# Impact of connection density on regional cost differences for network operators in the Netherlands

A REPORT PREPARED FOR ENERGIEKAMER

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# Impact of connection density on regional cost differences for network operators in the Netherlands

# Executive Summary

## *Background*

Energiekamer has an obligation to investigate the extent to which the electricity and gas distribution businesses (DNOs) in the Netherlands face different structural environments that result in regional cost differences which, in turn, could justify tariff differences.

On the basis of previous studies, Energiekamer has identified "water crossings" and "local taxes" as allowable regional differences. To account for them, Energiekamer has introduced an adjustment to the regulated revenues formula in order to guarantee a level-playing field to the Dutch DNOs.

In addition to these factors, it has been claimed that connection density may have an impact on distribution costs and that, therefore, regulated revenues should be adjusted to compensate for regional differences in connection density between DNOs. However, so far, the research in this field has been unable to identify a sufficiently robust relationship between cost and connection density to support this claim.

In order to address this issue, Energiekamer has asked Frontier Economics and Consentec to further investigate the relationship between connection density and distribution costs in the Netherlands. Therefore, our analysis has aimed at determining whether, and to what extent, connection density in the Netherlands is a significant driver of the costs of electricity and gas distribution networks.

## *Basic relationship between connection density and cost*

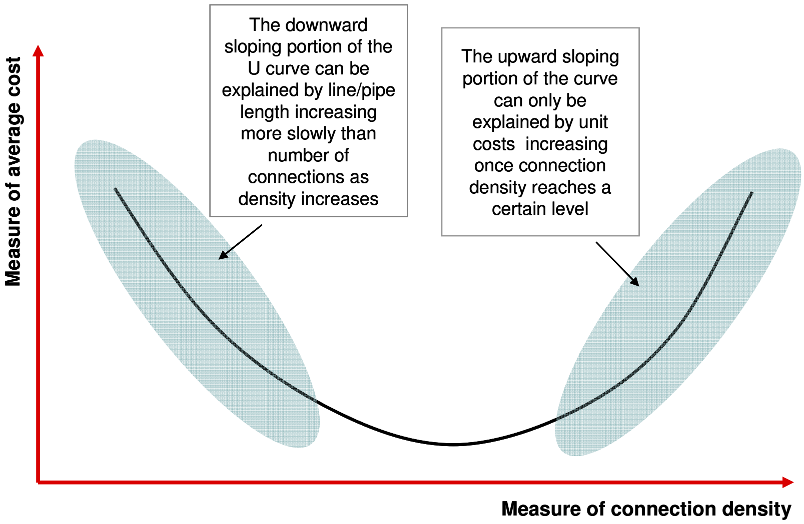
There are potentially two countervailing effects that connection density has on cost:

- **Geometric effect** - According to basic logic, one of the main causal relationships between connection density and cost could be the dependence of asset volumes on connection density. Specifically, in areas of low density, the length of cables and pipes required for each connection to the network would need to be longer on average than in areas of relatively higher density. This would suggest a **<u>negative</u> relationship between connection density and cost** per connection, whereby connections in less densely populated areas are more expensive to provide than in denser areas.

- **Urbanisation effect** - On the other hand, the so-called "urbanisation effect" claims that **costs would <u>increase</u> in more densely populated areas**, as the unit costs (as measured e.g. in €/km of line) of building and maintaining the network would necessarily be higher there.

The combined results of these two competing effects may suggest the existence of a U-shaped relationship between connection density and average cost of connection. This could be the case if, for low levels of connection density, the geometric effect prevails, while, for high concentration levels, the urbanisation effected is stronger.

**Relationship between connection density and average connection costs**



For the curve to be upward sloping as connection density increases, it must be the case that, for the relevant range of connection densities, the "urbanisation effect" more than compensates for decreasing costs per connection associated with higher density. We also note the possibility that companies in the relevant sample may be scattered around the turning point of the U-curve (provided it exists in the first place) so that while this density-cost relationship may exist in principle, it *may not lead to material differences between firms* in the Netherlands. Similarly, it might be the case that all Dutch companies have highly similar patterns of connection density in their operating regions. Also in this case, we would not observe a significant relationship between connection density and cost in the Netherlands.

## Our approach

We have carried out the analysis in order to help Energiekamer answer the following three questions:

- Is connection density a significant cost driver in electricity and gas networks in the Netherlands?

- If so, which functional form (e.g. U-shaped) does this relationship have in the Netherlands?

- Finally, based on the evidence collected, is the influence of connection density sufficiently well-determined to be considered a regional difference in the Dutch regulatory framework?

The answer to the last question relies on assessing whether the evidence found fulfils the key criteria of objectivity and significance which Energiekamer has set out. These criteria are used to determine whether claimed regional differences should be accounted for in the regulatory framework.

For our technical analysis – matching the above three questions, we have adopted a framework based on the combined use of engineering and econometric techniques. The two types of techniques are tightly interwoven, for example as the engineering modelling, the Model Network Analysis (MNA), provides some of the alternative measures of connection density which we use in the econometric analysis to identify a potential relationship with observed average connection costs. Our technical study has involved three steps.

- **Step 1 - Differences between firms.** In Step 1, we have carried out a descriptive analysis of the observed density and cost data for DNOs, for both gas and electricity. The purpose of this analysis has been to gauge the scale of connection density and cost variation between DNOs also in order to understand the 'richness' of the available data sample to be used in the econometric analysis. As noted above, if, for example, we were to find that in one sector all Dutch firms exhibit comparable connection densities, then we would not expect connection density to explain cost differences between the firms.

- **Step 2 - Density-cost relationship**. Then, in Step 2, we have investigated the relationship between observed costs and various measures of connection density using econometrics. We have approached this issue from two different angles.

    - Observed cost and connection density - In Step 2a, we have attempted to estimate the relationship between observed average costs per connection and various measures of connection density. We have used directly observable and MNA-based measures of connection density in this analysis. For electricity, we have carried out this analysis for two different cases. In one case, we have completely excluded all HV-related costs from the DNOs' cost bases. In the second case, we have excluded HV-related costs with the exception of Stedin's and 10% of Continuon's (that is, including Cross Border Lease).

  - Hypothetical cost and connection density - In Step 2b, we have assessed the relationship between actual network length (as a proxy for cost) and modelled network length (as a proxy for the complexity of the operating environment which includes connection density). This has also allowed us to estimate the extent to which the modelled results approximate the actual data and, hence, assess the applicability of the MNA's results to the case of the Netherlands. The MNA analysis has been carried out excluding all HV levels from the modelling.

- **Step 3 - Assessment of key criteria**. Finally, in Step 3, we have brought together the results of the previous steps of the analysis and provided an assessment of whether, on the basis of the evidence found, the key criteria (objectivity and significance) for the inclusion in the regulatory framework of a correction factor for differences in connection density are fulfilled.

## *Our results*

**Step 1 - Differences between firms.** In the first step of the analysis, we have found similar results for both gas and electricity. Specifically, we have noticed that the DNOs tend to differ significantly in terms of levels of connection density. However, these variations do not appear to be matched by similar variations in costs per connection or per unit of Composite Output. The differences in costs appear to be smaller for electricity than for gas, but, in both cases the DNOs tend to be more similar in terms of costs than in terms of connection density.

This observation implies that it is sensible to progress to the second step of analysis and explore the connection density-cost relationship in greater detail.

Our statistical analysis relies on a very small sample, twelve DNOs for gas and nine DNOs for electricity. As a consequence, there is limited scope for us to employ highly sophisticated econometric analysis. We therefore also rely on graphical analysis in addition to formal statistical analysis.

By applying MNA we have estimated the impact of the observed differences in (actual) connection density on the (theoretically) required amount and cost of electricity lines and gas pipes. The cost estimate was based on unit cost data (i.e. cost per km of line/pipe) provided by some of the DNOs. According to the MNA the actual differences in connection density between the supply areas of the Dutch DNOs suggest a significant difference in line/pipe related cost per connection. Additionally, the MNA shows that the impact of connection density on the line/pipe *length* per connection substantially outweighs the *unit cost* differences between different degrees of urbanisation. The resulting relationship between connection density and costs per connection resulting from the MNA is therefore negative. We therefore find no evidence for the existence of a so-called U-curve in the range of connection densities found in the Netherlands.

**Step 2 - Density-cost relationship.** In Step 2, we have turned to assessing the relationship between the DNOs' costs and measures of connection density using econometric techniques. We have approached this issue from two different angles.

*Step 2a - Observed cost and connection density.* In Step 2a, we have attempted to estimate the relationship between average actual costs and various measures of connection density. However, the analysis in Step 2a failed to identify a statistically significant relationship. The same conclusions hold for both gas and electricity (both when HV levels are completely excluded and when only Cross Border Lease HV levels are included). We have used alternative definitions of costs and connection density but no specification has yielded statistically significant econometric results. Moreover, we have not found any significant difference in the results depending on whether all HV levels are excluded or only Cross Border Lease levels are included. The lack of significant results may be attributed to the small sample size, which makes this type of analysis more likely to be less statistically robust, and on the relatively low variance in the cost data. On the basis of this econometric analysis alone, it is therefore difficult to draw strong conclusions on the relationship between connection costs and connection density in the Netherlands.

*Step 2b - Hypothetical cost and connection density.* In Step 2b, we have assessed the relationship between actual network length (as a proxy for cost) and modelled network length (as a proxy for the complexity of the operating environment given the underlying distribution of connection density). This has allowed us to estimate the extent to which the modelled results approximate the actual data and, hence, assess the applicability of the MNA's results to the case of the Netherlands.

The results for electricity as well as for gas yield clearly significant relationships between MNA output per connection (being a measure of connection density) and actual line/pipe length per connection (being a proxy of actual line/pipe related cost). This confirms the applicability of MNA in the Dutch context, thereby underpinning the relevance of the above mentioned MNA results. However, these findings cannot be used to determine the impact of connection density on the total cost of the DNOs, because we could not draw conclusions about actual line/pipe related cost shares per DNO based on the available cost data.

**Step 3 - Assessment of key criteria**. On the basis of the results presented above, we have attempted to assess whether the evidence we have collected fulfils Energiekamer's key criteria of objectivity and significance. If this were to be the case, connection density should be acknowledged by the regulatory framework as a regional cost difference.

With regards to **objectivity**, this criterion would be satisfied if the impact of connection density on costs can be objectively quantified and if such difference cannot be affected by management decisions.

On the latter aspect, the connection density measures we applied for the major part of the analysis – in particular for the application of the MNA – are exclusively based on the number and distribution of connections and the size of the supply area, which are both exogenous to the DNOs. This is, however, not the case when connection density is defined as connections per km of actual line or pipe, since the actual asset volumes are under control of the DNOs.

We have not been able to verify an impact of connection density on costs using actual data on Dutch DNOs. Therefore, any remaining hypothesis would be based on the outcome of the MNA. This MNA suggests a certain link between connection density and costs. Specifically, there appears to be a negative relationship between costs and connection density, leading to significant differences in modelled costs per connection. On the other hand, even when applying MNA we have not found evidence to support the hypothesis of an upward sloping part of the cost curve. That would imply that if a relevant relationship exists at all it is one of average cost falling with connection density and not rising with connection density.

The **significance** criterion is assessed along two dimensions.

First of all, the claimed regional differences need to be **substantial**. This happens if, for at least one DNO, the average cost per connection, expressed as percentage of Composite Output, exceeds the industry average cost per connection by more than one percentage point. This appears to be the case when comparing actual total costs. However, the lack of a clear empirical relationship between costs and connection density does not allow us to determine what share of these differences should be attributed to different levels of connection density. Similarly, the MNA results yield a relationship between connection density and line/pipe related cost shares, but the lack of data about the actual shares of line/pipe related cost of Dutch DNOs prevents its transformation to an impact on total cost. We are therefore unable to state whether this criterion is fulfilled.

Finally, regional differences should be **sustainable**, i.e. the differences between DNOs in terms of connection density remain similar over time and do not fluctuate significantly. Given the inconclusive results above, we have not carried out an inter-temporal analysis of costs. We are therefore unable to comment on this criterion on an empirical basis. However, one can generally expect that the connection density of a DNO's supply area does not change rapidly over time as it is related to demographic and economic developments.

Overall, the evidence collected is not sufficiently strong to determine whether connection density fulfils the key criteria for inclusion in the regulatory framework. While the engineering modelling suggests that this may be the case, the actual data on total cost do neither support nor contradict this result.

# 1 Introduction

## 1.1 Background and motivation for this study

Energiekamer has an obligation[1] to investigate the extent to which the electricity and gas distribution businesses (DNOs) in the Netherlands face different structural environments that result in regional cost differences which, in turn, could justify tariff differences.

On the basis of previous studies, Energiekamer has identified "water crossings" and "local taxes" as allowable regional differences. To account for them, Energiekamer has introduced an adjustment to the regulated revenues formula in order to guarantee a level-playing field to the Dutch DNOs.

In addition to these factors, it has been claimed that connection density may have an impact on distribution costs and that, therefore, regulated revenues should be adjusted to compensate for regional differences in connection density between DNOs. However, so far, the research in this field has been unable to identify a sufficiently robust relationship between cost and connection density to support this claim.

In order to address this issue, Energiekamer has asked Frontier Economics and Consentec to further investigate the relationship between connection density and distribution costs in the Netherlands.

The results of this study are intended to aid Energiekamer in its decision process on whether the current regulatory regime should be modified to include a correction for regional differences in connection density.

## 1.2 Structure of this report

This report presents the results of our analysis. Specifically,

- In Section 2, we describe the key objectives of this analysis and our approach. We also provide an overview of the techniques we have used.
- In Section 3, we present the detailed results of our analysis.
- Finally, in Section 4 we bring together the results from the various strands of the analysis and provide our views on whether any evidence we have found

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[1] Agreement on Regulation of Electricity Grid Tariffs (2001 - 2006) [Regulering Nettarieven Elektriciteit (2001 - 2006)] of 26 May 2003, and the Agreement on the Regulation of Gas Transmission Tariffs (2002 - 2007) [Regulering Transporttarieven Gas (2002 - 2007)] of 3 November 2003.

fulfils Energiekamer's key criteria for the addition of a revenue correction factor in the regulatory regime.

# 2 Methodology

In this section we describe the objective of the analysis and the key criteria that will need to be assessed to determine whether connection density has a significant impact on DNOs' costs. We also provide an overview of our approach and of the techniques we have used, namely network modelling and econometric analysis.

## 2.1 Objective of the analysis

The aim of our analysis has been the investigation of whether, and to what extent, connection density in the Netherlands is a significant driver of the costs of electricity and gas distribution networks. We have carried out this analysis to address the claim that connection density may have a significant impact on DNOs' costs. If this were to be the case, the regulatory regime may need to be modified to account for these differences and adjust the DNOs' regulated revenues accordingly.

There are potentially two countervailing effects that connection density has on cost:

- **Geometric effect** - According to basic logic, one of the main causal relationships between connection density and cost could be the dependence of asset volumes on connection density. Specifically, in areas of low density, the length of cables and pipes required for each connection to the network would need to be longer on average than in areas of relatively higher density. This would suggest a **<u>negative</u> relationship between connection density and cost** per connection, whereby connections in less densely populated areas are more expensive to provide than in denser areas.

- **Urbanisation effect** - On the other hand, the so-called "urbanisation effect" claims that **costs would <u>increase</u> in more densely populated areas**, as the unit costs (as measured e.g. in €/km of line) of building and maintaining the network would necessarily be higher there.

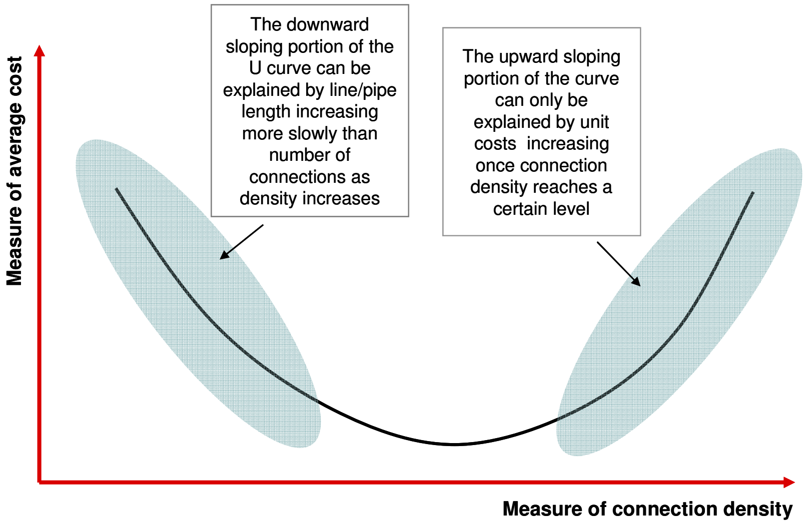
The combined results of these two competing effects may suggest the existence of a U-shaped relationship between connection density and average cost of connection. This could be the case if, for low levels of connection density, the geometric effect prevails, while, for high concentration levels, the urbanisation effected is stronger.

For the curve to be upward sloping as connection density increases, it must be the case that, for the relevant range of connection densities, the "urbanisation effect" more than compensates for decreasing costs per connection associated with higher density. We also note the possibility that companies in the relevant sample may be scattered around the turning point of the U-curve (provided it exists in the first place) so that while this density-cost relationship may exist in principle, it *may not lead to material differences between firms* in the Netherlands. Similarly, it might be the case that all Dutch companies have highly similar patterns of connection density in their operating regions. Also in this case, we would not observe a significant relationship between connection density and cost in the Netherlands.

In order to prove the existence a U-shaped relationship we need to answer two questions. First, we need to determine whether a U-shaped relationship could exist in principle. Then, if this is the case, we need to assess whether the structural conditions in the Netherlands are such that the observed levels of connection density extends to the upward sloping part of the curve. We address this issue in Section 3.2.1.

An illustration of the so-called U-curve is provided in **Figure 1**. Some empirical evidence of a U-curve, albeit weak, has been found by previous studies.[2] However, these studies relied on a combination of observations from different countries and do not appear to have an immediate applicability to the case of the Netherlands.

**Figure 1.** Relationship between connection density and average connection costs



We have carried out the analysis in order to help Energiekamer to answer the following three questions:

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[2] For example: PWC (2006), *The Economic Impact of Connection Density in Dutch Energy Distribution* (report prepared for Delta Netwerkbedrijf B.V.

- Is connection density a significant cost driver in electricity and gas networks in the Netherlands?
- If so, which functional form (e.g. U-shaped) does this relationship have in the Netherlands?
- Finally, based on the evidence collected, is the influence of connection density sufficiently well-determined to be considered a regional difference in the Dutch regulatory framework?

The answer to the last question relies on assessing whether the evidence found fulfils Energiekamer's key criteria of objectivity and significance, which we present in the following section.

## 2.2 Key criteria

In order for Energiekamer to be able to treat differences in connection density as regional cost differences and to adjust the regulated revenue formula to account for them, they need to fulfil two key criteria.

These criteria apply to all claims for regional differences. At present, as noted in the introduction, only corrections for local taxes and water crossings have been able to pass this scrutiny. These key criteria are:

- **Objectivity**. This criterion is satisfied if the impact of the regional difference on cost can be objectively quantified and if such difference cannot be affected by management decisions.
- **Significance**. This requirement is assessed along two dimensions:
    - The claimed regional difference needs to be **substantial**. This is the case if, for at least one DNO, the average cost per connection, expressed as percentage of Composite Output, exceeds the industry average cost per connection by more than one percentage point; and,
    - The claimed regional difference is **sustainable**. This is the case when the differences between DNOs remain similar over time and do not fluctuate significantly.

In the last section of the report, after presenting the results of our study, we provide our view regarding whether the evidence we have found fulfils Energiekamer's criteria.

## 2.3 Approach

### 2.3.1 Overview

For our technical analysis, we have adopted a framework based on the combined use of engineering and econometric techniques. The two types of techniques are tightly interwoven, for example as the engineering modelling, the Model Network Analysis (MNA), provides some of the alternative measures of connection density which we use in the econometric analysis to identify a potential relationship with observed average connection costs.

As illustrated in **Figure 2**, our approach involves three main steps, all based on four alternative measures of connection density.

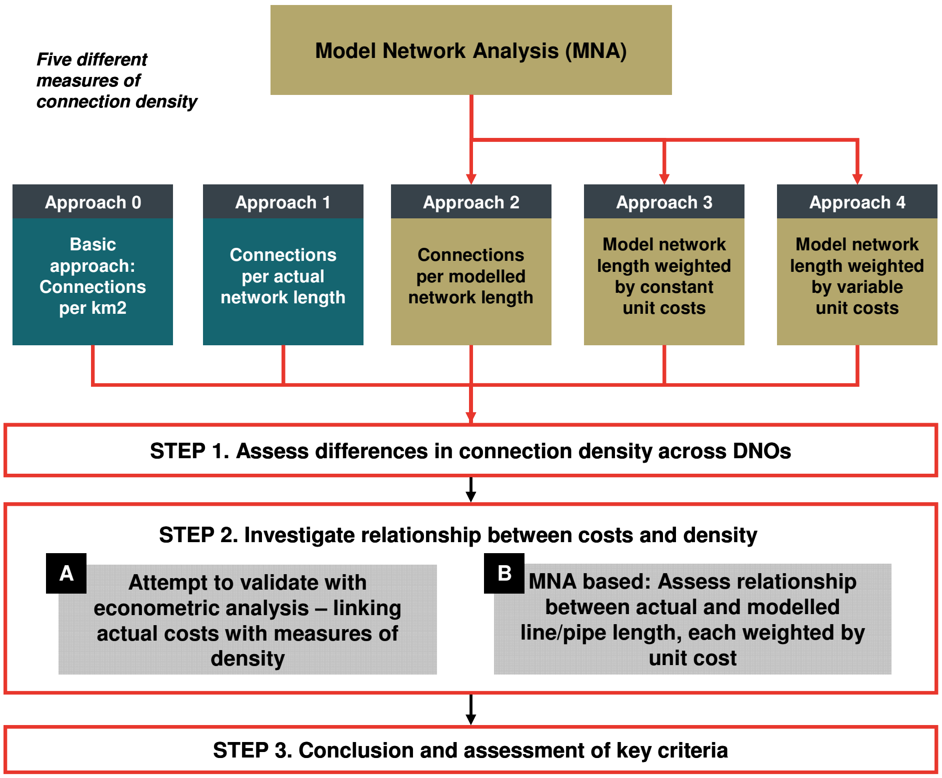
- **Step 1 - Differences between firms.** In Step 1, we carry out a descriptive analysis of the observed density and cost data for DNOs, for both gas and electricity. The purpose of this analysis is to gauge, in a preliminary way, the scale connection density and cost variation between DNOs and also to understand the 'richness' of the available data sample to be used in the econometric analysis. If, for example, we were to find that in one sector all Dutch DNOs exhibit comparable connection densities, then we would not expect connection density to explain cost differences between the firms.

- **Step 2 - Density-cost relationship**. Then, in Step 2, we investigate the relationship between observed costs and various measures of connection density using econometrics. We approach this issue from two different angles.
  - Observed cost and connection density - In Step 2a, we attempt to estimate the relationship between observed average connection costs and various measures of connection density. We use directly observable and MNA-based measures of connection density in this analysis.
  - Hypothetical cost and connection density - In Step 2b, we assess the relationship between actual network length (as a proxy for cost) and modelled network length (as a proxy for the complexity of the operating environment which includes connection density). This has also allowed us to estimate the extent to which the modelled results approximate the actual data and, hence, assess the applicability of the MNA's results to the case of the Netherlands.

- **Step 3 - Assessment of key criteria**. Finally, in Step 3, we bring together the results of the previous steps of the analysis and provide an assessment of whether, on the basis of the evidence found, the key criteria (objectivity and significance) for the inclusion of a correction factor for differences in connection density are fulfilled.

In the following subsections, we provide a more detailed overview of the techniques that we used for this study, namely the Model Network Analysis (MNA) and the econometric analysis of the relationship between connection density and costs.

**Figure 2.** Illustration of approach used



## 2.3.2 Model Network Analysis (MNA)

### *Motivation for applying MNA in this study*

A straightforward and basic measure of connection density would be to divide the total number of connections of a DNO by the size of its supply area. However, empirical analyses rarely detect a significant impact of this *average* connection density on network cost.

Research in recent years showed that this does not necessarily mean that connection density *in general* is not a significant cost driver. Rather, it could be shown that the average connection density is a too simple definition, because it neglects the heterogeneity of the supply tasks although the degree of heterogeneity is relevant for the cost impact.

For example, one could consider two DNOs that have very different supply tasks. DNO A serves one big city and a very rural area around it. Supply area A is therefore very heterogeneous. DNO B serves an area consisting only of very similar, medium sized towns. Supply area B is therefore rather homogeneous. If both supply areas have the same number of connections and the same area size, their average connection densities is identical. But one can show that the require different volumes of grid assets – in particular, lines (electricity) or pipes (gas) – to serve their respective connections.

The technique, by which it is possible to detect this effect and to quantify its relevance, is the MNA. With the help of MNA it becomes possible to consider the connection density with the required level of detail in order to properly assess its cost impact.

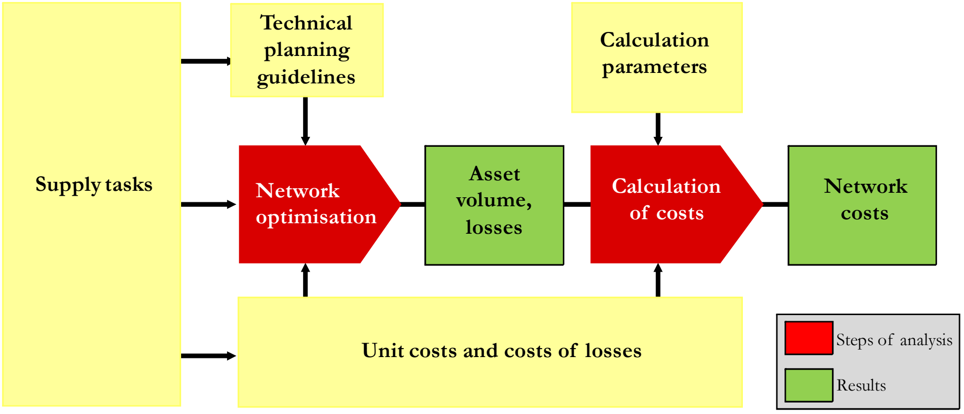
MNA was successfully applied (including empirical proofs of applicability) in Germany and Austria. Given that the Netherlands are similar to these countries in terms of economic development and basic framework of electricity and gas supply, we consider it reasonable to apply MNA also with respect to the Netherlands. Moreover, the proof of its applicability in the Dutch context is part of our later analysis (section 3.2.3).

### *Basic concept of MNA*

Model Network Analysis is an Analytical Cost Modelling (ACM) methodology. Its basic idea is to simulate the greenfield network planning process in order to identify the correlation between key characteristics of the supply tasks (including connection density), network planning, costs and other aspects.

This is achieved in two steps (**Figure 3**): First a network optimisation is performed in order to determine the network configuration that is required to fulfil a given supply task (i.e. to connect all network customer connections with the appropriate capacity) under consideration of technical planning guidelines (e.g. choice of equipment dimensions, technical restrictions, redundancy requirements). The relevant result of this step is the volume of grid assets (and, depending on the application context, the amount of losses). In the second step modelled costs for the greenfield development are determined by weighting the asset volume with the unit cost of the different asset types.

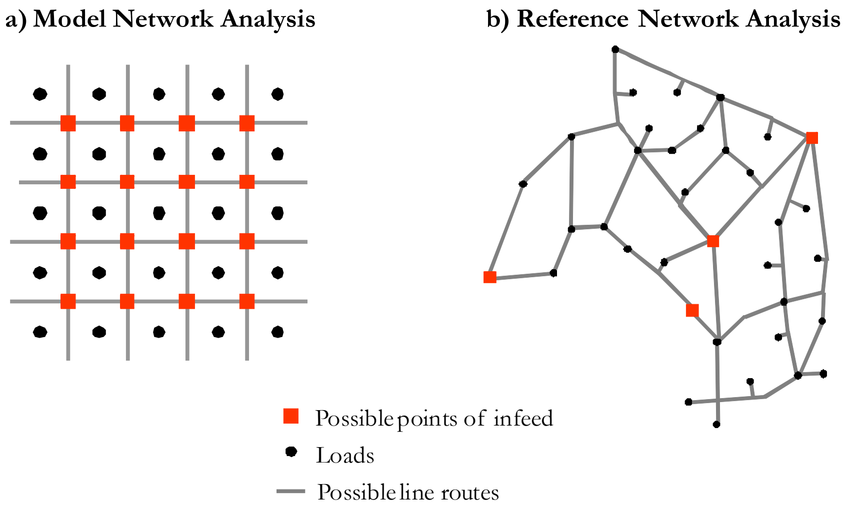
**Figure 3.** Basic structure of Model Network Analysis



Source: Consentec

As with every modelling approach, a key decision is to trade off accuracy and complexity on the one hand and practicability (e.g. related to input data requirements) on the other hand. This has led to a variety of different ACM approaches. Reference Network Analysis (RNA), for instance, aims at identifying an optimal network for a specific real supply task. It is, among other purposes, used by network operators to support long term network planning. In order to be able to achieve the degree of accuracy that is necessary for this application purpose, it requires a detailed description of the supply task, including the amount of individual consumer loads, their geographical locations and information on possible routes (**Figure 4b**).

**Figure 4.** Models of supply task



Source: Consentec

In contrast to this, MNA is a more abstract technique. It has been designed for the assessment of fundamental correlations in supply tasks, asset volume and network cost. MNA is especially appropriate for relative cost comparisons and not suited for analysing absolute costs of individual networks. Consequently, the supply task is modelled in an abstract way by assuming a homogeneous distribution of identical loads (**Figure 4a**). This allows us to describe the supply task using very few parameters. Nevertheless, the heterogeneity[3] of real supply tasks can be considered using the MNA. This is achieved by splitting the supply area into sub areas, each of which is considered to be homogeneous (**Figure 5**).[4] The network optimisation and cost calculation steps are then performed separately for each sub area before the results are aggregated to obtain the total cost estimate of the entire supply area.

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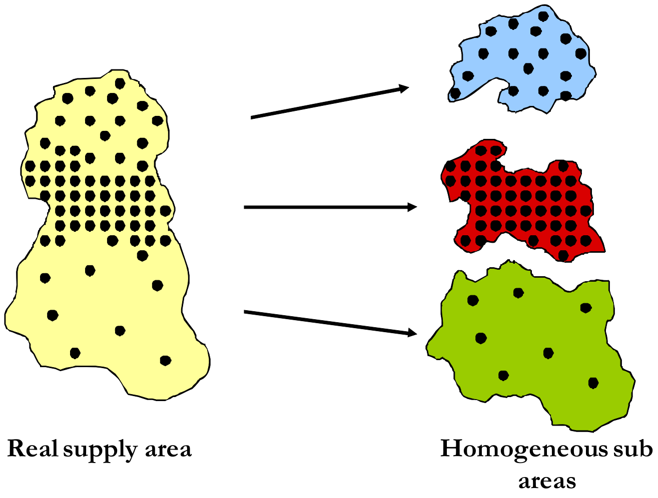
[3] A supply task is heterogeneous if for any property (e.g. connection density) the average value of any part of the supply area (local average) differs from the average of the entire area (global average). Real supply tasks are always heterogeneous. What matters here is that supply tasks of different DNOs have different degrees of heterogeneity, i.e. local and global averages differ to different extents.

[4] This technique makes use of the fact that the difference in the degrees of heterogeneity between real supply tasks can largely be captured by taking account of the different local average properties of reasonably small sub areas (such as postcode areas), because the additional extent of heterogeneity inside each sub area is a "second order effect", i.e. it differs less from one DNO to the other than the local averages differ between the sub areas.

**Figure 5.** Consideration of heterogeneity by MNA



Source: Consentec

MNA is applied in a similar way for electricity and gas networks. The main difference between the two sectors is the treatment of voltage and pressure levels, respectively. In electricity networks there is a well established and typically adopted demarcation of specific network voltage levels, whereas there is no clear and commonly adopted international split definition of pressure levels in gas networks. This has led to a relatively large variety of gas network constructions, e.g. several superposed or parallel pressure levels. Therefore, the MNA considers different voltage levels for electricity (with separately defined parameters of the supply task), but only one aggregated class of connections for gas (irrespective of actual pressure levels).

## *Experience from former applications*

In recent years we have applied MNA in various studies:

- For the German and Austrian regulatory authorities MNA was applied in cost driver analyses that served as input for the design of the respective DNO benchmarking concepts.[5]

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[5] Germany: cf. "Bericht der Bundesnetzagentur nach § 112a EnWG zur Einführung der Anreizregulierung nach § 21a EnWG", 30.06.2006:

http://www.bundesnetzagentur.de/media/archive/6715.pdf (as of 18.02.2009)

Austria: cf. MMag Dr. Aria Rodgarkia-Dara (E-Control GmbH), "Die inhaltliche Ausgestaltung der Anreizregulierung", presentation held at the official information session introducing incentive regulation in the Austrian electricity distribution sector, Vienna, 14.12.2005, http://www.e-

- In numerous investigations for individual DNOs MNA was applied with various foci, such as internal cost optimisation, contributions to regulatory debates about cost drivers, and quality of supply regulation.

In these studies the generally accepted planning rules implemented in the MNA were applied either to real data of actual DNOs or to wide varieties of synthesised supply tasks and then verified by comparison with actual DNOs' data. As a result these studies identify or confirm, inter alia, some basic relations between connection density and the required asset volumes:

- In homogeneous sub areas, the line/pipe length per area [km/km²] increases with connection density [connections/km²], following approximately a square root relation. (In electricity networks this relation applies to each voltage level separately). This means that if one supply area has twice as many connections as another area, but the same area size, its line/pipe length is higher by a factor of square root of 2. Consequently, line/pipe length per connection [km/connection] decreases with connection density (**Figure 6a**).

  Line/pipe cost per connection are proportional to line/pipe length per connection if constant unit cost (i.e. cost per km of line/pipe) are assumed (**Figure 6b, green curve**). "Constant unit cost" here means that the cost of one km of line or pipe do not depend on the connection density of the area where the line/pipe is laid.

  If unit cost increase with connection density (this would represent the urbanisation effect as introduced in section 2.1) the downward slope of the relation becomes weaker; for strongly increasing unit cost the relation between connection density and line/pipe cost per connection can assume a U-shaped relationship with connection density (**Figure 6b, blue curves**).

- The number and total capacity of stations (transformer-substations or gas pressure regulators) is approximately proportional to the network load. Hence, if two supply areas have identical total load, but different connection densities, this difference has no significant impact on the cost of substations.

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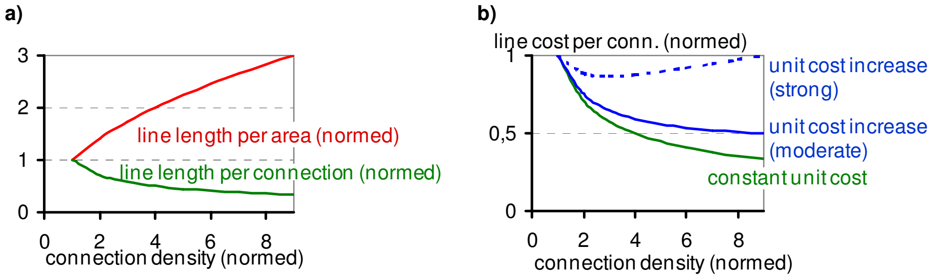
control.at/portal/page/portal/ECONTROL_HOME/NEWS/INFOVERANSTALTUNG/ANREIZ_20051214/20051214_ARO.PDF (as of 18.02.2009)

**Figure 6.** Basic relations between line/pipe length and connection density in homogeneous (sub) areas as identified by previous MNA studies



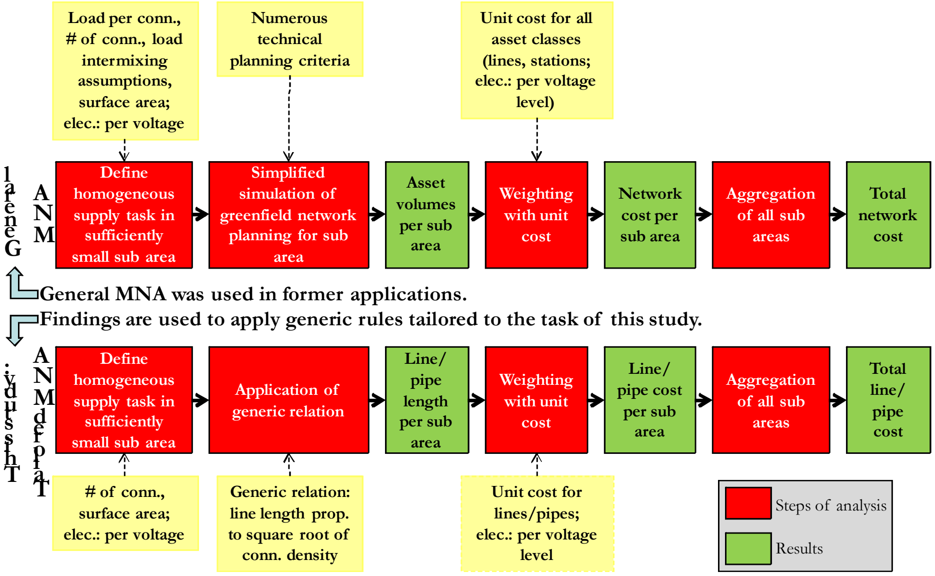
Source: Consentec

Due to the non-linearity of the above relation between connection density and line/pipe length the impact of connection density on the asset volume (and, consequently, on cost) cannot be accurately expressed by the *average* connection density of a supply area. Instead, the *heterogeneity* of the supply task must be taken into consideration. The revelation of this finding underlines the value of MNA in the context of analysis of this kind; moreover, MNA does not only confirm the need to consider the heterogeneity, but also provides a way to do so: The model network cost of a supply area (consisting of several sub areas) constitutes an aggregated measure of the heterogeneous connection density. This aggregate measure per DNO lends itself for use as control variable in regression analyses (cf. section 2.3.3 below).

### *Application in the context of this study*

As mentioned above, MNA is a generic technique that is used in different contexts. In order to tackle the specific objective of this analysis we tailor the MNA by using the generic findings from previous studies (**Figure 7**):

**Figure 7.** Application of tailored MNA in this study



Source: Consentec

- We focus on line/pipe related cost.

- In order to consider the heterogeneity of the supply tasks the supply areas are disaggregated to sub areas at the level of 4-digit postcodes.

- For each sub area the line/pipe length is derived from connection density, which in turn is derived from the number of connections and the surface as far as it is typically covered by grid.
  - Connections include customer connections and substations/reducing stations.
  - Electricity and gas networks typically do not cover the entire supply area. For example, there is usually no low voltage grid in forests. In this analysis the relevant surface (i.e. surface typically covered by grid) is defined according to the type of land use. For electricity, the surface definition is differentiated by voltage level. Moreover, we check the sensitivity of results with respect to the surface definition by applying three different definitions for both gas and electricity. Details on the

definitions can be found in section 2.4 below. In each postcode area the relevant surface is assumed to be contiguous.[6]

- The line/pipe length $\ell$ per postcode (electricity and per voltage level) is calculated as from the number of connections $N$ and the relevant surface area $A$.[7]
- For electricity, no HV levels have been taken into account in the MNA analysis.

The above approach avoids unnecessary data requests and increases the efficiency of the analysis while allowing for capturing the essential impact of connection density as identified by the MNA. In particular, the application of the generic formula to derive line/pipe length from connection density and area size implicitly assumes identical planning guidelines, thereby ensuring an isolated analysis of the relative impact of the supply task on network cost.

### *Summary of approximations*

To summarise the above descriptions, MNA helps analysing the fundamental relations between properties of the supply task and network cost by simulating the way in which network planners actually design their grids. The network planning process is modelled in a simplified way, which allows also describing the supply task with a limited amount of data. Effectively, with the help of MNA a quite complex description of connection density (i.e. based on connections and surface sizes per postcode area) can be transformed into a single figure per DNO that describes the major cost driving effect of connection density as far as network assets are concerned.

The approximations applied in this context are deliberate decisions based on profound experience (analytical experience entered into the planning model as well as empirical analysis by actual DNOs' data assessment). When assessing these approximations, it is useful to be aware that also the straightforward definition of connection density (average connection density, i.e. total number of connections per total area) is based on assumptions, albeit more subtle and less consciously. **Table 1** gives a comparison between the generic and tailored MNA and the average connection density.

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[6] Even if the supplied area is split into smaller parts that are separated by unsupplied area this is not cost relevant as long as the parts are large enough to allow for efficient grid planning. Only if the parts are so small that some equipment cannot be utilised as efficiently as in large contiguous areas (e.g. when there are so few loads that they do not entirely utilise the smallest efficient transformer) there is a cost effect of the supply area being scattered. Hence, by assuming contiguous areas per postcode the MNA implicitly assumes that the relative cost impact of scattered, isolated loads is small or reasonably similar among the DNOs.

[7] Note that the applicability of this assumption in the Dutch context is verified as part of our analysis, cf. section 3.2.3.

**Table 1.** Increased accuracy with MNA due to fewer approximations compared to average connection density

| Aspect | Generic MNA | Tailored MNA (applied in this study) | Average connection density |
|---|---|---|---|
| Impact of connection density on cost in homogeneous areas | Result of applying realistic planning rules | Square root relation of line/pipe length in homogeneous sub areas (conclusion from applying generic MNA) | Linear relation to cost |
| Urbanisation effect | Considered by assuming unit cost depending on connection density per sub area | Considered by assuming unit cost depending on connection density per sub area | Neglected |
| Heterogeneity | Considered (through homogeneous sub areas) | Considered (through homogeneous sub areas) | Neglected |
| Specification of area size and shape | Contiguous per sub area and per voltage level (electricity) | Contiguous per sub area and per voltage level (electricity) | Entirely contiguous |
| Load | Identical loads per sub area (electricity: per voltage level) | Disregarded (because shown to be irrelevant in previous studies) | Disregarded |
| Split of network levels | Electricity: yes, common split<br>Gas: no | Electricity: yes, common split<br>Gas: no | No |

Source: Consentec

### 2.3.3 Econometric analysis

As noted above, according to one of Energiekamer's criteria, the impact of connection density on costs needs to be measured in an objectifiable way. While the MNA can provide a robust engineering-based argument of the relevance of connection density as a regional difference, its applicability to the case of the Netherlands need to be confirmed by the analysis of actual data.

The econometric analysis therefore attempts to bridge the gap between the conclusion of the MNA and the actual cost and connection density data that we have received from Energiekamer. We address this issued from two angles.

- **Relationship between observed cost and connection density.** We estimate the relationship between average costs and four measures of connection density (see **Figure 2**). Three of the measures are calculated using the MNA. For each of the measures calculated by the MNA, we test three different surface definitions, with a view to provide a more rounded estimate. In addition to relating the companies' actual costs to their numbers of connections, we also carry out the analysis using the companies' cost per unit of Composite Output as dependent variable. Composite Output is a measure for cost drivers, used in the current regulatory framework for calculating each DNO's allowed revenues.[8] As it is defined taking into account some of the DNOs' specific characteristics (such as the number of connections), it allows us to control for intrinsic differences between companies. This type of analysis may reduce the likelihood of outliers, and therefore, of 'data noise' affecting the regression results.

- **Relationship between actual and modelled line/pipe length.** This analysis measures the strength of the link between modelled results and the corresponding actual data. We carry out this analysis for two main purposes:
  - to confirm (or reject) the relationship between the actual DNOs' data and connection density. We have carried out this analysis by using information on DNOs' line/pipe *lengths* as a proxy for line/pipe *costs*.
  - to support the choice of the most appropriate surface definition for the MNA analysis.

In the next section of the report, we present the detailed results of each step of our analysis.

## 2.4 Input data

### *Total cost*

We carried out the analysis using cost data on DNOs as provided by Energiekamer. We have not audited or otherwise verified this data. Compared to the present structure of DNOs the data we used differs in two aspects:

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[8] For an extensive description of Composite Output, see Energiekamer's regulation method decisions, e.g. paragraph 8.2.3 of:

http://www.energiekamer.nl/images/102449-167 Methodebesluit voor de regionale netbeheerders gas in de 3e periode_tcm7-114326.pdf

- Extra high pressure gas networks were outside the scope of the analysis; therefore, the DNO Zebra, which only operate on extra high pressure level, was disregarded.

- The data set is based on DNOs' data as of 2006. In that year ONS and ENECO (which later merged to Stedin) were still separate entities. In order to increase the sample size (which tends to improve the quality of statistical analyses) we considered ONS and ENECO as separate entities.

**Table 2** summarises the cost data for the gas DNOs. It also provides information on the number of connection points and the average cost per connection. Similarly, **Table 3** provides the same information for the electricity DNOs. Please note that the data presented for electricity include the costs associated to HV levels.

**Table 2.** List of gas DNOs (in 2006)

| Name | Total cost (EURm) | Connections (m) | Avg. cost per conn. (EUR) |
|---|---|---|---|
| N.V. Continuon Netbeheer | 265.4 | 2.13 | 124.4 |
| Netbeheerder Centraal Overijssel | 16.8 | 0.13 | 126.8 |
| DELTA Netwerkbedrijf B.V. | 19.2 | 0.18 | 104.4 |
| ENECO Netbeheer B.V. (Stedin) | 221.5 | 1.91 | 115.7 |
| Essent Netwerk B.V. | 188.9 | 1.88 | 100.5 |
| Intergas Energie B.V. | 26.7 | 0.14 | 183.1 |
| B.V. Netbeheer Haarlemmermeer | 7.1 | 0.05 | 119.9 |
| NRE Netwerk B.V. | 22.6 | 0.18 | 122.1 |
| Obragas Net N.V. | 26.4 | 0.19 | 132.6 |
| ONS Netbeheer | 3.7 | 0.03 | 105.6 |
| RENDO Netbeheer B.V. | 20.5 | 0.10 | 203.8 |
| Westland Energie Infrastructuur B.V. | 20.0 | 0.05 | 403.1 |

Source: Energiekamer

**Table 3.** List of electricity DNOs (in 2006)

| Name | Total cost (EURm) | Connections (m) | Avg. cost per conn. (EUR) |
|---|---|---|---|
| N.V. Continuon Netbeheer | 751.2 | 2.85 | 263.5 |
| Netbeheerder Centraal Overijssel | 12.5 | 0.05 | 236.1 |
| DELTA Netwerkbedrijf B.V. | 49.7 | 0.20 | 238.3 |
| ENECO Netbeheer B.V. | 545.8 | 2.03 | 267.8 |
| Essent Netwerk B.V. | 810.8 | 2.62 | 308.8 |
| NRE Netwerk B.V. | 28.8 | 0.10 | 271.7 |
| ONS Netbeheer | 9.8 | 0.04 | 252.8 |
| RENDO Netbeheer B.V. | 9.5 | 0.03 | 297.5 |
| Westland Energie Infrastructuur B.V. | 36.1 | 0.05 | 663.6 |

Source: Energiekamer

### *Unit cost*

For approaches 3 and 4 (cf. **Figure 2**) the modelled line/pipe length is weighted by the respective unit cost, i.e. cost per km of line or pipe. According to the general focus on relative differences between supply areas in this analysis, only the ratios between unit costs are relevant here:

- In approach 3 the electricity lines of different voltage levels are weighted by the relative unit cost in order to take into account that unit cost increase with voltage.[9]
- Approach 4 additionally considers the urbanisation effect, i.e. the increase of unit cost in densely populated areas. In agreement with Energiekamer, unit cost are differentiated according to the five urbanisation classes defined by the "Centraal Bureau voor de Statistiek" (CBS). A gradual urbanisation class is computed for each postcode area based on its number of addresses per km². The unit costs to be applied for this area are then derived by interpolation between the unit costs provided for rural (class 5), suburban (class 3) and city (class 1), cf. **Figure 8**.
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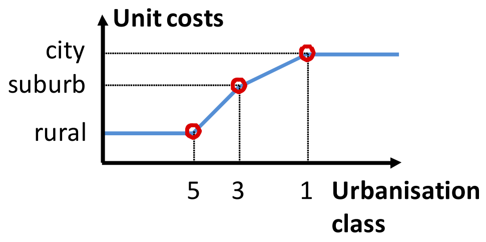
[9] Given that pressure levels are not differentiated in gas MNA, approaches 3 and 2 are identical for gas.

**Figure 8.** Illustration of determination of unit cost by interpolation between cost levels defined for discrete urbanisation classes



Source: Consentec

**Table 4** shows the normalised unit cost used for the analysis. They are mean values of data provided to Energiekamer by the DNOs. The differences between urban and rural areas amount to 20 % for gas and to 20-30 % for electricity.[10]

In our analysis we use these figures as our base case. Additionally, in order to evaluate the robustness of the results, we perform a sensitivity analysis where the bandwidth between urban and rural unit cost – and for electricity also between voltage levels – is shrunk or stretched by 50 %, respectively.

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[10] For example, in the low voltage level the ratio between urban and rural areas is 1.27 : 1, i.e. unit cost in urban areas are 27 % higher than in rural areas. On the "Medium voltage 2" level the ratio is 6.87 : 5.76 = 1.19, i.e. unit cost in urban areas are 19% higher than in rural areas.

**Table 4.** Standard unit cost (averages of data submitted to Energiekamer by the DNOs) – normalised figures

| **Gas** | | | **Approach 4 (varying unit costs)** | | |
|---|---|---|---|---|---|
| | Urbanisation | CBS class | 1 | 2, 3, 4 | 5 |
| | | addresses / km$^2$ | >2500 | 500..2500 | <500 |
| All pressure levels | Standard unit costs | €/m | **1,2** | **1,08** | **1** |

| **Electricity** | | | **Approach 4 (varying unit costs)** | | | **Approach 3 (constant unit costs)** |
|---|---|---|---|---|---|---|
| | Urbanisation | CBS class | 1 | 2, 3, 4 | 5 | All classes |
| | | addresses/km$^2$ | >2500 | 500..2500 | <500 | |
| Low voltage (0,4 kV) | Standard unit costs | €/m | **1,27** | **1,18** | **1** | **1** |
| Medium voltage 1 (1 kV - 20 kV) | Standard unit costs | €/m | **2,33** | **2,15** | **1,83** | **1,83** |
| Medium voltage 2 (>20 kV - 50 kV) | Standard unit costs | €/m | **6,87** | **6,30** | **5,76** | **5,43** |
| High voltage 1 (110 kV) | Standard unit costs | €/m | **-** | **16,30** | **14,81** | **14,07** |
| High voltage 2 (150 kV) | Standard unit costs | €/m | **24,50** | **21,11** | **19,79** | **18,74** |

Source: Consentec analysis based on Energiekamer's data (based on data of 4 DNOs)

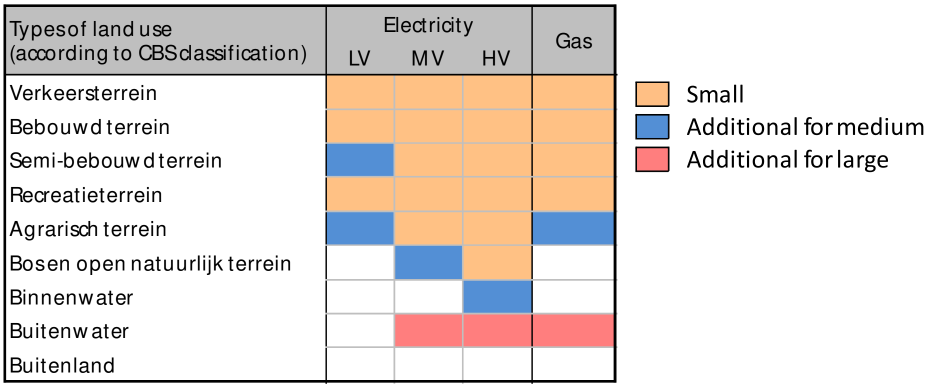
### *Supply task*

Data to describe the supply task in this analysis comprises the number of connections and the relevant surface area (given that connection density is the ratio between these). In addition, in the econometric analysis we also use data on the **Composite Output** per DNO.

Data on the **number of connections** has been requested and received from the DNOs by Energiekamer. With the exception of the high voltage level (electricity) all data has been provided on 4-digit postcode level. The relevant definitions have been developed in agreement with Energiekamer, including the treatment of special cases (e.g. connections in foreign countries). For the sake of practicability metering points were counted as connections.[11]

The **surface area** typically covered by grid is defined according to the types of land use. Respective data on 4-digit postcode level has been obtained by Energiekamer from the CBS. In agreement with Energiekamer and the DNOs we apply three alternative surface definitions – "small", "medium" and "large" (**Figure 9**).

**Figure 9.** Definitions for surface covered by grid



| Types of land use (according to CBS classification) | Electricity | | | Gas |
|---|---|---|---|---|
| | LV | MV | HV | |
| Verkeersterrein | 🟧 | 🟧 | 🟧 | 🟧 |
| Bebouwd terrein | 🟧 | 🟧 | 🟧 | 🟧 |
| Semi-bebouwd terrein | 🟦 | 🟧 | 🟧 | 🟧 |
| Recreatieterrein | 🟧 | 🟧 | 🟧 | 🟧 |
| Agrarisch terrein | 🟦 | 🟧 | 🟧 | 🟦 |
| Bos en open natuurlijk terrein | | 🟦 | 🟧 | |
| Binnenwater | | | 🟦 | |
| Buitenwater | | 🟥 | 🟥 | 🟥 |
| Buitenland | | | | |

🟧 Small
🟦 Additional for medium
🟥 Additional for large

Source: Consentec

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[11] It should be noted that for low voltage and for gas this definition tends to exaggerate the differences between areas of high and low density, because densely populated areas tend to have a higher share of multi-apartment buildings, i.e. a higher average number of metering points per physical connection to the network.

# 3 Results

In this section we present the detailed results of the first two steps of the analysis, namely the initial descriptive data analysis (Step 1) and our assessment of the relationship between average connection costs and connection density (Steps 2a and 2b). As noted previously, we carry out the analysis in Step 2 using two techniques: one based on the econometric analysis of actual cost data and the other based on the assessment of the relationship between actual network data and modelled network data. In the next and final section, we bring together the results from the various angles of the analysis and attempt to verify whether the evidence we gathered fulfils Energiekamer's key criteria.

## 3.1 Descriptive data analysis

Step 1 of our analysis involves the construction of descriptive statistics to assess the extent to which Dutch DNOs differ from each other, both in terms of average costs per connection and in terms of connection density. This analysis allows us to assess the 'richness' of the data sample for the econometric analysis and whether cost and connection density differences between Dutch DNOs exist in the first place. As the number of observations is very small (even when ONS is included in the data set), it is important that the dataset provides a good level of variation for both cost and density data for the econometric analysis to be able to capture a clear relationship between connection density and average connection costs. Moreover, as the small sample size imposes strong restrictions on the number of variables that can be included in the regression model to control for additional effects, it is also important that both sets of observations are relatively 'well-behaved', with no or very few outliers increasing the noise level in the data. For this analysis, as well as for the econometrics analysis later, we consider two costs definitions:

- **Total costs.** In this case we use the total costs as provided by DNOs to Energiekamer. This is the sum of all capital expenditure (CAPEX) and all operating expenditure (OPEX) of each DNO.
- **Approximation of infrastructure-related costs**. Infrastructure related costs are more likely to be directly linked to connection density. (It is reasonable to assume that connection density affects the amount and cost of the network assets, whereas it seems less likely that non-infrastructure related cost such as cost of operating centres or administrative buildings are affected by connection density.) However, no direct estimation of this share of costs was available at the time of the analysis. In agreement with Energiekamer, we roughly approximate these costs by considering 100% of capital expenditure but only 75% of

operating expenditure, in order to exclude costs that may not be directly related to infrastructures (e.g. excluding certain head office costs).

We have carried out the analysis using both costs definitions. However, the second cost definition, with the approximated infrastructure-related cost, has delivered consistently more robust and statistically significant results. Therefore, all the results presented in this report are based on the second type of cost definition.

We note that the results of the following analysis could, in principle, be more significant if information on line/pipe related cost was available. However, it is likely that the small sample size would still prevent the achievement of statistically significant results even if these costs were used.

### 3.1.1 Gas

**Figure 10** shows the variance of the average observed cost per connection for all gas DNOs. The costs are normalised for ease of comparison[12]. Only one DNO, Westland, is outside the scale of this chart. This is because its cost per connection is about three times higher than the industry average. The chart also shows the average of all observations and an interval equal to twice the standard deviation of the observations. The width of this interval, which by construction must contain most of the observations, provides an indication of the degree of variance of the dataset.

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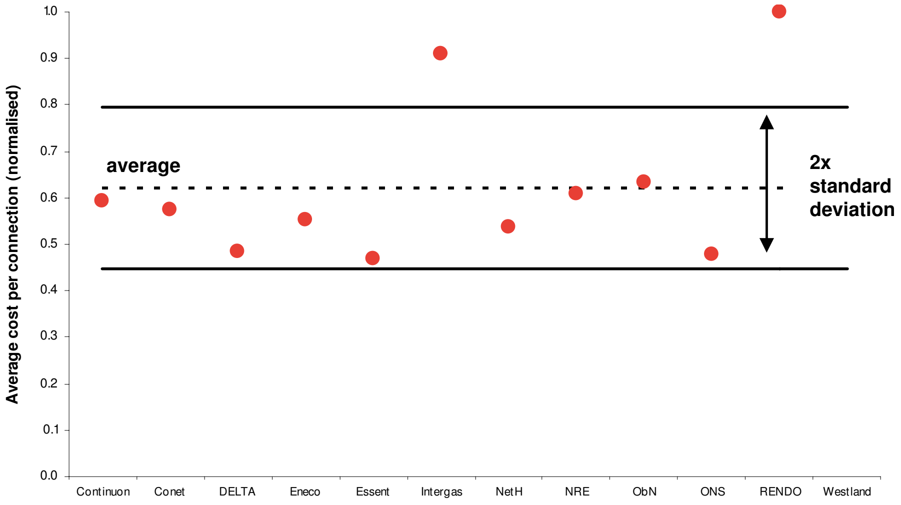
[12] We have normalised unit costs with respect to the company with the highest value (with the exception of Westland, which is an outlier). For gas, we have used RENDO as references, while Essent has been used for electricity.

**Figure 10.** Average cost per connection - GAS (normalised)



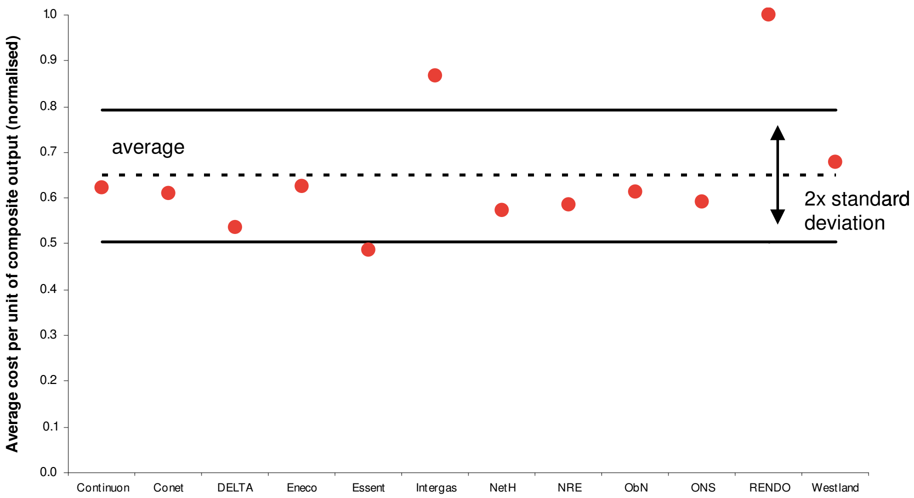
Source: Frontier Economics analysis using Energiekamer's data

With the exception of Intergas and Rendo (in addition to Westland, as noted above), most observations tend to be concentrated within a relative small range.

The higher costs per connection showed by some companies may be due to factors other than differences in connection density. For example, cost variations may depend from other network characteristics or differences in the level of efficiency between DNOs. However, some of these factors, such as the number of connection points for each DNO, may already be accounted for by the existing regulatory regime. To control for this issue, we also consider the DNOs' average costs per unit of Composite Output. The Composite Output is a measure defined in the current regulation, on which the allocation of regulated revenues is based. This measure already takes into account some of the characteristics of the network and customer base faced by each DNO (such as connection capacity).

**Figure 11** shows the average observed cost per unit of Composite Output for each gas DNO. The cost data are normalised in this case as well. In contrast to the previous chart, Westland no longer an outlier. This is because the definition of Composite Output explicitly takes into account the differences in average connection capacity between DNOs. After this correction, Intergas and Rendo appear to be the only companies with a cost per unit of Composite Output significantly different from the rest of the industry. However, in general, the level of variance in the cost data does not appear to be very high.

**Figure 11.** Average cost per unit of Composite Output - GAS (normalised)



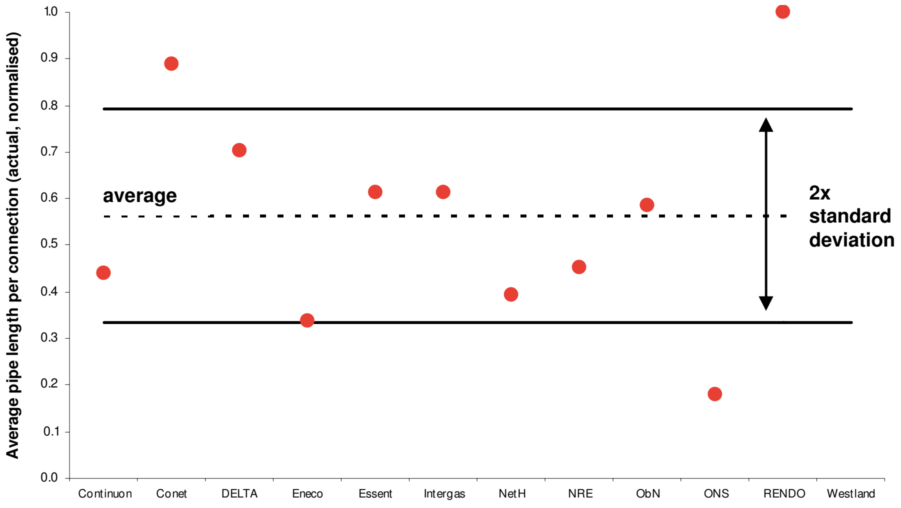
Source: Frontier Economics analysis using Energiekamer's data

In addition to looking at the variance of cost measures, we also consider the variation in average length of pipes per connection for each DNO. This is a proxy measure of connection density as DNOs operating in densely populated areas will tend to have a relatively shorter average length of pipes per connection. We analyse both actual average pipe length and modelled average pipe length, as derived from the MNA. We calculate average modelled pipe length for each of the surface definitions used in the MNA. The results are consistent across all three definitions: for brevity we present only those based on the 'medium' surface definition.

**Figure 12** shows the average *actual* pipe length for all gas DNOs. It can be seen that there appears a high level of dispersion, suggesting that the DNOs differ significantly in terms of average length of pipes per connection.

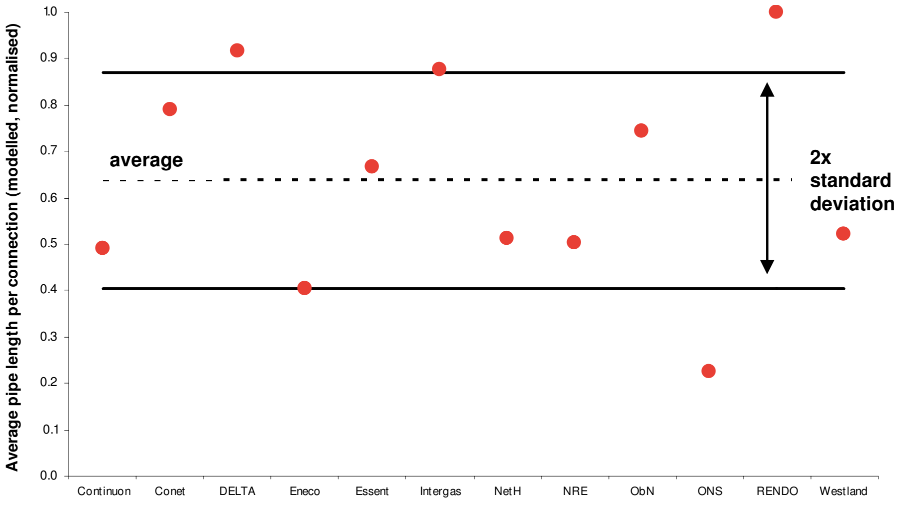
We see a similar distribution when we consider the average *modelled* pipe length (MNA results), as shown in **Figure 13**. Also in this case, the interval defined by twice the sample's standard deviation appears to be wide.

**Figure 12.** Average actual length of pipe per connection – GAS (normalised)



Source: Frontier Economics using Energiekamer's data

**Figure 13.** Average modelled length of pipe per connection - GAS (normalised)



Source: Frontier Economics, Consentec, using Energiekamer's data

### *Conclusion*

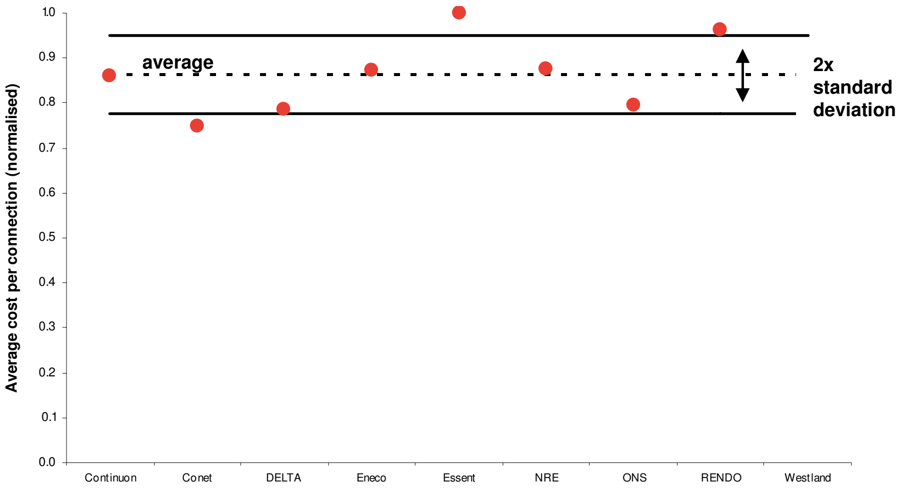
In general, the variation in average length of pipe per connection observed above does not appear to be matched by an equal variation in average costs. While this does not prove that connection density has no effect on costs, the combination of low variance in costs and the small sample size may make detecting this impact using econometric techniques more difficult.

## 3.1.2 Electricity

**Figure 14** shows the variance of the average observed cost per connection for all electricity DNOs. The costs, which include HV levels, are normalised. This is because the focus is on the comparison of relative positions rather than absolute values. Also in this case, Westland is an outlier and is outside the chart scale. Its average cost per connection is approximately twice the average of the rest of the industry. The chart also shows the average of all observations and an interval equal to twice the standard deviation of the observations. The width of this interval, which by construction contains most of the observations, provides an indication of the degree of variance of the dataset.

It can be seen that, with the exception of Westland, most observations are quite similar to the industry average. This suggests a degree of cost variation smaller than in the case of gas.

**Figure 14.** Average cost per connection - ELEC (normalised)



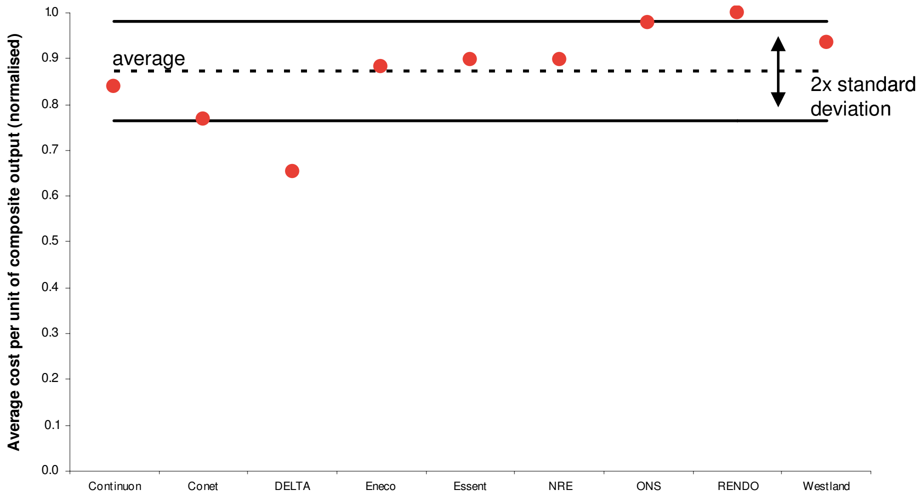
Source: Frontier Economics analysis using Energiekamer's data

As in the case of gas, the variation in cost per connection, especially in the case of Westland, may be due to factors other than differences in connection density. Using the same approach described above, we also consider the DNOs' average costs per unit of Composite Output, as this measure already takes into account some of the characteristics of the network and customer base faced by each DNO (such as connection capacity).

**Figure 15** shows the average cost per unit of Composite Output for each electricity DNO. Also in this case the cost data include HV levels and are normalised to facilitate comparisons across DNOs. With respect to the previous chart, Westland is no longer an outlier. This is because the definition of Composite Output explicitly takes into account the difference in average connection capacity between DNOs. With the alignment of Westland to the industry average, the level cost variance for electricity is confirmed to be small.

As in the case of gas, in addition to looking at the variance of cost measures, we consider the variation in average length of electricity lines per connection for each DNOs. We consider both actual average line length and modelled average line length. We calculate average modelled pipe length for each of the surface definitions used in the MNA. The results are consistent across all three definitions: for brevity we present only those based on the 'medium' surface definition.

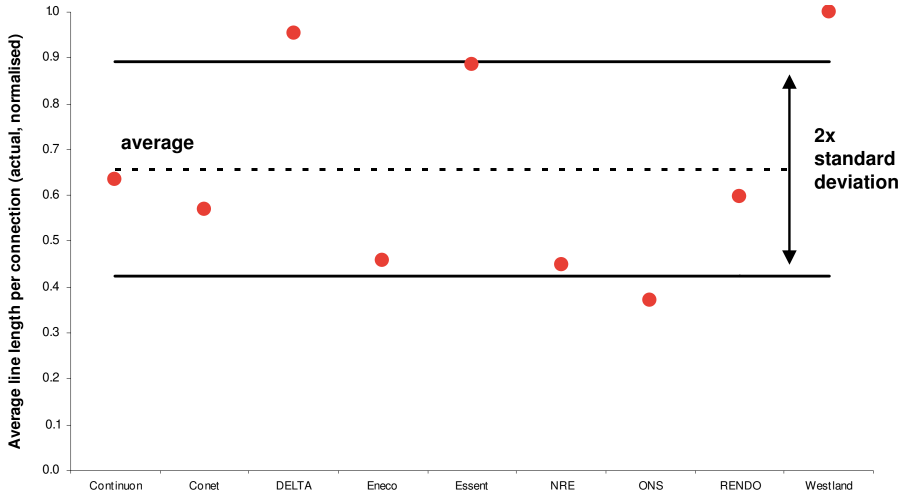
**Figure 15.** Average cost per unit of Composite Output - ELEC (normalised)



Source: Frontier analysis using Energiekamer data

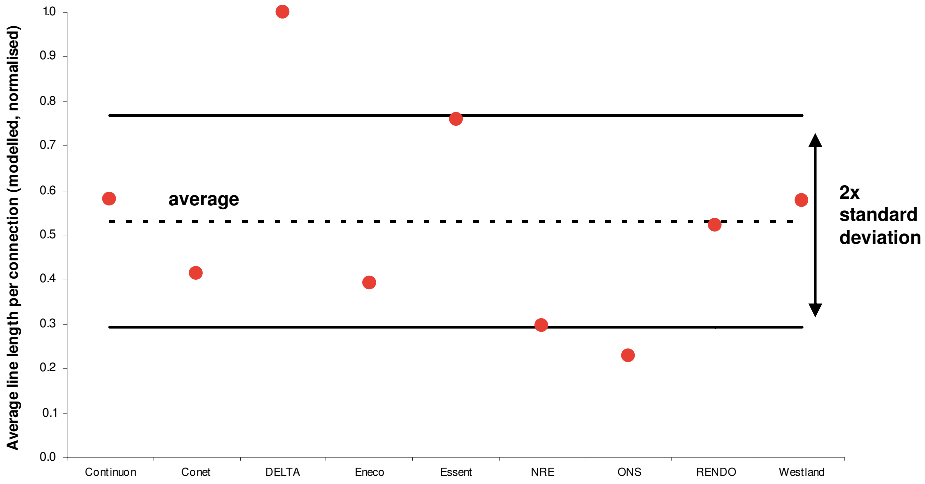
**Figure 16** shows the average *actual* line length for all electricity DNOs. It can be seen that there appears a high level of dispersion, suggesting that the DNOs differ significantly in terms of average length of lines per connection. The same conclusion can be reached also when we consider the average *modelled* line length (MNA results) per connection, as shown in **Figure 17**. Also in this case, the interval defined by twice the sample's standard deviation appears to be relatively wide.

**Figure 16.** Average actual length of line per connection - ELEC (normalised)



Source: Frontier Economics analysis using Energiekamer's data

**Figure 17.** Average modelled length of line per connection – ELEC (normalised).



Source: Consentec using Energiekamer's data

## *Conclusion*

This descriptive data analysis leads us to conclusions similar to those we have reached in the case of gas. Specifically, the large variation in the average length of line per connection does not seem to be matched by a similar variation in average cost per connection and average cost per unit of Composite Output. The differences in costs appear to be even smaller in the case of electricity than in the case of gas. Also in this case, the low variance in costs, together with the even smaller sample size, will make obtaining robust estimates of the impact of connection density on costs more difficult.

The exploratory analysis, Step 1, has allowed us to develop a better understanding of the 'richness' of the data available. As discussed previously, the ability of the empirical analysis to identify a significant relationship between connection density and costs (in case an impact of connection density on cost existed) would be enhanced if the dataset provided a good degree of variance for both density and cost data. As we have observed, however, while there appears to be a high degree of variation with regards to connection density, most DNOs tend to show similar average costs per connection.

In general, the conclusions of Step 1 of the analysis imply that it is sensible to progress to the second step of analysis and explore the connection density-cost relationship in greater detail.

## 3.2 Relationship between costs and density

After the initial data exploration, in Step 2 we turn to the analysis of the relationship between connection density and average connection costs in the Netherlands. First, we address the issue from an engineering point of view, using the MNA to determine whether, in a modelled network for the Netherlands, connection density could affect infrastructure related costs. This analysis also can help us determine whether, in principle, the characteristics of the Dutch network suggest the existence of a U-shaped relationship between connection density and costs.

After the MNA, we report the results of the econometric analysis. As described previously, we use this type of analysis in two ways.

- First, in Step 2a, we try to estimate the relationship between various measures of connection density (both actual and modelled) and actual measures of costs (average cost per connection and average cost per unit of Composite Output).

- Then, in Step 2b, we assess the strength of the relationship between actual network length (as a proxy of infrastructure-related costs) and modelled network length. This allows us to estimate the extent to which the modelled results approximate the actual data and, hence, assess the applicability of the MNA's results to the case of the Netherlands. A particularly strong correlation could support the results of the analysis carried out in Step 2a, especially if the latter was unable to identify strongly significant relationships.

### 3.2.1 Model network analysis

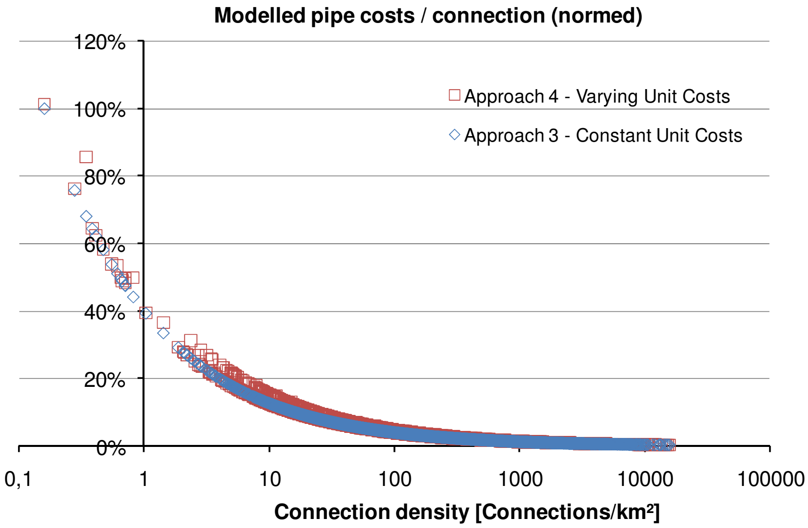
#### *Existence of U-curve*

According to theory the U-curve results from the superposition (i.e. the combined effect) of the decrease of line/pipe length per connection and the increase of unit cost (per km of line/pipe) for increasing connection density. With the MNA, the relevance of the unit cost impact can be analysed by comparing approaches 3 and 4 (cf. **Figure 2**) on the level of individual postcodes.

In **Figure 18** and **Figure 19** – for gas and electricity, respectively – each blue or red square represents one Dutch postcode area. The curve formed by the blue squares (constant unit cost, approach 3) represents the relation between connection density and line/pipe length per connection. The red squares are obtained by applying unit cost depending on the urbanisation class of each postcode (approach 4). It is clearly visible that this application of varying unit cost does not change the relation into a U-shaped curve, because the impact of connection density on the line/pipe length per connection by far outweighs the unit cost differences between different degrees of urbanisation.

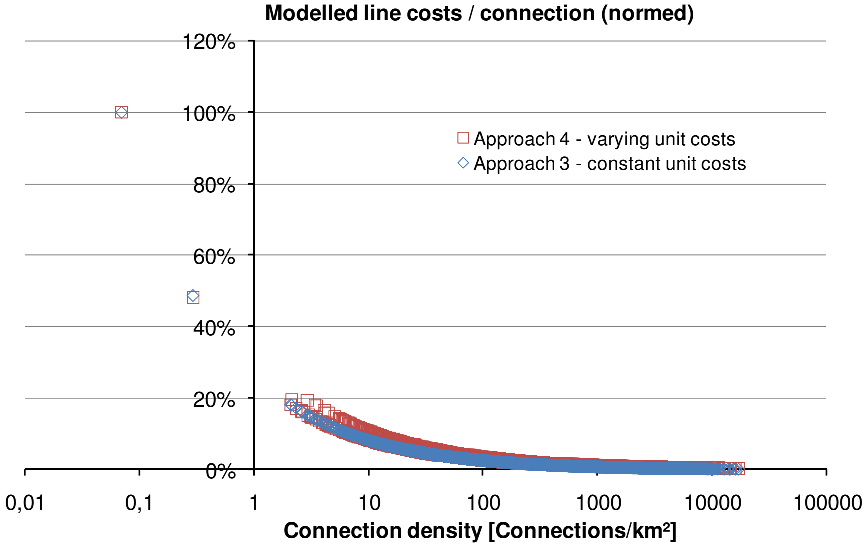
We conclude that there is no evidence for the existence of a so-called U-curve in the Netherlands.

**Figure 18.** Spread of modelled pipe cost per connection on postcode level – GAS ("medium" surface definition)



Source: Consentec based on Energiekamer's data

**Figure 19.** Spread of modelled line cost per connection on postcode level – ELEC (low voltage, "medium" surface definition)



Source: Consentec based on Energiekamer's data

## *Theoretical impact of connection density on line/pipe related costs*

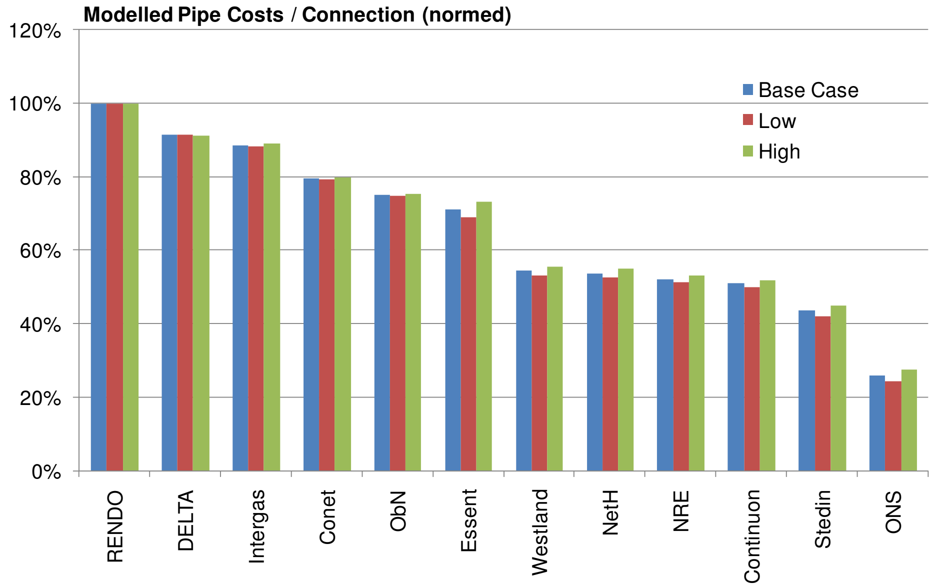
By applying MNA on the level of DNOs we analyse whether the actual distribution of connection density across Dutch DNOs' supply areas (including the bandwidth of average connection density as well as its degree of heterogeneity) suggests a significant difference in network cost per connection. Applying MNA here means firstly that this assessment is based on the generic relations assumed on the level of homogeneous sub areas (cf. section 2.3.2) and secondly that the analysis covers only the line/pipe related cost shares and not the entire DNOs' costs.

Among the two MNA approaches that deliver cost measures (approaches 3 and 4) approach 4 appears more advanced as it takes into account the differences in unit cost between areas of different levels of urbanisation. Therefore, the following results are based on approach 4. In order to obtain insight into the robustness of our results, we perform a sensitivity analysis by considering three cases of unit cost variation – base, high (bandwidth stretched by 50 %) and low (bandwidth shrunk by 50 %) – as described in section 2.4.

The exemplary results shown below are based on the “medium” surface definition for gas and the “small” surface definition for electricity. Other surface definitions lead to identical qualitative conclusions.[13]

**Figure 20** shows the results for gas networks. The figures are normalised separately for each case of unit cost variation in order to allow for an easy assessment of the respective degree of variation across the set of DNOs.

**Figure 20.** Modelled gas pipe cost per connection – medium surface definition; base, low and high unit cost variations



Source: Consentec analysis based on Energiekamer’s data

The figures show a notable bandwidth of modelled pipe cost per connection, with a factor of about four between the highest (RENDO) and lowest (ONS) cost level and still a factor of more than two if the DNO with the lowest figures (ONS) is disregarded.

Compared to this overall bandwidth across the sample the dependency of modelled cost per connection on the degree of variation of unit cost (base case, low, high) is rather weak. Hence it is a robust conclusion that according to the MNA the actual differences in connection density between the supply areas of the Dutch DNOs suggest a significant difference in pipe cost per connection.

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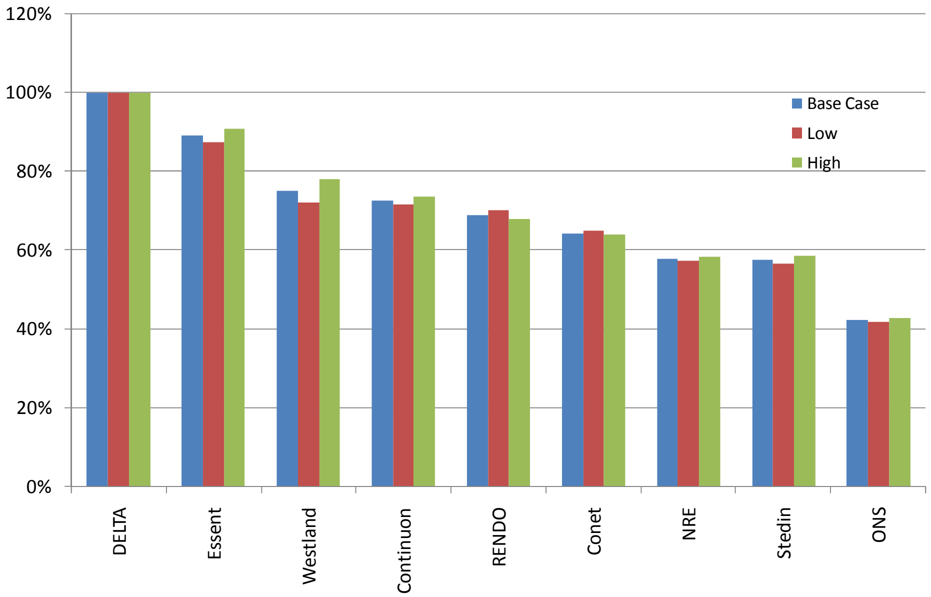
[13] A more in-depth analysis of the impact of the surface definition on the quality of the results is provided in section 3.2.3.

**Figure 21** shows the results for electricity networks. Again the figures are normalised separately for each case of unit cost variation.

**Figure 21.** Modelled electricity line cost per connection – small surface definition; base, low and high unit cost variations (no HV levels included)



Source: Consentec analysis based on Energiekamer's data

Although the bandwidth of modelled cost per connection across the sample is slightly less broad than for gas, the general conclusions can be confirmed: Also for electricity networks the actual differences in connection density between the supply areas of the Dutch DNOs suggest a significant difference in line cost per connection, and this conclusion is robust against the assumptions concerning the dependency of unit cost on the level of urbanisation.

In the next section we verify if the above findings on *modelled* cost can be confirmed by statistical assessment of *actual* cost. In this context it is important to keep in mind that the modelled cost only relate to lines/pipes, whereas total cost additionally include substation cost and non-infrastructure cost.

### 3.2.2 Relationship between observed cost and connection density (Step 2a)

We use econometric analysis to estimate the relationship between the DNOs' costs and various measures of connection density. Specifically, we consider the following approaches to measuring connection density:

- **Basic approach:** number of connections per km$^2$
- **Approach 1:** number of connections per actual line or pipe length;
- **Approach 2:** number of connections per modelled line/pipe length;
- **Approach 3:** modelled network length weighted by constant unit costs; and,
- **Approach 4:** modelled network length weighted by variable unit costs.

We first assess the potential relationship between observed costs and connection density using basic measure, defined as number of connections per km$^2$. This basic approach allows us to directly verify whether the actual data for the Netherlands reveals the existence of a relationship between costs and connection density and could potentially identify a U-shaped relationship, as shown in **Figure 1**.

This approach could be sufficient if the supply task of each DNO was sufficiently homogenous. However, in this specific context this does not appear to be the case. Therefore, more refined measures, especially those based on the MNA, are required to truly capture the heterogeneity of the supply task of each DNO. We continue the econometric assessment using these measures.

For each of the MNA-based approaches (Approaches 2, 3 and 4) we also use three alternative surface definitions: “small”, “medium” and “large”.

Using alternative measures of connection density and, for each, different surface definitions, allows us to carry out a wide-spectrum analysis of the relationship between costs and connection density. In this section we present a summary of the results obtained using each approach.

As in the case of the descriptive data analysis presented in section 3.1, we have carried out this analysis using both total costs and an approximation of infrastructure related costs. In agreement with Energiekamer, we have defined the latter as the sum of 100% of the DNOs’ capital expenditure plus 75% of their operating expenditure, in order to exclude costs that are not directly related to infrastructures, such as head office costs.

The second type of cost definition delivers consistently more robust results than when we use total costs. Therefore, the results we present here are those based on the analysis carried out using this measure.

In addition, the electricity cost data have been further corrected to exclude the costs associated to high voltage assets that have been transferred away from the DNOs to TenneT. In order to explore the impact of alternative HV arrangement we have considered two cases:

- No HV costs included

- No HV costs included with the exception of Stedin's and 10% of Continuon's (remaining Cross Border Lease).

Before presenting the results of the econometric analysis we believe it is important to note that the small size of the dataset may limit the ability of the econometric analysis to identify statistically significant relationships.

Due to the very small data sample, we have been constrained in terms of the number of explanatory variables that we could add to the regression model. Therefore, we have carried out the analysis trying to explain variations in unit costs exclusively using measures of connection density. We have not used any additional explanatory variable.

We have also carried out the econometric analysis of the relationship between actual costs and connection density using an alternative approach, under which connection density is measured by considering the network length by $km^2$. The results of this analysis are presented in Annexe 1.

### Gas

We start the analysis by trying to estimate the relationship between actual average cost per connection and the basic measure of density defined as number of connections per $km^2$. This provides a direct link with the type of relationship illustrated in **Figure 1**.

**Figure 22** shows all the observations for the gas DNOs as well as the regression line of 'best-fit' that we have estimated. According to the figure there does not appear to be a relationship between average costs per connection and number of connections per $km^2$.

We have also repeated the analysis excluding Westland from the sample but, while this markedly improves the statistical significance of the relationship, the overall result fails to reach an acceptable significant threshold. In order to capture any non-linearity in the relationship we have also introduced a quadratic term in the model specification. However, also in this case the regression analysis fails to produce significant results. The results are presented in **Table 5**. Generally, the results of the analysis can be considered statistically significant if the significance level is equal to 95% or higher, which is notably beyond the significance levels obtained here.

**Figure 22.** Actual average cost per connection vs. number of connections per km$^2$ (Basic approach) - GAS

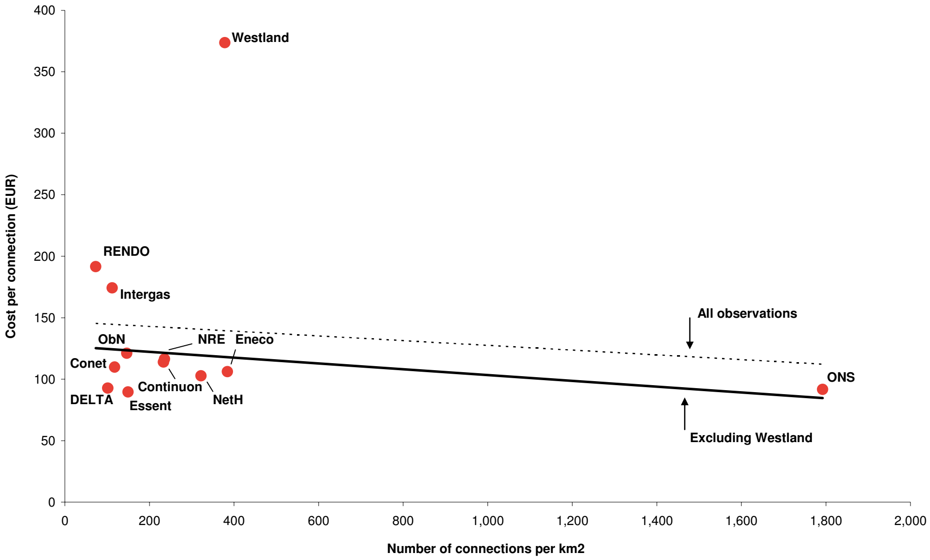


**Table 5.** Average cost per connection vs. number of connections per km$^2$: regression significance results

| Model specification | Including Westland | Excluding Westland |
|---|---|---|
| **Without quadratic term** | 28% | 71% |
| **With quadratic term** | 65% | 80% |

Source: Frontier analysis using Energiekamer data

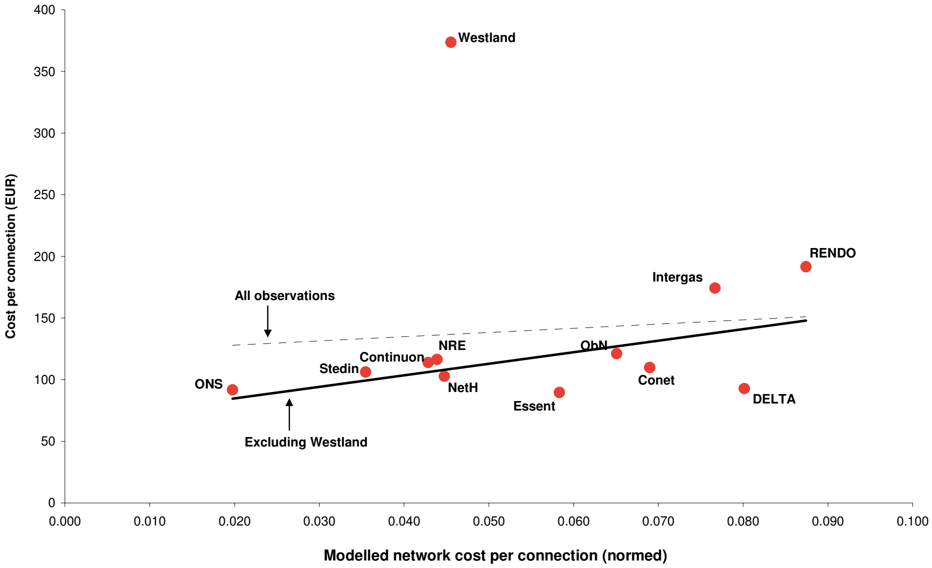
The inability of this simple regression analysis to find significant results may be due the fact that the basic measure of connection density used in this case does not fully capture the heterogeneity of the supply task of each DNOs.

In order to better take this complexity into account, we continue the analysis using further measures of connection density, as described in the previous section. **Figure 23** and **Figure 24** show scatter plots of the observations for gas DNOs.

For brevity, we present only those obtained using Approaches 3 and 4, respectively, calculated using the 'medium' surface definition. Approaches 1 and 2, and the other types of surface definitions, lead to very similar results. The charts also show the line of best fit obtained by the regression analysis.[14] As Westland appears to be an outlier in this dataset, we also repeat the analysis excluding this observation.

The two charts provide similar conclusions. When all observations are included in the analysis, the line of best fit is almost flat, suggesting the absence of a relationship between measures of connection density and cost. When the observation for Westland is removed, the regression analysis appears to suggest a weakly positive relationship between average connection costs and connection density (here measured by using MNA).

**Figure 23.** Actual average cost per connection vs. modelled network cost per connection (Approach 3, medium surface definition) - GAS



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[14] It is important to note that for the MNA-based measures of connection density a linear regression (i.e. a model without a quadratic term) is exhaustive, because the potential non-linearity of the density impact on asset volumes (and hence line/pipe cost) is already captured within the transformation using the MNA.

**Figure 24.** Actual average cost per connection vs. modelled network cost per connection (Approach 4, medium surface definition) - GAS

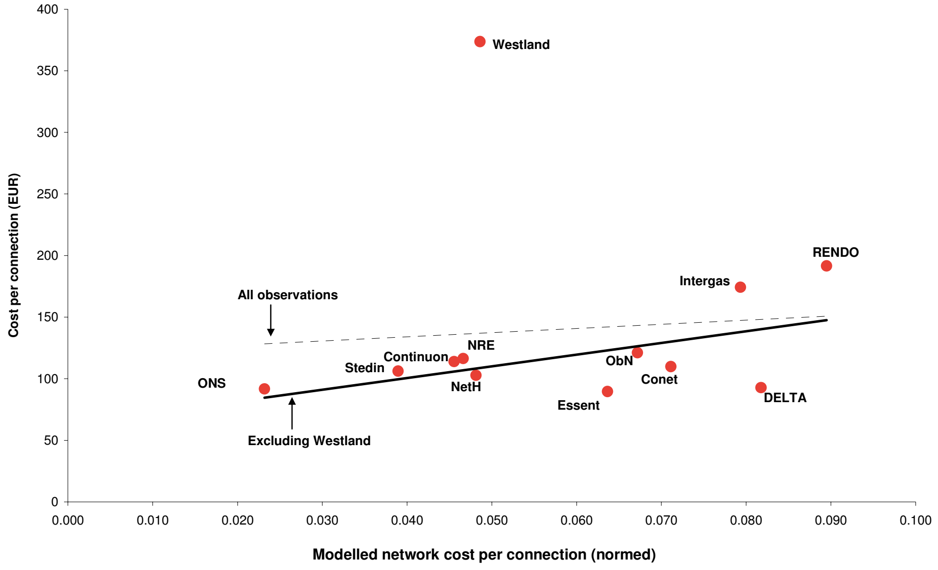

**Table 6** provides the statistical significance results of the regression analysis for all approaches and all surface definitions. As Westland is a clear outlier, we present only the results of the analysis carried out excluding this observation from the sample.

**Table 6.** Average cost per connection: regression significance results, all observations excl. Westland - GAS

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 91% | 91% | 91% |
| **Approach 2** | 88% | 94% | 81% |
| **Approach 3** | 88% | 94% | 81% |
| **Approach 4** | 86% | 94% | 79% |

Source: Frontier Economics analysis using Energiekamer's data

As noted above, the results of the analysis can be considered statistically significant if the significance level is equal to 95% or higher. In this case, no linear regression yields this result, although all of them show good levels of significance. The best results are obtained using the 'medium' surface definition, which yields levels of significance which are, in most cases, very close to the 95% threshold.

This analysis would therefore suggest the existence of a weakly significant positive relationship between connection density and the average cost of connection if Westland is excluded from the sample.

As noted during Step 1 of the analysis, Westland's position is due to differences in average connection capacity. To address this issue, similarly to what we have done for the descriptive analysis above, we carry out the regression analysis using the DNOs' average cost per unit of Composite Output as dependent variable instead of the average cost per connection. The Composite Output measure explicitly takes into account connection capacity.

**Figure 25** and **Figure 26** show the scatter plots of the observations for gas DNOs. Also in this case we present only the results obtained using Approaches 3 and 4. It can be seen that as expected Westland is no longer an outlier.

In both cases, the charts appear to suggest the existence of a positive relationship between measures of connection density and the cost per unit of Composite Output.

**Figure 25.** Actual cost per unit of Composite Output vs. modelled network cost per connection (Approach 3, medium surface definition) - GAS

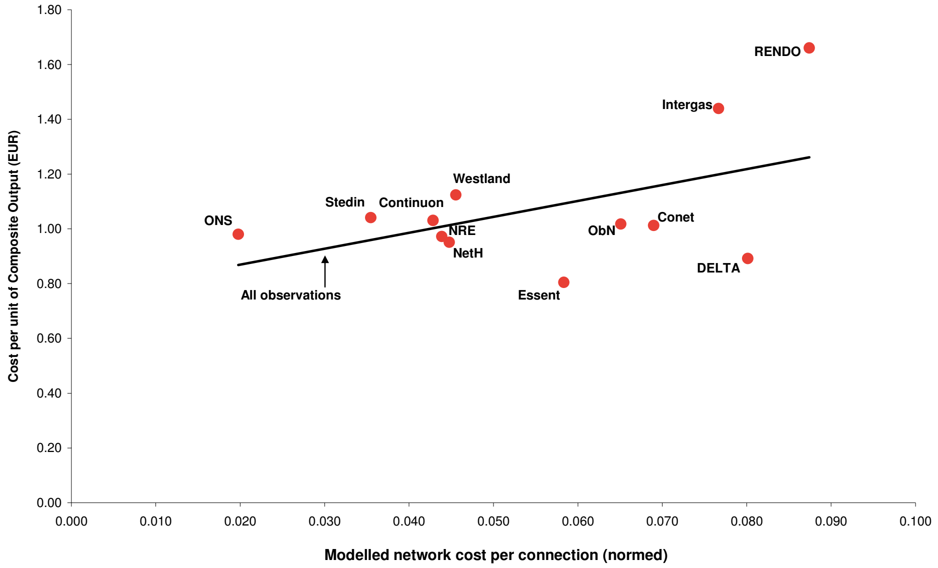

**Figure 26.** Actual cost per unit of Composite Output vs. modelled network cost per connection (Approach 4, medium surface definition) - GAS

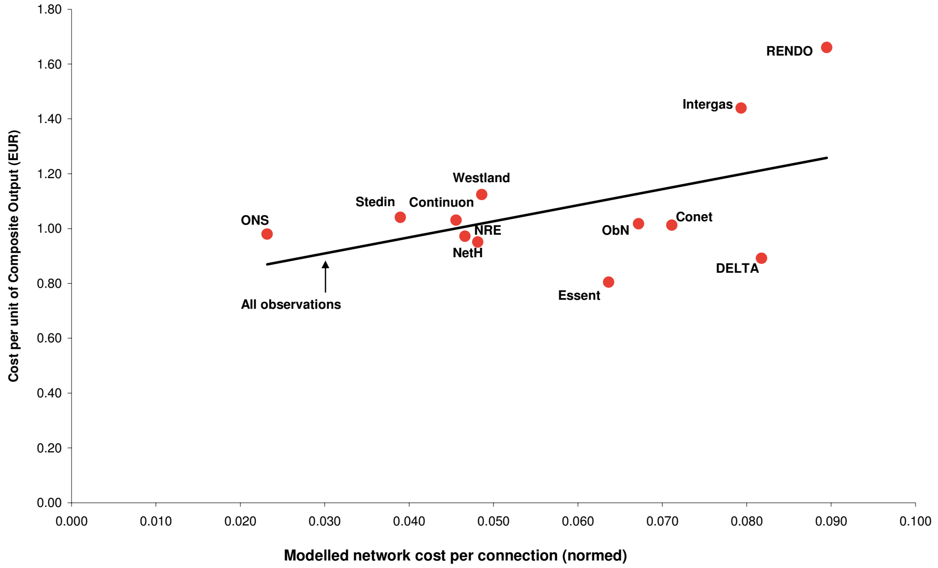

**Table 7** provides the statistical significance results of the regression analysis for all approaches and all surface definitions. In this case, as Westland is no longer an outlier, we present the results of the analysis carried out including all observations in the sample.

**Table 7.** Cost per unit of Composite Output: regression significance results, all observations - GAS

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 90% | 90% | 90% |
| **Approach 2** | 72% | 90% | 74% |
| **Approach 3** | 72% | 90% | 74% |
| **Approach 4** | 68% | 89% | 72% |

Source: Frontier Economics analysis using Energiekamer's data

Despite the use of an alternative measure of unit cost, which aligns Westland's position with that of the rest of the industry, the significance of the relationships identified by the econometric analysis is lower than those obtained previously, suggesting a very weak relationship. As in the case of the average cost per connection, the 'medium' surface definition yields the highest results, which, however, only reach the 90% level of significance.

In general, the analysis for gas, using both cost definitions, has failed to confirm the existence of a significant relationship between observed costs and connection density.

### Electricity

We have used the same approach for electricity. Unfortunately, in this case, the number of observations available is lower than in the case of gas. This further reduces the likelihood of the regression analysis to identify robust relationships.

As noted above, the electricity cost data have been further corrected to exclude the costs associated to high voltage assets that have been transferred away from the DNOs. In order to explore the impact of alternative HV arrangements, we have considered two cases:

- No HV costs included
- No HV costs included with the exception of Stedin's and 10% of Continuon's (remaining Cross Border Lease).

As a sensitivity analysis, we have also carried out the same analysis without applying any high voltage correction to the cost data. We note that the results, shown in Annexe 2, are not significantly different from those presented in this section.

As for the case of gas, we start the analysis by trying to estimate the relationship between actual average cost per connection and the basic measure of density defined as number of connections per km$^2$. This provides a direct link with the type of relationship illustrated in **Figure 1**. We have carried out this analysis only for the case in which HV costs are fully excluded. This is because the results are not expected to vary between the two cases.

As shown in **Figure 27**, there does not appear to be a relationship between average costs per connection (excluding HV levels) and number of connections per km$^2$.

We have also repeated the analysis excluding Westland from the sample but, while this markedly improves the statistical significance of the relationship, the overall result fails to reach an acceptable significant threshold. In order to capture any non-linearity in the relationship we have also introduced a quadratic term in the model specification. In this case, the significance results of the regression are worse, suggesting the absence of any non-linearity in the relationship between average cost per connection and average connection density. The results are presented in **Table 8**.

**Figure 27.** Actual average cost per connection vs. number of connections per km$^2$ (Basic approach) – ELEC – No HV costs

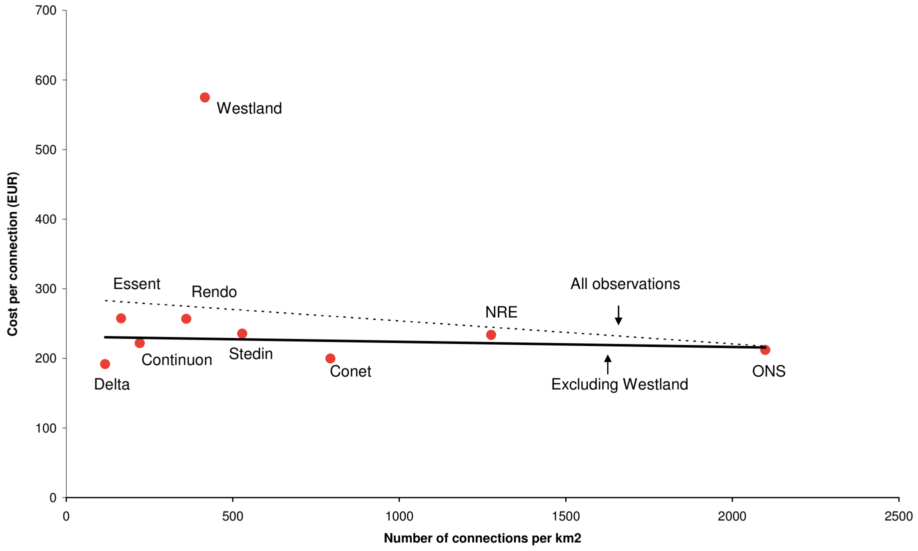

**Table 8.** Average cost per connection vs. number of connections per km$^2$: regression significance results – No HV costs

| Model specification | Including Westland | Excluding Westland |
|---|---|---|
| **Without quadratic term** | 35.8% | 38.1% |
| **With quadratic term** | 15.6% | 8.7% |

Source: Frontier analysis using Energiekamer data

The inability of this simple regression analysis to find significant results may be due the fact that the basic measure of connection density used in this case does not fully capture the heterogeneity of the supply task of each DNOs.

**Figure 28** and **Figure 29** show scatter plots of the observations for electricity DNOs.[15] Also in this case, we present only the charts obtained using approaches 3 and 4, respectively, calculated using the 'medium' surface definition. All the

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[15] These figures, as well as **Figure 30** and **Figure 31**, show only the case in which HV levels are completely excluded from the cost base. This is because the charts for the case in which only Stedin's and 10% Continuon's HV costs (remaining Cross Border Lease) would look very similar to those presented here and would not add new significant information. The same applies to all figures presented in Annexe 1.

other approaches, and the other types of surface definitions, lead to very similar results. The charts also show the line of best fit obtained by the regression analysis. As Westland appears to be an outlier in this dataset, we also repeat the analysis excluding this observation.

**Figure 28.** Actual average cost per connection vs. modelled network cost per connection (Approach 3a, medium surface definition) – ELEC – No HV costs

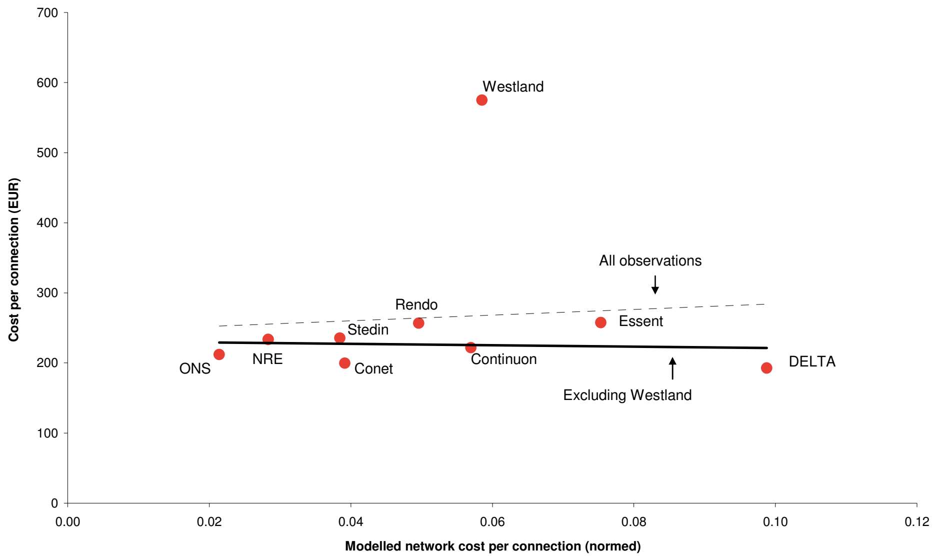
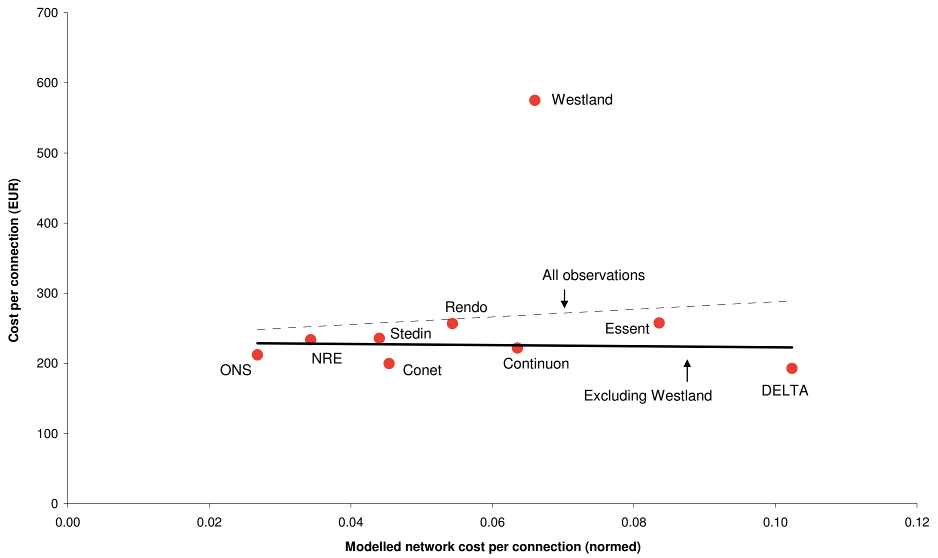


**Figure 29.** Actual average cost per connection vs. modelled network cost per connection (Approach 4a, medium surface definition) – ELEC – No HV costs



The two charts provide similar conclusions. When all observations are included in the analysis, the line of best fit appears to suggest a weak positive relationship between measures of connection density and cost. When the observation for Westland, a clear outlier, is removed, the relationship between density and average cost per connection almost disappears.

**Table 9** provides the statistical significance results of the regression analysis for all approaches and all surface definitions. These results have been estimated excluding Westland from the sample.

**Table 9.** Average cost per connection: regression significance results, all observations excl. Westland – ELEC – No HV costs

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 9 % | 8% | 9% |
| **Approach 2** | 12% | 20% | 25% |
| **Approach 3** | 16% | 20% | 27% |
| **Approach 4** | 9% | 15% | 24% |

Source: Frontier analysis using Energiekamer's data

In addition to the econometric analysis carried out without any HV-related costs, we also considered the impact of including Stedin's and 10% of Continuon's High Voltage assets. As it can be seen from **Table 10**, the results are not dissimilar from those shown above.

**Table 10.** Average cost per connection: regression significance results, all observations excl. Westland – ELEC – Only Stedin's and 10% Continuon's HV costs

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 0% | 1% | 0% |
| **Approach 2** | 4% | 12% | 18% |
| **Approach 3** | 7% | 12% | 20% |
| **Approach 4** | 1% | 8% | 17% |

Source: Frontier analysis using Energiekamer's data

All the results of the regression analysis are very far from the 95% threshold which is required for statistical significance. None of the approaches suggests the existence of a relationship between average electricity connection costs and measures of connection density. The results presented above are calculated excluding Westland from the sample, as it was a clear outlier. In order to address this issue, we also carried out the regression analysis the DNOs' average cost per unit of Composite Output instead of the average cost per connection. **Figure 30** and **Figure 31** show the scatter plot obtained in this case for approaches 3 and 4, once again using the 'medium' surface definition.

**Figure 30.** Actual cost per unit of Composite Output vs. modelled network cost per connection (Approach 3, medium surface definition) – ELEC – No HV costs

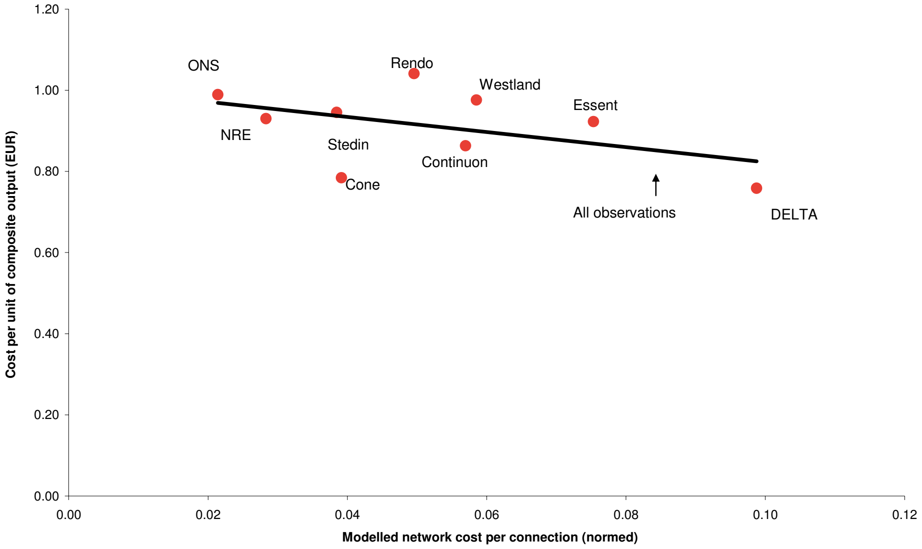
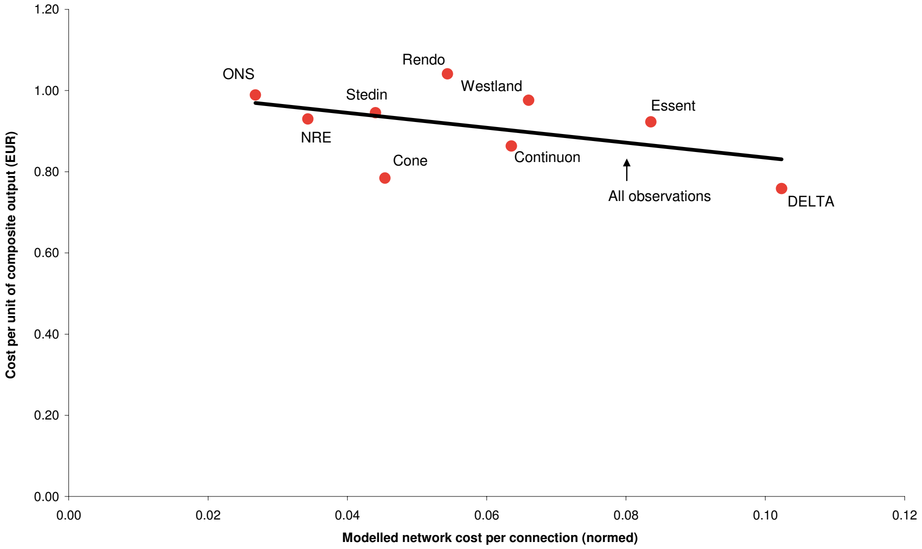


**Figure 31.** Actual cost per unit of Composite Output vs. modelled network cost per connection (Approach 4a, medium surface definition) – ELEC – No HV costs



In this case, Westland is no longer an outlier as the definition of Composite Output takes explicitly into account connection capacity.

The charts suggest the existence of a relationship between measures of connection density and cost per unit of Composite Output. However, in this case the relationship appears to be negative, implying that a lower cost per unit of Composite Output may be associated to higher modelled cost per connection and hence to lower levels of density.

**Table 11** provides the statistical significance results of the regression analysis for all approaches and all surface definitions. These results have been estimated using the average cost per unit of Composite Output as dependent variable and including all observations in the analysis.

**Table 11.** Cost per unit of Composite Output: regression significance results, all observations – ELEC – No HV costs

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 51% | 52% | 51% |
| **Approach 2** | 85% | 81% | 82% |
| **Approach 3** | 82% | 80% | 81% |
| **Approach 4** | 81% | 79% | 80% |

Source: Frontier analysis using Energiekamer's data

In addition to the econometric analysis carried out without any HV-related costs, we also considered the impact of including Stedin's and 10% of Continuon's High Voltage assets. As it can be seen from **Table 12**, the results are not dissimilar from those shown above.

**Table 12.** Cost per unit of Composite Output: regression significance results, all observations – ELEC – Only Stedin's and 10% Continuon's HV costs

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 42% | 42% | 42% |
| **Approach 2** | 79% | 75% | 76% |
| **Approach 3** | 77% | 74% | 76% |
| **Approach 4** | 76% | 73% | 75% |

Source: Frontier analysis using Energiekamer's data

As in the case of gas, the regression analysis carried out using the cost per unit of Composite Output as dependent variable leads to results that are closer to the 95% significance threshold. These results therefore suggest the existence of a very weak relationship between connection density and costs.

In general, the analysis for gas, using both cost definitions, has failed to confirm the existence of a significant relationship between observed costs and connection density.

### 3.2.3 Correlation between modelled network length and actual network length (Step 2b)

The econometric assessment presented in the previous section yields no strong statistical significance of a relation between alternative measures of connection density and actual cost. However, given the properties of the sample, this does neither allow for a confirmation nor a rejection of the assumption that connection density has an impact on cost.

However, as discussed in section 3.2.1, the MNA does suggest a correlation between connection density and the *share* of cost which relates to lines/pipes.

Theoretically, one could try and verify this finding using a regression of MNA output (i.e. modelled line/pipe cost) and actual line/pipe cost, i.e. purely infrastructure-related costs. However, as noted earlier, we could not draw conclusions about actual line/pipe related cost shares per DNO based on the available cost data.

Nevertheless, a verification of the MNA findings is possible, albeit with some approximation:

- The analysis aims at identifying relative cost impacts, i.e. cost ratios between DNOs.

- If actual unit cost (per km of line/pipe) were identical across all DNOs, the length of lines/pipes would be proportional to their cost.

- Consequently, under the assumption of reasonably similar unit cost among the DNOs we can use the line/pipe length ratios between DNOs as proxy for line/pipe cost ratios. Data on line/pipe lengths have been provided to Energiekamer by the DNOs.

Hence a regression of actual and modelled line/pipe lengths can be used to verify the theoretical results of the MNA. Moreover, it can be used to identify which surface definition leads to the "best fit" to real circumstances. However, it should be noted that such assessment does not allow us to estimate the quantitative impact of connection density on total cost, since the ratio of line/pipe cost and total cost may differ between DNOs.

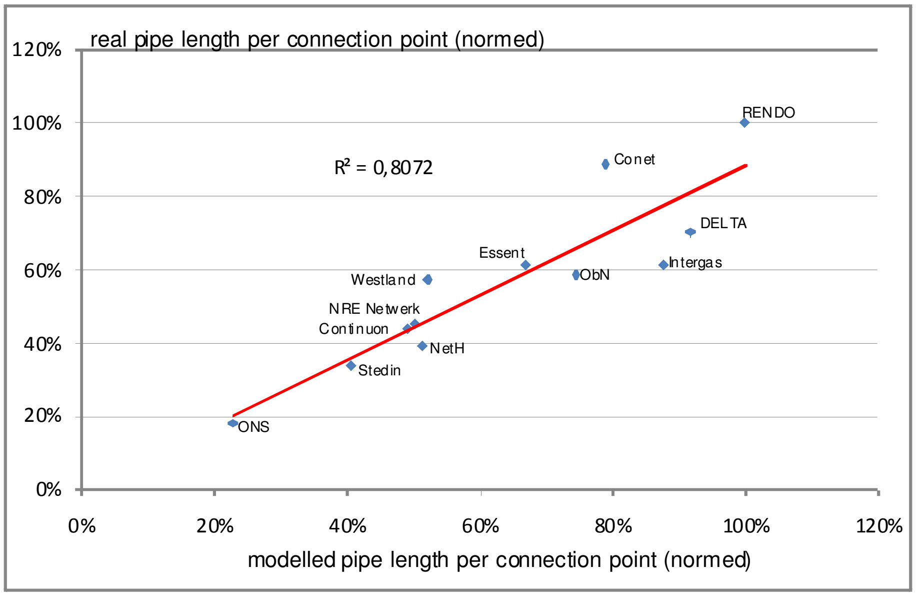
### Gas

As the MNA for gas does not differentiate between pressure levels, the MNA output for approaches 2 and 3 (cf. **Figure 2**) only differs by a constant factor; hence these approaches are identical as regards a relative comparison between gas DNOs.

Data on actual pipe length are only available at an aggregate level per DNO, and not broken down by area. Therefore, approaches 4 (variable unit cost) and 3 (constant unit cost) cannot be compared in this assessment, as this would require actual pipe length data on postcode level.

**Figure 32** shows a scatter plot of the relation between actual and modelled pipe length for the "medium" surface definition. This definition yields the highest correlation for gas; a comparison of the three definitions is given below in the course of the joint evaluation of gas and electricity results.

**Figure 32.** Real vs. modelled pipe length per connection – medium surface definition



Source: Consentec based on Energiekamer's data

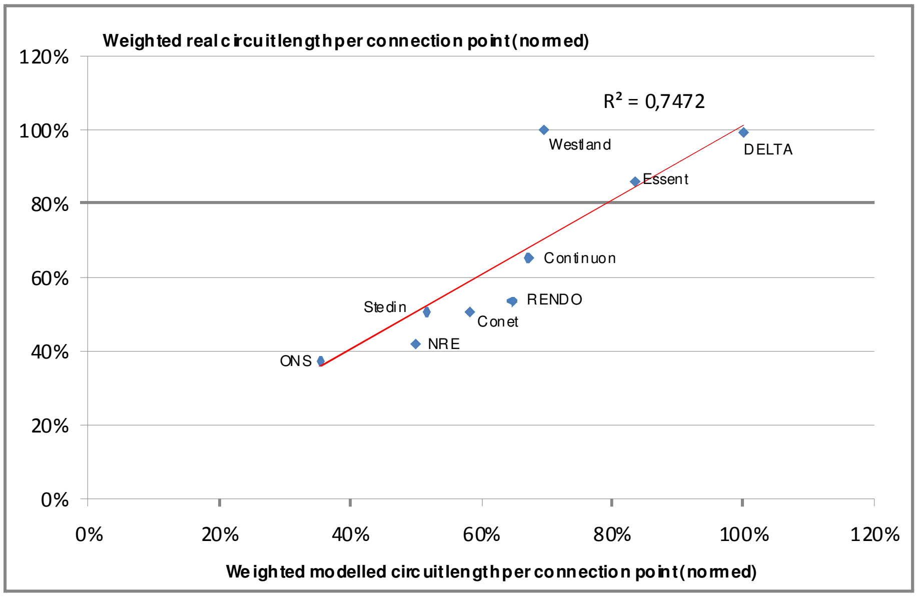
## *Electricity*

For electricity approaches 2 and 3 differ from each other. Approach 3 takes account of the different voltage levels by considering that their relative importance for the total line cost does not only depend on the length, but also on the unit cost, which are higher for higher voltages. Consequently, we weight the line length with relative unit cost per voltage level, using the constant unit cost data as given in **Table 4**. This is done consistently for the modelled lengths (i.e. approach 3) and for actual lengths. We note that HV levels are not included in the analysis.

Again approach 4 cannot be compared to approach 3, because actual line length data are not available on postcode level.

**Figure 33** shows a scatter plot of the relation between weighted actual and modelled line (exactly: circuit) length for the "small" surface definition. This definition yields the highest correlation for electricity; a comparison of the three definitions is given below in the course of the joint evaluation of gas and electricity results.

**Figure 33.** Weighted real vs. weighted modelled line length per connection (approach 3) – small surface definition, no HV levels included.

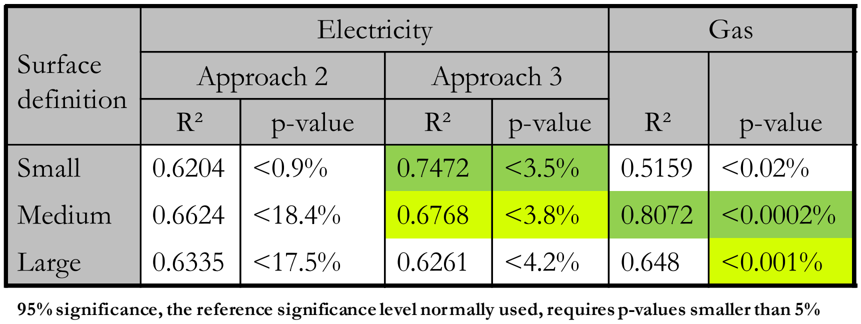


Source: Consentec based on Energiekamer's data

## *Evaluation – Gas and Electricity*

**Table 13** gives a summary of the regression results for gas and electricity, based on two indicators, $R^2$ and *p*-value. A high $R^2$ indicates a high correlation between actual and modelled line/pipe length. The *p*-value denotes the level of statistical significance; for a significance level of 95 %, *p* must be smaller than 5 %.

**Table 13.** Significance of relations between actual and modelled line/pipe length – comparison of approaches and surface definitions



| Surface definition | Electricity | | | | Gas | |
|---|---|---|---|---|---|---|
| | Approach 2 | | Approach 3 | | | |
| | $R^2$ | p-value | $R^2$ | p-value | $R^2$ | p-value |
| Small | 0.6204 | <0.9% | 0.7472 | <3.5% | 0.5159 | <0.02% |
| Medium | 0.6624 | <18.4% | 0.6768 | <3.8% | 0.8072 | <0.0002% |
| Large | 0.6335 | <17.5% | 0.6261 | <4.2% | 0.648 | <0.001% |

95% significance, the reference significance level normally used, requires p-values smaller than 5%

Source: Consentec analysis based on Energiekamer's data

For electricity, approach 3 clearly surpasses approach 2, which appears logical from a conceptual perspective given the better approximation of cost differences between voltage levels.

The results for electricity (approach 3) as well as for gas yield clearly significant relationships between MNA output per connection (being a measure of connection density) and actual (weighted) line/pipe length per connection (being a proxy of line/pipe related cost). This confirms the applicability of MNA in the Dutch context, thereby underpinning the relevance of the results presented in section 3.2.1. However, these findings cannot be used to determine the impact of connection density on the total cost of the DNOs, because we could not draw conclusions about actual line/pipe related cost shares per DNO based on the available cost data.

A comparison between the three surface definitions shows that – consistently with respect to $R^2$ and the *p*-value – the "small" definition is most significant for electricity, while the "medium" definition fits best for gas. This result is clearer for gas than for electricity, where "small" and "medium" definitions yield similar significance levels.

# 4 Conclusion

In this section, Step 3 of our analysis, we bring together the results of the previous steps of the analysis and provide an assessment of whether, on the basis of the evidence found, the key criteria for the inclusion of a correction factor for differences in connection density are fulfilled.

## 4.1 Summary of key results

**Step 1 – Differences between firms.** In the first step of the analysis, we have found similar results for both gas and electricity. Specifically, we noted that the DNOs tend to differ significantly in terms of levels of connection density. However, these variations do not appear to be matched by similar variations in costs per connection or per unit of Composite Output. The difference in costs appears to be smaller for electricity than for gas, but, in both cases the DNOs tend to be more similar in terms of costs than in terms of connection density.

This observation implies that it is sensible to progress to the second step of the analysis and explore the connection density-cost relationship in greater detail.

According to the MNA the actual differences in connection density between the supply areas of the Dutch DNOs suggest a significant difference in line/pipe related cost per connection. Additionally, the MNA shows that the impact of connection density on the line/pipe *length* per connection by far outweighs the *unit cost* (i.e. cost per km of line/pipe) differences between different degrees of urbanisation. Hence there is no evidence for the existence of a so-called U-curve in the Netherlands.

**Step 2 – Density-cost relationship.** In Step 2, we have turned to assessing the relationship between the DNOs' costs and measures of connection density using econometric techniques. We have approached this issue from two different angles.

*Step 2a – Observed cost and connection density.* In Step 2a, we have attempted to estimate the relationship between average observed costs and various measures of connection density. For electricity, we have carried out this analysis both excluding all HV levels and also including only the HV levels related to the Cross Border Lease. The analysis in Step 2a has failed to identify a statistically significant relationship between observed costs and measures of connection density. The same conclusions hold for both gas and electricity (for the latter, both when HV levels are completely excluded and also when only Cross Border Lease HV levels are included). We have used alternative definitions of costs and connection density but no specification has yielded statistically significant econometric results. The lack of significant results may be attributed to the small sample size, which makes this type of analysis less robust. Therefore, any conclusion regarding the impact of connection density on costs may need to be based on the results of the MNA alone. As noted above, we did not use actual infrastructure-related costs in the analysis as this information was not available. However, it is possible that the small sample size would still prevent obtaining statistically significant results. In fact, using infrastructure-related costs does not provide any guarantee that the results will be statistically significant.

*Step 2b – Hypothetical cost and connection density.* In Step 2b, we have assessed the relationship between actual network length (as a proxy for cost) and modelled network length (as a proxy for the complexity of the operating environment which includes connection density). This has allowed us to estimate the extent to which the modelled results approximate the actual data and, hence, assess the applicability of the MNA's results to the case of the Netherlands. We note that the MNA analysis has been carried out excluding all HV levels from the modelling.

The results for electricity as well as for gas yield clearly significant relationships between MNA output per connection (being a measure of connection density) and actual line/pipe length per connection (being a proxy of actual line/pipe related cost). This confirms the applicability of MNA in the Dutch context, thereby underpinning the relevance of the above mentioned MNA results. However, these findings cannot be used to determine the impact of connection density on the total cost of the DNOs, because we could not draw conclusions about actual line/pipe related cost shares per DNO based on the available cost data.

## 4.2 Fulfilment of key criteria

**Step 3 - Assessment of key criteria**. On the basis of the results presented above, we have attempted to assess whether the evidence we have collected fulfils Energiekamer's key criteria of objectivity and significance. If this were to be the case, connection density should be acknowledged by the regulatory framework as a regional cost difference.

With regards to **objectivity**, this criterion would be satisfied if the impact of connection density on costs can be objectively quantified and if such difference cannot be affected by management decisions.

On the latter aspect, the connection density measures we applied for the major part of the analysis – in particular for the application of the MNA – are exclusively based on the number of connections and the size of the supply area, which are both exogenous to the DNOs. This is, however, not the case when connection density is defined as connections per km of actual line or pipe, since the actual asset volumes are under control of the DNOs.

We have not been able to verify an impact of connection density on costs using actual data on Dutch DNOs. Therefore, any remaining hypothesis would be based on the outcome of the MNA. This MNA suggests a certain link between connection density and costs. Specifically, there appears to be a negative relationship between costs and connection density, leading to significant differences in modelled costs per connection. On the other hand, even when applying MNA we have not found evidence to support the hypothesis of an upward sloping part of the cost curve. That would imply that if a relevant relationship exists at all it is one of average cost falling with connection density and not rising with connection density.

The **significance** criterion is assessed along two dimensions.

First of all, the claimed regional differences need to be **substantial**. By this Energiekamer means that if, for at least one DNO, the average cost per connection, expressed as percentage of Composite Output, exceeds the industry average cost per connection by more than one percentage point. The lack of a clear empirical relationship between costs and connection density does not allow us to determine what share of these differences should be attributed to different levels of connection density. Similarly, the MNA results yield a relationship between connection density and line/pipe related cost shares, but the lack of data about the actual shares of line/pipe related cost of Dutch DNOs prevents its transformation to an impact on total cost. We are therefore unable to state whether this criterion is fulfilled.

Finally, regional differences should be **sustainable**, i.e. the differences between DNOs in terms of connection density remain similar over time and do not fluctuate significantly. Given the inconclusive results above, we have not carried out an inter-temporal analysis of costs. We are therefore unable to comment on this criterion on an empirical basis. However, one can generally expect that the connection density of a DNO's supply area does not change rapidly over time as it is related to demographic and economic developments.

Overall, the evidence collected is not sufficiently strong to determine whether connection density fulfils the key criteria for inclusion in the regulatory framework. While the engineering modelling suggests that this may be the case, the actual data on total cost do neither support nor contradict this result.

# Annexe 1: Alternative econometric analysis

In this section we present the results of the econometric analysis of Step 2a carried out using modelled network length per km$^2$. This analysis is an alternative approach with respect to what has been presented in the main body of this report. As it can be seen from the remainder of this Annexe, the results of the analysis lead to conclusions which are very similar to those presented in the main body.

## Relationship between actual cost and connection density

We use econometric analysis to estimate the relationship between the DNOs' unit costs and various measures of connection density. Specifically, we consider the following approaches to measuring connection density:

- **Approach 1:** number of connections per actual line or pipe length;
- **Approach 2:** number of connections per modelled line or pipe length;
- **Approach 3:** modelled network length weighed by constant unit costs per km$^2$; and,
- **Approach 4:** modelled network length weighted by variable unit costs per km$^2$.

For each of the MNA-based approaches (Approaches 2, 3 and 4) we also use three alternative surface definitions: "small", "medium" and "large". This conforms to the illustration of the approach illustrated in **Figure 2**.

Using alternative measures of connection density and, for each, different surface definitions, allows us to carry out a wide-spectrum analysis of the relationship between costs and connection density. In this section we present a summary of the results obtained using each approach.

As in the case of the descriptive data analysis presented in section 3.1, we have carried out this analysis using both total costs and an approximation of infrastructure related costs. In agreement with Energiekamer, we have defined the latter as the sum of 100% of the DNOs' capital expenditure plus 75% of their operating expenditure, in order to exclude costs that are not directly related to infrastructures, such as head office costs.

In addition, the electricity cost data have been further corrected to exclude the costs associated to high voltage assets that have been transferred away from the DNOs to TenneT. In order to explore the impact of alternative HV arrangement we have considered two cases:

- No HV costs included

- No HV costs included with the exception of Stedin's and 10% of Continuon's (remaining Cross Border Lease).

As noted in section 3.1, the second type of cost definition, with the approximated infrastructure-related cost, delivers consistently more statistically significant results than when we use total costs. Therefore, the results we present here are those based on the analysis carried out using this measure.

Before presenting the results of the econometric analysis we believe it is important to note that the small size of the dataset may limit the ability of the econometric analysis to identify statistically significant relationships.

Due to the very small data sample, we have been constrained in terms of the number of explanatory variables that we could add to the regression model. Therefore, we have carried out the analysis trying to explain variations in unit costs exclusively using measures of connection density. We have not used any additional explanatory variable.

The remainder of this section presents a summary of the results of the analysis.

### *Gas*

We start the analysis by trying to estimate the relationship between actual average cost per connection and various measures of connection density, as described in the previous section. **Figure 34** and **Figure 35** show scatter plots of the observations for gas DNOs.

For brevity, we present only those obtained using Approaches 3 and 4, respectively, calculated using the 'medium' surface definition. Approaches 1 and 2, and the other types of surface definitions, yield very similar results. The charts also show the line of best fit obtained by the regression analysis. As Westland appears to be an outlier in this dataset, we also repeat the analysis excluding this observation.

The two charts provide similar conclusions. When all observations are included in the analysis, the line of best fit is almost flat, suggesting the absence of a relationship between measures of connection density and cost. When the observation for Westland is removed, the regression analysis appears to suggest a weak relationship between average connection costs and network density.

**Figure 34.** Actual average cost per connection vs. modelled network cost (Approach 3, medium surface definition) - GAS

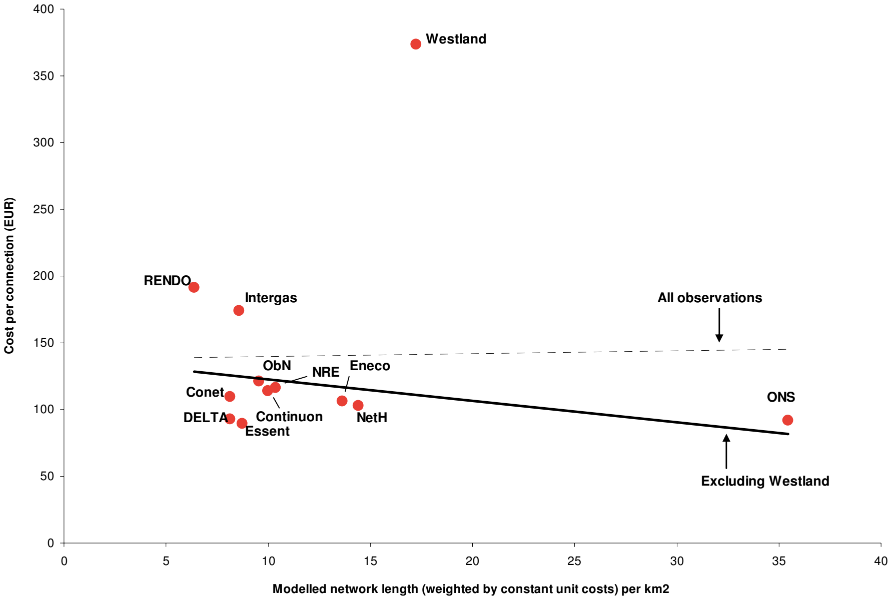


**Figure 35.** Actual average cost per connection vs. modelled network cost (Approach 4, medium surface definition) - GAS

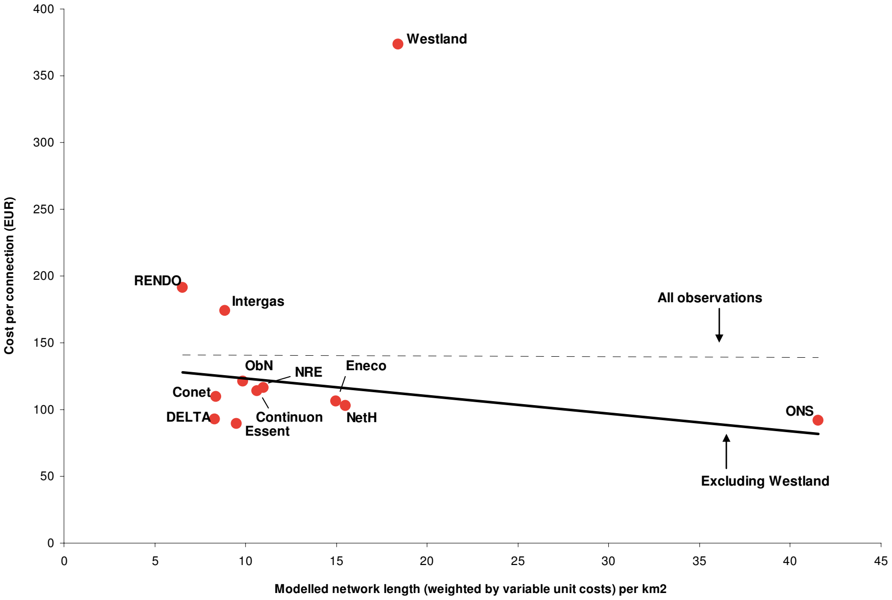


**Table 14** provides the statistical significance results of the regression analysis for all approaches and all surface definitions. As Westland is a clear outlier, we present only the results of the analysis carried out excluding this observation from the sample.

**Table 14.** Average cost per connection: regression significance results, all observations excl. Westland - GAS

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 78% | 78% | 78% |
| **Approach 2** | 74% | 76% | 77% |
| **Approach 3** | 74% | 76% | 77% |
| **Approach 4** | 73% | 75% | 77% |

Source: Frontier analysis using Energiekamer's data

Generally, the results of the analysis can be considered statistically significant if the significance level is equal to 95% or higher. In this case, no linear regression yields this result. On the contrary, none of the regressions provides a level of statistical significance higher than 79%. This analysis would therefore suggest that, for gas, there is no relationship between connection density and average observed unit costs, even when Westland is excluded from the sample.

Westland's position may be due to factors other than differences in connection density. To address this issue, similarly to what we have done for the descriptive analysis above, we carry out the regression analysis using the DNOs' average cost per unit of Composite Output as dependent variable instead of the average cost per connection. The Composite Output measure should already take into account some of the characteristics of the network and customer base faced by each DNO.

**Figure 36** and **Figure 37** show the scatter plots of the observations for gas DNOs. Also in this case we present only the results obtained using Approaches 3 and 4. It can be seen that, in this case, Westland does not appear to be an outlier anymore. This is probably because the characteristics that make it different from the rest of the industry are already accounted for in the Composite Output definition, at least partly.

In both cases, the charts appear to suggest the existence of a relationship between measures of connection density and the cost per unit of Composite Output.

**Figure 36.** Actual cost per unit of Composite Output vs. modelled network cost (Approach 3, medium surface definition) - GAS

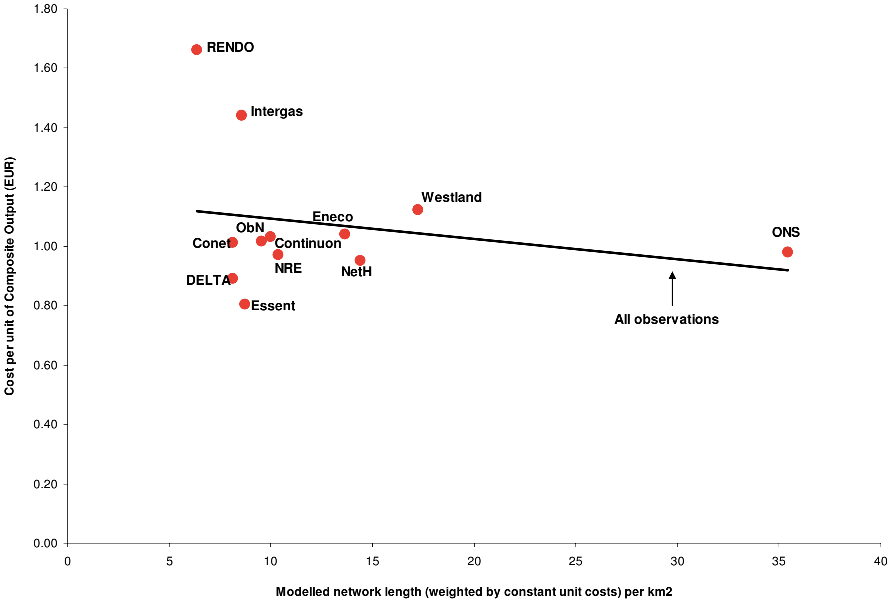


**Figure 37.** Actual cost per unit of Composite Output vs. modelled network cost (Approach 4, medium surface definition) - GAS

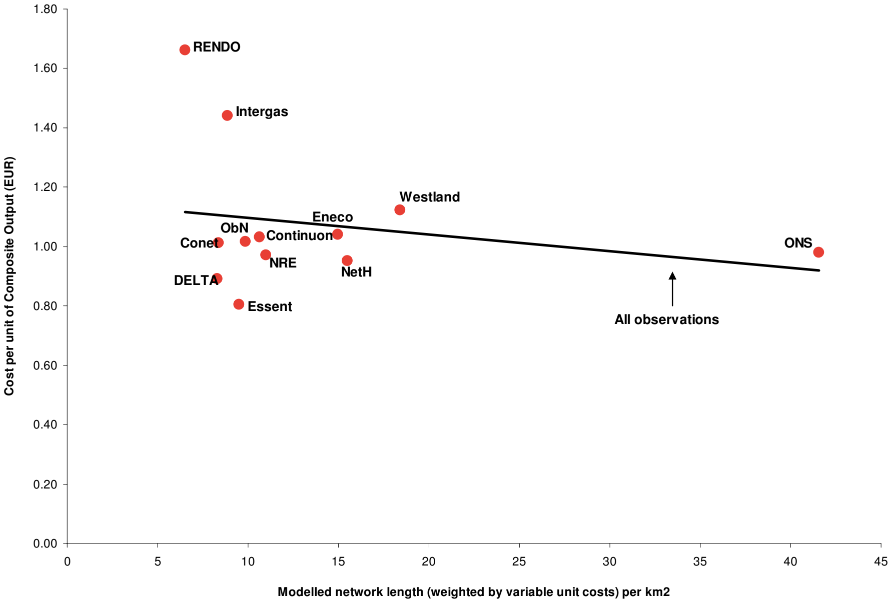


**Table 15** provides the statistical significance results of the regression analysis for all approaches and all surface definitions. In this case, as Westland is no longer an outlier, we present the results of the analysis carried out including all observations in the sample.

**Table 15.** Cost per unit of Composite Output: regression significance results, all observations – GAS

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 48% | 48% | 48% |
| **Approach 2** | 51% | 51% | 53% |
| **Approach 3** | 51% | 51% | 53% |
| **Approach 4** | 50% | 51% | 52% |

Source: Frontier analysis using Energiekamer's data

Despite the use of an alternative measure of unit cost, which aligns Westland's position with that of the rest of the industry, the significance levels of the relationships identified by the econometric analysis are lower than those obtained previously. As in the case of the average cost per connection, the 'medium' surface definition yields the highest results, which, however, are very far from the required 95% level of significance.

### Electricity

We used the same approach for electricity. For electricity, the number of observations available is lower than in the case of gas. This further reduces the likelihood of the regression analysis to identify robust relationships.

As noted above, the electricity cost data have been further corrected to exclude the costs associated to high voltage assets that have been transferred from the DNOs to TenneT. In order to explore the impact of alternative HV arrangements we have considered two cases:

- No HV costs included
- No HV costs included with the exception of Stedin's and 10% of Continuon's (remaining Cross Border Lease).

As for gas, we first try to estimate the relationship between actual average cost per connection and various measures of connection density.

**Figure 38** and **Figure 39** show scatter plots of the observations for electricity DNOs. Also in this case, we present only the charts obtained using Approaches 3a and 4a, respectively, calculated using the 'medium' surface definition. All the other approaches, and the other types of surface definitions, lead to very similar results. The charts also show the line of best fit obtained by the regression analysis. As Westland appears to be an outlier in this dataset, we also repeat the analysis excluding this observation.

**Figure 38.** Actual average cost per connection vs. modelled network cost (Approach 3a, medium surface definition) – ELEC – No HV costs

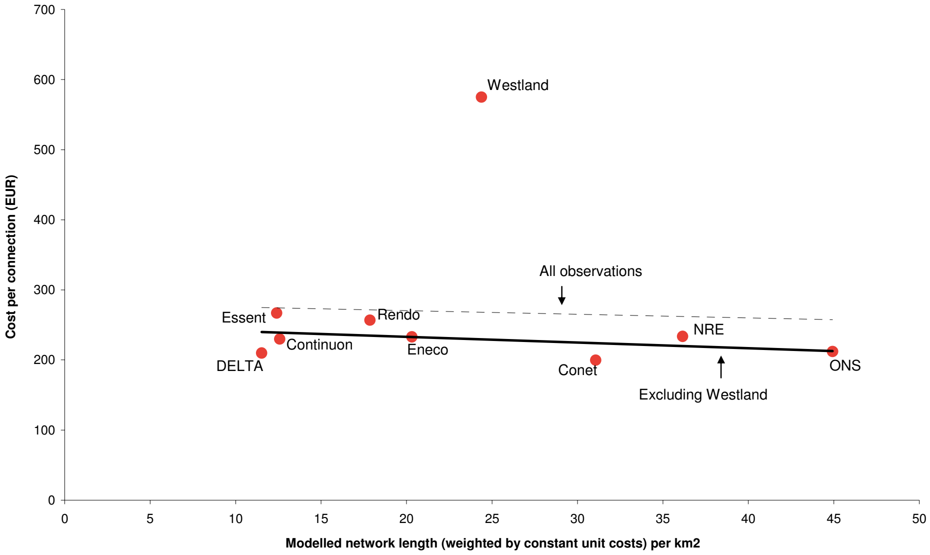
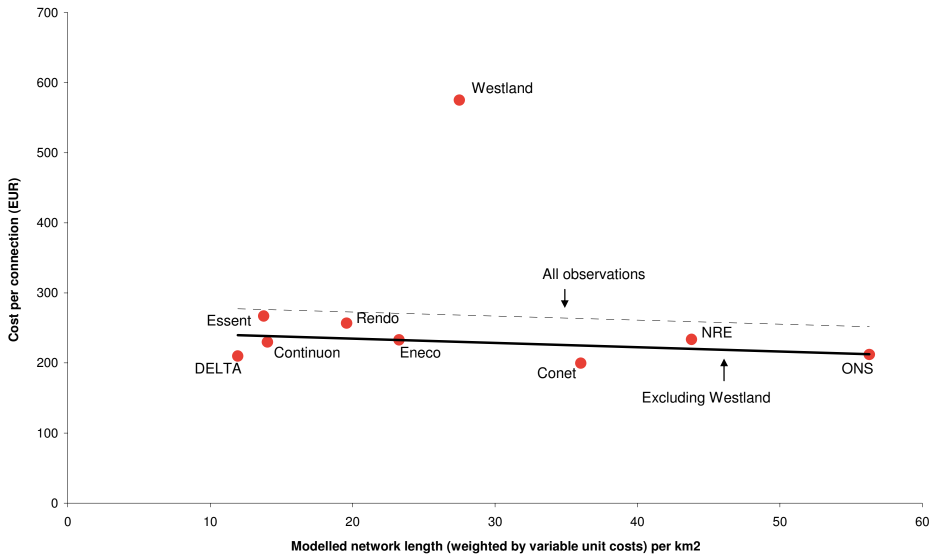


**Figure 39.** Actual average cost per connection vs. modelled network cost (Approach 4a, medium surface definition) – ELEC – No HV costs



The two charts provide similar conclusions. When all observations are included in the analysis, the line of best fit is almost flat, suggesting that no relationship exists between connection density and average observed connection costs. When the observation for Westland, a clear outlier, is removed, this conclusion does not appear to change. **Table 16** provides the statistical significance results of the regression analysis for all approaches and all surface definitions. These results have been estimated excluding Westland from the sample.

**Table 16.** Average cost per connection: regression significance results, all observations excl. Westland – ELEC – No HV costs

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 41% | 8% | 41% |
| **Approach 2** | 37% | 48% | 43% |
| **Approach 3** | 37% | 43% | 44% |
| **Approach 4** | 36% | 42% | 43% |

Source: Frontier analysis using Energiekamer's data

In addition to the econometric analysis carried out without any HV-related costs, we also considered the impact of including Stedin's and 10% of Continuon's

High Voltage assets. As it can be seen from **Table 17**, the results are not dissimilar from those shown above.

**Table 17.** Average cost per connection: regression significance results, all observations excl. Westland – ELEC – Only Stedin's and 10% Continuon's HV costs

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 41% | 1% | 42% |
| **Approach 2** | 38% | 44% | 44% |
| **Approach 3** | 38% | 44% | 45% |
| **Approach 4** | 37% | 43% | 44% |

Source: Frontier analysis using Energiekamer's data

All the results of the regression analysis are very far from the 95% threshold which is required for statistical significance. None of the approaches suggests the existence of a relationship between average electricity connection costs and measures of connection density.

The results presented above are calculated excluding Westland from the sample, as it was a clear outlier. In order to address this issue, we also carried out the regression analysis the DNOs' average cost per unit of Composite Output instead of the average cost per connection. **Figure 40** and **Figure 41** show the scatter plot obtained in this case for approaches 3a and 4a, once again using the 'medium' surface definition.

In this case, Westland ceases to appear as an outlier with respect to the rest of the industry suggesting that, also in the case of electricity, the factors that differentiate this company from the other DNOs are, at least partly, already accounted for in the definition of Composite Output.

In this case, the charts suggest the existence of a weak relationship between measures of connection density and cost per unit of Composite Output.

**Figure 40.** Actual cost per unit of Composite Output vs. modelled network cost (Approach 3a, medium surface definition) – ELEC – No HV costs

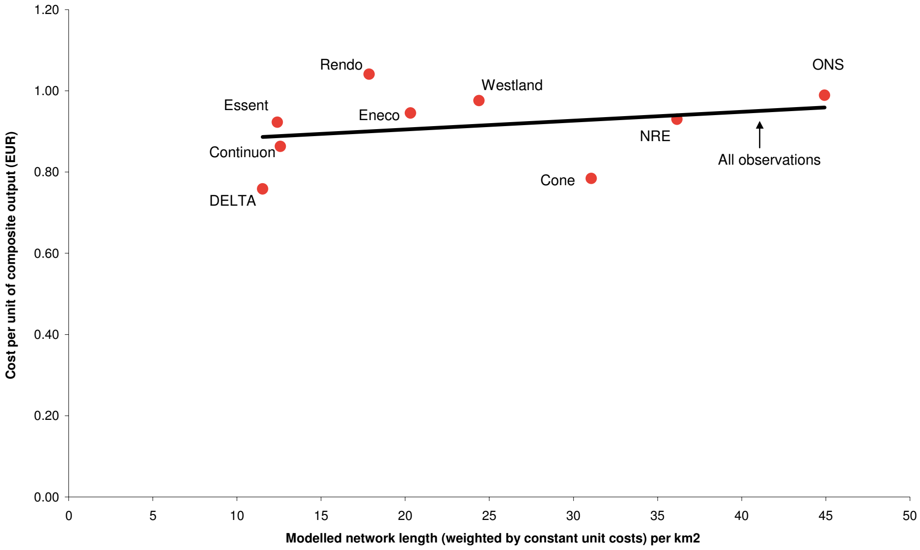


**Figure 41.** Actual cost per unit of Composite Output vs. modelled network cost (Approach 4a, medium surface definition) – ELEC – No HV costs

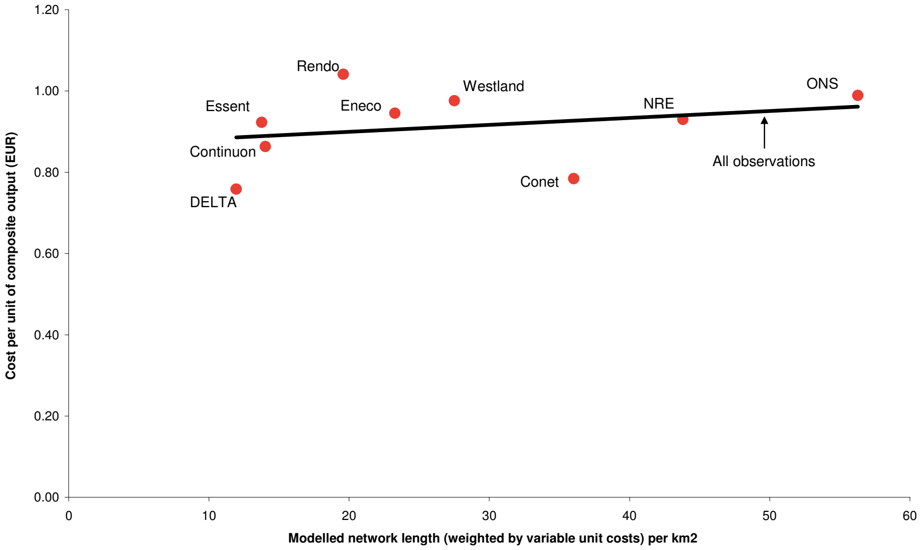


**Table 18** provides the statistical significance results of the regression analysis for all approaches and all surface definitions. These results have been estimated using

the average cost per unit of Composite Output as dependent variable and including all observations in the analysis.

**Table 18.** Cost per unit of Composite Output: regression significance results, all observations – ELEC – No HV costs

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 575 | 57% | 57% |
| **Approach 2** | 47% | 50% | 50% |
| **Approach 3** | 49% | 52% | 52% |
| **Approach 4** | 50% | 53% | 53% |

Source: Frontier analysis using Energiekamer's data

In addition to the econometric analysis carried out without any HV-related costs, we also considered the impact of including Stedin's and 10% of Continuon's High Voltage assets. As it can be seen from **Table 19**, the results are not dissimilar from those shown above.

**Table 19.** Cost per unit of Composite Output: regression significance results, all observations – ELEC – Only Stedin's and 10% Continuon's HV costs

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 57% | 57% | 57% |
| **Approach 2** | 46% | 50% | 49% |
| **Approach 3** | 47% | 50% | 50% |
| **Approach 4** | 50% | 51% | 51% |

Source: Frontier analysis using Energiekamer's data

The estimation of a relationship between costs and connection density using the cost per unit of Composite Output as dependent variable does not yield significant results and offers no improvement with respect to the previous estimation. Therefore, also for electricity the econometric analysis has not been able to identify a relationship between observed costs and connection density.

# Annexe 2: Analysis including HV costs

## Relationship between actual cost and connection density

In this annexe we present the significance results of the econometric analysis for electricity, carried out without applying any correction for high-voltage to cost data. As shown in **Table 20** and **Table 21**, also in this case the regression analysis fails to delivery statistically significant results.

**Table 20** provides the statistical significance results of the regression analysis for all approaches and all surface definitions. These results have been estimated excluding Westland from the sample.

**Table 20.** Average cost per connection: regression significance results, all observations excl. Westland – ELEC – HV costs included

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 39% | 40% | 23% |
| **Approach 2** | 34% | 30% | 21% |
| **Approach 3** | 32% | 30% | 21% |
| **Approach 4** | 38% | 34% | 25% |

Source: Frontier analysis using Energiekamer's data

**Table 21** provides the statistical significance results of the regression analysis for all approaches and surface definitions. These results have been estimated using the average cost per unit of Composite Output as dependent variable and including all observations in the analysis.

**Table 21.** Cost per unit of Composite Output: regression significance results, all observations – ELEC – HV costs included.

| | Small | Medium | Large |
|---|---|---|---|
| **Approach 1** | 65% | 65% | 65% |
| **Approach 2** | 92% | 92% | 92% |
| **Approach 3** | 91% | 91% | 92% |
| **Approach 4** | 90% | 89% | 91% |

Source: Frontier analysis using Energiekamer's data

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