The willingness to pay for energy performance of houses in periods of increased energy costs

A QUANTITATIVE STUDY IN THE CONTEXT OF THE MUNICIPALITY OF UTRECHT

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With pleasure and a sense of pride, I hereby present my thesis, through which I will complete my Master's degree in Spatial Planning at the Utrecht University. This marks the final step of my learning journey before I apply the knowledge and experiences gained in practical settings. Throughout the entire learning process, I have cultivated a strong interest in the financial aspects of spatial development. Consequently, both my current thesis and previous research projects have been focused on exploring this financial perspective.

I have received assistance from various individuals in different ways throughout the writing of this thesis. I would like to take this opportunity to express my gratitude to my parents Arjan & Elvira, brother Rik, girlfriend Maaike, family and friends for their genuine interest and motivation, which have contributed to making this journey even more enjoyable. Additionally, I would like to thank my supervisor, prof. dr. Buitelaar, for his valuable insights, constructive feedback, and prompt and pleasant responses during the writing period of this thesis. Even before I embarked on this research, you provided me with interesting ideas that led to the formulation of the final research topic. Additionally, I would like to express my gratitude to the persons and organisations with whom I had substantive discussions during the writing of my thesis, as they have made significant contributions. In particular, I am extremely grateful to Marielle van 't Oever from Watson+Holmes for promptly providing the crucial data for this research. Lastly, I extend my thanks to my fellow students in the Master's program in Spatial Planning for the pleasant time we have shared.

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ABSTRACT

Recently, energy costs have increased significantly to a record level in 2022. This increase in energy costs has affected households and in particular their overall cost of living. This study aims to examine whether the rise in energy costs has influenced the willingness to pay for energy performance. Specifically, the study investigates the changes in the willingness to pay for energy performance of houses using a multiple regression approach. To determine the willingness to pay for energy performance, the study employs the hedonic price technique within the multiple regression analysis. The dataset used in this study includes information on house prices, location, house characteristics, and an interaction variable between energy performance and the transaction date. The data used in this study comprises housing transactions within the municipality of Utrecht from January 2013 to March 2023. Subsequently, this development of willingness to pay for energy performance of houses was correlated with the development of energy costs. The analysis reveals a strong association between these two factors, as indicated by a Pearson correlation coefficient r of 0.678 with a three-quarter delay. This correlation analysis confirms that there is indeed an association between willingness to pay for energy performance and the fluctuations in energy costs.

Keywords: energy performance, house prices, increased energy costs, hedonic price technique, multiple regression, correlation, municipality of Utrecht

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CHAPTER 1: INTRODUCTION

In recent years, the world has experienced soaring energy costs (Ozili, 2022; World Bank Group, 2022; Zakeri et al., 2022). This trend has reached record levels in the European Union by 2022 (European Council, 2022a). Specifically, in the Netherlands, the energy costs saw an average increase of 114% in 2022 compared to 2021 (CBS, 2023a), resulting in a significantly higher cost of living for households (Haffner & Boumeester, 2015; CPB, 2022). The COVID-19 pandemic and sanctions imposed on Russia have played a significant role in driving up energy costs (Chomać-Pierzecka et al., 2022; IAE, 2022; Ozili, 2022; Zakeri et al., 2022), resulting in a considerable impact on households (Hoebergen et al., 2022).

A recent study has shown the negative relationship between energy costs and house prices. This relationship implies that higher energy costs can slow down the rise in house prices and eventually reduce house prices slightly (Vrieselaar & De Groot, 2022). This effect on house prices relates to the willingness to pay for houses, as house prices are the indicator of this (Tan, 2011; Freeman et al., 2019).

People are willing to make their houses more energy efficient in periods of high energy costs (Verening Eigen Huis, 2021). Energy efficiency in the built environment can play an important role in the reduction of global carbon emissions and therefore energy costs (Brounen & Kok, 2011). This energy efficiency of houses is indicated by an Energy Performance Certificate (EPC) which is mandatory for all houses and other buildings which are for sale or rent, or when construction is completed (Rijksoverheid, 2021). For the energy performance of housing, this EPC is used to determine the energy performance rating (Brounen & Kok, 2011).

Previous studies have also shown a relationship between energy performance ratings and house prices. This relationship implies that the better the energy performance, the higher the house prices (Brounen & Kok, 2011; Cerin et al., 2014; Ayala et al., 2016; Fuerst et al., 2015; Fuerst et al., 2016; Cajias et al., 2019; Zhang et al., 2020). The theoretical framework of this study elaborates on these previous theories and concepts.

1.1 PROBLEM DEFINITION AND KNOWLEDGE GAP

No prior research has been performed to examine the association between increased energy costs and the willingness to pay for the energy performance of houses. A study on the willingness to pay for the energy performance of houses described the knowledge gap as follows: “The literature on residential buildings is still limited but generally shows a positive relation between energy performance ratings and home prices or rental rates” (Ayala et al., 2016). The knowledge gap here is the yet unresolved association with increased energy costs. Besides this knowledge gap, an empirical gap will be filled by this study. This study namely examines how the willingness to pay for the energy performance of houses in the municipality of Utrecht is associated with periods of increased energy costs. This complements already existing knowledge and puts the results of previous studies in a broader context.

1.2 RESEARCH OBJECTIVE AND RESEARCH QUESTION

The aim of this study is to examine how the willingness to pay for energy performance of houses is related to increased energy costs by performing a quantitative study. This research will provide the answer to the following research question:

“What is the association between the willingness to pay for the energy performance of houses and energy costs?”

In examining the impact of recently increased energy costs on the willingness to pay for energy performance, two contrasting hypotheses can be formulated. The first hypothesis posits a significant association between energy costs and willingness to pay, while the second hypothesis suggests no such association, serving as the null hypothesis.

- *H0: There is no association between the willingness to pay for energy performance of houses and increased energy costs.*
- *H1: There is an association between the willingness to pay for energy performance of houses and increased energy costs.*

1.3 RELEVANCE

1.3.1 ACADEMIC RELEVANCE

Given that energy costs have recently increased due to COVID-19 and the war between Russia and Ukraine, the effects of this on house prices in relation to energy performance have been scarcely discussed in academic literature. As mentioned earlier, the academic relevance of this study is to bridge the knowledge and empirical gap. This study will therefore expand the existing knowledge and delve deeper into the findings of previous studies. It goes beyond examining the relationship between house prices and energy performance ratings. It also investigates how the willingness to pay has developed over time and its association with energy costs. As a result, it contributes valuable and timely insights to the existing academic knowledge in the field of willingness to pay for energy performance.

1.3.2 SOCIETAL RELEVANCE

Since 2021, approximately 1.2 million households in the Netherlands have been struggling with financial challenges caused by the escalating cost of living, which includes the increased energy costs (Haffner & Bouwmeester, 2015; Nationale Ombudsman, 2022). This issue is not exclusive to the Netherlands, as the entire continent of Europe is facing an energy crisis. However, the Dutch government has implemented measures to alleviate some of the impacts by implementing a price ceiling (Kennisdomein, 2023). Nonetheless, the consequences of this crisis extend beyond the financial well-being of households and also have implications for the energy transition, leading to an increased reliance on fossil fuels to address energy shortages (Nationale Ombudsman, 2022; Kennisdomein, 2023). In light of these circumstances, this study carries significant societal relevance by providing valuable insights into how the energy crisis influences the home purchasing decisions of households, with a specific emphasis on energy performance. These findings can contribute to more targeted and effective financial and sustainability policies to address similar future situations.

1.4 OUTLINE

After this introductory chapter, Chapter 2 provides a scientific description of previous studies to the core concepts, enabling the creation of a theoretical framework. Also the relations between the core concepts are described in this chapter. Next, Chapter 3 discusses the different research methods used in this study. Following this, the results are presented in Chapter 4 which is divided in two parts. First, the descriptive statistics and the results of the multiple regression are described. Second, the results of the correlation are presented. The conclusion is derived from these results, which is then followed by the discussion and recommendations section. Finally, the appendices have been included providing detailed information on the multiple regression and correlation.

CHAPTER 2: THEORETICAL FRAMEWORK

This chapter first reflects on the contemporary and past academic debate on the core concepts of this study by an extensive literature review. The three core concepts of this study are the willingness to pay for houses, energy performance of houses and energy costs. Also, the relationships between these three key concepts are described in this chapter. Since previous studies have examined the one-on-one relationships between the core concepts, this study will complement or contradict these theories by integrating all three concept in a comprehensive theoretical framework. The relationships are presented in a conceptual model at the end of the chapter.

2.1 WILLINGNESS TO PAY FOR HOUSES

Since this study examines willingness to pay for houses, this is one of the key concepts for this research. As this is a new study, there has been no previous research on the relationship between willingness to pay for energy performance of homes and higher energy costs. However, previous studies have examined the effects of energy performance on the willingness to pay for houses. This has been done, for example, in a study by Tan (2011) in which he examines the willingness to pay for housing in a sustainable neighbourhood. He quotes his result as: "… Because of a higher demand from the market, transacted house prices in such neighbourhoods have increased …." (Tan, 2011, p. 1). This shows that the willingness to pay for houses is examined by using the transacted house prices. This is in line with a more recent study by Freeman et al. (2019) examining the willingness to pay for clean air in China. In this study, they state: "… The positive correlation between housing price and air pollution, …" (Freeman et al., 2019, p. 203). This study also shows that the willingness to pay for houses is examined by looking into housing prices.

Although various studies may employ different terminology, they essentially refer to the same concept when discussing the willingness to pay for houses. In the context of numerous studies on house prices, the following are brief descriptions of various terms that have been used in previous research related to this study. In a study of Næss-Schmidt et al. (2016), the terms "house price" and "sales price" have been used interchangeably. In a similar study of Ayala et al. (2016) on the price of energy efficiency in Spain, the terms "housing price" and "house price" have been used interchangeably. In the studies of Brounen & Kok (2011) and Zhang et al. (2020) the term "transaction price" is used to clarify the effect. In many other studies the descriptive term is "house price" and the indicator for data is the "transaction price" (Hyland et al., 2013; Cerin et al., 2014; Fuerst et al., 2015; Fuerst et al., 2016; Dambon et al., 2022). As this is the most commonly used method, this study will use the term "house price" as a descriptor of willingness to pay which will be indicated by the "transaction price".

House prices depend on several factors which have to be taken into account when examining the association between the willingness to pay for houses and one independent factor (Chau & Chin, 2002; Ayala et al., 2016). The above studies therefore used various variables to make the effect on house prices to be studied as specific as possible. These house characteristics are the dependent variables in a hedonic price technique which is described in more detail in Chapter 3.2. According to Zhang et al. (2020), the variables can be distinguished into object-related and location-related variables. The object-related category encompasses variables that pertain to the characteristics of the house itself. On the other hand, the location-related category comprises variables that influence the house price due to the characteristics of the living environment and the surrounding area. The different variables are listed below in

Table 1. This list is based on multiple studies, indicating that not all variables were used in every study. Nonetheless, this table provides an overview of variables that hold potential relevance for this study.

Table 1. List of variables affecting house prices (Brounen & Kok, 2011; Hyland et al., 2013; Cerin et al., 2014; Fuerst et al., 2015; Ayala et al., 2016; Fuerst et al., 2016; Næss-Schmidt et al., 2016; Zhang et al., 2020; Dambon et al., 2022)

Object-related:	Location-related:
Construction year / age	City
Dwelling type	Postcode
Dwelling size (m^2)	Density (inhabitants / km^2)
Dwelling volume (m^3)	Ageing index (% > 65 years)
Monumental value (yes/no)	Average household income neighbourhood (€/month)
Number of rooms	Distance to highway (m)
Thermal characteristics	
Energy performance rating (A-G)	
Average time on the market (days)	
Year of transaction	

In the Netherlands, the average house price has increased the past 9 years (CBS, 2022). The annual development for the period between 1995 and 2021 is visualised in Figure 1. In 2008 the average house price in the Netherlands decreased due to an economic crisis (De Boer & Bitetti, 2014). However, there has been an increase in the average house price since 2013.

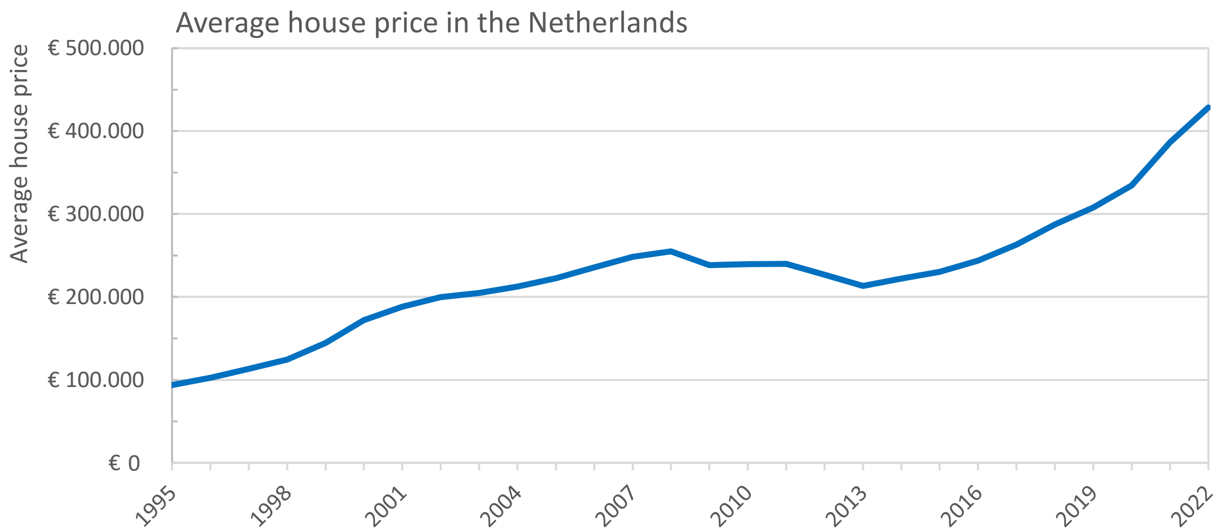

Figure 1. Development of the average house price in the Netherlands between 1995-2022 (CBS, 2023c, edited by author)

2.2 ENERGY PERFORMANCE OF HOUSES

The second core concept of this study is the energy performance of houses. Concerning the environmental aspect, findings from the Intergovernmental Panel on Climate Change (IPCC) indicate that without adequate measures, there is a potential for global temperatures to increase by 1.4 to 5.8°C by the end of the century as a result of greenhouse gas emissions and global warming. (Andaloro et al., 2010). Therefore, reducing emissions is of pivotal importance to address this global problem before it is impossible to reverse the temperature increase (Atwoli et al., 2021). In spatial planning, energy efficiency can play an important role in the reduction of global carbon emissions (Stern, 2008). The building sector accounts for 40% of the total energy consumption in the European Union which faces big challenges to meet the goal of transforming the existing building stock into a near zero-energy building stock by 2050 (Li et al., 2019). This importance has been recognised by introducing the Energy Performance of Buildings Directive (EPBD) in the beginning of 2003. This introduction led to the implementation of EPC for residential and commercial buildings across the European Union. The explicit goal of the EPC is to promote energy performance improvements in buildings (Brounen & Kok, 2011). In this study, the EPC is the descriptor for the energy performance of houses for several reasons. First, previous studies have also used the EPC to examine the association between the EPC and house prices (Brounen & Kok, 2011; Ayala et al., 2016; Zhang et al., 2020). Second, the EPC is mandatory in the Netherlands and registered as open accessible data (Rijksoverheid, 2021).

In previous studies the rating of the EPC of houses is described by various terms, namely "energy label" (Kok & Jennen, 2012; Ayala et al., 2016; Næss-Schmidt et al., 2016; Zhang et al., 2020), "energy label score" (Brounen & Kok, 2011), "energy performance level" (Cerin et al., 2014), "energy performance rating" (Brounen & Kok, 2011; Fuerst et al., 2015; Fuerst et al., 2016), "EPC rating" (Fuerst et al., 2015; Fuerst et al., 2016), "EPC band" (Fuerst et al., 2015; Fuerst et al., 2016), "energy efficiency label category" (Kok & Jennen, 2012) and "energy efficiency rating" (Brounen & Kok, 2011; Ayala et al., 2016; Næss-Schmidt et al., 2016). These terms can be divided into three categories, namely the "label"-, "performance"- and "efficiency"-terms. Since the descriptor for the energy performance of houses is related to "performance", this study has used the term "energy performance rating" as indicator to keep the term consistent and in line with previous studies.

Having an EPC when selling or renting out a property is mandatory since 2008 (Rijksoverheid, 2021). This is helpful for this study since the data for the willingness to pay for houses is indicated by a transaction price which has to be available at the same time as the energy performance rating. Within the sample of rated homes, the rating creates transparency in the energy performance of houses (Brounen & Kok, 2011). In 2022, 59% of the houses in the Netherlands had a registered EPC (Calcasa, 2022; RVO, 2023a). The number of registered EPC has increased over the years since the EPC has become mandatory and its validity for ten years (Rijksoverheid, 2021), which is shown in Figure 2.

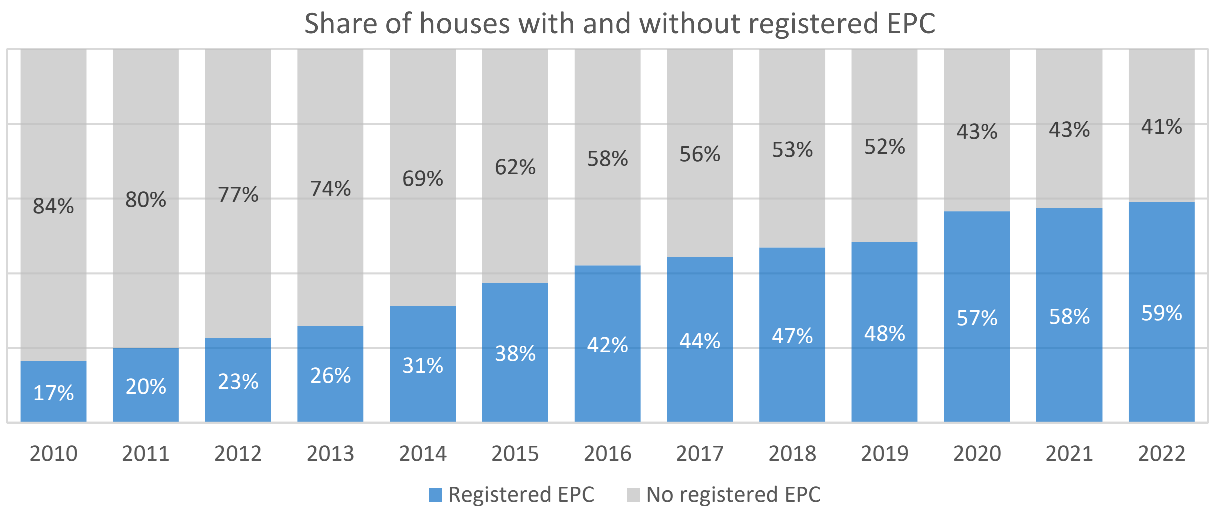

Figure 2. Development of the share of houses with and without registered EPC in the Netherlands (RVO, 2023a; edited by author)

In the Netherlands, the EPC and its calculation have undergone several updates since its introduction in 2003 (Rijksoverheid, 2020). Prior to 2018, energy performance ratings ranged from A++ to G, whereas it currently ranges from A++++ to G (Aedes, 2020; RVO, 2023b). In this rating system, G represents the least energy efficient rating, while A++++ represents the most energy efficient rating (ISSO, 2020; Milieu Centraal, 2021). The new EPC system is based on BENG requirements, which include indicators such as energy demand for heating and cooling (BENG 1), primary fossil energy consumption (BENG 2), and the use of renewable energy (BENG 3). The current NTA8800 calculation method uses predicted annual consumption per square meter in kilowatt-hours (kWh), in contrast to the energy index used in the previous determination method for the BENG 2 indicator (Aedes, 2020). Consequently, when reclassifying houses with existing EPC ratings, there may be a shift in the energy performance ratings. This shift will occur in approximately half of the cases and, in 90% of cases, will not exceed one energy performance rating (Aedes, 2021). In early 2018, the Energy Transition Progress Act (Wet Voortgang Energietransitie) was implemented in the Netherlands. As part of this act, one of the BENG requirements is to eliminate mandatory natural gas connections in houses. Consequently, new-build houses since 2018 are only connected to the gas network in exceptional situations (RVO, 2023c).

The energy performance rating of a house improves as it uses less fossil energy, resulting in lower carbon dioxide emissions (Milieu Centraal, 2021). Fossil energy is derived from coal, oil, and natural gas. The energy consumption of a house depends on various factors, such as insulation, existing installations, and the compactness of the building. A compact house, with fewer external walls, experiences less energy loss (Rijksoverheid, 2021). The use of renewable energy sources like solar panels, windmills, and heat pumps (Garrett-Peltier, 2017) further reduces the reliance on fossil energy, which is essential for achieving a sustainable built environment by 2050 and a more efficient energy performance rating (Li et al., 2019; Rijksoverheid, 2021). Figure 3 presents the distribution of energy performance ratings in the Netherlands, focusing only on registered ratings. It is important to note that the displayed proportions may not represent the entire housing stock, as not all houses have a registered Energy Performance Coefficient (EPC). Unrated houses are likely to have fewer A ratings (Calcasa, 2022).

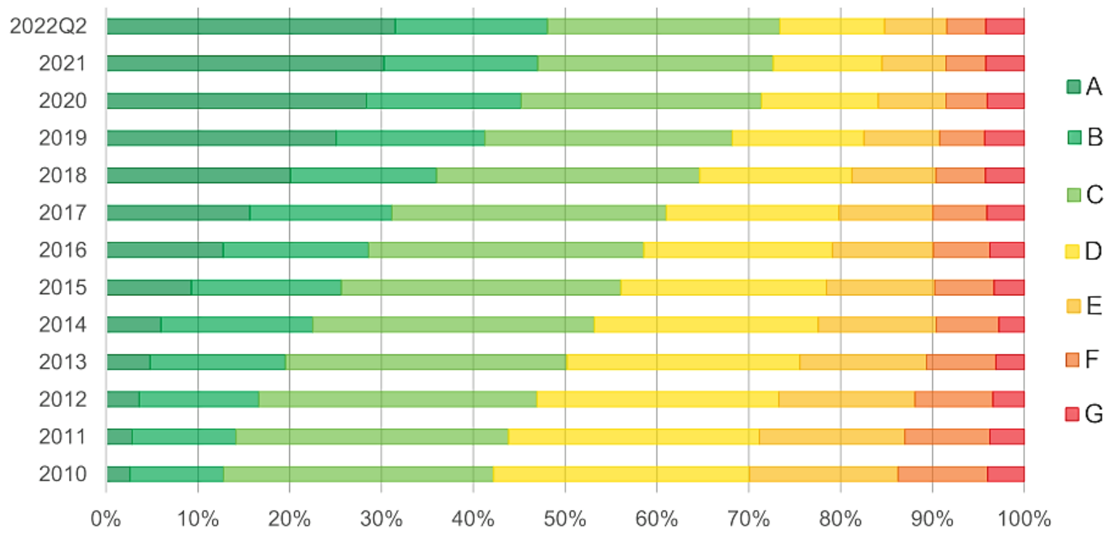

Figure 3. Distribution of registered energy performance ratings per year relative to the total housing stock (Calcasa, 2022)

2.2.1 HOUSE PRICES AND ENERGY PERFORMANCE

In this section, the relationship between the willingness to pay for houses and the energy performance of houses is presented. Several studies have examined the effect of the energy performance ratings on house prices across various countries and time periods. The relationships between these variables are summarised in Table 2, highlighting the references, time periods, and countries examined in each study.

Table 2. List of relationships between house prices and energy performance (own edit)

Reference:	Country:	Relationship:
Brounen & Kok (2011)	The Netherlands	Relative to D-rating: A=10%; B=5.5%; C=2%; E=-0.5%; F=-2.5%; G=-5%
Hyland et al. (2013)	Ireland	Relative to D-rating: A=9.3%; B=5.5%; C=1.7%; E=-0.4%; F/G=-10.6%
Cerin et al. (2014)	Sweden	A lower energy use results in a higher house price
Fuerst et al. (2015)	England	Relative to D-rating: A/B=5%; C=1.8%; E=-0.7%; F=-0.9%
Ramos et al. (2015)	Portugal	Relative to D-rating: ABC= 5.9%; EFG=-4%
Ayala et al. (2016)	Spain	A-B-C rating relative to D-E-F-G: 9.8% higher house price
Fuerst et al. (2016)	Wales (UK)	Relative to D-rating: A/B=14.4%; C=2.7%; E=-2.5%; F=-6.0%
Næss-Schmidt et al. (2016)	Denmark	C-rating is €26,800 higher than a similar G-rating house and €6,000 higher than a similar D-rating house
Zhang et al. (2020)	The Netherlands	Relative to D-rating: A=10%; B=4%; C=1%; E=0%; F=-1%; G=-4%

These studies have proven the relationship between house prices and energy performance. To indicate this relationship, studies compared the price premium or discount relative to the energy performance D-rating. The houses with an energy performance rating higher that D are considered as "green" and energy-efficient houses (Brounen & Kok, 2011; Ayala et al., 2015; Ramos et al., 2015). Although the specific monetary value that individuals are willing to pay for energy performance varies across studies, they consistently reveal a common trend. This trend indicates that individuals are willing to pay a higher price for houses with better energy efficiency. This consumer behaviour is reflected in the increased emphasis on energy efficiency ratings during the consumer buying process, as evidenced by a 261% rise in the filtering of energy efficiency ratings in the third quarter of 2022 compared to previous quarters (Funda, 2022).

2.3 ENERGY COSTS

The third core concept is energy costs, because the correlation between the development of the willingness to pay for energy performance of houses will be correlated to the development of the energy costs. The energy price determines the amount a household pays to the energy supplier and will therefore be expressed in transaction prices. Energy costs are set by the energy suppliers themselves and can therefore differ from one supplier to another. These energy costs are dependent on many factors, such as geopolitical conflicts, economical conflicts, production, storage, climate/weather conditions, suppliers, transportation, consumption (Essent, 2021; IEA, 2021; Ozili, 2022; Zakeri et al., 2022). An average household in the Netherlands consumes 2,241 kWh electricity and 1,074 m^3 gas annually (Luteijn & Wetzels, 2023).

In line with the previous two core concepts, previous studies have used several terms to describe this concept. In studies of Longstreth et al. (1985) and Strielkowski et al. (2021) the term "energy costs" had been used. Other studies on this concept used the term "energy prices" (Chomać-Pierzecka et al., 2022; Khan et al., 2022; Ozili, 2022; World Bank Group, 2022; Zakeri et al., 2022). The difference between the use of these terms depends on the perspective of the study. When referring to "energy costs," it is understood from the standpoint of the individual or entity responsible for payment or consumption. A more general study uses the term "energy prices". In the context of this study, the term "energy costs" is the most appropriate term, as it specifically targets the perspective of examining consumer purchasing behaviour in relation to energy expenses.

A consumer price index (CPI) shows the price movements of a set of goods and services purchased by an average Dutch household. The CPI of energy, as a result, includes not only energy prices but also prices associated with renting and reading meters, fixed charges, transport and supply are included (CBS, 2023d). Given that the development of electricity and gas follows a similar trend, there is no need to make a distinction between them (CBS, 2023b). The development over the period from 1996 to 2023 of the CPI of energy is shown in Figure 4, which shows that there is a sharp increase in the CPI of energy in the period from 2021 onwards.

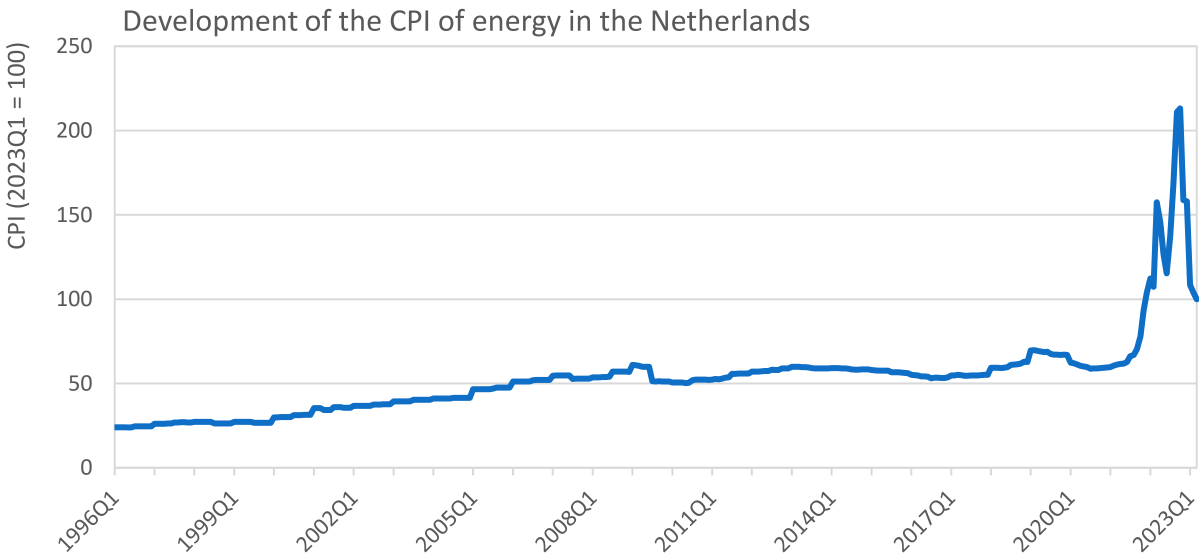

Figure 4. Development of the CPI of energy in the period from 1996 to 2023 (CBS, 2023b, edited by author)

Within this study, the development of the Consumer Price Index (CPI) for energy has been used to associate with the development of the willingness to pay for energy performance of houses. The CPI of energy is well-suited for this purpose as it encompasses all costs related to energy and represents the total amount households spend on energy. Since this study examines household purchasing behaviour, it is advantageous to include all costs related to energy. By including all costs related to energy, the complete effect of the increase in these costs are included and associated with the willingness to pay for energy performance. The use of the CPI of energy aligns with recent studies, such as Hoebergen et al., 2021; Hoebergen et al., 2022; Schep et al., 2022, focusing on the recent increase in energy costs. These recent studies utilise energy costs constructed in terms of the CPI (CBS, 2023d).

The recent increase in global energy costs can be attributed to the impact of the COVID-19 pandemic and the restrictions imposed on Russia (World Bank Group, 2022). In the period COVID-19 was most active, lockdowns and uncertainty caused temporary restrictions on the extraction of fossil fuels and disrupted supply chains, production and transport processes (Chomać-Pierzecka et al., 2022; Khan et al., 2022). The findings of recent studies show that energy costs are extremely vulnerable in the short run to the uncertainty related to the COVID-19 pandemic. Higher uncertainty caused by the pandemic results in fluctuating energy costs (Chomać-Pierzecka et al., 2022; Khan et al., 2022).

In the beginning of 2019, the European Union imported 83% of the total gas supply from countries outside of the European Union. Russia was the main supplier with 51.3% of the total imported gas supply in 2019 (European Council, 2023). Since Russia's invasion of Ukraine on February 2022 (Ozili, 2022), European Union gas imports from Russia have been significantly reduced to a percentage of 17.2% at the end of 2022. Therefore, other countries provided more gas to the European Union, mainly the United States, Nigeria, Qatar and Algeria (European Council, 2023). This uncertainty led of the gas supply led to an increase in gas prices. Because of the way the EU energy market currently works, along with gas prices, electricity prices have also risen sharply (European Council, 2022a; European Council, 2022b).

2.3.1 HOUSE PRICES AND INCREASED ENERGY COSTS

The relationship between house prices and the recently increased energy costs is discussed in only a few scientific studies. Vrieselaar & De Groot (2022), in a rapport on the Dutch context, state that the increased interest rates and energy crisis are depressing the demand for owner-occupied houses. This depressing demand has slowed down the increasing house prices and are therefore expected to fall slightly during 2023 (Vrieselaar & De Groot, 2022).

2.3.2 ENERGY PERFORMANCE AND ENERGY COSTS

A report of Multiscope (2022) on the heating, water and energy conservation, ventilation and insulation of houses, examined the effect of the increased energy costs on several factors. One of these factors is the willingness to make houses more sustainable. The findings are illustrated in Figure 5, revealing that 68% of Dutch residents planning to enhance the sustainability of their house in 2022 attribute their decision to the recent increase in energy costs. This is in line with a study of Vereniging Eigen Huis (2021) which state that 50% of the people will improve the energy performance of their house because of the recently increased energy costs. Also, a quarter of these people state that they will make changes in the short term to benefit from these measures. Both studies show that people are willing to improve the energy performance of houses in periods of increased energy costs. Another study by Funda is also in line with these studies, as it states that 53% of house buyers filters more on the energy performance because of increased energy costs. Moreover, according to this study, saving on heating costs and increasing home value top the list of main reasons to make their home more sustainable. This is followed by home comfort and the environment (Funda, 2023).

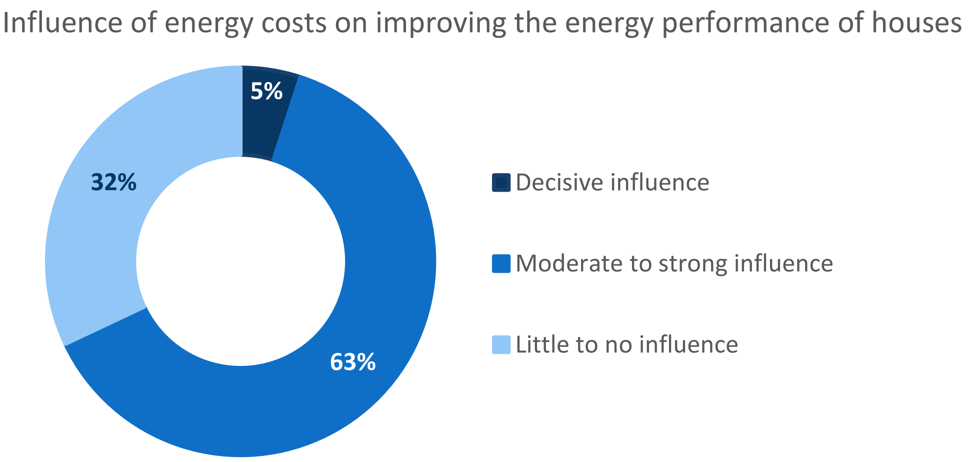

Figure 5. Relationship between energy performance and energy costs (Multiscope, 2022, edited by author)

2.4 CONCEPTUAL FRAMEWORK

The previous sectors of this chapter provided information about the different relationships between the core concepts of this study. Since this study examines the association between the willingness to pay for energy performance and increased energy costs, the financial relationships are of importance for this study. The previous described relationships show that there is a financial relationship between the willingness to pay for houses and the energy performance of houses which implies that people are willing to pay a higher transaction price for houses with a more efficient energy performance rating.

According to the above-described theoretical framework for this research, a simplistic flow scheme is drafted and presented in Figure 6. This conceptual framework presents the core concepts and the financial relationships between them and is based on the study by Andersson et al. (2014). Left, the "conventional" situation is described as baseline which refers to the always existing relation between the energy performance and house prices. Right, the increased energy costs can be seen as the external moderating factor. This is identified as the knowledge gap for this study as previous studies have not examined to what extent the increased energy costs are associated with the baseline.

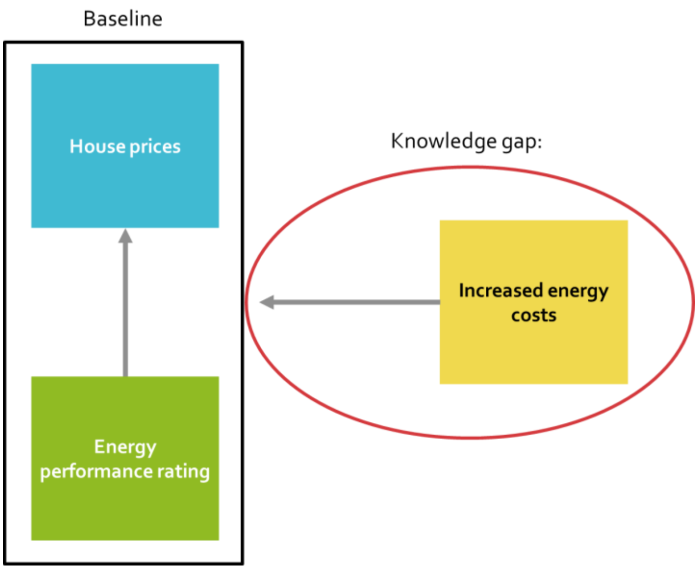

Figure 6. Conceptual model for this study (own edit)

CHAPTER 3: METHODS

This chapter presents the description and justification of the research methods used in the study. First, the overall research methodology is outlined. Subsequently, each research method is described in more detail. Here, the hedonic pricing technique, multiple regression and correlation have been elaborated. Besides a description, also the reasoning and explanations are presented.

3.1 RESEARCH METHODOLOGY

A comprehensive literature study was performed in order to draft the main research question which is stated in Chapter 1.2. The literature review was conducted by using different types of sources, namely scientific articles, reports, books and verified websites. By conducting this literature review, a knowledge gap was identified for which this study was initiated to fill it. Through the literature review, the key concepts for this study have been reviewed by elaborating previous findings on them. The relationships between these concepts based on previous studies were then combined, resulting in a conceptual model.

This study is a quantitative research that utilises the hedonic price technique to estimate the willingness to pay for energy performance. The hedonic price technique is implemented through a multiple regression analysis. The analysis is conducted for different time periods in the municipality of Utrecht to examine the evolving trends in willingness to pay for energy performance over time. Subsequently, the findings are compared to the changes in energy costs during the same period. Given the significant fluctuations in energy costs, particularly in recent years (CBS, 2023b), relying solely on annual data would not capture these variations adequately. Therefore, this study utilises quarterly data. The comparison between the changes in willingness to pay for energy performance and the fluctuations in energy costs reveals the degree of correlation and provides insights into the research question. The overall research model is illustrated in Figure 7.

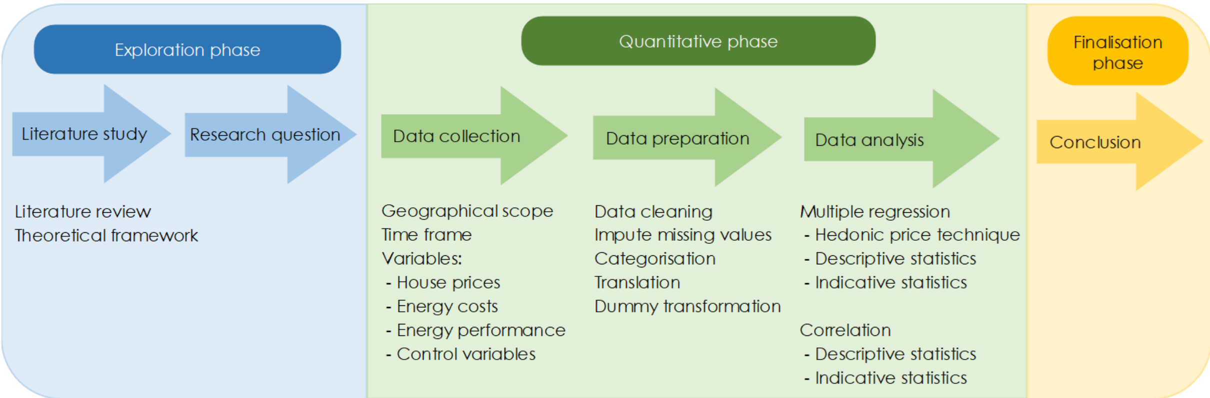

Figure 7. Visualisation of the research model (own edit)

3.2 HEDONIC PRICE TECHNIQUE

Considering the theoretical framework, the hedonic price technique is frequently used in similar studies as: Brounen & Kok, 2011; Hyland et al., 2013; Cerin et al., 2014; Fuerst et al., 2015; Ayala et al., 2016; Fuerst et al., 2016; Zhang et al., 2020 and Dambon et al., 2022. This method can be used to estimate what proportion of a price can be attributed to the different components of a house and living environment (Chau & Chin, 2002). In this study the willingness to pay for energy performance is examined by this technique. Here, the house prices are the dependent variable and the energy performance rating is the most important independent variable. In addition to energy performance, other factors also influence house prices. To prevent misattributing effects to energy performance that are actually influenced by other factors, it is essential to incorporate these variables into the hedonic pricing technique (Zhang et al., 2020). The control variables, which are independent variables, encompass these factors. This hedonic price technique works optimal when there are as many relevant control variables included that have a relationship with the dependent variable in the regression. Also, the independent and control variables should have no, or as little as possible, intercorrelation and the residuals should be normally distributed, with constant variance and a mean of zero (Francke & Van de Minne, 2021). The variables identified in the literature review are added to the baseline of the conceptual model shown below in Figure 8. This indicates that house prices serve as the dependent variable and are influenced by multiple variables. Within this study, the hedonic price technique serves to investigate the effect of the energy performance rating on house prices, while controlling for various object- and location-related factors.

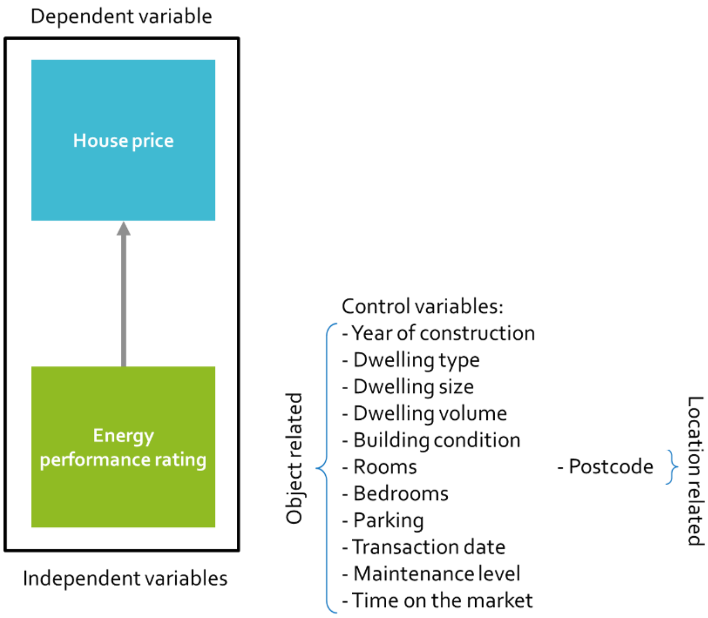

Figure 8. Conceptual model of the hedonic price technique (own edit)

To perform the hedonic pricing technique, data on the dependent, independent variables are required. In this study, a dataset provided by Watson+Holmes has been utilised. Watson+Holmes collect and combine data by utilising various sources, such as real estate agents, NVM, VBO, VGMNL, national, and regional platforms. This dataset comprises information on houses sold in the municipality of Utrecht, covering the period from January 2013 to the end of March 2023. Table 3 presents a comprehensive list of the variables included in the dataset, existing of the dependent, independent and independent control variables. Many of these variables align with those used in previous studies (Table 1). However, it is important to note that not all variables were considered in this particular study, which will be further explained in Chapter 3.3.

Table 3. List and description of variables of the collected data (own edit)

Variable:	Description:
Object related:	
House price	The transaction price of the house at the moment of selling.
Energy performance rating	The rating on the EPC of houses from a score from A-G.
Year of construction	The year of construction of the house in categories.
Dwelling type	The different dwelling types are: apartment; terraced house; semi-detached and detached house.
Dwelling size	The size of the property, measured in square metres of lettable floor area.
Dwelling volume	Gross volume of the dwelling in cubic metres.
Plot size	The size of the plot, measured in square metres of lettable floor area.
Existing/new construction	This dummy represents the construction condition at the time of the transaction.
Rooms	The number of registered rooms within the house.
Bedrooms	The number of registered bedrooms within the house.
Parking	A dummy representing the presence of a private parking lot.
Maintenance inside	Home maintenance score in the following categories: poor; moderate; reasonable; good; excellent.
Maintenance outside	Home maintenance exterior score in the following categories: poor; moderate; reasonable; good; excellent.
Transaction date	The moment of the transaction of the house, categorised by annual quarter.
Location related:	
Postcode	A dummy for each postcode to fix spatial effects. For this variable, the first 4 characters (also called postcode-4) were used to determine in which area the address is located.

In order to make the dataset usable for this study, it underwent preparation and organisation using Microsoft Excel. This involved cleaning the dataset by removing duplicate and irrelevant variables. Furthermore, missing values were handled by carefully examining the characteristics of the missing data variable. To impute certain energy performance ratings in cases where these were unknown, established methods such as analysing time-specific trends and other descriptive statistics were employed (Vastmans et al., 2012; Open University, 2023). Following the approach taken by Vastmans et al. (2012), cases where imputation was not possible were subsequently removed from the dataset. This process of imputation is discussed in detail in Chapter 4.1. Given that the original dataset contained numerous subcategories, these were consolidated into main categories, along with the corresponding justification, which is provided in Appendix 1.1.1 Subsequently, the dataset was translated from Dutch to English, as the original dataset was in Dutch. As a final step, the dataset was appropriately transformed by employing dummy variables for categorical variables, as outlined by De Vocht (2022).

3.3 MULTIPLE REGRESSION ANALYSIS

In this study, the multiple regression analysis is employed as the hedonic price technique is performed by means of a multiple regression. The purpose of a standard multiple regression analysis is to calculate the coefficients for the independent variables using the values of the dependent and independent variables (Moore et al., 2006; Nugus, 2009; Robinson, 2020). Each predictor value is assigned a weight based on its coefficient, which reflects its relative impact on the overall prediction (Moore et al., 2006).

In this study, apart from the standard multiple regression, an interaction term between energy performance and time is also included. To capture the temporal dynamics, quarterly dummy variables were employed, aligning with the quarterly data used to examine the fluctuation of energy costs. The interaction variable aims to capture the adjusted relationship between energy performance and the willingness to pay for houses across over time. The control variables are incorporated to account for other factors influencing house prices.

In a multiple regression with an interaction variable, the equation takes the following form (Pickery, 2008):

$$Y = a + \overbrace{b_1X_1 + b_2X_2 + \ldots + b_nX_n}^{\text{Control variables}} + \overbrace{\boldsymbol{b_{n+1}}X_1X_2}^{\text{Interaction variable}} + e$$

Where:

- Y is the dependent value;
- a represents the intercept on the y-axis, also known as the constant value;
- b_x are the regression coefficients of the X_x independent variables;
- n is the number of included variables;
- e stands for the error term that contains the price effect of omitted variables.

Some variables from Table 3 have not been included in the multiple regression due to various reasons. Firstly, since dwelling size is strongly correlated with house price, it has been incorporated by representing house price as price per square meter on the y-axis. Therefore the price is adjusted for the dwelling size, but not included as predicting variable in the multiple regression. This is a common practice in other similar studies, such as Brounen & Kok, 2011; Fuerst et al., 2016; Zhang et al., 2020; as they adopt a similar approach. Secondly, dwelling volume was excluded as dwelling size provides a similar adjustment since a storey is approximately a fixed size. Thirdly, plot size was removed since the dataset not only includes ground-bound houses but also apartments, which lack individual plots. Therefore, this variable is not applicable for a significant number of cases. Fourthly, the number of bedrooms was not included since it is already captured in the total number of rooms, which is considered as a separate variable. Fifthly, the maintenance levels were not included, following the subjective nature of these ratings, which may vary across different data sources which have been combined in this dataset. The exclusion of this variable aligns with similar studies, as they also didn't take maintenance levels into account. Sixthly, the variable of existing/new construction was excluded due to its overlap with the construction year categories. Almost all cases with a new construction are categorised within either the 2010-2017 or 2018-2023 category. Therefore this variable does not add new information to the dataset. However, the exclusion of variables has minimal impact on explaining the regression results as their effects are encompassed within the included variables (Vastmans et al., 2012).

In addition to house characteristics and a constant value, the equation includes spatial and time fixed effects. The spatial fixed effects are indicated by the postcode-4 areas which are intended to correct for the price effect of spatially clustered omitted variables. The time fixed effects are indicated by quarterly data on the transaction date which are intended to correct for the exogenous developments that affect transactions, such as economic growth or depression (Kuminoff et al., 2010; Buitelaar et al., 2014; Buitelaar et al., 2020; Francke & Van de Minne, 2021).

The equation takes the following form when all the included variables are filled in:

$$House\ price\ /\ m^2 = a + b_1 \cdot energy\ performance + b_2 \cdot transaction\ date + b_3 \cdot construction\ year + b_4 \cdot dwelling\ type + b_5 \cdot rooms + b_6 \cdot parking + b_7 \cdot postcode + (\boldsymbol{b_8} \cdot energy\ performance \cdot transaction\ date) + e$$

To perform this multiple regression analysis, the cleaned and transformed dataset was exported to the statistical computer program SPSS. Here the labels, decimals and type of variables are specified, after which the actual multiple regression has been performed. For this study, the coefficient of this interaction variable (b_8) is most important, as it indicates which part in time can be attributed to energy performance. Chapter 4 describes the results of this multiple regression analysis in depth.

3.4 CORRELATION ANALYSIS

Once the multiple regression analysis is completed, the obtained results can be further analysed using a correlation analysis. In this analysis, the relationship between the interaction variable and the energy costs during the same period is examined to determine the strength of their association. To conduct the correlation analysis, Pearson correlation coefficient *r* was employed within the SPSS software. There is no universally defined interpretation for the Pearson's *r*, but a higher coefficient indicates a stronger association. A correlation coefficient of 0 signifies no association, while a correlation of -1 or 1 denotes a perfect negative (-) or positive (+) association. According to De Vocht (2022), a Pearson's *r* of 0.5-0.7 indicates a strong positive association, while >0.7 represents a very strong positive association. The results of this correlation analysis are presented and discussed in Chapter 4.3 using this interpretation.

The correlation analysis requires data that is not included in the hedonic pricing technique dataset, namely the energy costs. Based on the literature review focusing on energy costs, it was determined that the CPI of energy is the most relevant data for this study, as this is commonly used in previous studies. The review also revealed substantial fluctuations in energy costs. To capture these dynamics, quarterly data rather than annual data was used in this analysis. The Central Bureau of Statistics (CBS) has compiled data from multiple energy suppliers, each charging different prices for energy. Therefore, the open dataset provided by CBS represents the average price development across various suppliers, offering a comprehensive overview rather than relying on a single supplier's data (CBS, 2023b). This dataset was utilised as it covers the general trend of energy costs in the Netherlands.

3.5 DATA VALIDITY AND RELIABILITY

To ensure both validity and reliability of the study, reputable data sources and established research methods were employed. The data used in this study was obtained from independent parties, namely Watson+Holmes and CBS. These organisations are recognised and trusted parties, enhancing the reliability of the data. Watson+Holmes collects data from various sources and combines them to have the most comprehensive dataset possible, ensuring that the statements made based on this research have the widest possible support. The CBS produces reliable official government statistics upon request from the government. The tasks of the CBS, as outlined in both EU and national laws, involve carrying out, publishing, and facilitating statistical research on behalf of the government to support scientific purposes (CBS, 2019).

This study uses three commonly used research methods in quantitative research. The hedonic pricing technique, introduced by Rosen (1974) in the housing market, has emerged as one of the most widely used models in real estate research (Wei et al., 2022). One of the advantages of the hedonic price technique is its reliability, as the analysis is verifiable and replicable. The results are derived from "hard data," which are actual housing transactions, reflecting realised preferences of buyers (Visser & Van Dam, 2006). Since the hedonic price technique is performed by means of a multiple regression, the information above also proves the validity and reliability of this research method. Also correlation analysis is a frequently employed quantitative research method due to its extensive utilisation in statistics. Correlation analysis is a suitable method for determining the association between two developments because it quantifies the strength of the relationship, measures linear relationships and provides a standardised measure (De Vocht, 2022; Open Universiteit, 2023). Therefore the correlation between the development of the willingness to pay for energy performance and the development of the energy costs has been done by a correlation analysis using the Pearson correlation coefficient *r*.

Furthermore, the data processing was conducted using recognised research approaches, ensuring a responsible analysis. Prior to the multiple regression analysis, the data was cleaned and processed following recognised approaches (Vastmans et al., 2012; Open Universiteit, 2023). Non-representative and irrelevant variables were removed from the dataset enhancing the validity of the results by focusing only on the relevant variables. For cases where energy performance ratings were missing, imputation was done based on descriptive statistics and time-specific trends whenever feasible. This imputation was only done for cases if it could be done with a ensuring of 99% or higher. Subsequently, the remaining cases with missing values were eliminated from the dataset as they were deemed unsuitable for this study. However, the specifics and descriptives of the incomplete and therefore excluded cases are outlined in Appendix 1.1.2, ensuring transparency. Based on this description, it can be concluded that the excluded cases do not represent a selective group.

CHAPTER 4: RESULTS

This chapter presents the results of the study. Firstly, this chapter provides an overview of the descriptive statistics of the dataset which has been used in the multiple regression. Secondly, the chapter provides the statistic results of the multiple regression, indicating the willingness to pay for different variables of housing. Here, the focus is on the development of the willingness to pay for energy performance indicated by the interaction variable. Thirdly, this chapter discusses the correlation analysis using the results of the multiple regression. Here, the results of the correlation between the development of the willingness to pay for energy performance and the development energy costs is described.

4.1 DESCRIPTIVE STATISTICS MULTIPLE REGRESSION

Within this section, the descriptive statistics of the multiple regression is described. Here, the statistics are based on the transformed dataset. The data is restricted to the municipality of Utrecht and includes postcode-4 areas to determine location fixed effects. The municipality of Utrecht consist of 47 postcode-4 areas of which the distribution is shown in Figure 9. From this, it can be concluded that the use of these postcode-4 areas will be sufficient to correct for differences between neighbourhoods and therefore spatially fix the results of the multiple regression.

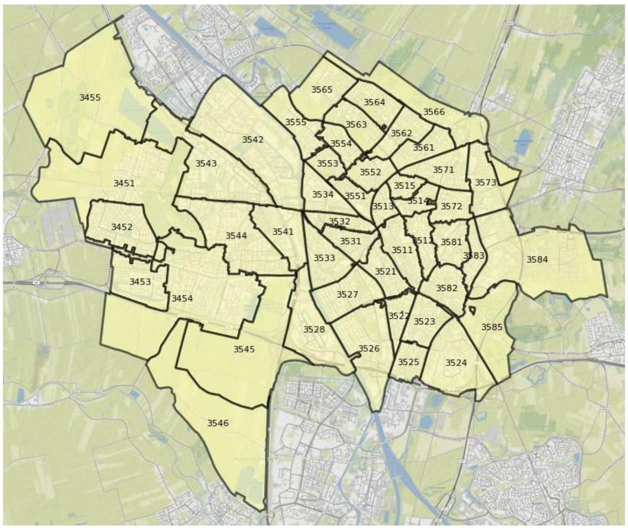

Figure 9. A map of the postcode-4 areas in the municipality of Utrecht (AlleCijfers, 2022a)

Since hedonic price techniques benefit from a large number of observations (Rico-Juan & Taltavull de La Paz, 2021), this study uses data from a period from the begin of 2013 to the end of the first quarter (March) of 2023. Figure 10 shows the number of transactions per quarter in the municipality of Utrecht. This shows that the number of transactions is relatively stable and always above 350 transactions. The total number of included transactions during this time period is 46,687.

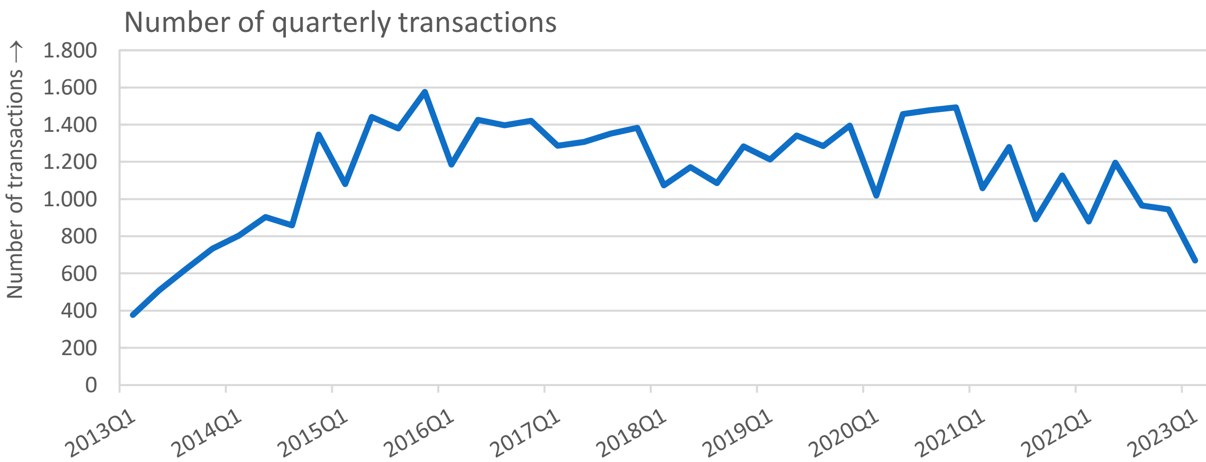

Figure 10. A visualisation of the quarterly number of transactions of houses in the municipality of Utrecht (own edit)

Given the emphasis of this study on the energy performance of houses, the subsequent statistics specifically focus on statistics in relation to the energy performance of houses. The distribution of energy performance ratings for the houses in the dataset is shown below in Figure 11. This shows that the energy performance rating A is most prevalent in the dataset. From the literature review, it is known that the EPC changed after 2018, resulting in two additional categories, A++++ and A+++. However, there are few cases within the dataset with an energy performance rating higher than A, namely A+ through A++++. This proportion corresponds to less than 5% of the total number of category A ratings. This can be explained by the fact that much of the data comes from the period when these categories did not yet exist. Therefore, cases with energy performance ratings from A++ to A++++ are not included as a separate category, but within the A category.

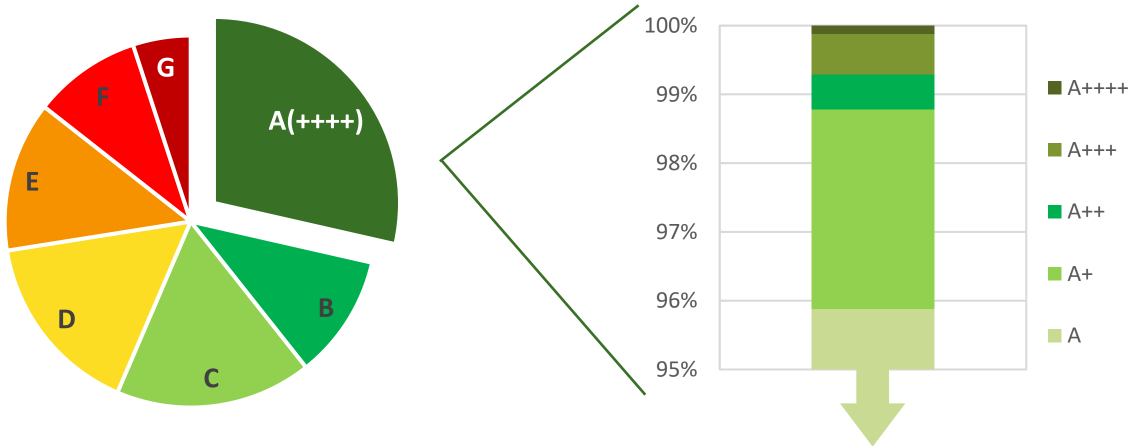

Figure 11. Distribution of the energy performance ratings (own edit)

As in other studies in the literature review, houses with energy performance A, B or C are considered as "green" and energy-efficient houses (Brounen & Kok, 2011; Ayala et al., 2015; Ramos et al., 2015). Therefore, the houses with an energy performance rating of A, B, or C will be compared to the energy-inefficient houses, namely the houses with an energy performance rating of D, E, F or G. The literature review also showed that houses built after 2018 are affected by BENG standards. This is reflected in the dataset as all cases built after 2018 fall into the ABC category. In addition, it can be observed in Figure 12 that >99% of houses built after 1990 also belong to the ABC category. Because of this, the houses built after 1990 whose energy performance rating is not known, is placed within the ABC energy performance rating category. This allows for an additional 7,718 cases which makes the multiple regression more robust. The remaining 4,236 cases have been excluded from the dataset. Appendix 1.1.2 discusses the descriptive statistics of this removed group and shows that these excluded cases is not a selective group.

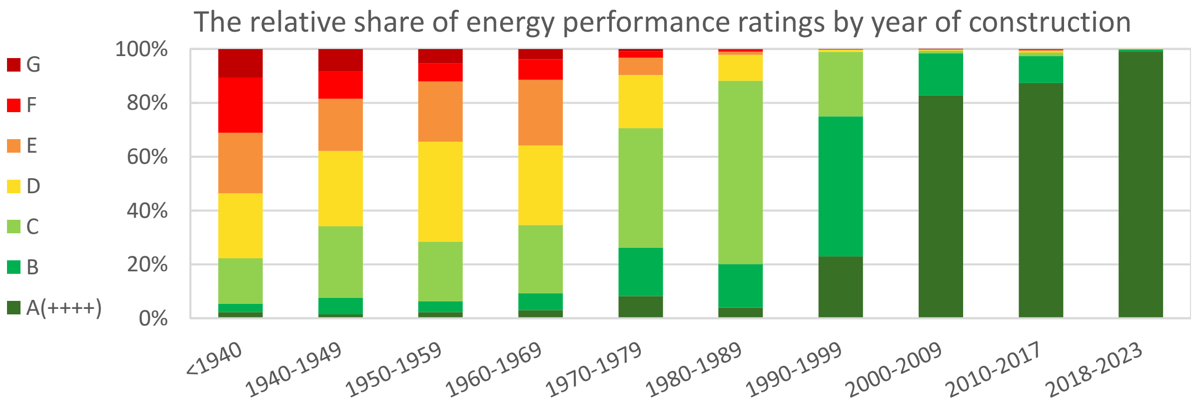

Figure 12. Distribution of the energy performance ratings related to the year of construction (own edit)

In addition to the relative distribution of energy performance ratings by year of construction category, the relative distribution by housing type was also examined. This included the four dwelling types, namely apartments, terraced, semi-detached and detached. The dataset shows that for all dwelling types, the majority exists of houses with energy performance rating category ABC which is visualised in Figure 13.

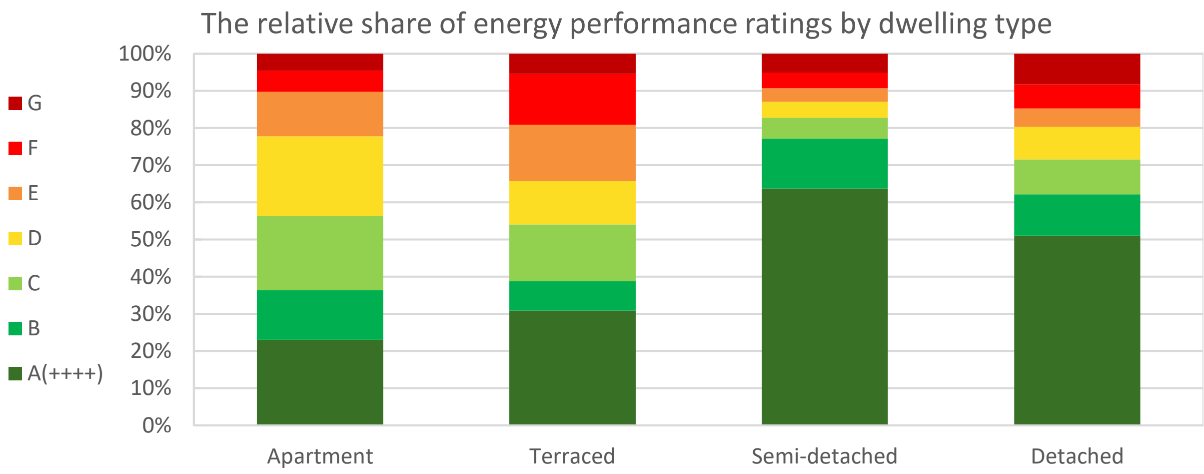

Figure 13. The distribution of energy performance ratings by dwelling type (own edit)

In addition to the distribution of energy performance categories within housing types, the average house price is visualised in Figure 14. This shows that apartments are on average the cheapest and detached houses on average the most expensive. The influence of the energy performance category has no overall impact on the house prices as it varies by dwelling type.

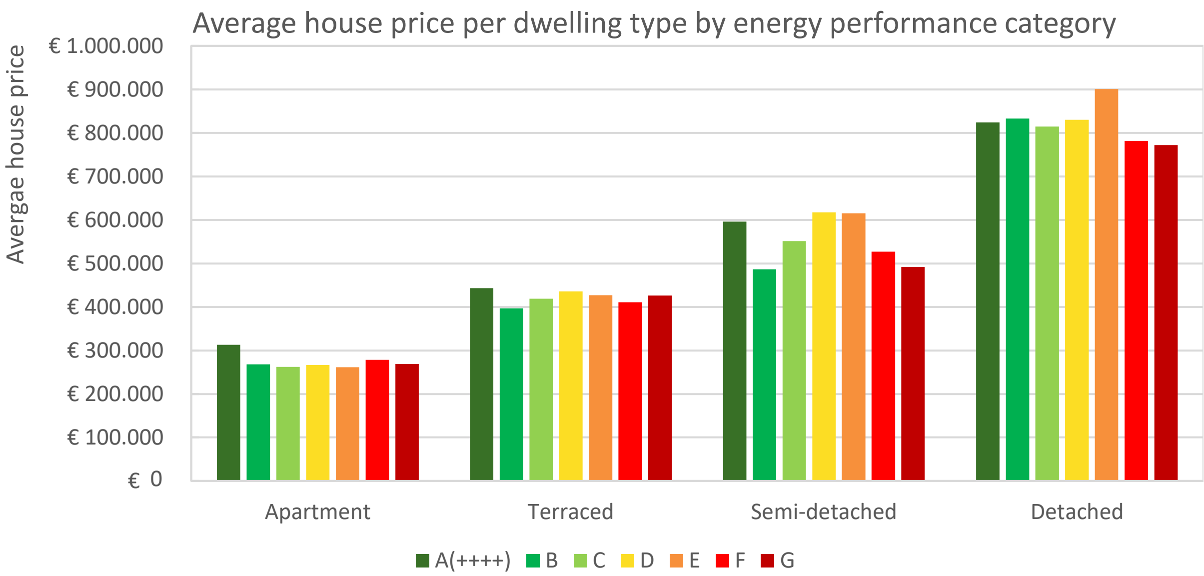

Figure 14. Distribution of the average house price per dwelling type by energy performance category (own edit)

Table 4 presents the numerical representation of the variables included in the multiple regression, in addition to the descriptive statistics visualised earlier. Here, the numbers of all main and subcategories are included, except for the postcode and interaction variable due to the large number of subcategories (see Appendix 1.2 for the full list). The minimum and maximum values are included for all main numeric categories.

Table 4. Summarised list of variables and descriptive statistics (own edit)

Variable:	Codes:	Description:	N:	Min:	Mean:	Max:	Std. dev.:
Total dataset		Dataset of transacted houses in the municipality of Utrecht	46,687				
Object related:							
House price	€/m²	The transaction price per square meter		703	3,690	9,975	1,346
Energy performance rating	(0/1)	The rating of the EPC					
A		The energy performance rating of A(++++)	11,163				
B		The energy performance rating of B	4,216				
C		The energy performance rating of C	6,679				
ABC (at first unknown)		The energy performance rating of A, B or C	7,617				
D		The energy performance rating of D	6,272				
E		The energy performance rating of E	5,107				
F		The energy performance rating of F	3,671				
G		The energy performance rating of G	1,962				
Year of construction	(0/1)	Categories of years in which the house is constructed		1400	1913	2023	43
< 1940		House construction before 1940	15,138				
1940 – 1949		House construction between 1940 – 1949	633				
1950 – 1959		House construction between 1950 – 1959	2,128				
1960 – 1969		House construction between 1960 – 1969	4,057				
1970 – 1979		House construction between 1970 – 1979	1,083				
1980 – 1989		House construction between 1980 – 1989	1,800				
1990 – 1999		House construction between 1990 – 1999	3,002				
2000 – 2009		House construction between 2000 – 2009	7,946				
2010 – 2017		House construction between 2010 – 2017	6,813				
2018 – 2023		House construction between 2018 – 2023	4,087				
Dwelling type	(0/1)	Categories of house typologies					
Apartment		House typology named apartment	21,589				
Terraced house		House typology named terraced house	22,068				
Semi-detached house		House typology named semi-detached house	2,050				
Detached house		House typology named detached house	980				
Rooms	Rooms	The number of registered rooms within the house		1	4	28	1
Parking	(0/1)	The presence of a private parking spot					
No		No included private parking spot	35,495				
Yes		Includes private parking spot	11,192				
Transaction date	(0/1)	The year in which the house has been sold					
2013Q1		House has been transacted in the first quarter of 2013	377				
2013Q2		House has been transacted in the second quarter of 2013	509				
…		… (See Appendix 1.2 for the full list)	…				
2022Q4		House has been transacted in the fourth quarter of 2022	944				
2023Q1		House has been transacted in the first quarter of 2023	669				
Location related:							
Postcode	(0/1)	First four numbers of the postcode					
3451		Houses located in the 3451 postcode area	1,602				
3452		Houses located in the 3452 postcode area	2,161				
…		… (see Appendix 1.2 for full list)	…				
3584		Houses located in the 3584 postcode area	348				
3585		Houses located in the 3585 postcode area	9				

4.2 MULTIPLE REGRESSION RESULTS

Within the regression, the numerical variables have been transformed by taking the natural logarithm (Ln), resulting in a log-log model (Benoit, 2011). This is common for studies employing hedonic price analysis (Brounen & Kok, 2011; Cerin et al., 2014, Fuerst et al., 2015; Ayala et al., 2016; Zhang et al., 2020; Dambon et al., 2022). According to Kok & Jennen (2012) and Van Moort (2019), this transformation enables straightforward interpretation of the findings, allowing the coefficients to be interpretated as percentages. However, it should be noted that interpretating the coefficient as percentage may not be equivalent to the exponent of the logarithm (Benoit, 2011; Giles; 2011). Hence, it was determined that the coefficients should not be directly interpreted as percentages, but rather after taking the exponent of the coefficients.

Another advantage of applying a logarithmic transformation to the numeric variable is that this brings the residuals closer to conforming to a normal distribution, which is one of the assumptions of a multiple regression (De Vocht, 2022). In addition to a normal distribution of residuals, the assumptions for a multiple regression include homoscedasticity, multicollinearity, and linearity. The elaboration of these assumptions is included in Appendix 1.3. From this elaboration, it is evident that the multiple regression satisfies all assumptions.

The postcode-4 area 3565 has been excluded from the multiple regression analysis due to the presence of only one case representing this specific area. This is because this is a business park with a limited number of residential addresses (AlleCijfers, 2022b).

4.2.1 MODEL SUMMARY

The regression model shows the effect of the included variables on the logarithm of the house prices. The regression model for this study has an adjusted R Squared value of 0.834. This means that 83.4% of the variance in the house prices is explained by the variance in the included independent control and interaction variables. This percentage aligns with the percentage of previous similar studies. (Wen et al., 2005; Cajias et al., 2019; Van Moort, 2019) The relationship between the predictor variables and the dependent variable of house prices is very strong, as a R Squared of more than 0.500 is very strong (De Vocht, 2022).

Table 5. Model summary of the multiple regression (own edit)

R	R Squared	Adjusted R Square	Std. Error of the Estimate
0.913	0.834	0.834	0.149

4.2.2 ANOVA

The probability of observing a value of 1,675 or bigger with 140 “degrees of freedom” (df) is less than 0.001. Therefore, it can be concluded that this regression model is significant since it contains significant explanatory variables.

Table 6. ANOVA table of the multiple regression (own edit)

	Sum of Squares	df	Mean Square	F	Significance
Regression	5,181.731	140	37.012	1,675.258	0.000
Residual	1,028.366	46,545	0.022		
Total	6,210.097	46,686			

4.2.3 COEFFICIENTS

Below, the output of the multiple regression is included. Table 7 presents the coefficients and their corresponding significance. Since the time, spatial and interaction variables would occupy a significant amount of space, their coefficients are not listed in Table 7. For the coefficients of these variables, please refer to Appendix 1.4. Below, the interpretation of coefficients for the most relevant variables is described.

By taking the exponent of the coefficients, the various variables from Table 7 have been interpreted. This reveals that houses with an energy performance rating of A, B, or C are valued 8.9% higher than houses with an energy performance rating of D, E, F, or G. These findings align with the studies from the literature reviewed, which also observe a price premium for energy-efficient houses compared to energy-inefficient houses.

The inclusion of quarterly data ensures that the other variables account for time fixed effects. Analysing the coefficients of these time fixed effects (Table 10), it is evident that house prices exhibited a gradual increase from the beginning of 2013 until the second quarter of 2022. However, this effect then declines until the first quarter of 2023, reaching a level similar to that of the first quarter of 2021. This observation aligns with a previous study by Buitelaar et al. (2014), which also found that time fixed effects do not always exhibit a consistent upward trend over multiple years. This variation in the time fixed effects can be attributed by exogenous developments that have an impact on all transactions, such as economic growth and decline, as well as policy changes (Buitelaar et al., 2014).

For the interaction variable, the interpretation was done based on two reference categories that correspond to the previous reference categories of the separate variables. As a result, the coefficients represent the price premium or discount compared to the DEFG energy performance and the first quarter of 2023. It is evident that the willingness to pay in 2023Q1 is relatively high as all the other coefficients are negative, except for 2022Q4. This indicates that the willingness to pay for energy performance has been particularly high recently. Although not all interaction coefficients are significant, they should still be included in the subsequent correlation analysis.

Table 7. Results of the multiple regression model (own edit) ***** p <0.01; ** p <0.05; * p <0.10**

	Unstandardised coefficients		Standardised coefficient
Variables:	**B**	**Std. Error**	**Beta**
Constant (Ln House price/m^2)	9.014***	0.012	
Energy performance category			
DEFG$_{ref}$			
ABC	0.085***	0.013	0.112
Year of construction			
< 1940$_{ref}$			
1940 – 1949	-0.030***	0.007	-0.010
1950 – 1959	-0.133***	0.004	-0.076
1960 – 1969	-0.215***	0.004	-0.166
1970 – 1979	-0.217***	0.006	-0.089
1980 – 1989	-0.137***	0.005	-0.072
1990 – 1999	-0.126***	0.004	-0.085
2000 – 2009	-0.086***	0.003	-0.089
2010 – 2017	-0.070***	0.003	-0.068

2018 – 2023	-0.034***	0.004	-0.026
Dwelling type			
Apartment$_{ref}$			
Terraced house	0.055***	0.002	0.076
Semi-detached house	0.193***	0.004	0.108
Detached house	0.328***	0.005	0.129
Ln Rooms	-0.185***	0.002	-0.199
Parking			
No$_{ref}$			
Yes	0.033***	0.002	0.039
Time fixed effects			
Quarterly data	Yes		
Spatial fixed effects			
Postcode-4	Yes		
Interaction variable			
2023Q1$_{ref}$ & DEFG$_{ref}$			
2013 Q1 ABC	-0.049 **	0.022	-0.010
2013 Q2 ABC	-0.024	0.019	-0.006
…	…	…	…
2022 Q3 ABC	-0.013	0.016	-0.004
2022 Q4 ABC	0.006	0.016	0.002

As not all coefficients of the interaction are included in Table 7, these are visualised in Figure 15. This visualisation, show that the willingness to pay in 2013 is relatively high compared to the following years. Also, it is notable that the coefficients remain relatively stable between an index of 90 and 95 during the period from the first quarter of 2014 to the fourth quarter of 2020. During the period from the first quarter of 2021 to the first quarter of 2023, a strong increase in the willingness to pay can be observed. Additionally, the highest willingness to pay for energy performance of houses was measured in the fourth quarter of 2022 throughout the entire research period.

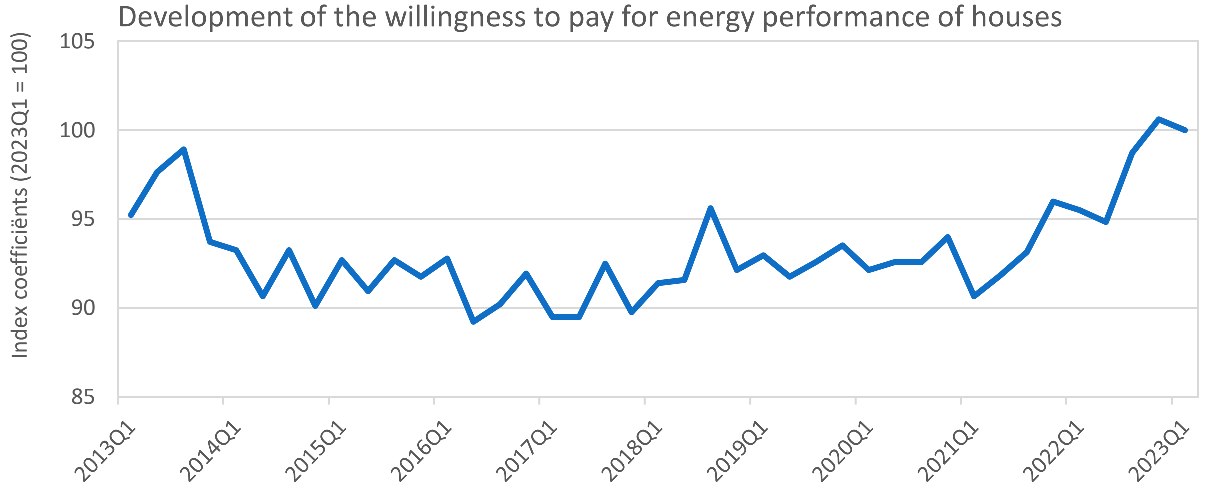

Figure 15. Visualisation of the development of the willingness to pay for energy performance of houses in the municipality of Utrecht (own edit)

4.3 CORRELATION RESULTS

To examine the relationship between energy performance and energy costs, a correlation analysis was conducted. In this analysis, the indexed coefficients of the interaction variables (Figure 15) represent the development of willingness to pay for energy performance. This development is correlated with the development of energy costs, which is shown in Figure 16. The literature review has shown that the development of the CPI of energy is the most suitable for this research. Below, the CPI of energy is indexed at the same time as the interaction variable, which is the first quarter of 2023. The table of the indexed interaction coefficients and the CPI of energy can be found in Appendix 2.

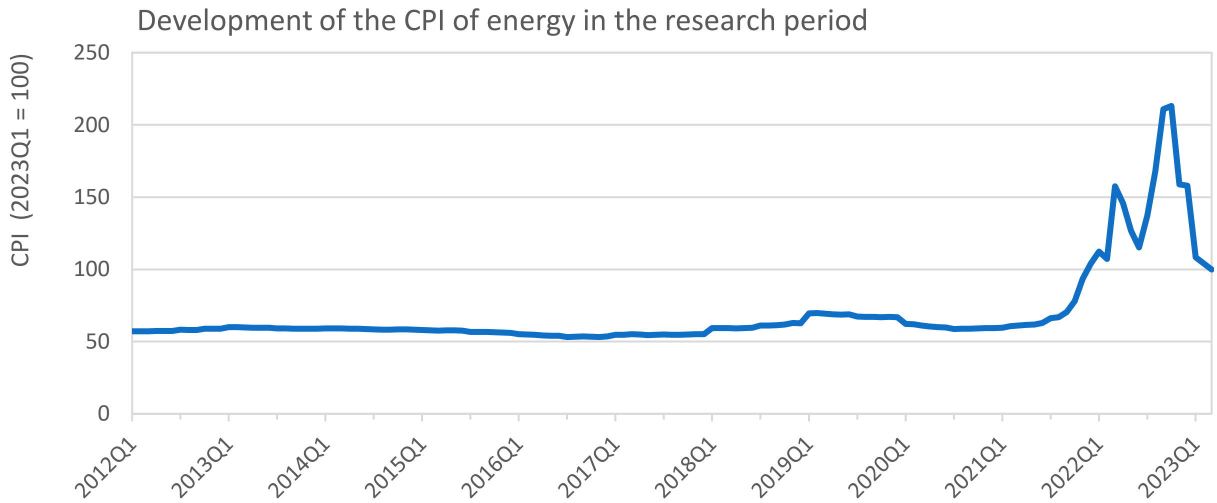

Figure 16. Development of the energy costs included in the correlation analysis (CBS, 2023b, edited by author)

The correlation was conducted for three different time periods. The first correlation includes the association for the entire study period, namely 2013 to 2023. The second correlation includes the association for the period from 2014 to 2023, excluding the peak in 2013. By doing this, these results provide insights into the effect of this peak in 2013 on the overall association. Additionally, the third correlation represents the association for the past five years which provides insights into whether the association has become stronger in the recent five years.

Previous studies, such as Capozza et al., 2002; Slacalek, 2009; Carroll et al., 2011, have shown that effects on house prices do not always occur immediately, and even when they do, eventual effects may be stronger. They argue that this is because of the inefficiencies in real estate markets (Capozza et al., 2002) and that households can be inattentive since they may not immediately notice and experience shocks to macroeconomic indicators (Carroll et al., 2011). Therefore, it was decided to not only examine the correlation between willingness to pay for energy performance and energy costs in the same quarter but also for energy costs of previous quarters. For this study this implies that it is possible that high energy costs from previous quarters have a bigger effect on willingness to pay for energy performance in a later quarter. In this study, the correlation was conducted for five different time points. The correlation coefficient without delayed effect indicates the degree of association between willingness to pay for energy performance and energy costs from the same quarter. In the associations with delay, the number of quarters represents how many quarters earlier the energy costs are correlated with willingness to pay for energy performance. Table 8 shows the correlation coefficients for the association between the interaction variable and the energy costs. The Pearson correlation coefficient *r* has been used since it involves numerical variables, namely the indices. The highest correlation coefficients per model and energy type are highlighted in bold. Further details on the content are provided below Table 8.

Table 8. Correlation matrix for the three time periods (own edit) *** p <0.001**

Pearson's *r*	2013 – 2023	2014 – 2023	2018 – 2023
No delayed effect	0.636*	0.764*	0.764*
1 Quarter delay	0.672*	0.799*	0.821*
2 Quarters delay	0.654*	0.773*	0.798*
3 Quarters delay	**0.678***	**0.801***	**0.832***
4 Quarters delay	0.578*	0.688*	0.700*

Using the interpretation of De Vocht (2022) which is described in Chapter 3.4, from Table 8 it can be concluded there is a strong positive association between the willingness to pay for energy performance in the municipality of Utrecht and the energy costs from 2013 to 2023. This positive association indicates that people are willing to pay more for energy performance of houses when energy costs increase. This can be attributed to the fact that households with energy efficient houses are less affected by high energy costs compared to households with energy inefficient houses, as they consume less energy. By consuming less energy, households with energy efficient houses have to pay less energy costs. This advantage becomes more appealing when energy costs are high, as the potential savings are higher in this scenario. Consequently, people are willing to pay more for energy performance of houses during periods of high energy costs since then the return on investment (ROI) is faster. For the situation from 2014 to 2023, the relationship is stronger than for the whole period (2013-2023) which indicates that 2013 has a depressing effect on the overall association. This can be attributed to the high coefficients in 2013 which do not overlap with the development of the energy costs in 2013. The correlation for data from 2018 to 2023 is even stronger which means that the association became stronger compared to ten and nine years ago. This can possibly be explained by the fact that sustainability is an increasingly mentioned topic (Google Trends, 2023; Hafez et al., 2023). Additionally, an important development that is not fully incorporated in the previous scenarios, but is included in the correlation of 2018-2023, is the requirement to have an EPC when selling a house. This may have created more awareness among house buyers and sellers, which could contribute to more conscious purchasing choices in terms of energy performance when it is of importance. This may be related to the previous argument made by Carroll et al. (2011), which suggests that households are more attentive due to this obligation compared to before.

Also, from Table 8 it can be argued that the effect of the increased energy costs does not affect the willingness to pay for energy performance immediately. This can be concluded since the association is stronger after one to three quarters delay with the most pronounced effect occurring with a three-quarter delay. As the energy costs have recently increased, this can distort this conclusion. When examining a delayed effect, in this case, the most recent energy costs are not included due to the comparison with prior energy costs and therefore neglecting the recent energy costs. When looking at energy costs of the correlation with a delay of three quarters, it shows a peak at the most recent quarters that only declines in the last quarter. This aligns best with the development of the willingness to pay for energy performance of houses and will therefore result in the highest correlation coefficient.

CONCLUSION

This research examines the relationship between the development of willingness to pay for energy performance of houses and the development of energy costs. The aim of this study is to gain insight into this relationship. Firstly, the development of willingness to pay for energy performance of houses in the municipality of Utrecht was calculated using a hedonic price technique in the form of a multiple regression. Subsequently, this development was correlated with the development of energy costs. By doing this, the following research question can be answered:

"What is the association between the willingness to pay for the energy performance of houses and energy costs?"

The analysis using multiple regression has provided insights into the evolution of the willingness to pay for energy performance of houses in Utrecht. The findings indicate a significant increase in the willingness to pay in recent quarters compared to previous quarters. This increase is strongly correlated with the development of energy costs, as evidenced by the correlation results. Several key conclusions can be drawn from these findings. Firstly, there is a clear and strong relationship between the development of willingness to pay for energy performance and the evolution of energy costs. Additionally, it is observed that the year 2013 has a dampening effect on the association between these two variables. Removing the peak in willingness to pay observed in 2013 leads to an increase in the Pearson's *r* from 0.678 to 0.801. These coefficients are highest with a delay of three quarters. This highlights the importance of considering delayed effects when examining housing price impacts. The results indicate that the correlation already exhibits strong association without the delay, but it can become even stronger over time. Moreover, the correlation results suggests that the association between the two developments has become stronger over the past five years. In summary, based on the results of this study, the null hypothesis can be rejected with a reliability of 99%. Therefore the results indicate that there is an association between the increased energy costs and the willingness to pay for energy performance of houses.

DISCUSSION AND RECOMMENDATIONS

In this chapter, the findings of the study on the relationship between willingness to pay for energy performance of houses and the development of energy costs are discussed and analysed. Here, the implications of the results are described which provide recommendations for future research based on the insights gained. These recommendations highlight interesting suggestions for future research that can build upon the findings of this study.

DISCUSSION

The results of this study indicate that there is an association between the willingness to pay for energy performance and energy costs which is in line with the findings of the theoretical framework. Firstly, the framework described the positive effect of energy performance of houses on house prices. Secondly, the framework included that people are more willing to make their house more sustainable in periods of increased energy costs. A combination of these relationships indicated there is indeed an association between both. Therefore the new insights derived from the results of this study are not contradictory to the previously established information, but rather an addition to it.

The study is subject to certain limitations that need to be acknowledged. However, this study has made efforts to mitigate these limitations through the choices made. Firstly, the data used for the analysis is limited to the municipality of Utrecht. This decision was made due to practical reasons, as obtaining a dataset with a large number of cases for the entire Netherlands would be challenging and require access to sensitive and non-public information on house prices. Moreover, previous studies focusing on the willingness to pay for energy performance at a national level have not specifically examined its development over time, as this study aimed to do. By choosing a more specific context, the hypotheses can be tested effectively within the context of Utrecht. While the findings demonstrate an association between the willingness to pay and energy costs in the municipality of Utrecht, it should be noted that these results may not directly apply to other municipalities or the entire Netherlands. The generalisability of the findings is limited to the specific context of this study, and caution should be exercised when extrapolating the results to a broader scale.

Secondly, it is important to acknowledge that this study primarily relied on quantitative research methods to address the research question. While the utilisation of well-established techniques such as the hedonic price technique, multiple regression, and correlation analysis is appropriate and reliable, it is worth noting that incorporating qualitative research methods could have provided valuable explanatory insights. By solely employing quantitative methods, the results of the study are predominantly based on numerical data. However, the inclusion of qualitative methods, such as expert interviews, could have shed light on the causality between the increased energy costs and the willingness to pay for energy performance, underlying reasons and practical implications of the observed effects. Despite the absence of qualitative research methods in this study, the research question was still effectively addressed, demonstrating that it was possible to obtain meaningful findings through the exclusive use of quantitative methods.

Thirdly, it is important to acknowledge that this study is limited due to its focus on an only recently relevant topic, namely the recent increase in energy costs. This recent development also implies that data on energy costs is still limited. This limitation is particularly important when considering the correlation with a delayed effect, as the most recent energy cost data is excluded in the analysis of the delayed effect. Despite this, it is worth noting that the results are presented for all scenarios, ensuring transparency across different situations. This demonstrates that even without the delayed effect, a significant and strong association exists.

The findings of this study have significant practical and academic implications. From a practical standpoint, the results are relevant to the current energy crisis and the ongoing energy transition. This study reveals that people are willing to pay more for houses with better energy performance during periods of high energy costs, highlighting the importance of addressing the energy crisis. It is observed that households facing high energy costs are more likely to live in energy-inefficient houses, which not only incurs additional expenses but also leads to a price discount on their house. To address these issues, policy recommendations can be made to prioritise the improvement of housing sustainability. This approach would help alleviate the burden of high energy costs and mitigate the price discount associated with inefficient houses. Furthermore, it would contribute to combating the energy transition by reducing reliance on fossil fuels. By implementing sustainable measures in housing, the future impact of rising energy costs can be mitigated, reducing the burden on households. This proactive approach aims to address the current pressing issue and prevent it from becoming a significant problem in the future.

In terms of academic implications, this study opens up avenues for further research to deepen our understanding of the subject matter. The subsequent section of this chapter discusses potential research areas that can build upon the findings of this study to expand the understanding of the willingness to pay for energy performance of houses.

FUTURE RESEARCH

The recommendations for future research are derived from the results and limitations of this study. Firstly, future research can investigate the same correlation for other geographical contexts since this study was limited to the context of the municipality of Utrecht. Such research would provide insights in the generalisability of the results of this study. When the results of this study are in line with other municipalities, the results can be generalisable on a broader scale. If the results of other municipalities show different results, the origin of such discrepancy would be relevant to study to gain more insight in this topic.

Secondly, future research can conduct the same research on a later moment in time, for instance in about two years. This research could result in a better estimate of the relevance of the delayed effect, since this research had to deal with very recent data on the increased energy costs. This will provide a better insight in the relevance and results of the delayed effect of energy costs on the willingness to pay for energy performance.

Thirdly, this study did not investigate whether the actual energy savings outweigh the price premium for energy performance ratings. For such research, more specific data is needed, including energy consumption and electricity and gas prices. This research would allow for the calculation and comparison of the payback period associated with the additional investment represented by a price premium for different energy performance ratings. It could provide valuable insights into whether the willingness to pay for energy performance aligns with the actual economic savings, or if there are other factors such as media attention, contributing to any over or underpaying for energy performance.

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APPENDIX 1: MULTIPLE REGRESSION

This appendix corresponds to Chapter 4 of the study. It encompasses several components. Firstly, it provides information on the assumptions and underlying methodology, with a detailed explanation of the data categorisation. Additionally, descriptive statistics of the incomplete and excluded cases are presented and discussed. Secondly, the complete version of Table 4 is included in this appendix. Thirdly, the results pertaining to the multiple regression assumptions are described in detail. Lastly, the complete version of Table 7 is included in this appendix.

APPENDIX 1.1 ASSUMPTIONS DATASET

This section provides an overview of the data cleaning and transformation phase, including the underlying information and choices made. Firstly, the categorisation of the data is discussed, followed by an explanation of the rationale behind handling missing values.

APPENDIX 1.1.1 CATEGORISATION OF DATA

In order to streamline the dataset and the multiple regression analysis, certain variables have been categorised. This categorisation process was applied to the energy performance ratings, year of construction, dwelling types, as well as the maintenance levels both inside and outside the properties.

The dataset originally included the specific energy performance ratings. Other studies defined houses with a energy performance rating of A, B or C as "green" and energy efficient houses (Brounen & Kok, 2011; Ayala et al., 2015; Ramos et al., 2015). It is also known from the literature review that the common reference category is energy performance rating D. This makes the remaining category consist of the least energy efficient energy performance ratings, namely EFG. This categorisation corresponds with the study of Ramos et al. (2015).

The original dataset included a range of construction years from 1250 to 2023, encompassing a total of 247 unique construction years. To simplify the analysis, the data has been grouped into ten categories. The first category comprises the oldest houses, constructed prior to 1940. A category which refers to a year of construction before a specific year is common in similar studies, for example Brounen & Kok (2011); Cerin et al. (2014); Ramos et al. (2015); Ayala et al. (2016); Fuerst et al. (2016); Næss-Schmidt et al. (2016). Another characteristic shared by certain studies is that the categories encompassing houses with more recent construction years tend to have a narrower range, as observed in studies such as Brounen & Kok (2011), Ramos et al. (2015), and Fuerst et al. (2016). This approach was also applied in this study, along with the consideration of the BENG standard, which mandates that every home constructed after 2018 must meet higher sustainability requirements (RVO, 2023c). As a result, the most recent category includes houses built in and after 2018.

The original dataset consisted of an extensive list of dwelling subtypes. Similar studies, such as Brounen & Kok (2011), Cerin et al. (2014), Fuerst et al. (2015), and Zhang et al. (2020), categorised dwellings into four main types: apartments, terraced, semi-detached, and detached. This categorisation approach has also been adopted in this study. However, subcategories were only relevant for terraced houses and semi-detached dwellings, as apartments and detached houses did not have subcategories. Therefore, four dwelling subtypes—end-house, intermediate house, corner-house, and terraced house—have been merged into the terraced category. Similarly, the terraced semi-detached and semi-detached categories have been merged into the semi-detached category.

APPENDIX 1.1.2 MISSING VALUES

Within the original dataset, the energy performance rating for 11,853 houses (23%) was missing/unknown. As energy performance ratings are one of the key variables in this study, a solution was sought to utilise a portion of these cases. Chapter 3 elaborated on the approach taken to address missing data, and the resulting choices were explained in Chapter 4.1. It was found that energy performance ratings for houses constructed after 1990 could be reliably assigned to the energy performance category ABC. This reduced the number of unusable cases from 11,853 to 4,236. However, for the remaining cases, it was not possible to confidently assign them to a specific energy performance category. As a result, these remaining 4,236 cases were excluded from the dataset and therefore from the regression analysis. The main descriptive statistics of the removed group were compared with the remaining cases to ensure that this was not a selective removal, thus improving the reliability of the study.

First, the relative distribution of construction years prior to 1990 was compared. Since the unknown energy performance ratings for houses constructed after 1990 were filled in, those years were not relevant for this comparison. Figure 17 demonstrates that the distribution of the removed cases with unknown energy performance ratings matches the distribution of the remaining cases. This indicates that no specific construction period was selectively excluded from the dataset used.

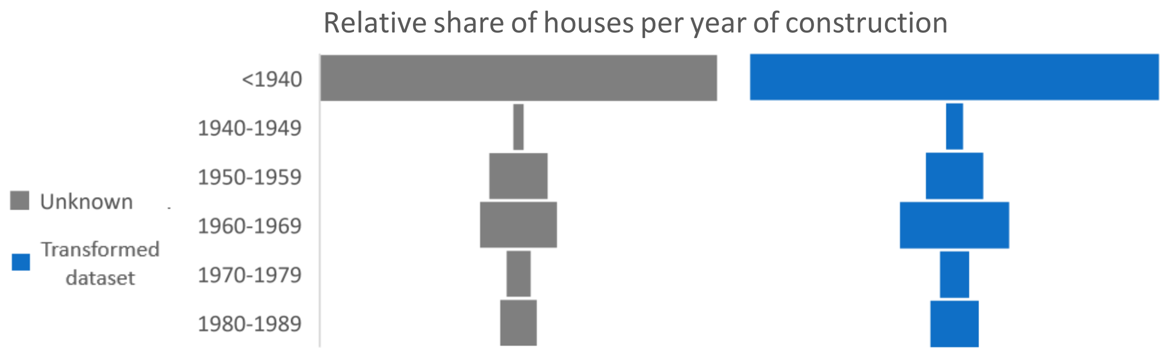

Figure 17. Comparison of the relative share of cases per year of construction (own edit)

Secondly, the relative distribution of the dwelling types was compared. Figure 18 illustrates that the distribution is largely similar, although the removed cases exhibit a relatively higher proportion of apartments and a lower proportion of terraced houses. However, the proportion of other housing types aligns with the remaining cases. This indicates that there was no selective removal of cases based solely on dwelling type, as it was not limited to a specific housing category.

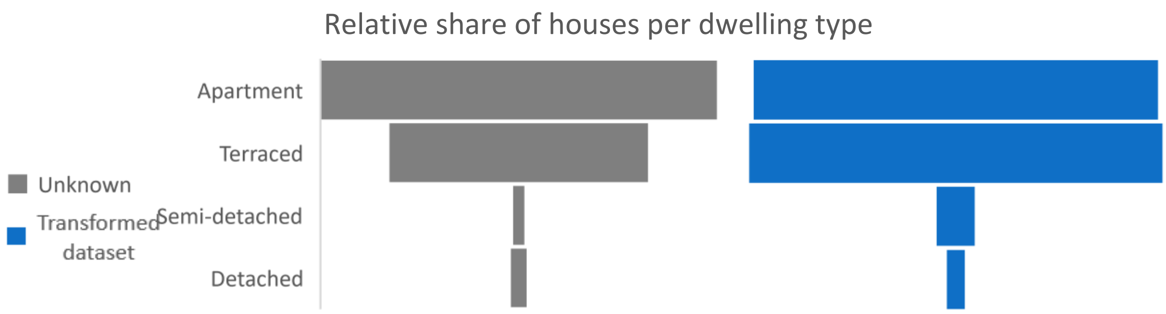

Figure 18. Comparison of the relative share of houses per dwelling type (own edit)

Thirdly, the average house prices were compared by housing type. Figure 19 illustrates that the average house price for each housing type is slightly higher among the removed cases. However, the comparison still reflects the same pattern, with apartments having the lowest average house price and detached houses having the highest. This suggests that the excluded cases were constructed in a similar manner to the remaining cases.

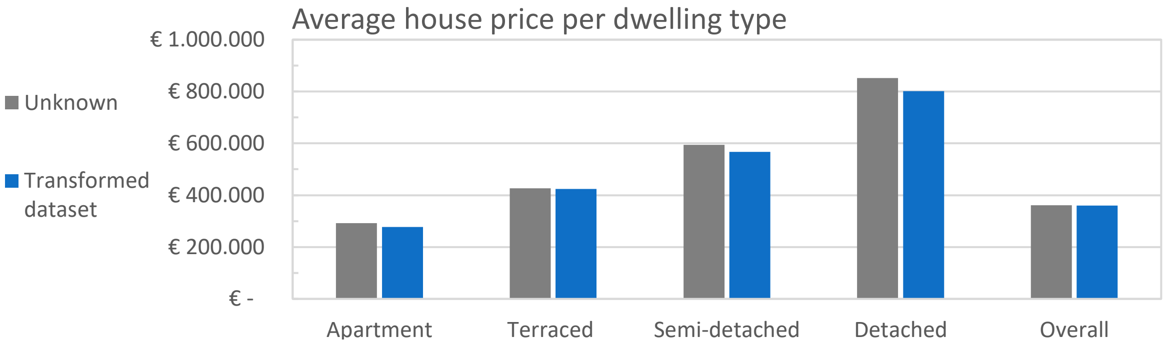

Figure 19. Comparison of the average house price per dwelling type (own edit)

Fourthly, the number of transactions per quarter was compared. A significant observation from examining Figure 20 is that even after excluding the unknown cases, each quarter still contains a substantial number of cases, with at least 400 transactions. However, it is worth noting that the majority of the excluded cases were sold between 2013 and 2015. In the subsequent period, the number of transactions has remained relatively stable.

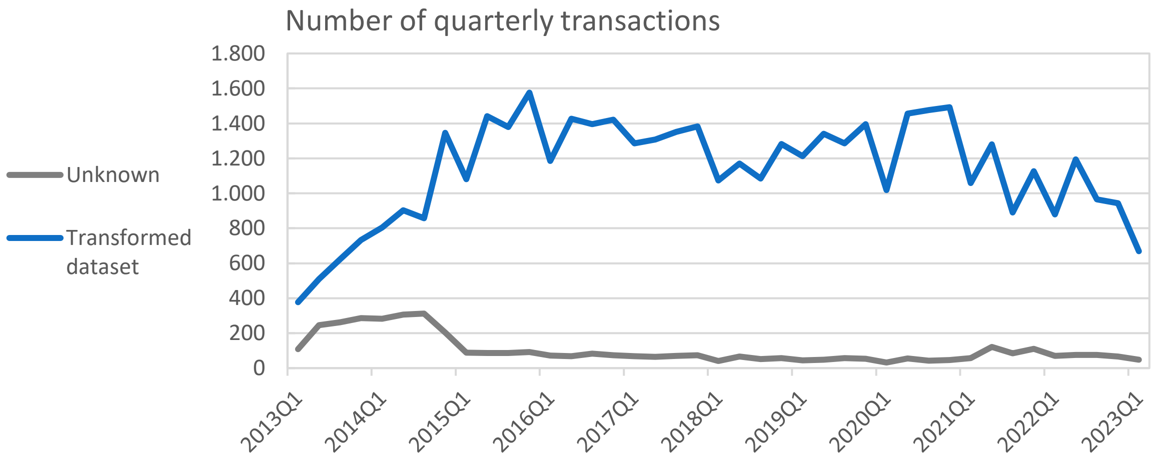

Figure 20. Comparison of the number of quarterly transactions (own edit)

APPENDIX 1.2 FULL DESCRIPTIVE LIST OF VARIABLES

The complete version of the descriptive statistics table is provided below, as only a summarised version is included in Chapter 4.1. This table includes the complete variables of transaction date, postcode, and the interaction variable.

Table 9. Full list of variables and descriptive statistics (own edit)

Variable:	Codes:	N:	Min:	Mean:	Max:	Std. dev.:
Total dataset		46,687				
Object related:						
House price	€/m²		703	3,690	9,975	1,346
EPC rating	(0/1)					
DEFG$_{ref}$		17,012				
ABC		29,675				
Year of construction	(0/1)		1400	1913	2023	43
< 1940$_{ref}$		15,138				
1940 – 1949		633				
1950 – 1959		2,128				
1960 – 1969		4,057				
1970 – 1979		1,083				
1980 – 1989		1,800				
1990 – 1999		3,002				
2000 – 2009		7,946				
2010 – 2017		6,813				
2018 – 2023		4,087				
Dwelling type	(0/1)					
Apartment$_{ref}$		21,589				
Terraced house		22,068				
Semi-detached house		2,050				
Detached house		980				
Rooms	Rooms		1	4	28	1
Parking	(0/1)					
No$_{ref}$		35,495				
Yes		11,192				
Transaction date	(0/1)					
2023Q1$_{ref}$		669				
2013Q1		377				
2013Q2		509				
2013Q3		623				
2013Q4		733				
2014Q1		804				
2014Q2		903				
2014Q3		858				
2014Q4		1,346				
2015Q1		1,080				
2015Q2		1,442				

2015Q3		1,380
2015Q4		1,576
2016Q1		1,186
2016Q2		1,426
2016Q3		1,396
2016Q4		1,421
2017Q1		1,286
2017Q2		1,308
2017Q3		1,352
2017Q4		1,383
2018Q1		1,073
2018Q2		1,171
2018Q3		1,085
2018Q4		1,283
2019Q1		1,212
2019Q2		1,341
2019Q3		1,285
2019Q4		1,395
2020Q1		1,018
2020Q2		1,457
2020Q3		1,477
2020Q4		1,493
2021Q1		1,058
2021Q2		1,280
2021Q3		891
2021Q4		1,127
2022Q1		879
2022Q2		1,195
2022Q3		965
2022Q4		944
Location related:		
Postcode	(0/1)	
3512 ref		975
3451		1,671
3452		2,161
3453		1,162
3454		1,663
3455		56
3511		1,199
3513		1,157
3514		1,317
3515		737
3521		1,049
3522		1,461
3523		1,611

3524	1,305	
3525	585	
3526	1,058	
3527	1,803	
3528	40	
3531	2,025	
3532	1,288	
3533	1,307	
3534	247	
3541	2,903	
3542	15	
3543	1,536	
3544	3,222	
3545	530	
3546	13	
3551	1,448	
3552	1,139	
3553	1,742	
3554	1,018	
3555	1,239	
3561	490	
3562	633	
3563	541	
3564	542	
3565	1	
3566	23	
3571	1,271	
3572	2,158	
3573	724	
3581	1,557	
3582	1,152	
3583	758	
3584	378	
3585	13	
Interaction variable:		
Transaction date · EPC (0/1)		
$2023Q1_{ref}$ & $DEFG_{ref}$	17,481	
2013Q1 ABC	280	
2013Q2 ABC	347	
2013Q3 ABC	463	
2013Q4 ABC	501	
2014Q1 ABC	579	
2014Q2 ABC	662	
2014Q3 ABC	576	
2014Q4 ABC	919	

2015Q1 ABC	718
2015Q2 ABC	850
2015Q3 ABC	874
2015Q4 ABC	992
2016Q1 ABC	693
2016Q2 ABC	801
2016Q3 ABC	864
2016Q4 ABC	874
2017Q1 ABC	822
2017Q2 ABC	778
2017Q3 ABC	894
2017Q4 ABC	900
2018Q1 ABC	641
2018Q2 ABC	681
2018Q3 ABC	659
2018Q4 ABC	767
2019Q1 ABC	759
2019Q2 ABC	807
2019Q3 ABC	772
2019Q4 ABC	896
2020Q1 ABC	590
2020Q2 ABC	826
2020Q3 ABC	887
2020Q4 ABC	887
2021Q1 ABC	667
2021Q2 ABC	887
2021Q3 ABC	565
2021Q4 ABC	786
2022Q1 ABC	596
2022Q2 ABC	832
2022Q3 ABC	663
2022Q4 ABC	651

APPENDIX 1.3 ASSUMPTIONS OF THE MULTIPLE REGRESSION ANALYSIS

To conduct a multiple regression analysis, four assumptions need to be fulfilled: normal distribution of residuals, homoscedasticity, independence of variables, and linearity. Firstly, in order to meet the requirements for multiple regression analysis, the categorical variables were transformed into dummy variables before running the regression (De Vocht, 2022). For each assumption, a plot generated by SPSS and Excel is presented to demonstrate its fulfilment.

APPENDIX 1.3.1 NORMAL DISTRIBUTION OF RESIDUALS

The first assumption of multiple regression is that the residuals must be normally distributed. The distribution of the residuals of the multiple regression is shown in Figure 21. It can be observed that this assumption is met as the distribution displays a bell-shaped curve.

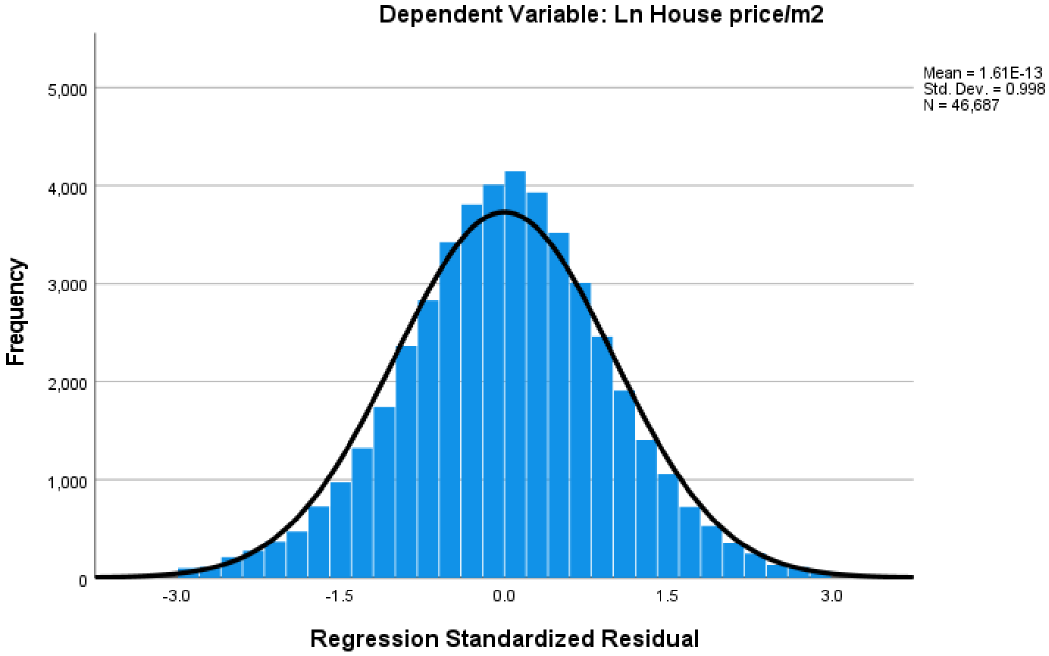

Figure 21. Plot of the distribution of the residuals (own edit)

APPENDIX 1.3.2 HOMOSCEDASTICITY

The homoscedasticity test is the second assumption and checks whether the standard deviation of the model residuals is the same for every value of Y. When the residuals are evenly distributed around zero, this condition is met. Figure 22 illustrates that this is indeed the case in this study.

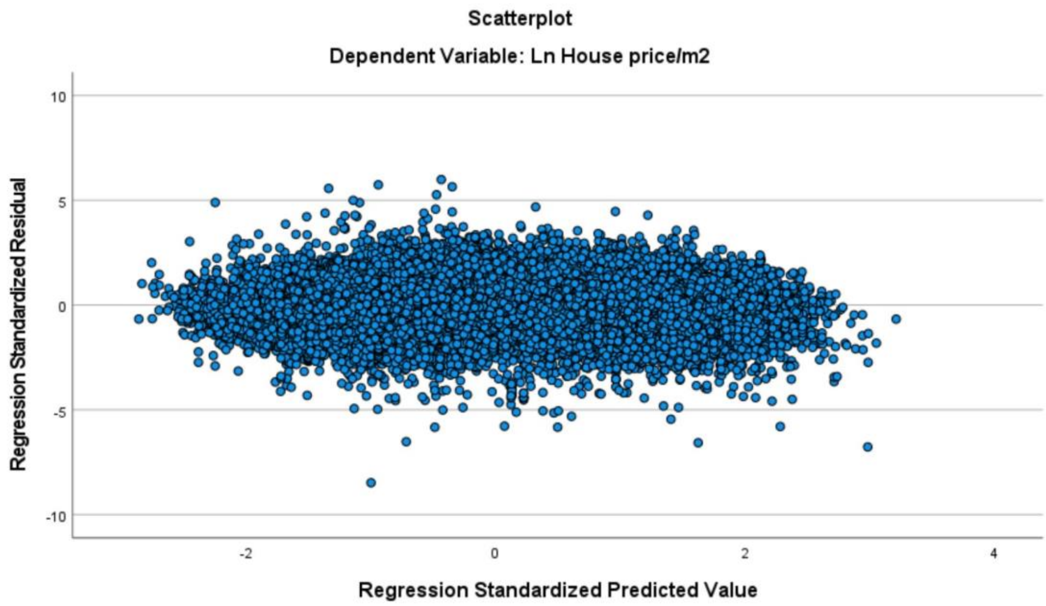

Figure 22. Homoscedasticity test of the multiple regression (own edit)

APPENDIX 1.3.3 MULTICOLLINEARITY

The third assumption of regression is that the variables should be independent of each other and have limited intercorrelation, typically below 0.9 (De Vocht, 2022). Since this study incorporates an interaction variable, a test for multicollinearity was conducted on a regression model where the interaction variables were excluded. This was done to avoid strong correlations between the interaction variable and the variables it is derived from, namely energy performance and transaction date.

The correlation matrix is visualised in Figure 23. Since it is difficult to read due to the large number of variables, below are the highest correlations described and explained. Firstly, there is a correlation pattern between energy performance and construction years. The explanation for this correlation can be based on Chapter 4.1, where it is discussed that there is a positive relationship between the energy performance and the construction year, indicating that energy performance tends to improve in more recent construction years. Secondly, some of the construction years are correlated with the postcode-4 areas. For example, the highest correlation, which is between postcode-4 area 3524 and the construction years of 1980-1989, has a correlation of 0.54. This can be explained by certain areas being built during specific periods. In the case of postcode-4 area 3524, 66.7% of the buildings were constructed between 1980 and 1989. This relatively high percentage results in a strong correlation between the two variables. Although these correlations are relatively high, they remain far below 0.9, indicating that this study satisfies the assumption of multicollinearity.

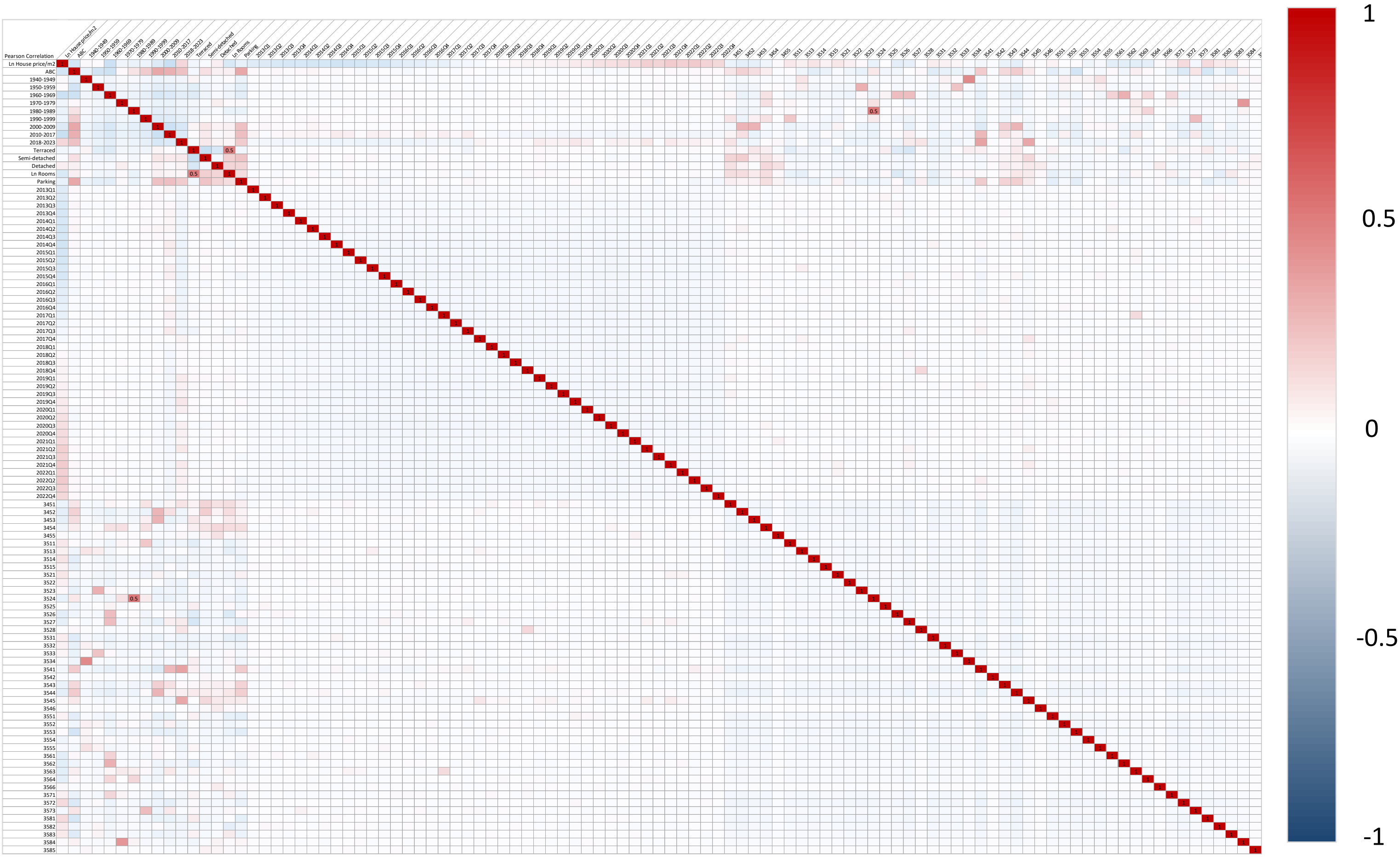

Figure 23. Intercorrelation matrix of the multiple regression (own edit)

APPENDIX 1.3.4 LINEARITY

The fourth and final assumption is that there should be a linear relationship between the predicting variables and the dependent variable Y. From the linearity graph shown in Figure 24, it can be concluded that this condition is also met since both lines almost completely overlap. Therefore all assumptions are met, it can be concluded that the multiple regression is justified to use.

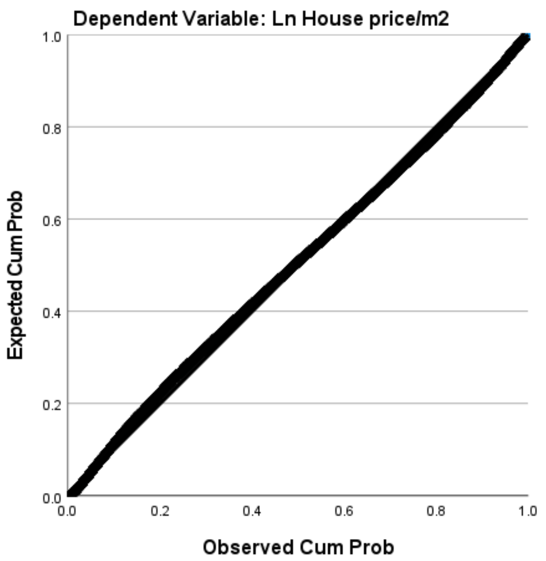

Figure 24. Linearity plot of the multiple regression (own edit)

APPENDIX 1.4 FULL INDICATIVE STATISTICS OF THE MULTIPLE REGRESSION

The comprehensive results of the multiple regression analysis are presented below, as Chapter 4.2 only includes a summarised version. This table encompasses the complete set of variables, including transaction date, postcode and the interaction variable.

Table 10. Full list of the results of the multiple regression (own edit)

	Unstandardised coefficients		Standardised coefficient	Significance coefficients	
Variables:	**B**	**Std. Error**	**Beta**	**T**	**Sig**
Constant (Ln House price/m^2)	9.014	0.012		735.704	0.000
Energy performance					
$DEFG_{ref}$					
ABC	0.085	0.013	0.112	6.749	<0.001
Year of construction					
$< 1940_{ref}$					
1940 – 1949	-0.030	0.007	-0.010	-4.385	<0.001
1950 – 1959	-0.133	0.004	-0.076	-34.192	0.000
1960 – 1969	-0.215	0.004	-0.166	-58.544	0.000
1970 – 1979	-0.217	0.006	-0.089	-38.700	<0.001
1980 – 1989	-0.137	0.005	-0.072	-27.759	<0.001
1990 – 1999	-0.126	0.004	-0.085	-32.239	<0.001
2000 – 2009	-0.086	0.003	-0.089	-25.353	<0.001
2010 – 2017	-0.070	0.003	-0.068	-20.124	<0.001
2018 – 2023	-0.034	0.004	-0.026	-8.148	<0.001
Dwelling type					
$Apartment_{ref}$					

Terraced house	0.055	0.002	0.076	28.250	<0.001
Semi-detached house	0.193	0.004	0.108	47.118	0.000
Detached house	0.328	0.005	0.129	60.195	0.000
Ln Rooms	-0.185	0.002	-0.199	-78.449	0.000
Parking					
No$_{ref}$					
Yes	0.033	0.002	0.039	16.747	<0.001
Transaction date					
2023Q1$_{ref}$					
2013Q1	-0.781	0.018	-0.192	-42.416	0.000
2013Q2	-0.769	0.016	-0.219	-48.929	0.000
2013Q3	-0.781	0.016	-0.246	-49.482	0.000
2013Q4	-0.744	0.014	-0.254	-51.824	0.000
2014Q1	-0.710	0.014	-0.253	-49.089	0.000
2014Q2	-0.683	0.014	-0.258	-48.010	0.000
2014Q3	-0.704	0.014	-0.259	-51.223	0.000
2014Q4	-0.660	0.013	-0.303	-51.810	0.000
2015Q1	-0.670	0.013	-0.276	-51.134	0.000
2015Q2	-0.622	0.012	-0.295	-51.131	0.000
2015Q3	-0.612	0.012	-0.284	-49.234	0.000
2015Q4	-0.586	0.012	-0.290	-48.121	0.000
2016Q1	-0.563	0.012	-0.243	-45.115	0.000
2016Q2	-0.498	0.012	-0.235	-41.166	0.000
2016Q3	-0.482	0.012	-0.225	-39.083	0.000
2016Q4	-0.443	0.012	-0.209	-36.036	<0.001
2017Q1	-0.414	0.013	-0.186	-32.893	<0.001
2017Q2	-0.377	0.012	-0.170	-30.515	<0.001
2017Q3	-0.366	0.013	-0.168	-29.031	<0.001
2017Q4	-0.332	0.013	-0.154	-26.551	<0.001
2018Q1	-0.298	0.013	-0.122	-23.423	<0.001
2018Q2	-0.269	0.012	-0.115	-21.581	<0.001
2018Q3	-0.256	0.013	-0.106	-20.115	<0.001
2018Q4	-0.226	0.012	-0.101	-18.273	<0.001
2019Q1	-0.227	0.013	-0.099	-17.963	<0.001
2019Q2	-0.195	0.012	-0.089	-15.831	<0.001
2019Q3	-0.192	0.012	-0.086	-15.477	<0.001
2019Q4	-0.169	0.012	-0.079	-13.578	<0.001
2020Q1	-0.123	0.013	-0.049	-9.624	<0.001
2020Q2	-0.096	0.012	-0.046	-7.952	<0.001
2020Q3	-0.080	0.012	-0.038	-6.533	<0.001
2020Q4	-0.058	0.012	-0.028	-4.762	<0.001
2021Q1	0.020	0.013	0.008	1.546	0.122
2021Q2	0.091	0.013	0.041	7.012	<0.001
2021Q3	0.114	0.013	0.043	8.506	<0.001
2021Q4	0.131	0.013	0.055	9.912	<0.001
2022Q1	0.151	0.014	0.056	11.027	<0.001
2022Q2	0.134	0.013	0.058	10.238	<0.001
2022Q3	0.057	0.014	0.022	4.193	<0.001
2022Q4	0.004	0.014	0.002	0.327	0.743
Postcode					
3512$_{ref}$					

3451	-0.398	0.007	-0.199	-55.154	0.000
3452	-0.391	0.007	-0.225	-55.710	0.000
3453	-0.455	0.008	-0.194	-59.728	0.000
3454	-0.364	0.007	-0.180	-50.178	0.000
3455	-0.416	0.023	-0.036	-18.311	<0.001
3511	-0.045	0.008	-0.018	-6.005	<0.001
3513	-0.176	0.007	-0.072	-23.755	<0.001
3514	-0.079	0.007	-0.033	-10.858	<0.001
3515	-0.172	0.008	-0.055	-20.957	<0.001
3521	-0.137	0.008	-0.053	-18.120	<0.001
3522	-0.209	0.007	-0.095	-29.439	<0.001
3523	-0.209	0.007	-0.098	-29.029	<0.001
3524	-0.379	0.008	-0.162	-47.911	0.000
3525	-0.257	0.009	-0.075	-29.604	<0.001
3526	-0.444	0.008	-0.175	-57.011	0.000
3527	-0.412	0.007	-0.212	-57.509	0.000
3528	-0.317	0.025	-0.025	-12.739	<0.001
3531	-0.231	0.007	-0.122	-34.060	<0.001
3532	-0.221	0.007	-0.094	-30.406	<0.001
3533	-0.172	0.007	-0.074	-23.279	<0.001
3534	-0.401	0.013	-0.076	-31.535	<0.001
3541	-0.415	0.007	-0.275	-60.474	0.000
3542	-0.476	0.047	-0.019	-10.027	<0.001
3543	-0.421	0.007	-0.206	-58.261	0.000
3544	-0.428	0.007	-0.297	-64.306	0.000
3545	-0.514	0.009	-0.149	-54.395	0.000
3546	-0.665	0.045	-0.028	-14.644	<0.001
3551	-0.296	0.007	-0.134	-41.629	0.000
3552	-0.322	0.007	-0.131	-43.378	0.000
3553	-0.349	0.007	-0.172	-50.426	0.000
3554	-0.406	0.008	-0.158	-53.752	0.000
3555	-0.359	0.007	-0.154	-49.113	0.000
3561	-0.462	0.009	-0.123	-49.109	0.000
3562	-0.524	0.009	-0.155	-57.691	0.000
3563	-0.512	0.009	-0.145	-56.333	0.000
3564	-0.547	0.009	-0.153	-59.373	0.000
3566	-0.201	0.033	-0.012	-6.073	<0.001
3571	-0.124	0.007	-0.052	-16.699	<0.001
3572	-0.092	0.007	-0.049	-13.580	<0.001
3573	-0.267	0.008	-0.090	-32.158	<0.001
3581	-0.051	0.007	-0.023	-7.159	<0.001
3582	-0.099	0.007	-0.039	-13.255	<0.001
3583	-0.060	0.008	-0.019	-7.266	<0.001
3584	-0.102	0.011	-0.024	-9.603	<0.001
3585	-0.219	0.050	-0.008	-4.367	<0.001
Interaction variable					
2023Q1$_{ref}$ & DEFG$_{ref}$					
2013Q1 ABC	-0.049	0.022	-0.010	-2.259	0.024
2013Q2 ABC	-0.024	0.019	-0.006	-1.264	0.206
2013Q3 ABC	-0.011	0.019	-0.003	-0.579	0.563
2013Q4 ABC	-0.065	0.017	-0.018	-3.750	<0.001
2014Q1 ABC	-0.070	0.017	-0.021	-4.063	<0.001

2014Q2 ABC	-0.098	0.017	-0.032	-5.824	<0.001
2014Q3 ABC	-0.070	0.017	-0.021	-4.238	<0.001
2014Q4 ABC	-0.104	0.015	-0.040	-6.797	<0.001
2015Q1 ABC	-0.076	0.016	-0.026	-4.793	<0.001
2015Q2 ABC	-0.095	0.015	-0.035	-6.392	<0.001
2015Q3 ABC	-0.076	0.015	-0.028	-5.041	<0.001
2015Q4 ABC	-0.086	0.015	-0.034	-5.807	<0.001
2016Q1 ABC	-0.075	0.015	-0.025	-4.885	<0.001
2016Q2 ABC	-0.114	0.015	-0.041	-7.682	<0.001
2016Q3 ABC	-0.103	0.015	-0.038	-6.829	<0.001
2016Q4 ABC	-0.084	0.015	-0.031	-5.585	<0.001
2017Q1 ABC	-0.111	0.015	-0.040	-7.262	<0.001
2017Q2 ABC	-0.111	0.015	-0.039	-7.313	<0.001
2017Q3 ABC	-0.078	0.015	-0.029	-5.150	<0.001
2017Q4 ABC	-0.108	0.015	-0.041	-7.128	<0.001
2018Q1 ABC	-0.090	0.016	-0.029	-5.785	<0.001
2018Q2 ABC	-0.088	0.015	-0.029	-5.727	<0.001
2018Q3 ABC	-0.045	0.016	-0.015	-2.887	0.004
2018Q4 ABC	-0.082	0.015	-0.029	-5.396	<0.001
2019Q1 ABC	-0.073	0.015	-0.025	-4.753	<0.001
2019Q2 ABC	-0.086	0.015	-0.031	-5.732	<0.001
2019Q3 ABC	-0.077	0.015	-0.027	-5.105	<0.001
2019Q4 ABC	-0.067	0.015	-0.025	-4.456	<0.001
2020Q1 ABC	-0.082	0.016	-0.025	-5.209	<0.001
2020Q2 ABC	-0.077	0.015	-0.028	-5.180	<0.001
2020Q3 ABC	-0.077	0.015	-0.029	-5.193	<0.001
2020Q4 ABC	-0.062	0.015	-0.023	-4.185	<0.001
2021Q1 ABC	-0.098	0.016	-0.032	-6.219	<0.001
2021Q2 ABC	-0.085	0.015	-0.032	-5.479	<0.001
2021Q3 ABC	-0.071	0.016	-0.021	-4.365	<0.001
2021Q4 ABC	-0.041	0.016	-0.015	-2.611	0.009
2022Q1 ABC	-0.046	0.017	-0.014	-2.764	0.006
2022Q2 ABC	-0.053	0.016	-0.019	-3.353	<0.001
2022Q3 ABC	-0.013	0.016	-0.004	-0.819	0.413
2022Q4 ABC	0.006	0.016	0.002	0.367	0.713

APPENDIX 2: CORRELATION DATA

Below is the table showing the indexed coefficients of the interaction variable and the CPI of energy. For correlations with delay, the coefficients of the interaction variable are shifted upward. For the correlation with a one quarter delay, the column of coefficients will start one row above compared to the situation without delay. As a result, the energy costs of a previous quarter are correlated with the willingness to pay for energy performance. However, by doing this, the most recent quarter and its corresponding energy costs are excluded. For example the interaction with four quarters delay excludes the energy costs from 2022Q2. Therefore this delayed correlation excludes the highest energy costs in the period from 2013 to 2023. Considering that the increase is still a recent development, makes it an interesting point for future repeated research as stated in the discussion.

Table 11. List of indexes included in the correlation analysis (own edit) *** quarter(s) delay**

Quarter	Energy CPI	Interaction (0*)	Interaction (1*)	Interaction (2*)	Interaction (3*)	Interaction (4*)
2012Q1	57.084	-	-	-	-	95.218
2012Q2	57.330	-	-	-	95.218	97.629
2012Q3	58.044	-	-	95.218	97.629	98.906
2012Q4	58.934	-	95.218	97.629	98.906	93.707
2013Q1	59.871	95.218	97.629	98.906	93.707	93.239
2013Q2	59.591	97.629	98.906	93.707	93.239	90.665
2013Q3	59.003	98.906	93.707	93.239	90.665	93.239
2013Q4	58.877	93.707	93.239	90.665	93.239	90.123
2014Q1	59.169	93.239	90.665	93.239	90.123	92.682
2014Q2	58.752	90.665	93.239	90.123	92.682	90.937
2014Q3	58.141	93.239	90.123	92.682	90.937	92.682
2014Q4	58.329	90.123	92.682	90.937	92.682	91.759
2015Q1	57.524	92.682	90.937	92.682	91.759	92.774
2015Q2	57.667	90.937	92.682	91.759	92.774	89.226
2015Q3	56.627	92.682	91.759	92.774	89.226	90.213
2015Q4	56.096	91.759	92.774	89.226	90.213	91.943
2016Q1	54.743	92.774	89.226	90.213	91.943	89.494
2016Q2	54.097	89.226	90.213	91.943	89.494	89.494
2016Q3	53.504	90.213	91.943	89.494	89.494	92.496
2016Q4	53.583	91.943	89.494	89.494	92.496	89.763
2017Q1	55.085	89.494	89.494	92.496	89.763	91.393
2017Q2	54.629	89.494	92.496	89.763	91.393	91.576
2017Q3	54.726	92.496	89.763	91.393	91.576	95.600
2017Q4	55.211	89.763	91.393	91.576	95.600	92.127
2018Q1	59.368	91.393	91.576	95.600	92.127	92.960
2018Q2	59.625	91.576	95.600	92.127	92.960	91.759
2018Q3	61.396	95.600	92.127	92.96	91.759	92.589
2018Q4	62.675	92.127	92.960	91.759	92.589	93.520
2019Q1	69.305	92.960	91.759	92.589	93.520	92.127
2019Q2	68.808	91.759	92.589	93.520	92.127	92.589
2019Q3	67.061	92.589	93.520	92.127	92.589	92.589
2019Q4	66.924	93.520	92.127	92.589	92.589	93.988
2020Q1	61.213	92.127	92.589	92.589	93.988	90.665
2020Q2	59.780	92.589	92.589	93.988	90.665	91.851

2020Q3	58.974	92.589	93.988	90.665	91.851	93.146
2020Q4	59.448	93.988	90.665	91.851	93.146	95.983
2021Q1	61.207	90.665	91.851	93.146	95.983	95.504
2021Q2	62.812	91.851	93.146	95.983	95.504	94.838
2021Q3	70.407	93.146	95.983	95.504	94.838	98.708
2021Q4	103.958	95.983	95.504	94.838	98.708	100.602
2022Q1	157.530	95.504	94.838	98.708	100.602	100.000
2022Q2	115.248	94.838	98.708	100.602	100.000	-
2022Q3	210.987	98.708	100.602	100.000	-	-
2022Q4	158.021	100.602	100.000	-	-	-
2023Q1	100.000	100.000	-	-	-	-