A quantitative analysis of the spatial characteristics of households trapped in energy poverty in the Netherlands

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Abstract

Energy poverty has become more of a problem due to the rising cost of energy since late 2020. A plethora of research was done in the Netherlands to quantify how many households are affected by energy poverty. However, an underexposed phenomenon is the capability of households to get out of energy poverty. A quantitative analysis of data on 46658 households in the Netherlands was done to determine the share of households that is trapped in energy poverty. The concept of energy poverty was split into two categories, measured(mEP)- and hidden energy poverty(hEP). Households in mEP spent too much of their disposable income on energy, while households in hEP restrict their energy consumption below basic needs. Households are considered to be trapped in energy poverty when they are unable to increase the energy efficiency of their dwelling. Multiple reasons for this inability were aggregated into an indicator called non-participatory energy poverty. In the Netherlands, 2,5% of the population was found to be trapped in mEP. For hEP this was found to be 3,1%. Beyond these numbers, the spatial distributions were examined. Congruent with similar studies, trapped households in mEP were concentrated in rural areas. However, trapped households in hEP were concentrated in the Randstad and especially, the Hague. A weak yet significant linear relation was found between the degree of urban density of the surrounding neighborhood and hidden energy poverty. This study illuminates the variety of spatial distribution for different types of energy poverty, a phenomenon not earlier described in literature.

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Contents

1. Background

Energy poverty(EP) is a growing, multifaceted problem in the Netherlands (Mulder et al., 2021). Ep has various negative consequences such as (mental) health- and economic issues (Oliveras *et al.*, 2021;Cheng *et al.*, 2022). Properly identifying EP among citizens is vital to identifying which citizens need assistance.

However, there is no conclusive singular definition of EP. Different indicators are used to identify different aspects of EP by different scholars, but the same scholars all call it energy poverty despite their different methods for measuring it. For example, Mulder et al. (2021) divide EP indicators into three groups. These groups are *affordability*, *housing quality* and *the ability to participate in the energy transition*. Alternatively, there is the work of Meyer *et al.* (2018), which identifies EP in three different ways and categorizes them into *measured energy poverty* (spending too much of your disposable income on energy)*(mEP)*, *hidden energy poverty* (restricting energy consumption below basic human needs) *(hEP)*, and *perceived energy poverty*(expecting that one is not able to afford energy bills in the future) *(pEP)*. Finally, there is the work of Rademaekers *et al.* (2016), dividing the EP indicators into *expenditure-based* and *consensual-based* indicators. The indicators of Rademaekers et al. (2016) describe more or less the same phenomenon using slightly different methods.

Similar to the work of Meyer et al. (2018) in Belgium, the spatial characteristics of energy poverty in the Netherlands can be examined. Furthermore, when comparing rural and urban areas in Belgium, there were indications of difference in EP. Identifying different types of EP on a regional and urban-to-rural scale within the Netherlands could be helpful in designing an appropriate regional policy.

2. Research Problem

Determining what type of EP people suffer from and then determining if there is any overlap between mEP, hEP and pEP has been studied in Belgium (Meyer et al., 2018). A surprising lack of overlap was found between the pEP group and the mEP and hEP groups. This means that households that were already paying above the threshold of their disposable income on energy(mEP) or households that were throttling their energy consumption below basic needs(hEP) did not expect to be unable to pay their energy bills in the future. This means that households that were in EP by definition did not perceive themselves as such in terms of the definition of perceived energy poverty.

Even though consensual indicators (such as pEP) can help provide in-depth understanding, there are also some concerns that make them unreliable for measuring energy poverty. For example, there is a problem of subjectivity due to self-reporting. Participants' judgments of perceived energy poverty are highly subjective and unsuitable for comparison across time and place.

The aim of this study is to find out to what extent households in the Netherlands are stuck in EP. For this purpose, the households are identified either in mEP, hEP or non-participatory energy poverty(npEP)(see section 3 for definition of npEP). It is then determined how many households in either mEP or hEP are also in npEP. Households that are in two groups are thus identified as trapped in EP as they live in energy poverty and are unable to reduce their energy expenditure by increasing the energy efficiency(EE) of their homes.

In addition, this study aims to identify potential spatial differences when it comes to households being trapped in EP. This study uses three spatial indicators to identify spatial differences as accurately as possible. These indicators are *corop-gebied*, *address density*, and whether the household is located in G*4, G40* or *rest* city.

Following from the aim is the research question for this study, which is:

To what extent are Dutch households trapped in energy poverty in the Netherlands and what are the spatial characteristics of these households?

To answer this question multiple sub research questions need to be answered. These consist of:

- *(I) When is a household considered trapped in energy poverty?*
- *(II) What part of Dutch households is in both measured and non-participatory energy poverty?*
- *(III) What part of Dutch households is in both hidden and non-participatory energy poverty?*
- *(IV) How are Dutch households trapped in energy poverty spatially distributed within the Netherlands?*
- *(V) How are urban density and the phenomenon of being trapped in energy poverty related?*

3. Theoretical framework

Originally, identification of energy poverty began with a simple quantitative method called the *fuel poverty ratio* (Boardman, 1991). It was called the fuel poverty ratio because the term *fuel poverty* existed before the term EP. A household is in EP according to the fuel poverty ratio method if it spends more than 10% of its disposable income on energy. Methodology and research on EP has evolved over the following three decades, but the core principle of Boardmans' (1991) work is still used today (Moore, 2012; Meyer *et al.*, 2018).

Specifying, *measured energy poverty* is considered an improved version of the fuel poverty ratio method. Where the fuel poverty ratio has a fixed value of 10%, mEP uses a flexible threshold based on the energy expenditures of the population (Meyer *et al.*, 2018). In addition, mEP excludes households with sufficient energy efficiency and disposable income. The *disposable income* of a household is defined in the Dutch context by the former Ministry for Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (ministry of VROM) as the income that remains after paying taxes and receiving subsidies (Project IIVS, 2021). How disposable income and energy expenditures result in the mEP metric is further explained in the methodology section.

However, by definition, measured energy poverty only qualifies households as living in energy poverty if their energy expenditures are above the mEP threshold. For this reason, mEP is criticized for its inability to take into account the full extent of energy poverty. Consequently, this means that households that throttle their energy expenditures below a reasonable standard of living are not defined as living in energy poverty under the mEP standard. In order for households to achieve an acceptable quality of life, however, access to sufficient energy is required (Kitchen and OReilly, 2016). A household that cannot afford its energy bills is therefore living below an acceptable quality of life. According to the definition of hidden energy poverty in EP (Meyer et al., 2018), these households are still considered to be living in EP. The ability to also identify another group of households that are in EP makes hEP a suitable complementary indicator for mEP.

In addition, it would be a resource-intensive process to identify every single household in the Netherlands whose energy expenditure falls below an acceptable quality of life. Therefore, households are estimated to be in hEP by determining how much a household should spend based on the energy expenditures of similar households. Households that spend significantly less than estimated to maintain an acceptable quality of life are estimated to be classified in hEP (Meyer et al., 2018).

A solution for the households in mEP or hEP could be increasing the energy efficiency(EE) of their homes to decrease their expenditures or increase their standard of living. Increasing the EE of homes is a common method for alleviating energy poverty, alongside consumer protection and financial support measures (Das *et al.*, 2022). As the aim of this study is investigating the phenomenon of being trapped in energy poverty, the focus is on increasing home EE, since that is what households have more control over compared to consumer protection and financial support measures. To operationalize this focus, only households in houses that are not energy efficient are selected for the analysis. In the Netherlands, the *energie-label* is used to categorize the energy efficiency of a dwelling (RvO NL, 2017). The energie-label ranges from G (poor) to A(+) (good).

Specifically, increasing the EE of houses to reduce their energy consumption is core to the *trias energetica*, a strategy for energy efficient design (RvO NL, 2013). With this design strategy, participation in the energy transition can be increased. The *Energy transition* can be defined as a fundamental change from one energy system to another. Part of this is the shift towards renewable energy sources, as is the increased energy efficiency of houses (S&P global, 2020). The third type of energy poverty examined in this article concerns participation in the energy transition. This group is defined as "not being able to participate in the energy transition", and are part of the *non-participatory energy poverty*(npEP) group.

Additionally, households fall into energy poverty when they are in mEP or hEP and are unable to improve their home's EE (Chaton and Lacroix, 2018). This means that households are trapped in energy poverty if they are in either mEP or hEP and additionally in npEP.

As far as the spatial aspect is concerned, studies by Mulder et al. (2021) highlighted that EP is spatially distributed in the Netherlands. No research has examined the spatial characteristics of the phenomenon of being trapped in energy poverty. In addition, before studying the spatial distribution of households trapped in EP, the parameters for the distribution should be established. For this study, the Corop-Gebied mapping, a spatial mapping of the Netherlands for statistical comparison of regions, was chosen to identify regional differences ((CBS, no date). The mapping divides the Netherlands into 40 areas, each containing a core and a fringe area. Furthermore, the *type of* place is divided into three categories: G4, rest G40, the rest. The G4 municipalities contain the four biggest Dutch cities. The G40 consist of the G4 and 36 additional municipalities that contain cities in the Netherlands. *The rest* as a category consists of all municipalities that are outside the G4 and G40 municipalities.

Besides *Corop*-gebied, the type of location where households are located is another indicator used in this study to further develop an understanding of the spatial distribution of mEP and hEP. In particular, the impact of urban density on being trapped EP is examined to develop a better understanding of the spatial differences in EP. The households trapped in either mEP or hEP in the Netherlands are to be identified in this study, as shown in Figure 1.

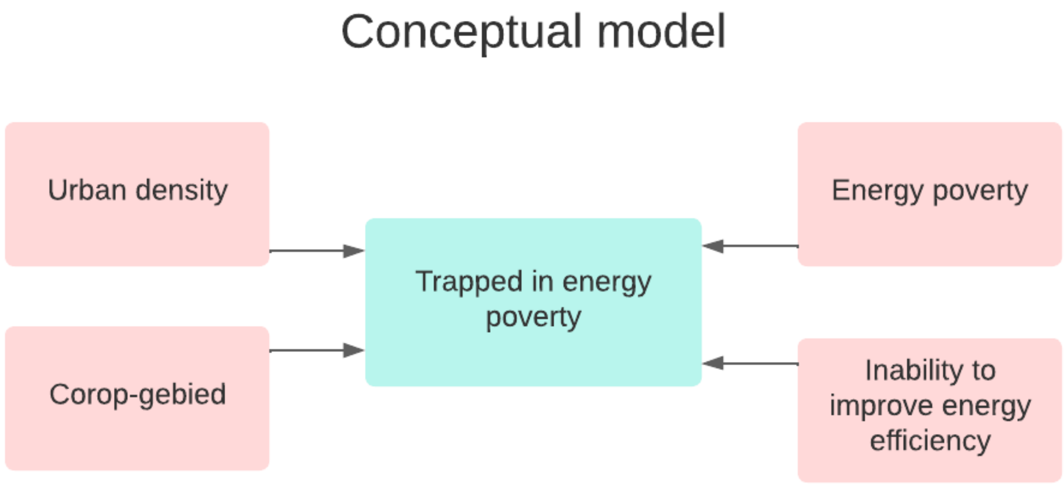

Figure 1 - Conceptual model

3.1 Hypotheses

A recent study by (Mulder et al., 2023) examined energy poverty in the Netherlands. Mulder et al. (2023) found that rural areas have more households in almost all types of EP compared to more urbanized areas. In addition, the same authors found that energy poverty is only highly concentrated in 13% of all districts in the Netherlands.

However, a similar level of detail in spatial distribution will not be identified by this study regarding the mapping of measured and hidden energy poverty due to limitations in available data. But, examining the spatial characteristics between households trapped in either mEP or hEP is something that will be added by study on a Corop-gebied level.

It may be that the spatial distribution for households trapped in energy poverty is similar to the distribution found by (Mulder, Batenburg and Dalla Longa (2023), as they found that both mEP, hEP and npEP are quite similarly concentrated in the Netherlands. The overlap of these groups in the Netherlands, to be examined in this study, is expected to be distributed in the same way, meaning that rural areas in the North, east and South of the Netherlands are expected to have the highest proportion of households trapped in energy poverty.

4. Methodology

This section discusses the methodology for answering research (II), (III), (IV) and (V). Research question (I) has been answered in the theoretical framework and requires no additional methods to answer.

The data for this study was initially collected by the Dutch Statistics Office (CBS). This agency carries out a housing study in the Netherlands every three years, the so-called “woOn study”. This particular study uses the latest woOn21 database (Stuart-Fox et al., 2021). The CBS collects data from government records, tax records, energy companies, in-person and telephone interviews, and Internet surveys. Respondents are selected in such a way that the data set is representative for the whole Netherlands. The data set consists of 46658 respondents. Parameters not available at data gathering are estimated by using a “standard procedure”. However data is only included if there is 95 percent confidence in its accuracy (CBS, 2023).

Focusing on research question (II) “*What part of the population is in both measured and non-participatory energy poverty?”*, two main concepts need to be determined, namely the degree of mEP and npEP.

To determine mEP this study follows the method used by Meyer *et al.* (2018). A household is considered to be in measured energy poverty if it is above the threshold of the mEP indicator. The threshold is determined by these authors using the following method:

“In concrete terms, the threshold used for the mEP indicator is equal to twice the median ratio obtained by dividing energy expenditures related to the dwelling by the household’s disposable income excluding housing costs (e.g. rent or monthly mortgage repayment). Accounting for the notion of ‘low income’ the indicator only considers households belonging to the first five deciles of equivalized disposable income.” - (Meyer *et al.*, 2018, p 277)

The woOn21 dataset contains disposable income, household gas expenditure, and electricity expenditure as parameters. These are all the required parameters to determine which households are in mEP.

Turning now to the determination of non-participatory energy poverty, an indicator that the energy efficiency of a home cannot be increased is required. The npEP group includes both homeowners and renters, but due to the limitation in the woON21 dataset, both groups are identified in different ways and then grouped together.

First, *homeowners in npEP* are identified in this study by two indicators. Two possible answers for not increasing the EE of their house were “a lack of funds” or “my owners association does not allow this”. Both answers show that it is not possible to increase the EE of their home. Since other responses explain the lack of motivation or need to increase energy efficiency, it could be argued that respondents who gave either of these two inability responses show a motivation to increase EE. Therefore, it could be argued that they cannot participate in the energy transition and that their households count as non-participatory energy poverty.

Second, tenants in npEP cannot be identified using the indicators for homeownership since they cannot make decisions about increasing the EE of their home. Tenants can be identified using the hLEK indicator which stands for *tenants in dwellings with low energy efficiency & unable to improve the energy efficiency* (Mulder et al., 2021). The woON21 dataset contains variables that indicate *energy efficiency*, *home ownership,* and *rental type*. *Low energy efficiency* is defined by Mulder, Longa and Straver (2021) as all houses with energie-label D or lower and half of the C group. In this study, only the households with a D or lower are considered prudent. If omitting the C group reduces the number of cases too much for analysis, they are considered to be included. Tenants in homes with low energy efficiency are therefore identified as in npEP. Furthermore, renters that do not pay their own energy bills will be excluded from this group.

The answer to research question (II) is determined by how many households that are in mEP are also in npEP. The identification of these households can be done by selecting the households that belong to both groups.

To answer research question (III): "*What part of the population is in both hidden and non-participatory energy poverty?"* the method for determining the hEP should be established. To this end, Meyer *et al.* (2018) have a method for calculating which households belong to this group. The methodology for determining which households belong to hEP follows a similar strategy to that of the mEP, but in reverse. Since the goal is to identify households that reduce their energy consumption below basic requirements, it is first necessary to estimate what a household should pay. This is estimated by Meyer *et al.* (2018) by comparing households energy expenditures to that of similar households. A threshold is calculated by averaging the median energy expenditure of households with a similar number of rooms and inhabitants. This amount is then halved as an estimate for basic requirements. The formula is therefore as follows, where EE means energy expenditures.

$$hEP\ threshold\ for\ household\ with\ x\ members\ in\ a\ house\ with\ y\ rooms\ = \frac{(\text{median of EE of all hx})+(median\ of\ EE\ of\ all\ ry)}{2}$$

(Meyer *et al.*, 2018)

Households whose energy expenditure is below their calculated threshold belong to the hEP group. To answer research question (III), the overlap of the hEP and npEP groups can be determined by selecting households that fall into both categories. The proportion of households that belong to both groups is therefore considered to be trapped in hidden energy poverty. Finally, in order to make good use of the data, two additional changes are made. The number of rooms was divided into categories from one to ten and eleven or more rooms. A similar categorization was made for the number of inhabitants, dividing them into groups of one to eight and nine or more people. This grouping makes the groups large enough to produce robust results

After determining the percentage of households trapped in either mEP or hEP, a spatial dimension can be added by answering research question (IV) *"How are the households trapped in energy poverty spatially distributed within the Netherlands?".* To answer this question, the two spatial factors from the woOn21 dataset are used, i.e. the *corop-gebied* and *type of living area*. The Corop area is a division of the Netherlands into 40 areas and is therefore a nominal value. In order to determine the corop-gebied distribution of the households trapped in EP, two diagrams are created for both mEP and hEP. A map is the most appropriate tool to show the differences. The *type of living area* is a nominal value as it follows earlier described G4/G40/rest groups. The differences between these three groups can be determined by descriptive statistics presented in the form of a bar graph. A possible connection between these factors can be determined with a Chi2 test.

The final research question (V) *"How are urban density and households trapped in energy poverty related?"* can be answered by describing the relationship between *urban density* and the groups of households trapped in energy poverty. For this study, urban density is defined as the number of addresses per square kilometer in the neighborhood. It is defined as such because it is the best available indicator within the dataset used for this study. The level of urban density is divided into five categories in the woOn21 dataset and is classified as ""very urban (>=2500 addresses/km2)", "urban (between 1500 to 2500 addresses/km2)", "suburban (1000 to 1500 addresses/km2)", "rural (500 to 1000 addresses/km2)", very rural (< 500 addresses/km2)". These urban density levels are determined for the neighborhoods in which the individual households are located. Calculating the relationship between the degree of urban density and the percentage of households included in EP can be done by performing a one-way Anova test on both households trapped in mEP or hEP. Alternatively, spearman ranking correlation is more suited for this purpose when a linear relationship is suspected.

In addition, it may be important to consider research ethics when handling sensitive household data. The data collection agency indicates the split between personal data and answers to questions in its records (CBS, 2012). Additionally, another anonymized version of the woOn21 dataset is used for this study, excluding zip codes and neighborhood names, as that is all the students are allowed to use. Despite these measures, the data set will not be used for any purpose other than determining the answers to the research questions and will not be shared with third parties.

5. Results

In this section, the results of the quantitative analysis are discussed and the research questions (II), (III), (IV), and (V) are answered in turn. Comparisons with similar studies and a discussion of the societal implications of the data follow in Section 6.

5.1 The phenomenon of households trapped in measured energy poverty

Based on the mEP threshold, the energy expenditure versus disposable income threshold was calculated to be 13.98%. This was surprisingly high compared to results from similar studies (Meyer et al., 2018; Mulder et al., 2023). Given that the Mulder et al. (2023) use newer data than the woOn21 data set and is supposed to describe the same population, this is even more surprising. The number of households in the Netherlands identified as having measured energy poverty using the threshold is 23.1% (Table 1, Appendix 1).

Furthermore, by filtering out the houses with energy label C or better, the households in the non-participatory energy poverty group were identified. The aggregation of tenants and homeowners in this group again resulted in a surprisingly high percentage of the population being in npEP, namely 21,8% (table 2, Appendix 1). However, this might be less reliable as an indicator as 72.9% of the survey participants had not fully answered the questions required to determine whether or not they were in npEP. Participants either did not report their energy label or gave reasons for not improving the energy efficiency of their home. Since the remaining 27.1% of the dataset still contains 12623 cases, the data was still considered usable and representative of the population. However, this study questions the validity of the statement that 21,8% of households in the Netherlands are in *non-participatory energy poverty*.

However, despite the surprisingly high percentage of the population in either measured or non-participatory energy poverty, only 2,5% (table 1) of the population is in both mEP and npEP and are therefore effectively trapped in measured energy poverty. This means that 10,8% (23.1 / 2.5 = 10.8%) of the households that are in mEP cannot improve the energy efficiency of their dwelling.

Households_trapped_in_mEP

		Frequency	Percent	Valid Percent
Valid	,00	35993	77,1	97,5
	1,00	938	2,0	2,5
	Total	36931	79,2	100,0
Missing	System	9727	20,8	
Total		46658	100,0	

(Table 1 – Households trapped in measured energy poverty)

However, it should be discussed that 21.8% of households live in non-participatory energy poverty. There can be doubts about the correctness of this statement for two reasons. The first reason is the high number (72.9%) (table 2, appendix 1) of missing cases due to lack of complete data. The second reason is the large difference, at 48%, found in a similar study that included more accurate and complete data (Mulder, Longa, and Straver, 2021). The proportion of households in npEP is directly related to all the results of this study. Therefore, the results may not adequately reflect the severity of energy poverty in the Netherlands.

For example, the 2.5% of households trapped in measured energy poverty is one such number that could be impacted by npEP numbers that underrepresent the problem. Other studies did not examine the overlap of households living in both some form of energy poverty and being unable to participate in the energy transition. A direct numerical comparison is therefore not possible.

5.2 The phenomenon of households trapped in hidden energy poverty

Continuing the hidden energy poverty, the thresholds were set for each combination of room count and population count. This was done to keep the case groups large enough to remain representative of the population. According to the results, 9.7% (Table 3, Appendix 1) of the population was found to be in hEP. This is less than half of the measured energy poverty group, but still almost three times higher than the degree of hEP found in Belgium in 2015 by Meyer et al. (2018). Effectively this means that 9,7% of the population is reducing their energy consumption compared to similar households.

Furthermore, the overlap of households in hEP and npEP leads to the group of households that is trapped in hidden energy poverty. This was 3,1% (table 2). This is not only larger than the 2,5% of households trapped in mEP, but is all the more remarkable considering that the mEP group is more than twice the size of the hEP group. Additionally, a staggering 31.9% of households experiencing hidden energy poverty are unable to improve the energy efficiency of their homes. The difference between households trapped in mEP versus hEP shows an interesting dynamic. Households are more likely to be in mEP (21.8%) than in hEP (9.7%), but households in hEP are much more likely to be trapped in their situation. One should keep in mind that the 3,1% could be an underestimate of the percentage of households trapped in hEP due to the questionable accuracy of the npEP calculation.

households_trapped_in_hEP

		Frequency	Percent	Valid Percent
Valid	,00	32709	70,1	96,9
	1,00	1038	2,2	3,1
	Total	33747	72,3	100,0
Missing	System	12911	27,7	
Total		46658	100,0	

Table 2 – Households trapped in hidden energy poverty

5. 3 The spatial distribution of households trapped in energy poverty

After identifying the percentage of households that are affected by either measured or hidden energy poverty, the spatial aspect follows. Two different spatial patterns emerged for both types of energy poverty. Figures 2 and 3 show the spatial differences of the households trapped in EP by corop-gebied.

In rural areas in the north, east and south of the Netherlands, a higher concentration of households can be observed in mEP (Figure 2). The highest proportion of households trapped in mEP (7.5%) was found in the Delfzijl en Omgeving in the north-east of the country. A similar pattern for measured energy poverty was found by Mulder, Longa, and Straver (2021) in their study of energy poverty. They also found a higher concentration of energy poverty in rural areas and lower concentrations in the west and central Netherlands in relation to mEP.

To nuance this further, a study by Cyrek and Cyrek (2022) found that overall poverty in the Netherlands is not concentrated in rural areas. This means that the discovered spatial distribution of energy poverty should be caused by an energy-related factor and not by a general poverty factor.

However, this study measured the extent of households being trapped in mEP and not merely the extent of mEP. Thus, what was found here is the confirmation that there is no difference between the spatial distributions of households in mEP and households trapped in mEP.

In contrast to figure 2, figure 3 shows an almost opposite spatial pattern for households trapped in hEP. Here, the urban center of the Netherlands called “the Randstad” is where a larger percentage of the population is trapped in hEP. Especially in "agglomeratie The Hague" there is a high concentration (7.6%) of households trapped in hEP. In addition, in Rijnmond and Zuidoost Zuid-Holland, in the same province as The Hague, there is a high proportion of households trapped in hEP. The level of households trapped in the Randstad is the only outcome of the results that differs from other studies on the spatial distribution of energy poverty in the Netherlands.

Continuing with the spatial dimension and examining the G4, the rest of the G40 and the rest of the Netherlands, no major differences can be seen between these three categories for mEP. Table 3 shows that the rest of the Netherlands has slightly lower scores compared to the G4 and G40 cities. Which leads to the question of whether there is a significant difference between these groups. A Chi2 test was performed to determine if there was a link between G4/G40/rest of NL and households trapped in mEP. A very significant relationship was found (<.001, Table 6, Appendix 1). More importantly, the relationship between these factors was found to be very weak (0.022, Table 7, Appendix 1). So there is a difference, but it's not very meaningful.

G4/g40/rest * Households_trapped_in_mEP Crosstabulation

			Households_trapped_in_mEP		
			,00	1,00	Total
G4/g40/rest	G4	Count	5597	167	5764
		% within G4/g40/rest	97,1%	2,9%	100,0%
	rest G40	Count	10439	317	10756
		% within G4/g40/rest	97,1%	2,9%	100,0%
	rest NL	Count	19957	454	20411
		% within G4/g40/rest	97,8%	2,2%	100,0%
Total		Count	35993	938	36931
		% within G4/g40/rest	97,5%	2,5%	100,0%

Table 3 – The G4/Rest G40/rest of NL division of households trapped in mEP

In addition, there is greater diversity between categories in hEP-trapped households than in mEP-trapped households. Table 4 shows that hEP is more severe in the G4 than in the rest of the G40 and especially more severe than in the rest of the country.

The concentration of households trapped in hEP in the G4 appears to be consistent with the spatial pattern in figure 3. The G4 cities are all in corop-gebieden with a relatively high percentage of households trapped in hEP. The Hague (7.6%), Rotterdam (5.3%), Amsterdam (4.4%), and Utrecht (4.2)% are all above the average (3.6%) of the rest of the G40. Explaining the concentration of households trapped in hEP in the G4 cities is beyond the scope of this study. But it can be speculated that higher prices for rental units in the Randstad could lead to households being trapped in hEP because there is less disposable income remaining for energy after housing costs (HWD, 2023). These households should have high energy expenditure based on the selection criteria for the households (energie label D or worse).

5. 4 The relation between urban density and households trapped in energy poverty

Concluding the results, a linear relationship between urban density and households trapped in energy poverty was found using Spearman's rho test. A linear decline in households trapped in mEP is already visible with decreasing urban density in Table 3. The assumption that there is a significant linear relationship between these two factors is confirmed by Spearman's rho test (Table 10, Appendix 1). The relationship was found to be significant at the >0.01 level. However, the correlation coefficient is only -0.052, meaning that the linear relationship between the urban density of the neighborhood and the percentage of households trapped in mEP is very weak. One could argue that a strong linear relation was unexpected, due to the contradictory nature of the previous findings in this study. The spatial pattern in Figure 2 indicated an increase in measured energy poverty in rural areas. However, the linear pattern found in Table 5 suggests the opposite. It is therefore not possible to draw firm conclusions about the relationship between these two factors.

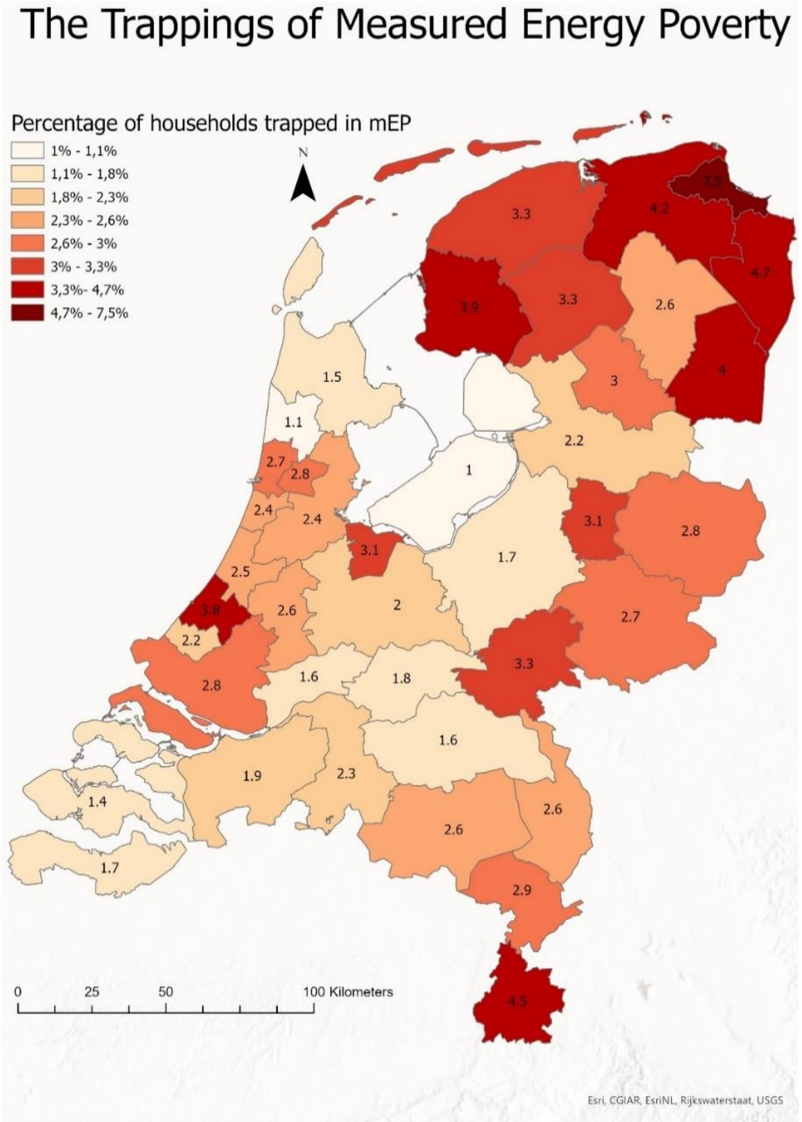

Figure 2 – Households trapped in mEP by corop-gebied

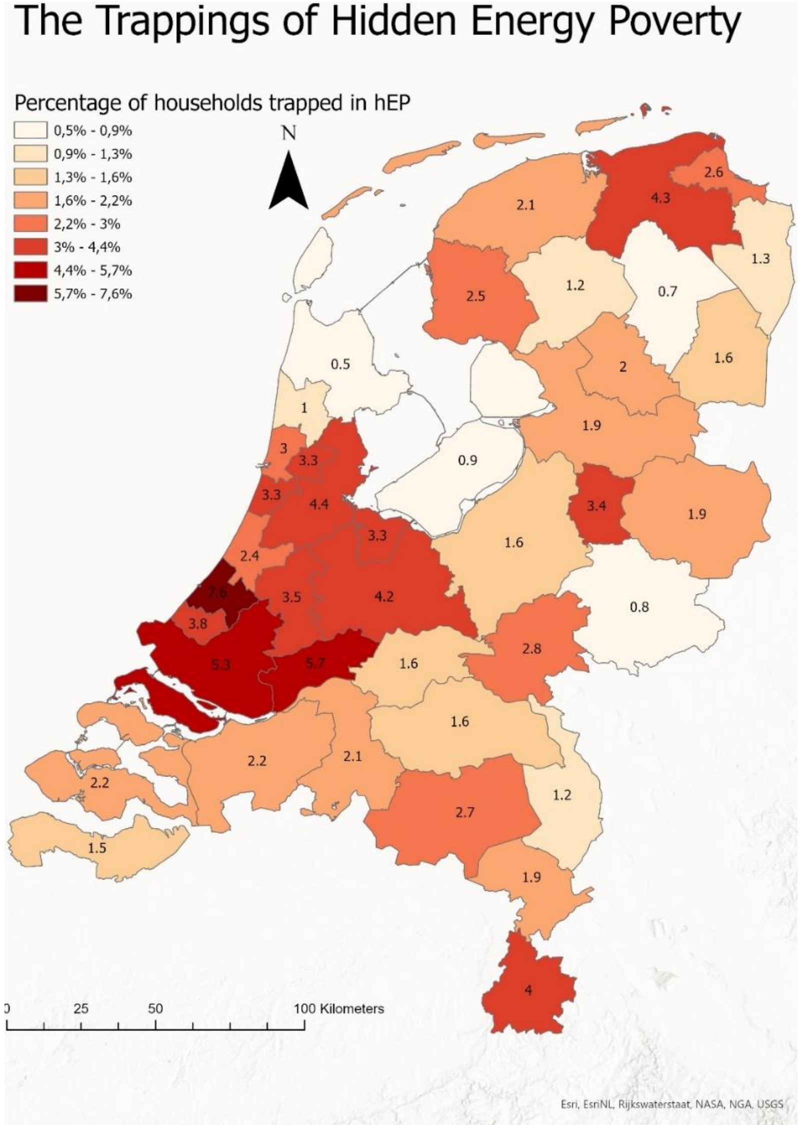

Figure 3 – Households trapped in hEP by corop-gebied

G4/g40/rest * households_trapped_in_hEP Crosstabulation

			households_trapped_in_hEP		
			,00	1,00	Total
G4/g40/rest	G4	Count	4715	338	5053
		% within G4/g40/rest	93,3%	6,7%	100,0%
	rest G40	Count	9635	361	9996
		% within G4/g40/rest	96,4%	3,6%	100,0%
	rest NL	Count	18359	339	18698
		% within G4/g40/rest	98,2%	1,8%	100,0%
Total		Count	32709	1038	33747
		% within G4/g40/rest	96,9%	3,1%	100,0%

Table 4 – The G4/Rest G40/rest of NL division of households trapped in hEP

In addition, a similar linear relationship was found between the urban density of the surrounding neighborhood and the percentage of households trapped in hidden energy poverty. As with mEP, Table 6 shows a negative linear pattern for hEP. However, the correlation appears to be stronger, since the decline in households included in hEP is much more evident here. This negative linear relationship is again confirmed at the >0.01 level by the Spearman's rho test (Table 11, Appendix 1). However, the correlation coefficient is 0.13, which again means that there is a weak association between the two factors. Here, however, the correlation found is somewhat stronger and there is no contradiction in the data. Figure 3 shows an increase in households trapped in hEP in the Randstad, which is considered to be the area with the highest urban density in the Netherlands. The G4 and other cities in the G40 (Table 4) already had a higher level of hEP.

The weak relationship between households trapped in energy poverty and urban density found in this study cannot be directly compared to other studies due to methodological differences caused by including the phenomenon of households trapped in energy poverty. The link between urban density and energy poverty has been studied before, but shows conflicting results. Poruschi and Ambrey (2007) found that "for a low-income household, a two-fold increase in density is associated with a much greater likelihood of experiencing fuel poverty". However, the Dutch situation shows a significant decrease in energy poverty in general as urban density increases (Mulder et al., 2021). Moreover, the study by Mulder et al. (2021) even shows a correlation between an hEP-like indicator and urban density in the sense that hidden energy poverty decreases with decreasing urban density. No definitive conclusion can be drawn as to what is causing the concentration of hEP-trapped households.

Urban density of neighborhood * Households_trapped_in_mEP Crosstabulation

			Households_trapped_in_mEP		
			,00	1,00	Total
Urban density of neighborhood	Very urban (>=2500 addresses/km2)	Count	8167	331	8498
		% within Urbanity neighborhood	96,1%	3,9%	100,0 %
	Urban (between 1500 and 2500 addresses /km2)	Count	9276	271	9547
		% within Urbanity neighborhood	97,2%	2,8%	100,0 %
	Suburban (between 1000 and 1500 addresses /km2)	Count	6870	128	6998
		% within Urbanity neighborhood	98,2%	1,8%	100,0 %
	Rural (between 500 and 1000 addresses /km2)	Count	6091	114	6205
		% within Urbanity neighborhood	98,2%	1,8%	100,0 %
	Very Rural (<500 addresses /km2)	Count	5589	94	5683
		% within Urbanity neighborhood	98,3%	1,7%	100,0 %
Total		Count	35993	938	36931
		% within Urbanity neighborhood	97,5%	2,5%	100,0 %

Table 5 - The relation between urban density and households trapped in mEP

Urban density of neighborhood * households_trapped_in_hEP Crosstabulation

			households_trapped_in_hEP ,00	households_trapped_in_hEP 1,00	Total
Urban density of neighborhood	Very urban (>=2500 addresses/km2)	Count	7290	564	7854
		% within Urbanity neighborhood	92,8%	7,2%	100,0%
	Urban (between 1500 and 2500 addresses /km2)	Count	8502	272	8774
		% within Urbanity neighborhood	96,9%	3,1%	100,0%
	Suburban (between 1000 and 1500 addresses /km2)	Count	6214	100	6314
		% within Urbanity neighborhood	98,4%	1,6%	100,0%
	Rural (between 500 and 1000 addresses /km2)	Count	5608	71	5679
		% within Urbanity neighborhood	98,7%	1,3%	100,0%
	Very Rural (<500 addresses /km2)	Count	5095	31	5126
		% within Urbanity neighborhood	99,4%	0,6%	100,0%
Total		Count	32709	1038	33747
		% within Urbanity neighborhood	96,9%	3,1%	100,0%

Table 6 - The relation between urban density and households trapped in hEP

6. Conclusion

To summarize the results, the findings for each research question are summarized. This is done to answer the main research question. A household is considered to be trapped in energy poverty if it belongs to either the measured or hidden energy poverty group and in addition to the non-participatory energy poverty group. Households were determined to be in measured energy poverty when they spent more than 13.98% of their disposable income on energy. It has been found that 2.5% of Dutch households are trapped in this situation. Households were found to be in hidden energy poverty when they were spending less then they should be spending on energy compared to their peers. It has been found that 3.1% of Dutch households are trapped in hidden energy poverty. Due to the limitations of the dataset, the extent of non-participatory energy poverty could not be accurately determined. As a result, the percentage of households trapped in energy poverty could be, and almost certainly will be, higher.

It has been found that the spatial distribution is different for households affected by either measured or hidden energy poverty. The concentration of households trapped in mEP was higher in the rural north, east and south of the Netherlands and lower in the more urbanized west and center of the country. This is in line with other studies on energy poverty in the Netherlands.

More interestingly, an opposite spatial distribution was found for households trapped in hEP. The highest concentration of this group was found to be in the Randstad, the Dutch urban core, and in particular in the Hague and the surrounding areas. Previous research on this issue has not reported the concentration of households in hidden poverty who are unable to improve the energy efficiency of their homes.

In addition, the same relation was established between the degree of urban density of the surrounding neighborhood and the degree of hidden energy poverty. This means that neighborhoods with higher urban density had a higher proportion of households in hEP. The weak but significant correlation indicates that there is a measurable but small difference in concentration.

Urban density was found to have a very weak but significant association with households in measured energy poverty. The significance of this result could be due to the large sample size and is therefore questionable at best.

If one conclusion could be drawn from this study, it is that there appears to be a weak but very significant association between the level of urban density and the percentage of households trapped in hidden energy poverty. Or to be clear, there are proportionately more households in cities than in rural areas that reduce their energy consumption to make ends meet. The generalizability of these results is subject to spatial limitations. The results provide robust results for the Dutch setting. However, the methodology is also widely applicable in other spatial contexts.

Looking ahead, further studies on this topic could focus on several aspects of this study. First, a study could be conducted to verify the results of this study. A particular focus should be on improved methodology or data for the non-participatory energy poverty indicator. The second recommended study could examine the spatial relationship between households trapped in hidden energy poverty and urban density. The connection should first be confirmed by further tests. If this is confirmed, an explanation could be sought through a case study on the high concentration of hEP-trapped households in The Hague.

In conclusion, clear policy recommendations to address specific outcomes cannot be made for a number of reasons. The first reason is the questionable validity of the percentage of households in non-participatory energy poverty, as the data set lacks the data required for this indicator. The second reason is that policies that help households in measured energy poverty also help households in hidden energy poverty. For example, subsidizing energy spending would help the households of both groups. The promotion of measures to improve the energy efficiency of houses benefits the households of both groups equally. Both of these measures would improve household livelihoods and are therefore still recommended, however no specific measure would only help households trapped in mEP or hEP. Policies targeting a group of households living in energy poverty in a specific neighborhood are not recommended due to the weak association found in this study.

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Appendix 1: Table with statistics

Households_in_mEP

		Frequency	Percent	Valid Percent
Valid	,00	33983	72,8	76,9
	1,00	10191	21,8	23,1
	Total	44174	94,7	100,0
Missing	System	2484	5,3	
Total		46658	100,0	

Table 1 – Households in measured energy poverty

Households_in_npEP

		Frequency	Percent	Valid Percent
Valid	,00	9865	21,1	78,2
	1,00	2758	5,9	21,8
	Total	12623	27,1	100,0
Missing	System	34035	72,9	
Total		46658	100,0	

Table 2 – Households in non-participatory energy poverty

Households_trapped_in_mEP

		Frequency	Percent	Valid Percent
Valid	,00	35993	77,1	97,5
	1,00	938	2,0	2,5
	Total	36931	79,2	100,0
Missing	System	9727	20,8	
Total		46658	100,0	

(Table 3 – Households trapped in measured energy poverty)

Households in hidden Energy Poverty

		Frequency	Percent	Valid Percent
Valid	,00	30218	64,8	90,3
	1,00	3253	7,0	9,7
	Total	33471	71,7	100,0
Missing	System	13187	28,3	
Total		46658	100,0	

Table 4 – Households in hidden energy poverty

Chi-Square Test for G4/g40/rest * Households_trapped_in_mEP

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	18,396[a]	2	<,001
Likelihood Ratio	18,274	2	<,001
Linear-by-Linear Association	14,336	1	<,001
N of Valid Cases	36931		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 146,40.

Table 6 – Chi square test G4/g40/rest * Households_trapped_in_mEP

Measures of Association G4/g40/rest * Households_trapped_in_mEP

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Nominal by Nominal	Phi	,022			<,001
	Cramer's V	,022			<,001
Interval by Interval	Pearson's R	-,020	,005	-3,787	<,001[c]
Ordinal by Ordinal	Spearman Correlation	-,021	,005	-4,066	<,001[c]
N of Valid Cases		36931			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

Table 7 - Measures of Association G4/g40/rest * Households_trapped_in_mE

Chi-Square Test for G4/g40/rest * Households_trapped_in_hEP

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	330,922[a]	2	<,001
Likelihood Ratio	292,970	2	<,001
Linear-by-Linear Association	322,488	1	<,001
N of Valid Cases	33747		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 155,42.

Table 8 - Chi-Square Test for G4/g40/rest * Households_trapped_in_hEP

Measures of Association G4/g40/rest * Households_trapped_in_hEP

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Nominal by Nominal	Phi	,099			<,001
	Cramer's V	,099			<,001
Interval by Interval	Pearson's R	-,098	,006	-18,044	<,001[c]
Ordinal by Ordinal	Spearman Correlation	-,094	,006	-17,297	<,001[c]
N of Valid Cases		33747			

a. Not assuming the null hypothesis.
b. Using the asymptotic standard error assuming the null hypothesis.
c. Based on normal approximation.

Table 9 - MoA G4/g40/rest * Households_trapped_in_hEP

Spearman's rho test for the relation between urban density and households trapped in mEP

			Stedelijkheid buurt	Households_trapped _in_mEP
Spearman 's rho	Stedelijkheid buurt	Correlation Coefficient	1,000	-,052**
		Sig. (2-tailed)	.	<,001
		N	46658	36931
	Households_trapped_in_mEP	Correlation Coefficient	-,052**	1,000
		Sig. (2-tailed)	<,001	.
		N	36931	36931

**. Correlation is significant at the 0.01 level (2-tailed).

Table 10 – Spearman's rho test for the relation between urban density and households trapped in mEP

Spearman's rho test for the relation between urban density and households trapped in hEP

			Stedelijkheid buurt	households_trapped _in_hEP
Spearman 's rho	Stedelijkheid buurt	Correlation Coefficient	1,000	-,130**
		Sig. (2-tailed)	.	<,001
		N	46658	33747
	households_trapped_in_hEP	Correlation Coefficient	-,130**	1,000
		Sig. (2-tailed)	<,001	.
		N	33747	33747

**. Correlation is significant at the 0.01 level (2-tailed).

Table 11 – Spearman's rho test for the relation between urban density and households trapped in hEP