impact on rental prices in other provinces. Making these calculations, assumes that the dataset is complete and covers the whole area.

Table 8, estimates of the depreciation in rental revenues in million euros

	Total	**3.6%**	**8.6%**	**18.8%**
Northern provinces	270	9.7	23	51
Limburg	244	8.8	21	46

A noticeable earthquake in the northern provinces would account for a temporary decline in rents which results in a loss of 23 million euro. If a heavier earthquake occurs, which generates PGVs of above 0.6 cm/s the temporary decline in rents would result in a 51 million euro loss. Earthquakes with PGVs of 0.3 cm/s result in a loss of nearly 10 million euros for commercial property.

The total commercial property rental incomes depreciate with 21 million euros in the baseline case where earthquakes occur that generate PGVs of 0.5 cm/s in Limburg. In the case of stronger earthquakes, the rental revenues depreciates with 46 million euros and the case of non-noticeable earthquakes it is has a depreciation of almost 9 million euros.

6.2.2 Scenario 2

This scenario assumes that earthquakes would occur during the whole production period, both in the same as lower and higher amount and magnitudes as in Groningen. This would mean that a discount on rents would take place as long as shale gas extraction is taking place. This reflects the depreciation of rents over multiple time entities, in other word the costs created by the earthquakes. Using the Net Present Value (NPV), over the average period of 30 years of extraction, generates the depreciation on the rents due to the earthquakes. The next formula describes the net present value:

$$NPV = \sum_t \frac{CF_t}{(1+r)^t}$$

Where *CF* is the annual cash flow in time *t* and *r* represents the discount rate. The discount rate determines how much the money is valued in the future. Commonly used by states is a discount rate of 5 percent (EBN, 2014). To account for sensitivity in the model, the analyses is carried out using a discount rate ranging from 1 to 10 percent. Furthermore, the model assumes a rental price increase of 2 percent annually and costs for the owner are 12 percent of the rental revenues (TNO, 2008).

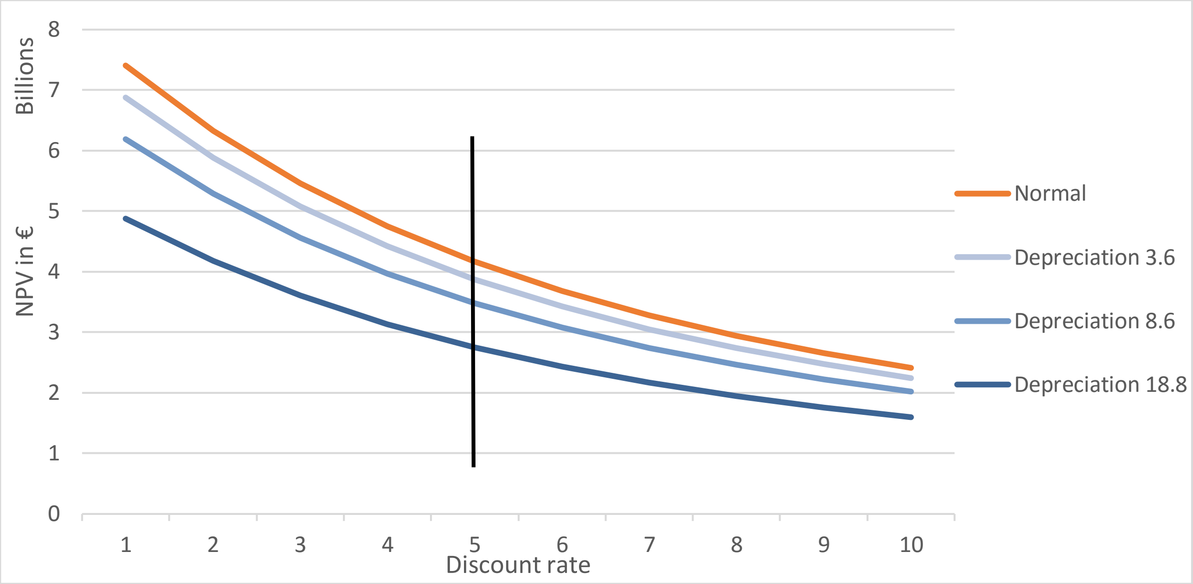

Figure 6, the net present values of the Peel area discounted over 30 years at different discount rates with the weak, baseline and strong earthquake scenarios. The line 'normal' refers to the NPV without earthquakes, so there is no depreciation of the rents.

Figure 6 shows that the NPVs over 30 years changes considerably when the discount rates vary. The orange line depicts the net present values of the commercial property rents when there is no depreciation. As expected, the higher the depreciation, the higher is the decrease in net present value. It also shows that with a higher discount rate, the difference in depreciation moves towards each other. This provides the conclusion that the discount rate is preferred to be low, in order to generate a high NPV. When the discount rate is higher, the differences emerge, although the scenario with low depreciation seems the most favorable one.

At the commonly used discount rate of 5 percent for states, the difference between revenues with and without depreciation would be 0.7 billion euros in the baseline scenario. For the low scenario 0.3 billion euros would be missed and 1.4 billion euros in the strong earthquake scenario.

Both the discount rate and the percentage depreciation define whether shale gas extraction is profitable. These are not the only factors, since this are only external costs. In the next section, the net present values of production itself are determined, both with and without the costs of depreciation of commercial property.

6.2.3 Investment in shale gas production

Investment in shale gas production depends upon the profitability of the investment, which depends upon both the costs and revenues. Costs are still highly depended upon the technological developments but they also rely on the region where the drillings have to take place. Shales situate relatively deep in the Netherlands and this increases the costs. In comparison with the US, Dutch production costs are twice as high (Triple, 2014). European estimates of production costs vary from 0.09 to 0.71 euro per m^3. EBN has made estimates where convenient locations have 0.13 euro production costs per m^3 and inconvenient locations have 0.27 euro per m^3 (CE Delft, 2015). Since there is no distinction between investment and production costs, the costs are assumed investment costs and all occur in year 0. Furthermore, the analysis uses the assumption that shale gas production occurs in the whole Peel area.

Although prices of natural gas and oil are related, they are not perfect substitutes of each other. In the Netherlands, the gas price historically connects to the oil prices but for new production, this connection is no longer relevant (Triple, 2014). Gas prices are hard to predict, so to find the revenues from the shale gas extraction the analysis uses different scenarios as done at EBN (EBN, 2014). The prices in the worst case, baseline and best-case scenario are respectively 0.15, 0.20 and 0.25 euro per m^3. Prices are based on gas with the same quality as in Groningen, as mentioned in paragraph 5.1.5, natural gas from shales will be of better quality so prices are expected to be a fraction higher. However, this is hard to predict so the above-mentioned scenarios are used. Shale gas extraction extracts 50 percent of the total natural gas in the first 10 years of production. Therefore, the 50 percent of revenues are less discount and generate a higher net present value then when the revenues equally distribute across 30 years. The technological possibilities are based on the scenarios as described in chapter 5.3.1.

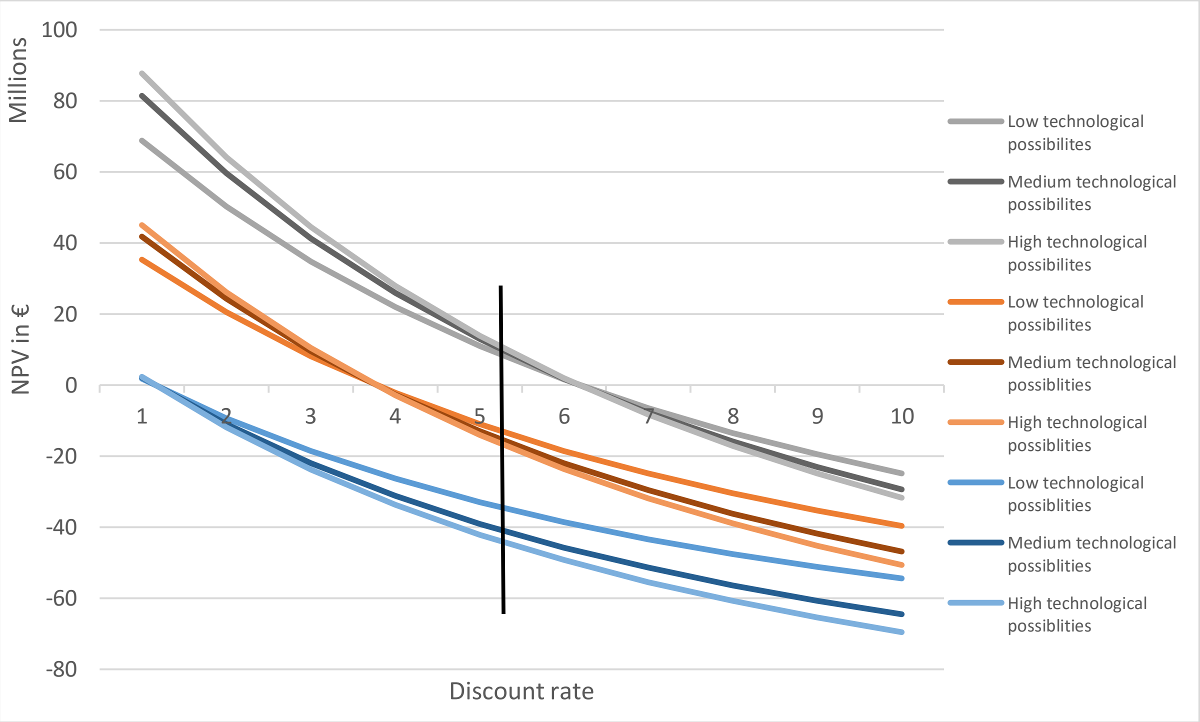

Figure 7, net present value of the business case without depreciation using the low cost scenarios and differing technological possibilities and prices, discounted over 30 years. The grey lines represent a high price, the orange lines represent a medium price and the blue lines represent a low price at differing technological possibilities.

Figure 7 shows that shale gas production is not a self-evidenced case since not all the scenarios generate positive net present values. The grey lines represent the different GPIP scenarios in the case of a high price. Costs are minimum in this scenario and a project would break even if the discount rate is 6 percent. A higher discount rate would result in negative net present values. The orange lines represent the GPIP scenarios with a medium price and low costs. The case of low costs, low price and low PGIP only results in a positive value when the revenues are discounted at the 1 percent level. Since the assumption of only investment costs still holds, this implies that there are no costs during the production period. So even the positive NPV's might become lower when there are also production costs taken into account. None of the high costs scenarios generates a positive NPV; appendix F contains the graph including the low cost scenarios. The preferred discount rate for states only generates positive NPV's in the most positive scenario with high prices.

Because this study showed that earthquakes generate a discount on the rental prices, it is interesting to see how the net present value of the positive business case changes, when the negative influence of the discount is taken into account. The low costs and high price and high technological possibilites scenario is considered here because that generates the highest net present value in normal circumstances (greys lines in figure 7).

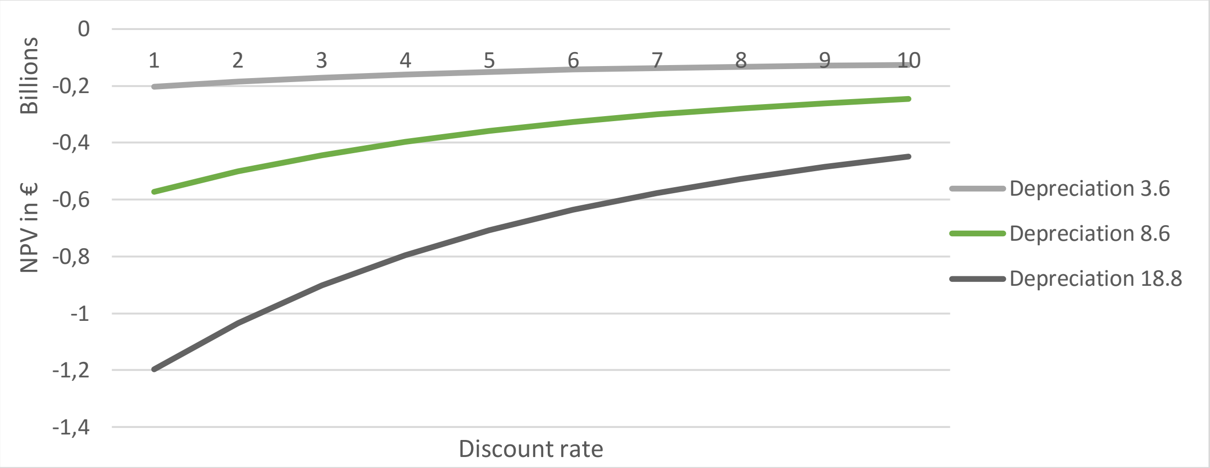

Figure 8, net present value of the business case including rental depreciation. At the low costs, high price and high technological possibilities scenario, with different depreciation rates.

Figure 8 shows that even in the best-case scenario with lowest depreciation rates, is still not a viable business case to start the shale gas extraction. The discounted costs cause the curve to slope upwards because they are increasing[10] over time while the revenues stay the same. Higher costs are therefore discounted more and this causes the line to move upwards. The graph shows that either the costs of the required technology should decrease or the natural gas price should increase in order to have a viable business case in the Peel area.

A prediction of decreasing production costs is hard, but it is possible to vary the natural gas price. Figure 9 varies the gas price, to see what price is necessary to make shale gas extraction a viable business case. This estimate uses the best-case scenario, high technological possibilities, low costs and a minimum impact due to earthquakes (3.6 percent discount). A discount rate of 5 percent is used (EBN, 2014).

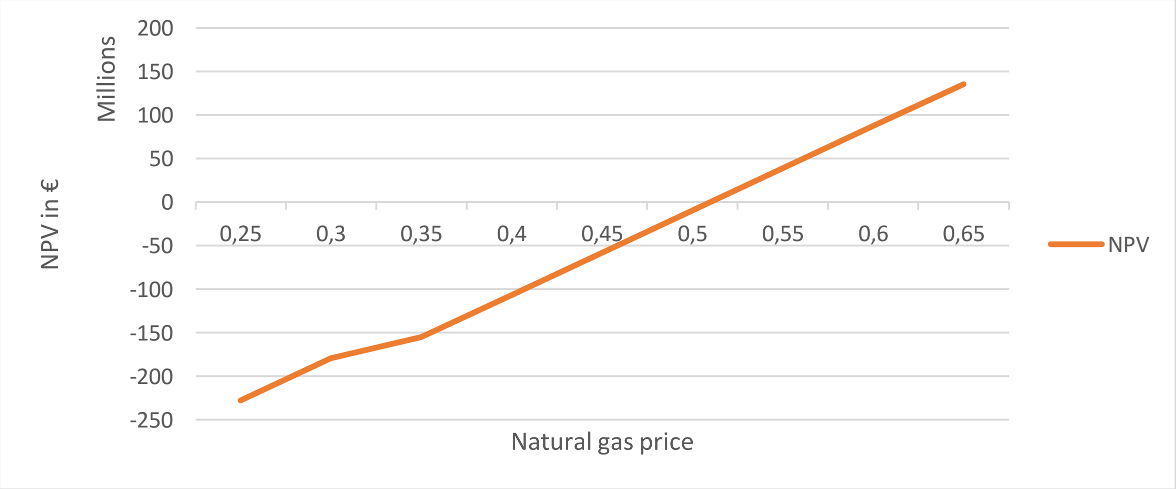

Figure 9, net present value at varying price levels and 5 percent discount rate. This is the price without taxes and VAT tariffs.

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[10] Due to the assumed annual increase in rents.

As figure 9 shows, a viable business case is reached when the price lies between 0.5 and 0.53 euro per m^3. This is a relatively high price for natural gas, as the price has not gone above 0.27 euro per m^3 since 2011. To compare and make the connection with the oil price, when a barrel of oil was 100 US dollar in June 2014, the natural gas price in the Netherlands was 0.24 euro per m^3 (van de Ven, 2016; Macrotrends, 2016). Even though the connection between the two is partially disconnected, this indicates that it is not very likely that natural gas will reach the estimated price that is necessary to make shale gas extraction in the Netherlands a viable business case. Therefore, before shale gas can be extracted in the Peel area, technologically improvements have to be made which reduce the costs in such a way that a higher price is not necessary.

7. Discussion and Conclusion

7.1 Discussion

This chapter will discuss the contents of this study and will outline its limitations. First, I would like to discuss the data availability. The empirical analysis consists of relatively few observations, which might compromise the outcomes. When a dataset is limited, the outcomes are more sensitive to outliers than when the dataset is very big. To overcome this problem, the results of some tests found one outlier and the observation was deleted from the dataset. The included variables in the analysis do not explain all the variation because of the limited data, so this might indicate an overestimate of the outcomes. Hence, one should interpret the results as a ceiling of impacts that could occur.

Second, some limitations of the hedonic price method will be discussed. The model assumes that owners are fully informed about the positive and negative externalities of the property. This might not be the case in this commercial property study because some of the rental prices were already set before the earthquakes started. Therefore, it is possible that the negative price externality of the earthquakes is not included in those prices. In addition, even though the analysis tried to exclude any multicollinearity by not including variables which had a high correlation, the data might still suffer from it. The hedonic price method assumes that every house or rental price can be explained by its individual characteristics. While in Groningen, the negative effects of natural gas extraction are widely known and it can be expected that these negative effects can explain a part of the price, in de Peel area the effects are still unknown and the effects aren’t explainable in the price yet. This could be marked as a flaw in the method, but without such assumptions, it is not possible to estimate any effects on forehand. In addition, the influences on commercial property are higher than on houses (Koster & van Ommeren, 2015) and although further research is needed to confirm this, this might be caused by the fact that owners only get compensation for the monetary costs and their business might suffer from the temporary inoperability. This risk reflects in the depreciation of the rents. Implications of this finding can be to implement an externality tax, so that it results in the internalization of the external costs.

Third, for the extrapolation quite some assumptions had to be made in order to give an estimate of possible impacts. Even though the outcomes are depending upon many factors, this way gives an estimate and range of the impacts. The conclusion therefore needs to be interpreted with caution and differs whenever one of the assumption changes. Not only is the amount of potential shale gas still highly uncertain due to the absence of exploratory drillings. The natural gas price, the costs and technological development are all predictors of the viability of shale gas extraction and remain as well uncertain. The natural gas price will depend upon the technological improvements of the extraction methods but no statements can be made about that. Costs are based upon a one-time investment, while it is clear that there are both investment costs and costs over the whole production period. This might even lower the net present values more and result in a more negative outcome. As stated, the outcomes should be interpreted as the maximum occurring changes because of these assumptions that are made. To work with the overestimation, different scenarios are used. Whenever models are used, it is an oversimplification of reality but this model is highly adaptable and whenever there is more certainty about one of the parameters, the model could be adapted.

7.2 Conclusion

The Dutch government keeps its interest in shale gas extraction, but this extraction may have short- and long-term impacts on the direct environment, as it did in Groningen. In Groningen, house owners are compensated for any structural damage but they still have non-monetary costs. Commercial property suffers from the same damage but the influences of this might be of another kind. To find what the influence of induced earthquakes of shale gas extraction would be, this study is carried out according to the following research question:

'What are the possible impacts of shale gas extraction on commercial property values in the Netherlands?'

Using different scenarios, the impacts of induced earthquakes due to shale gas extraction in the Netherlands is such that it is not a viable business case yet. Based on data of the northern provinces of the Netherlands, the commercial property rental price does indeed get negatively affected by induced earthquakes. The quantity of the negative influence largely depends on the magnitude of the earthquakes. Earthquakes with low magnitudes are of low negative influence (3.6 percent) on the prices, noticeable earthquakes cause an 8.6 percent's depreciation and high magnitudes caused 18.8 percent depreciation. Due to different subsurface conditions in Groningen and the Peel area, direct extrapolation is not possible. Therefore, scenarios were used to extrapolate the depreciation factor of Groningen to the Peel area, in order to get a sense of the influences. It is concluded that shale gas extraction might be a viable business case when there is no negative external effect of induced earthquakes with low costs and medium or high natural gas prices. Hence, with changing discount rates, the NPV of rental revenues that would not be lost in the low depreciation case is between 0.2 – 0.5 billion. In the medium depreciation case between 0.4 – 1.2 billion and in the high depreciation case between 1.8 - 2.5 billion euros. Whenever there is such a negative commercial property depreciation, the net present values of the extraction will be negative even in the most optimistic scenario. The most optimistic scenario (high price, high technological possibilities and low costs) would only result in positive NPVs when the price of natural gas would at least be between 0.5 and 0.53 euro per m^2.

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Appendices

Appendix A

Relation between the peak ground velocity and the epicentral distance.

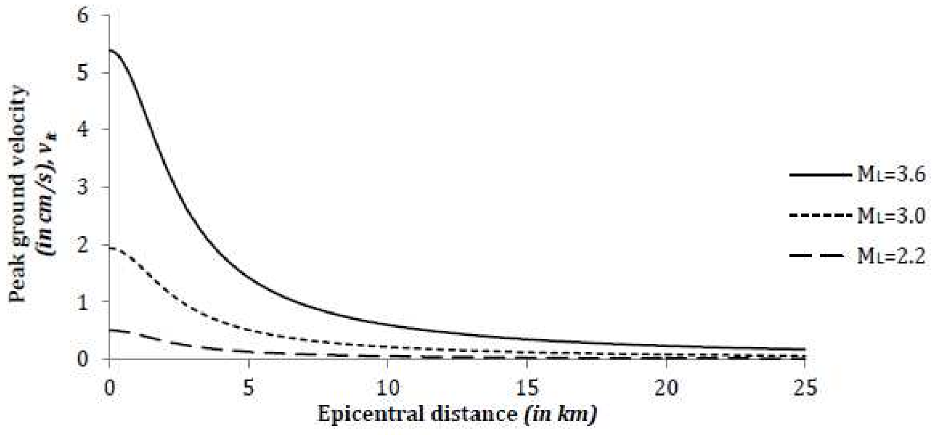

FIGURE A2 — EARTHQUAKE'S LOCAL MAGNITUDE USING AN ATTENUATION FUNCTION

Figure 10, Source: Koster & van Ommeren (2015)

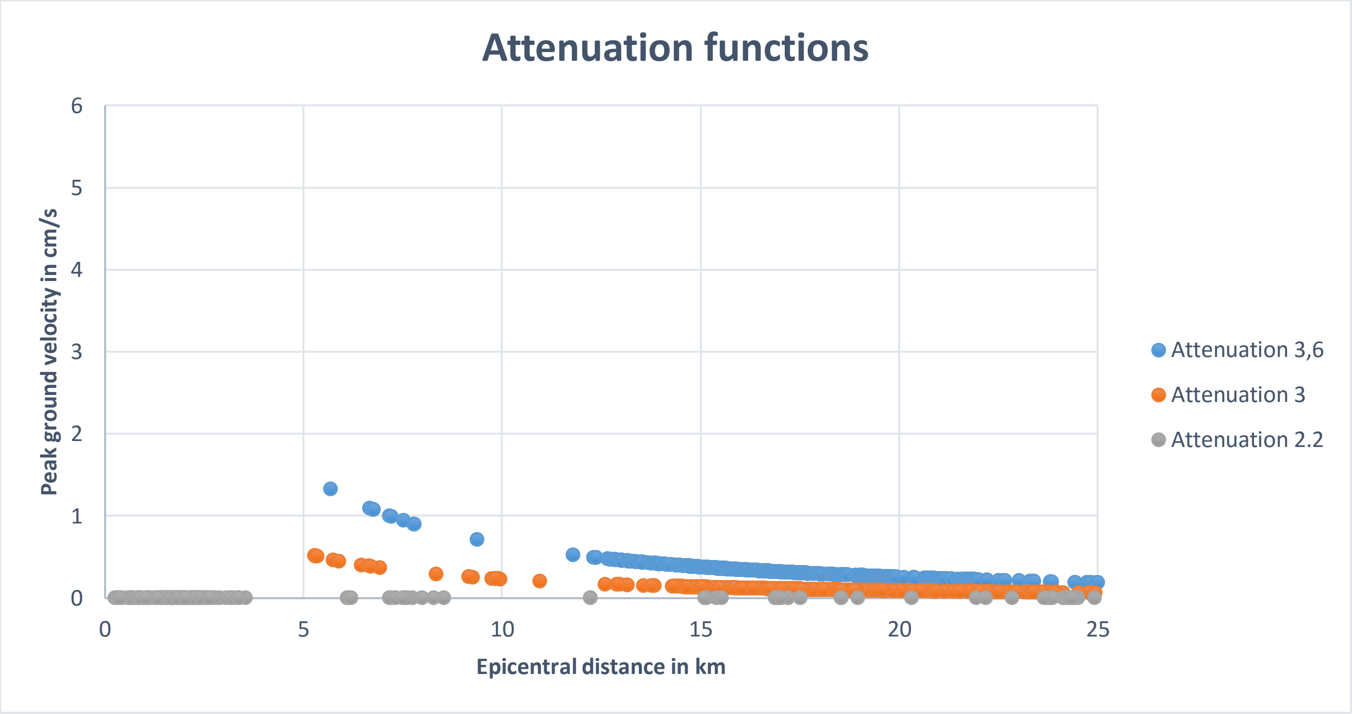

Figure 11, own figure

Appendix B

This figure shows the designated Peel area with its land uses and the areas, which cannot be used for shale gas extraction, due to its protected status.

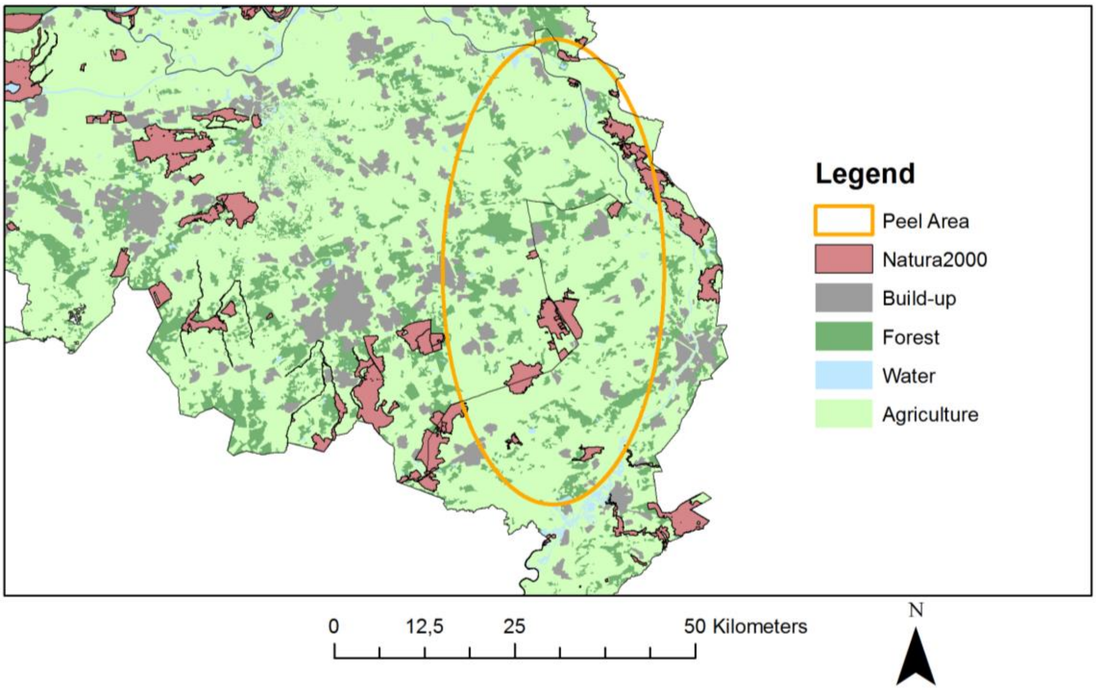

Figure 12, land use Peel area (own figure based on data of Kadaster (2015))

Appendix C

Figure 13 shows the spatial analysis about the reachability of the shale gas. With at least 1 kilometer taken from urban and protected areas at a technological horizontal drill of 1500 meter, 74 km2 cannot be reached so that gas cannot be extracted. At 1000 meters 189 km2 cannot be reached and at 500 meter 374 km2 is unreachable.

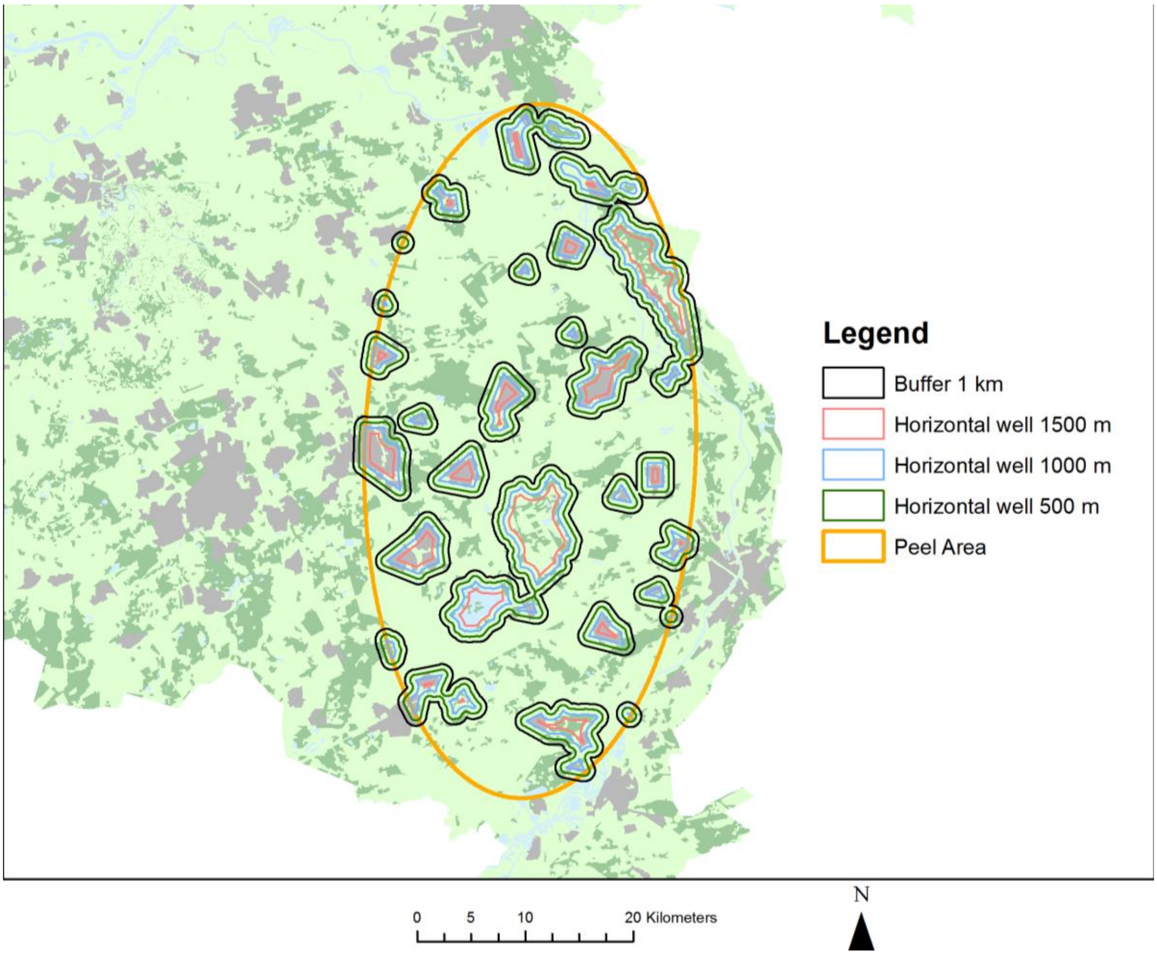

Figure 13, unreachable areas Peel (own figure, based on data of Kadaster (2015))

Appendix D

Figure 14 and 15 show the subsurface in Groningen and de Peel respectively. It is a simplified representation of subsurface in Groningen, characterized by formations, which contain sand-clay-sand-clay.

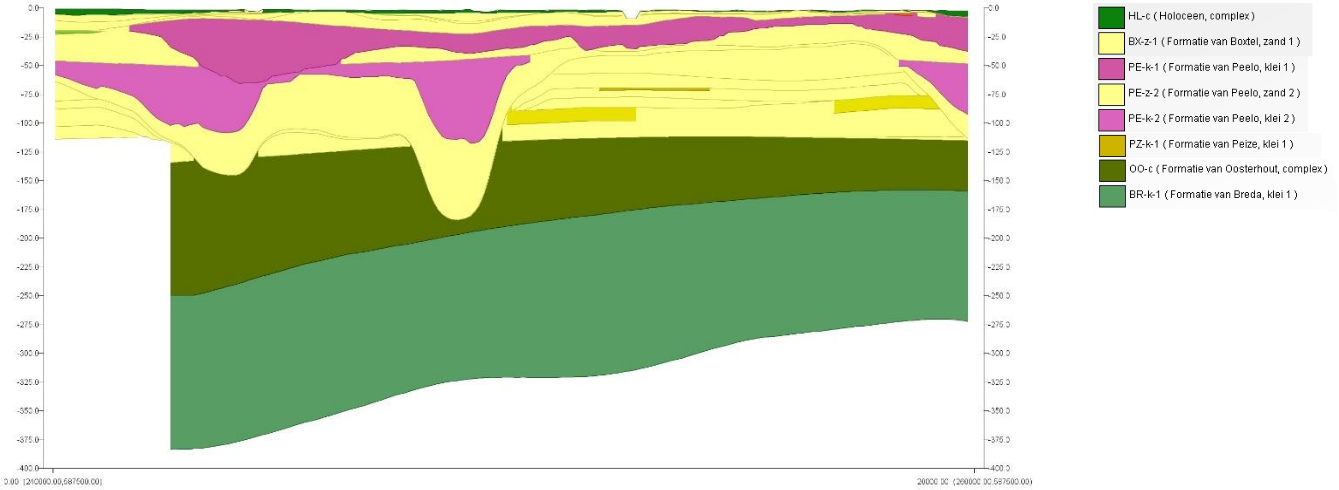

Figure 14, West- Loppersum *East – Delfzijl (source: Dinoloket (2015))*

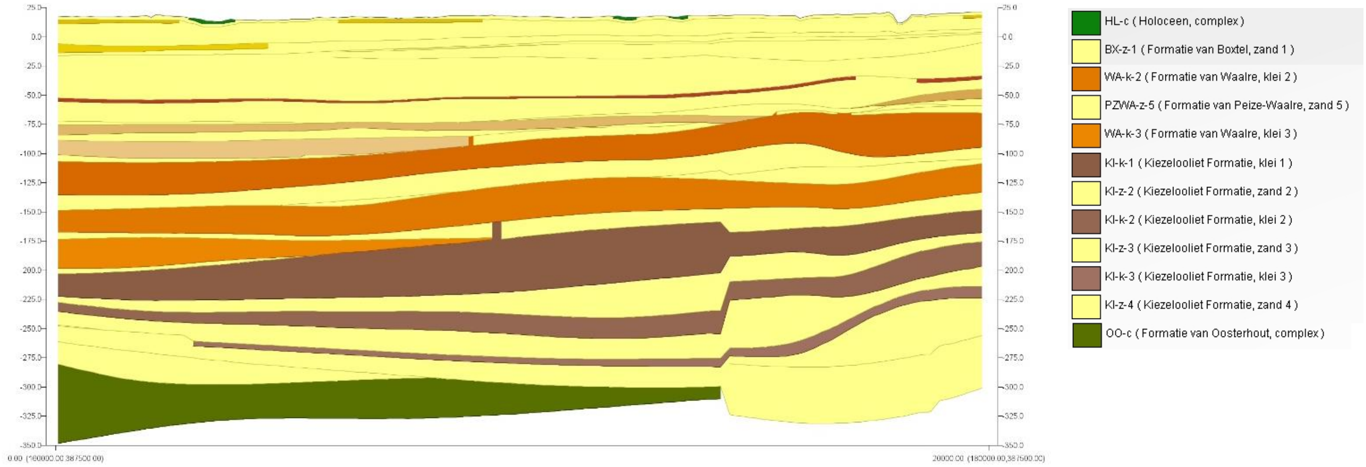

Figure 15, West – Eindhoven *East- Venlo (source: Dinoloket (2015))*

Appendix E

Table 9 show the results of the conducted spatial autocorrelation tests.

Table 9

TEST			MI/DF	z-VALUE	PROB
Moran's	I	(error)	-0.0002	0.3114	0.75552
Lagrange	Multiplier	(lag)	1	1.0592	0.3034
Robust	LM	(lag)	1	1.5145	0.21846
Lagrange	Multiplier	(error)	1	0.3547	0.55148
Robust	LM	(error)	1	0.8099	0.36814
Lagrange	Multiplier	(SARMA)	2	1.8691	0.39275

H_0: there is no spatial autocorrelation between the observations in the study area.
H_1: spatial autocorrelation exists between the observations in the study area.

Neither Moran’s I or the other tests are significant. The tests fail to reject the null hypothesis and normal OLS model can be used without having problems with spatial dependency because there is no spatial autocorrelation.

Appendix F

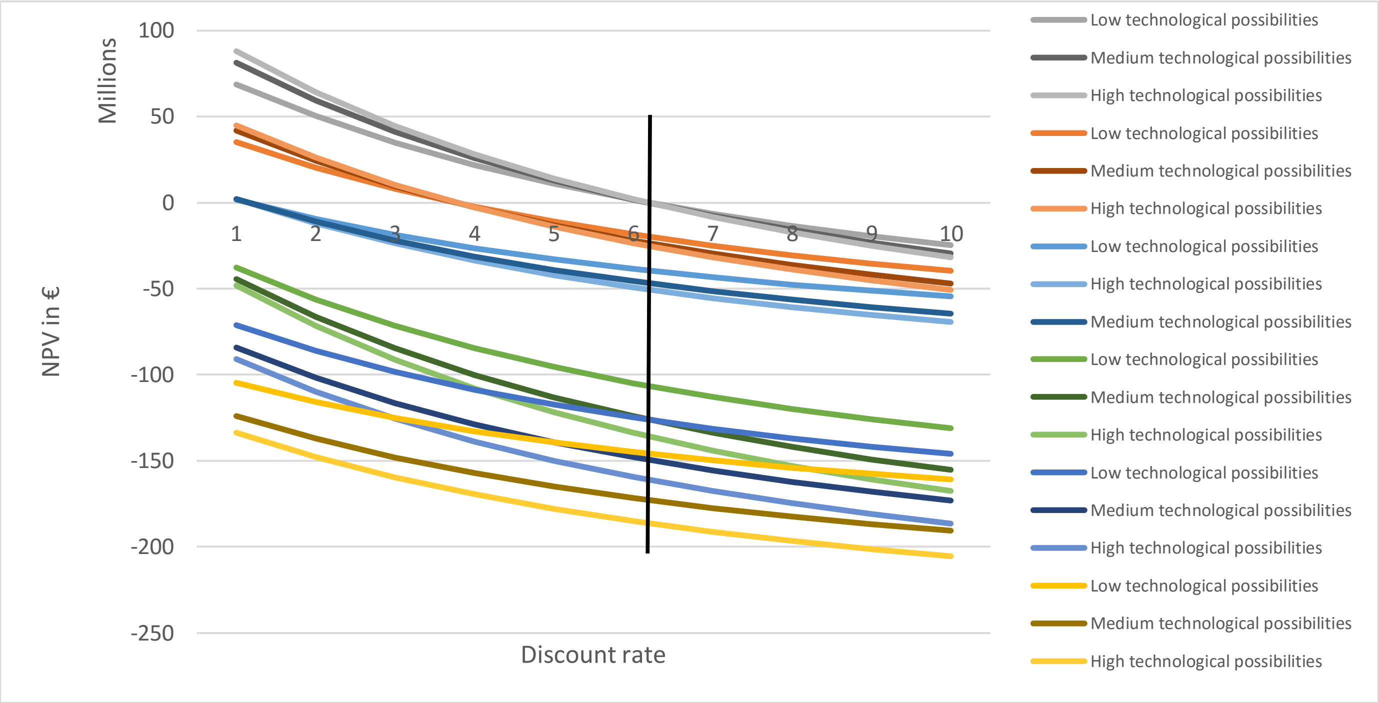

Figure 16, net present value of all business cases without rental revenues depreciation. The grey, orange and light blue line represent the NPV with low costs. The grey line has a high price, the orange line a medium price and the light blue line a low price. The green, dark blue and yellow lines represent the NPV when there are high costs involved, where the green lines have a high price, the dark blue lines a medium price and the yellow lines a low price. The NPV is discounted over 30 years.