What is the value of a green dwelling?

- The heterogeneity in price valuation of EPC labels in The Netherlands -

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Title	What is the value of a green dwelling? - The heterogeneity in price valuation of EPC labels in The Netherlands -
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ABSTRACT

Implementation of EPC labels in the Dutch housing market is expected to reduce carbon emissions and energy consumption by inducing home owners, to invest in improving energy efficiency. This study is the first to draw an image of the current improvement stage regarding EPC labels and the energy transition in the Dutch housing market. In addition, it investigates effects of EPC labels on most recent transaction prices for the entire Dutch housing market, adding to the already large amount of literature on this topic. Furthermore this research is first to analyze heterogeneity concerning buyer types as well as building types, by applying an hedonic price model on strongly representative registry data containing over 1.2 million observations in The Netherlands between 2012 and 2022, made available by Het Kadaster. With the use of interaction effects, the extent to which both the building type and buyer type are capitalized differently is examined. Results show similar price premiums to previous literature, where willingness to pay for houses increases with energy efficiency. When looking further into first-time-buyers (FTBs), the study reveals little difference in a higher valuation for most efficient labels (A and B) yet strong conclusions remain unreached. However, stronger heterogeneity in valuation in greenness can be found for different building types. Buyers of apartments tend to value greenness more than buyers of other building types, being terraced houses, corner houses and semi-detached houses. The same price premium for energy efficiency, yet smaller in size, is visible for buyers of detached houses.

Keywords: hedonic price model, EPC labels, Energy transition, Utility theory, First-time-buyers.

1. INTRODUCTION

1.1. Motivation

The concept of sustainability and the need for environmental change has become an indispensable part of the global agenda. Warnings about risks and challenges of global warming are the order of the day. As a part of this thought, the European Commission released its 'European Green Deal': a roadmap for stimulating the economy in the EU to become sustainable by turning climate and environmental challenges into opportunities for all policy areas (European Commission, 2019). It is supposed to gain awareness and attention for the energy transition, to which the EC-president Ursula von der Leyen adds:

'The European Green Deal is our new growth strategy – for a growth that gives back more than it takes away. We can all be involved in the transition and we can all benefit from the opportunities.' (European Commission, 2019, p.1)

To do so, and as part of the Green Deal, the initiated 'Renovation Wave' prioritizes; 1) tackling energy poverty and the worst-performing buildings, 2) the renovation of public buildings, and 3) decarbonisation of heating and cooling (European Commission, 2020b). The energy transition, and more specifically making our houses more sustainable, are therefore ought to be very important for the global policy makers.

In addition to the already large ecological pressure to improve energy efficiency, events on the global scale, such as the current gas crisis taking hold on both the European and Dutch economy, strongly call for a more energy-efficient world. Russia currently supplies lower amounts of gas to Europe than agreed, increasing the risk of gas shortages (Rijksoverheid, 2022). The already increasing gas prices since 2020, shown by figure 1, rose to over 6,5 eurocents per kilowatt-hour where this was half its price in the beginning of 2021. Such increases directly affect the utility bills of Dutch households.

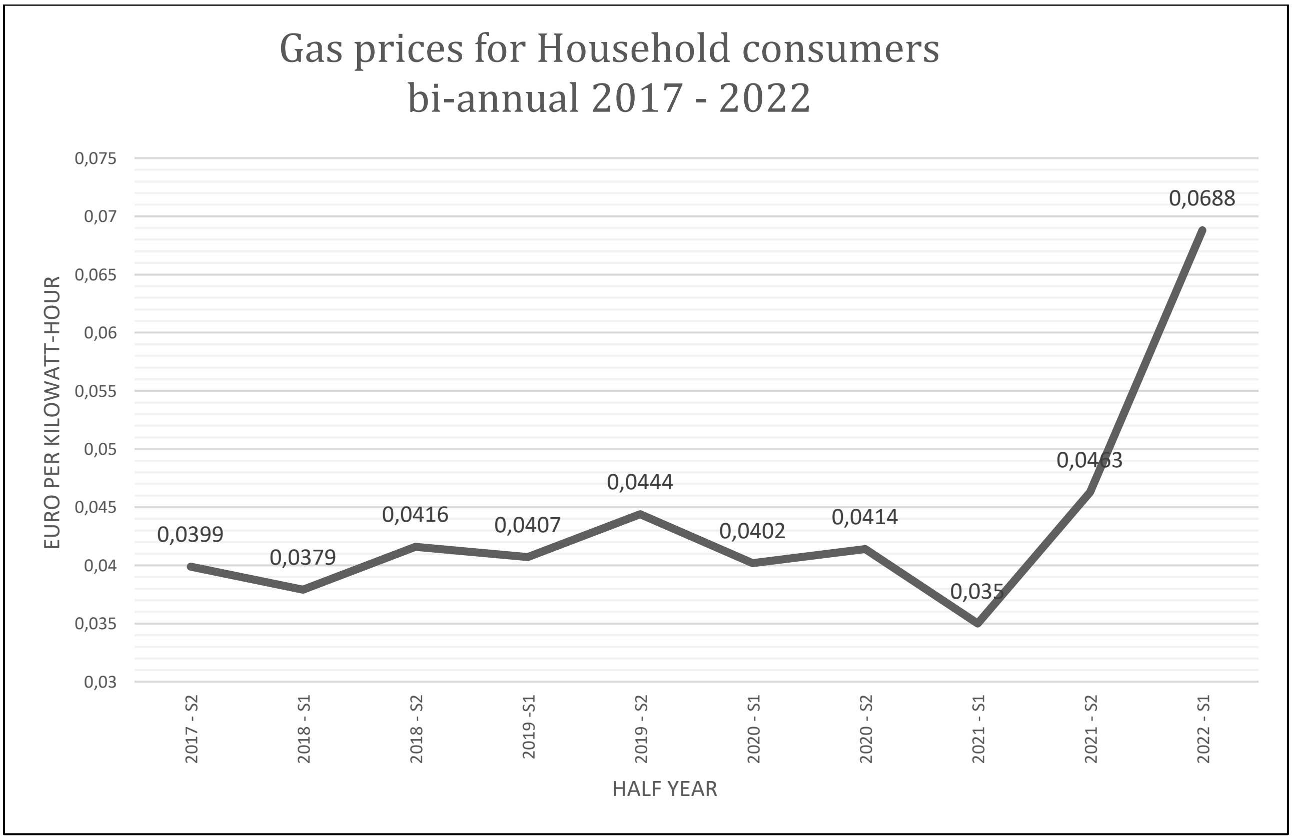


Figure 1. Gas prices for household consumers between 2017 and 2022, bi-annually (€ per kWh) (Eurostat, 2023)

Apart from global challenges regarding energy efficiency, political pressure in the Netherlands adds to the need for seeking improvements in energy security. Natural gas forms the largest source for building heating in the domestic energy production, as well as the key fuel for industry (International Energy Agency, 2020). Regardless of the pressures of war, the Groningen gas field in the north of the Netherlands tapped gas for decades, causing earthquakes that damaged more than 10 000 buildings. With ongoing, yet long ignored, complaints over tremors, Groningen lost its "social license to operate" as was concluded by The Hague Centre for Strategic Studies in 2019 (Laurent, 2022).

Numbers on social welfare policies regarding energy poverty show that, even though The Netherlands is often associated with a large legacy as social welfare state, large improvements can be made here.

A TNO report by Mulder et al. (2021) found 550.000 cases of households suffering from energy poverty in the Netherlands, which is 7% of the entire population. NRC stated that by March 2022, the energy poverty in the country even increased to 630.000 households (Weeda, 2022). The same TNO report found that in 2021, almost half of the Dutch households (48%) lives in a poorly or moderately isolated house, without the ability to change this (Mulder et al., 2021). This is not only because of low incomes, yet also because of lacking possibilities to invest in energetic qualities, potentially still causing payment problems when the gas prices further increase.

The final energy consumption in the Netherlands consisted, in 2020, for 28% of households' consumption from the residential sector (Eurostat, 2022). This reveals large potential for the built environment to contribute to global change, as well as opportunities for initiatives and actions aiming to reduce negative ecological impacts. Today however, around 75% of the building stock in the European Union is energy inefficient, meaning that large parts of the energy go to waste (European Commision, 2020a). Therefore, The Climate Act requires the Dutch emission of Greenhouse Gas (GHG) to be reduced by 95% in 2050 (versus the 1990 levels) with an interim target of a 49% decrease by 2030 (Ministry of Economic Affairs and Climate Policy, 2019).

For this purpose, policy makers target stricter energy-efficiency mandates and standards on the real estate sector. In the European Union, the European Performance of Buildings Directive (EPBD) is considered the main legislative instrument to improve the energy performance of buildings since 2002, leading to the measuring of energy efficiency using Energy Performance Certificates (EPCs) (Bio Intelligence Service, Ronan Lyons and IEEP, 2013). Since 2008 and following the transpositions in the EPBD into the Dutch law, all houses currently sold, rented or completed in the Netherlands need an energy performance rating in the form of an EPC label (RVO, 2017). In 2021, the method of became stricter, as a professional method for determination of the label is now mandatory, as well as an attachment of the EPC-label in selling and renting advertisement.

Changes in attitudes towards the EPC labels perhaps altered in the Netherlands, as a result form recent policy adjustments. Whereas the energy label has met considerable resistance and a lack of interest in the Netherlands, the government obliges house sellers to provide a professionally registered EPC label since 2021, by fining up to €435 when failing to do so (Inspectie Leefomgeving en Transport, 2021). As of 2022, sellers are even required to mention the EPC label corresponding to the listed house in the sales advertisement (Rijksoverheid, 2021). Since reliable EPC labels became an obligatory part of the selling process, it could affect the decision-making process of the, better informed, buyers even more. Therefore, this research focuses on the price valuation of these EPC labels.

A group of buyers that specifically could benefit from affordable green housing is that of first-time buyers. Whereas this group of buyers from mostly younger generations benefits from more equalized employment opportunities for men and women and deeper mortgage markets in many countries, the same generations also face stagnant wages, increasing levels of inequality and increasingly expensive housing (Flynn, 2020). This, in combination with the increase in sustainability awareness potentially leads (younger) home-buyers to search for dwellings containing green concepts such as a high energy efficiency (Kam et al, 2018), and a resulting different valuation for houses that meet certain green standards. The addition of raising utility bills resulting from the increasing gas prices potentially makes it more difficult for them, as well as for other renters willing to join the housing market. The ability to save for the purchase of a (green) house might decrease, making it more difficult to realize first-time buyers' housing preferences.

Utility bills are to a large extent related to the type of building the households occupies. Research by Milieucentraal (2022) states that gas and energy usage relies on the type of building, for example since apartments are often small and surrounded by neighbours, whereas detached houses are larger and have higher gas uses than other building types. These gas use differences are estimated at 1000m^3 gas for an older, small apartment versus 2400m^3 for an older and larger detached dwelling which is more than double the use. It is therefore interesting to further look into any disparities in price valuation for greener dwellings per building type.

1.2 Academic Relevance

Previous literature on the valuation of energy efficiency and EPC labels often found price premiums for dwellings that prove to be energy efficient, both with or without attaching an EPC label. Research on transaction prices and energy efficiency compared prices of A- till G-labelled houses and found that, relative to medium efficient dwellings (C- or D-labelled), price premiums exist for more energy efficient dwellings (Brounen and Kok, 2011; Fuerst et al., 2015; Chegut et al., 2016; Fuerst et al., 2016). Similar findings can be found in studies on rents and EPC labels (Hyland at al., 2013; Feige et al., 2013; Dresller and Cornago, 2017), and on listing prices and corresponding energy efficiency. (Hyland et al., 2013).

Even though two studies in the Dutch context found similar price premiums for energy efficient dwellings (Brounen and Kok, 2011; Chegut et al, 2016), another study did not find a change in buyer's valuation for EU energy labels after putting more focus on the energy efficiency that is not captured in the EPC label. (Aydin et al., 2017). Olaussen et al. (2017), researched the value of EPC labels in general in Norway, and found no or a slightly negligible effect of the measure. This, however, all took place before the recent policy changes regarding the determination of EPC labels, potentially capturing more energy efficiency measures in the labels.

Whereas the price valuation of EPC labels is thus often looked into, a complete image of the current stage in The Netherlands remains missing. The studies mentioned above, including those researching The Netherlands, all use data samples or subsets of the entire population. Therefore, risks of selection bias are inevitable. Even though certain methods are used in these studies to tackle problems regarding subsamples or selection bias, this study is better able to draw the full picture. This is in addition to creating the opportunity to gain insights from overviewing the entire EPC label distribution stage and its developments in The Netherlands, and a more recent view on the stage after policy changes.

Apart the complete picture, a deeper look into the nature of the valuation, and especially heterogeneity within the price valuation is also neglected in prior research. Even though Khazal and Sønstebø (2020) look at differences in valuation between professional and non-professional buyers, and Chegut et al. (2016) investigate the commercial affordable housing market specifically, there is no clear distinction made in the valuation of energy efficiency for different buyer types in the owner-occupied housing market. The same holds for potential heterogeneity in buyers of different building types, and the extent to which EPC valuation differs for different type of buildings.

There is, however, reason to believe that the perceptions on the housing markets, and the valuation of alternatives, differs for first-time buyers (FTBs) versus more seasoned buyers. As Jones and Mostafa (2022) found several barriers for FTBs to join the housing market as buyers, there might be, compared to more seasoned buyers, less ability to realize certain housing preferences such as energy efficiency, resulting in a lower willingness to pay. On the other hand, an increase in sustainability awareness among younger, and mostly first-time, buyers as found by Taylor and Keeter (2010 leads to the expectation of valuating energy efficiency more. Since no research touched upon this heterogeneity, and literature on FTBs reveals different expectations, study regarding different valuation of energy efficiency is necessary, both a higher or lower valuation of greenness among FTBs.

Such heterogeneity also needs investigating regarding several building types. Since structure of building stock, and the resulting energy efficiency measures, varies strongly among building types, difference in valuation is expected yet neglected in prior research. Multi-family dwellings tend to be unresponsive to fuel prices (Maruejols and Young, 2011), increasing the expected valuation for energy efficiency among apartment buyers, compared to buyers of single-family homes. Even though existing building envelope designs function as passive energy efficiency strategies (Sadeneni et al., 2011), potential higher valuation for energy efficiency in apartments, compared to other building types, has not been explored in previous literature.

1.3 Research problem statement

In a growing interest for energy efficiency on the housing market, the value of an EPC label in the current Dutch market needs to be further assessed. A clear and complete overview of the recent changes in EPC labels, their locations, owners and the corresponding price ranges is necessary in order to create an image of the stage of the energy transition the Dutch housing market is in, with regards to the EPC registration. Furthermore, to the current knowledge on this topic, this study is the first to investigate the potential heterogeneity in the valuation of EPC labels among different buyer types as well as building types. This is all in order to answer the central research question:

'What is the economic value and heterogeneity in the valuation of the Energy Performance Certificate (EPC) in terms of house prices in the Netherlands between 2015 and 2022?'

In order to find an answer to this research question, the following sub-questions are answered:

1) *What knowledge on EPC valuation and incentives on energy performance for home-owners can be found in existing literature?*
2) *What is the association between EPCs and house prices in the Dutch housing market?*
3) *To what extent are variations present in the valuation of EPCs across buyer types in the Dutch housing market?*
4) *To what extent are variations present in the valuation of EPCs across building types in the Dutch housing market?*

The remaining of this research is structured as follows. The second chapter provides an overview of the current literature regarding this topic, as well as elaboration on the concepts used in this study. The third chapter draws an image of the context in place, in the area related to this study on the energy transition in the Dutch housing market. Added to this data analysis, the methodology for answering the third and fourth question will be explained in the fourth chapter.

After that, results show the conducted analyses, providing insights in the current distribution stage of the EPCs in the Dutch housing market. Lastly, conclusions, policy implications and future research possibilities will be stated, combined with a critical reflection and discussion.

2. THEORY, LITERATURE REVIEW & HYPOTHESES

2.1 Financial incentives and price valuation

Many researches already acknowledged the economic valuation of EPCs in European residential markets. The impact of energy performance is mostly capitalized in transaction price, rental value or occupancy.

TABLE 1: LITERATURE REVIEW WITH MAIN RESULTS ON EPC VALUATION

Author(s)	Country	Method	Dependent variable	Main findings
Brounen and Kok (2011)	Netherlands	Logit regression	Transaction price / m²	Relative to D-labels, A-labelled homes sell at a 10.2% price premium and G-labelled homes at a 5% discount
Cajias and Piazolo (2013)	Germany	Hedonic regression	Transaction price / m² Rents / m²	-1% energy consumption results in a premium of 0.45% in sales price and 0.08% in rental price
Hyland et al. (2013)	Ireland	Hedonic regression	Listed price Rents	Relative to D-labels, A-labelled homes sell at a 9% price premium and rent at a premium just under 2%
Feige et al. (2013)	Switzerland	Hedonic regression	Rents / m²	Sustainable features positively relate to rents
Högberg (2013)	Sweden	Hedonic regression	Transaction price	+1% energy performance results in a premium of 0,04% in sales price
Cerin et al. (2014)	Sweden	Hedonic regression	Transaction price / m²	Energy performance levels command higher property values relative to reference values of similar properties
Fuerst et al. (2015)	England	Hedonic regression + Repeat sales	Transaction price / m²	Relative to D-labels, A- and B-labelled homes sell at a 5% price premium. C-labelled at a 1.8% premium. E- and F-labelled at a 1% discount. G-labelled homes sell at a 7% discount
Chegut et al. (2016)	Netherlands	Hedonic regression	Transaction price / m²	Relative to C-labels, A-labelled homes sell at a 6,3% premium. B-labelled at a 2% premium.
Wahlström (2016)	Sweden	Hedonic regression	Market value	No premium prices for energy efficient houses found
Fuerst et al. (2016)	Finland	Hedonic regression	Transaction price	Relative to D-labels, A-, B- and C- sell at a 3.3% price premium
Olaussen et al. (2017)	Norway	Hedonic regression + Repeat sales	Transaction price / m²	Energy label itself has no or a slightly negligible effect
Kholodilin et al. (2017)	Germany	Hedonic regression	Asking price / m² Rents / m²	Energy efficiency is capitalized in house prices
Dressler and Cornago (2017)	Belgium	Hedonic regression	Rents / m²	Highly energy efficient dwellings result in an average rent premium of 4.8%
Aydin et al. (2017)	Netherlands	Hedonic regression + Repeat sales	Transaction price	EU energy labels do not lead to change in buyer's valuation
Cajias et al. (2019)	Germany	Hedonic regression	Rents	Energy efficient rentals receive small premiums
Khazal and Sønstebø (2020)	Norway	Hedonic regression	Rents	Relative to non-labelled homes, rent premiums of respectively 6.9%, 6.6% and 5.5% for A-, B- and C-labels.

Several researchers thus look into the financial incentive to make houses more sustainable, as becomes clear in table 1. The ability to value such a financial incentive strongly relies on the utility theory and the application of this way of thinking in the hedonic price model. Using an utility function, the utility theory aims to explain how much a consumer will pay, at the margin, for additional units of a particular good of service (Smith and Kroll, 1989). In this study, this mentality is linked to the additional unit of energy improvements. Following, among others, the assumption that individuals are able to rank order all possibilities, and that people base their decisions on such rankings, analyses can assign imaginary utility values to original values, here transaction prices. Less abstractly formulated, this theory assumes that individuals behave by maximizing the utility, not the amount of money attached to this. Yet, monetary values can be used to reveal individual's preferences.

Following this real estate economics perspective, studies in table 1 mostly aim to find the impact of EPC labels on pricing processes and market dynamics using the hedonic price model. For this, Rosen (1974) established the foundation by examining hedonic models, operatively solved through Ordinary Least Squares for detecting price determinants in real estate housing properties, in order to study the relation between housing prices and environmental qualities. Such hedonic analysis was the most frequently applied among traditional approaches concerning housing market analysis, specifically for detecting structural, environmental and neighbourhood attributes, according to a review on traditional hedonic price models by Malpezzi (2002). After the evolution of this contextual framework, and consequently the evolution of applying methods, a growing literature has been produced in which many studies aim to find an impact of EPC labels on market dynamics and pricing process. The same holds for the operationalization, where a vast number of such studies utilize the hedonic price model, visible in table 1.

Generally in the residential market, energy efficient dwellings show higher transaction prices, where the size of these premiums depends on the energy efficiency levels (Brounen and Kok, 2011; Cerin et al. 2014; Feige et al., 2013; Hyland et al., 2013). A-labelled buildings transact at a 10,2% premium compared to similar D-rated dwellings (Brounen and Kok, 2011). Smaller, yet similar positive price premiums are shown by Fuerst et al. (2015) as well as by Brounen and Kok (2011) with C-labelled dwellings in the same comparison to D-labelled houses (1.8% - 3.5%). When taking A- B- and C-labelled houses together, Brounen and Kok (2011) find a 3.7% price premium for 'green ratings'.

Later research however shows conflicting results regarding the EPC label. Both Hårsman et al. (2016) and Wahlström (2016), albeit with the same Swedish dataset, found no additional premium on, respectively, sales price or market value related to the label itself. However, they do find a willingness to pay for housing attributes that improve a dwellings' energy efficiency. The assumption that a buyer's expectation regarding one's own energy use is equal to the seller's, is provided as a too strong assumption by Hårsman et al. (2016). Since they use energy consumption in their regression model, results could be contradictive as a result. Olaussen et al. (2017) find the same absence of evidence for a price premium in Norway, using an hedonic time dummy model. In the Dutch context, Aydin et al. (2017) conclude the signalling effect of the EPCs non-significant after controlling for actual energy consumption and multiple dwelling characteristics.

The valuation of the EPC label cannot only be found in sales prices. Two studies used listing behaviours for determining whether or not buyers are willing to pay more for green dwellings. A first study by Fregonara et al. (2017) investigated the economic effects of EPC label regulations in Italy on such listing behaviours by measuring the influence on listing prices. This is done in order to analyse the degree to which the mandatory EPC label is significant in in affecting dwelling prices. Only lower EPC levels (Label F) are found to be of significant influence, leaving the conclusion that EPC labels solely partially explain listing prices. A second study by Fregonara et al. (2019) added market liquidity, by considering both listing prices and transaction prices, in particular the difference between those two, as well as the time on the market. Apart from the EPC labels, building construction period and main dwelling characteristics were modelled. The study showed that only 6-8 percent of the price variation are explained by the lower EPC labels (G, F and E), where this impact disappears after including the house characteristics. Results of both studies therefor allow for questioning the explicative power of EPC labels on property prices.

A recent study by Chen and Marmolejo-Duarte (2019) looked into differences between dwellings of which energy efficiency affects price formation and those of which the energy efficiency does not impact pricing processes. They aimed to investigate differences regarding architectural and location characteristics between both dwellings showing an increase in EPC rating marginal prices, and dwellings whose EPC seems not to be relevant for the valuation. With the use of a Spatial Error Model for exploring multifamily house prices in Barcelona, they found a general correlation between house and spatial characteristics, revealing a weight varying in function of the building location (spatial effects). This is in line with the research by Hyland et al. (2013) who found that the marginal impacts of energy efficiency are different in various temporal submarkets, locations, as well as dwelling typologies in Ireland.

In 2021, Barreca et al. (2021) purposed to explore the same pricing processes of residential properties, seeking the influence of EPC labels and relevant dwelling attributes on prices, added by the spatial context. They found that lower EPC labels (G, F and E) have a significant negative effect on housing prices, whereas higher EPC labels (A4, A3, A2, A1 and B) show a positive (yet lower) influence. Furthermore, there are intrinsic dwelling attributes appearing to be particularly able to influence the property valuation, namely the building category and the housing unit maintenance level. Barreca et al. (2021) claim that in this effect, different spatial clusters behave as different sub-markets. By comparing the effects of dwelling attributes in two spatial sub-samples, they found some variables to be always significant, though several differences appeared.

Apart from the quantitative approach, more qualitative methods find similar results to the mostly found green valuation. De Ayala et al. (2016) suggested a green premium when researching the opinion value with the use of a survey applied to Spanish households. Murphy et al. (2012) conducted interviews with EPC stakeholders involved in the design, lobbying, implementation, promotion and evaluation of the label. Interviewees generally regret the ‘false start’ the EPC had in the Netherlands, after which the revised EPC now allows for the introduction of a better enforcement regime. They see a role for the EPC that goes beyond its original theory of generating market demand for green dwellings, yet also one where EPC ratings are integrated in property taxation mechanisms (Murphy et al., 2012). In that case, EPC valuation found in house prices would become more a certainty than a side-effect. According to the interviewees, the considered ease of communicating the EPC rating jumps to home owners could drive obligation to more integrate the EPC rating in house valuations (Murphy et al., 2012).

Studies on commercial real estate generally find higher transaction prices and rents for buildings that environmentally certified buildings, compared to conventional buildings (Chegut et al., 2016). The same applies for stability in occupancy rates. Hyland et al. (2013), however, found the green premium to be higher for selling than for renting a house. In this rent sector, Groh et al. (2022) compared the marginal costs with the marginal benefits gained from a green premium and showed that monetary advantages after possible rent increases are far from sufficient in order to compensate for the costs of retrofits (if there are no public subsidies).

2.2 The EPC label as an energy efficiency inducer

Although the financial incentives presented by previous studies are present, the persistency in carrying out cost effective safety measures enjoyed attention in the literature multiple times as well (Murphy, 2014). Retrofitting is often proven a stubborn behaviour to stimulate (Comeford et al., 2018). The recovery of the investment and the initial costs is one of the most important aspects considered by the owners before undertaking a renovation (Artola et al., 2016). Added, energy efficiency strategies are often not applied because of uncertainty about the amount of investment needed and the efficiency of the relevant energy saving strategies (Gonzales-Cacares et al., 2019). Even when monetary and non-monetary investments in installing energy efficient technologies are heavily reduced, few households retrofit (Allcott and Rogers, 2014). Allcott and Greenstone (2012) found a large and strong difference between the levels of energy efficient investments that appear to be privately beneficial and investments that the private individuals actually pursue. When looking at the role of information and transaction costs in determining such household-level decisions, Fowlie et al. (2015) document that, for an energy efficiency retrofit with zero out of pocket costs and around $5,000 of improvements to their home, household's take-ups are at a very low rate. Furthermore, these take-ups are modestly increased when households are informed, via multiple channels, about the sizeable benefits and zero monetary costs.

The extent of information available for home owners considering energy efficiency, EPC labels and the potential benefits can thus play a role in the inducement to retrofit. Comeford et al. (2018) investigated whether the salient colour-letter grades in the EPC labels serve as targets that motivate vendors to invest in energy efficiency. They conclude an induced investment after EPC requirements, showing potential from energy efficiency labels to green the housing stock, by demonstrating a causal effect of energy labelling on investment in energy-saving technologies. The observed effects is accounted for by both monetary and some non-monetary costs and benefits influencing the retrofitting decision. Intervention aimed at people trading their homes is especially fruitful (Comeford et al., 2018). Therefore, this study uses the EPC label as a proxy for measuring the energy efficiency of a house, where improvements in energy efficiency led to a 'greener' EPC label, with the following question as a limiting factor.

Although there are several articles claiming the success of this measure (Volt et al., 2020; Brocklehurst, 2017; Khazal and Sønstebø, 2020), no complete conformity can be found here. Khazal and Sønstebø (2020) find the EPC an important instrument as it enhances the energy performance of buildings by providing the right information for involved actors, highlighting the ability to solve concerning asymmetric information and to achieve a higher pricing accuracy. These opportunities to become better informed are expected to increase the willingness-to-pay (WTP) by rational actors in the housing market, for marginal increases in energy efficiencies. However, implementation issues and negative responses from buyers and sellers in many EU Member States made the EPC not the empowering measure in the energy transaction as was expected, according to several qualitative studies (Watts et al., 2011; Amecke, 2012; Student et al., 2017). Brounen and Kok (2011) even show that adoption rates are low and declining over time, corresponding with the negative attitude towards the labels in the popular media. The implementation of EPCs differs significantly across different EU Member States regarding scope and information availability, leading to limited reliability, compliance, market penetration and/or user acceptance (Zuhaib et al., 2022).

Christensen et al. (2014), claim the EPC in its current form insufficient in encouraging homeowners to undertake energy retrofits of their home. Whereas they found that most homeowners consider the EPC reliable and easy to understand, their results suggest relatively few find it a useful source of information for home retrofits. This usefulness is supported by Bartiaux et al. (2014) who, with the use of in-depth interviews, support that the EPC does not seem to have an influence on any of the renovations for private houses that already have an EPC in the three investigated countries, being Belgium, Denmark, Portugal. Bartiaux et al. (2014) also acknowledge these barriers in the decision-making, and conclude their study by mentioning the need to understand that energy retrofits must be socially contextualized and comprehended resulting from co-evolving know-how, laws and other institutionalized procedures, social norms, and technologies and products. Without such co-evolution, no new practice or changed practice can be formed, in which EPCs are no exception since they fail to create a practice of green home renovation by themselves (Bartiaux et al., 2014). Based on the contradictions in the literature on EPC labels (not) functioning as in inducer to make a house more energy efficient, it is to be questioned whether home-owners include the EPC label of a desired house in the valuation process. Added to that, yet beyond the aim of this study, the question arises to what extent EPC labels can be used to stimulate home-owners in the energy transition.

2.3 First-time-buyers

In the case of first-time-buyers (FTB), there are several reasons to assume that valuation of the EPC label differs from non-FTBs. Their decision-making process, and their resulting WTP, is found to be divergent on various grounds. Aims to buy a house derive in their situation from perceived long-term financial benefits (Mostafa and Jones, 2019). Added to that, there are non-financial benefits, such as the opportunity to live in a comfortable home (CML, 2010). With this, FTBs face strong barriers to home ownership compared to buyers that are already on present on the housing market. Jones and Mostafa (2022) recognize three different constraints prospective FTBs face in order to get on the "housing ladder":

1) *Mobility constraint:* this barrier arises when the house seeker does not expect a long stay in the upcoming house, resulting in renting as a more practical option;
2) *Wealth constraint:* if mobility is no barrier, and the expected stay is perceived long enough, the household's savings need to be sufficient to pay a down payment and transaction costs (owning costs) and otherwise keep renting;
3) *Income constraint:* if the maximum mortgage loan is not sufficient to buy the target house, based on the household's income, then the buyers should either downgrade (in terms of location, space or quality) or keep renting until they save enough money to buy a more expensive house.

Especially the third barrier would potentially make FTBs' perspective on EPCs and the valuation of such labels decreasing, since it would increase the barrier and decrease their chances to enter the housing ladder. When looking at the second and third constraints, the financial barriers, the down payment is an important factor regarding whether or not a FTB is able to become home-owner. Added to the down payment, the ability of households to purchase their first time is also conditional to the house prices relative to incomes at any point in time (Jones and Mostafa, 2022). With younger generations, that of FTBs, that nowadays face stagnant wages, increasing inequality levels and more expensive houses, it should make it more difficult for FTBs to realize their housing preferences (Flynn, 2020). Based on the notion that FTBs already face several barriers to enter the market, the decreasing ability to fulfil housing preferences apart from these constraints potentially lowers their willingness to pay for energy efficiency. It this case, it is expected that FTBs value a greener EPC label to a lesser extent, than seasoned buyers.

Another reason, yet contractionary, to believe that FTBs potentially show a different valuation for EPC labels and energy efficiency, is that of their generational characteristics. Most FTBs stem from generation Y, born between 1986 and 2000. Taylor and Keeter (2010) found that a certain increase in sustainability awareness has led homebuyers to search for houses practising green concepts, such as energy efficiency, where this generation Y is willing to spend more for environmentally green home produces. Kam et al. (2018) link this willingness-to-pay to young buyers preferring houses that utilize sustainable technologies due to high consciousness of green practices. They found that the green practices included in their sample represent the main factor to influence Generation Y to prefer sustainable houses. Expectations from previous literature on FTBs and their preferences for green dwellings are therefore twofold, as the generation characteristics show a potential positive effect on the valuation. However, their budget constraints and financial situation might be a reason for these FTBs not to be able to capitalize their preferences as much as other buyer types.

2.4 Building types

Since households in apartments and terraced houses are, often times, not the only occupant of the building, there are reasons to believe that the valuation of energy efficiency partly depends on such building types for certain buyers. An occupant can affect building energy use both actively and passively, driving the energy consumption (Jia et al. 2017). The argument that type of building, as a result of its type of tenure, affects the price valuation of the EPC is twofold as a result.

Firstly, the structure of the building stock, and specifically the existing energy efficiency measures, can vary strongly per building type. For example, when looking at apartments, district heating (DH) is often the preferred energy carrier for the apartment building stock of many colder European countries (Weinberger and Moshfegh, 2021). The starting condition, and therefore the valuation of the EPC of an apartment with district heating might be higher than that of a detached house without district heating, regardless of the EPC. Added, such differences in energy improvement starting conditions could also lead to lower ability to make energy-efficient upgrades as home-owner, decreasing the valuation of the existing EPC label. The same holds for the ability of options to self-upgrade the dwelling. Whereas an owner of a detached house has multiple building envelope energy efficiency options, this might not be the case for an owner fully attached to other apartments. On the other hand, an existing and proper architectural design of a building envelope can function as a passive energy efficiency strategy (Sadineni et al., 2011), which can be valued higher than modes of energy saving that require more effort and maintenance.

Secondly, barriers to energy-improvements beyond such relate to eligibility for programme participation, arising since many occupants of multi-family units are renters, many of whom the utility costs are part of the monthly rental payments (Maruejols and Young, 2011). The same applies to owner-occupants of whom these costs are included in condominium fees. Following this line of reasoning, regardless of the energy efficiency, utility bills of all families in the building are only partly buyer's own responsibility. The study by Maruejols and Young (2011) examined the energy-related behaviour of owners of multi-family dwellings in Canada, a category that contains a wide variety of structures including apartments, row-houses and semi-detached houses. They conclude with the notion that regardless of who pays for the utilities, occupants of multi-family dwellings are generally unresponsive to fuel prices. It might be expected that this group of multi-family house-buyers group indifferent to the EPC label related to responsiveness to fuel prices as well.

2.5 Control Variables

Khayatian et al. (2017) highlight that EPC indicators may be unsuitable for supporting the decision-making strategies regarding large scale retrofits, since such labels can be insensitive to the building characteristics. Objectives of past and current energy saving policies treat older parts of the building stock as a homogenous group, ignoring the actual consumption (which is generally not known) and building age (Aksoezen et al., 2015). Aksoezen et al. (2015) however indicate that the energy saving potentials vary greatly among the several construction-age groups, where buildings constructed before 1921 show significantly lower energy consumption levels than buildings constructed in the period 1947-1979 in Basel. The same need for controlling applies to house size and energy efficiency. Clune et al. (2012) found that house size has a greater influence on total level of emissions when the thermal performance is lower. For houses that show higher levels of thermal performance, house size is to a smaller extent suitable as a significant predictor of overall emission. A clear overview of which control variables to use and why, can be found in the methodology section.

2.6 Hypotheses

Based on the above stated literature review, the following hypotheses are formed in order to test the actual effects of the EPC label on the house price valuation. Firstly, the price valuation of each label will be conducted, after which will be tested whether or not the valuation per EPC label differs. Therefore, and based on the literature review, the first hypothesis will be that a more energy efficient EPC label shows a higher transaction price.

In order to test for heterogeneity, two other hypotheses will are formed. The second hypotheses tests whether the valuation of each label (A to G) is the same for all buyer types, no matter the (lack of) presence on the housing market. The direction of this hypothesis can be twofold, as the literature review reveals reasons to believe that starter both value greenness due to their generational characteristics, yet are also in a financial position that limits their alternatives to choose in the housing market.

Thirdly, expectations based on prior research show that multi-family homes, and the inability to self-certify dwellings, might affect the willingness to pay for houses that show favourable conditions regarding the energy efficiency. The difference of valuation of greenness for different building types will thus be investigated, using the following (third) hypothesis: The valuation of a dwellings' greenness is higher for multi-family dwellings, being apartments and terraced houses, and to smaller extent semi-detached houses and corner houses.

3. EMPIRICAL CONTEXT

Over the last twenty years, legislations regarding the energy efficiency on both European and national level led to the development of the EPC label as in operation today. Figure 2 shows the timeline in which the Dutch government acted on the advice provided by the European Union and the EPBD.

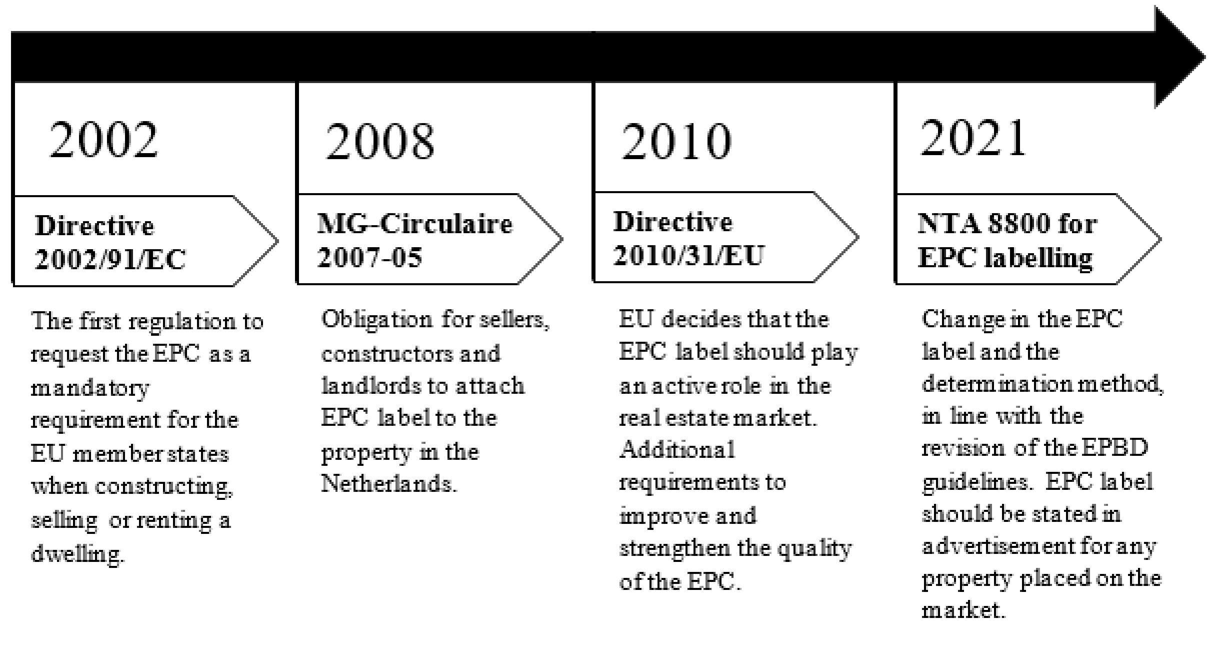


Figure 2. Timeline legislation regarding EPCs in the Netherlands (Li et al., 2019; RVO, 2017; Rijksoverheid, 2021).

In order to answer each research question, it is important to draw an image of the EPC labelling process in the Netherlands. As mentioned before, Energy Performance Certificates (EPCs) for buildings show the energy-efficiency of homes, but also for offices and hospitals. Added to this, they also suggest measures to improve energy-saving (Government of the Netherlands, 2022). When selling or renting a property, owners are required to provide tenants or buyers with a definitive ‘energielabel’. To receive one, the following steps are needed: 1) find a qualified energy adviser on the central website; 2) allow an on-site assessment of the accommodation, in which building plans, documentation and invoices for improvement measures need to be available for the assessor; and 3) the energy advisor calculates and records the energy performance, resulting in the definitive ‘energielabel’ (Government of the Netherlands, 2022). This label is then valid for ten years (RVO, 2017). The label should in the first place inform owners and potential buyers and tenants about the building’s energy efficiency (Cacares and Diaz, 2018).

The definitive EPC label consists of six components, being insulation (e.g. facades, facade panels, roofs, floors, windows, exterior doors), installations (e.g. heating, warm water, sun boiler, ventilation, cooling, solar panels), natural gas connection, heating demand in winter months, risk of high indoor temperatures in summer months, and the share of renewable energy (Energielabel, 2022). Improvements in these areas would lead to improvements of the EPC label. The score resulting from measuring the components is transformed into an energy performance index (EPI), a continuous measure assigning the dwelling to a label class, ranging from “G” for highly inefficient houses to “A++” when a home is exceptionally energy-efficient (Aydin et al., 2017). Since the certificate includes reference values such as the minimum energy performance, as well as the overall energy performance of the building, the label allows for comparison with other buildings of the same type (Cappelletti et al., 2015). Added to providing information on energy efficiency, the certificate is required to include recommendations for cost-effective and cost-optimal improvements in the energy performance, either standardized or tailor-made (Cacares and Diaz, 2018).

The National Energy Atlas (RVO, 2022) analysed the highest and lowest costs of each possible label shift for a terraced house in building year class 1945 – 1964. Table 2. shows an overview of this, in which for example a shift from label G to label C is at least €4.664, but where investments could increase up to €18,863 if starting conditions are at worst. Such starting conditions are determined by the existing energy-saving measures and different composition of such measures, resulting in a (un)favourable starting point of the investments regardless of the current label.

TABLE 2: INVESTMENT COSTS OF TRANSITION FROM 'BEST' STARTING CONDITION TO 'WORST' STARTING CONDITION IN EACH LABEL CATEGORY (IN €) (RVO, 2022)

EPC-Label	A investment	B investment	C investment	D investment	E investment	F investment
G	14.423 - 35.070	10.765 - 27.386	4.664 - 18.663	2.294 - 10.102	854 - 7.173	854 - 4.748
F	9.437 - 34.846	7.173 - 25.546	2.372 - 14.512	854 - 9.185	854 - 3.930	
E	7.799 - 31.617	4.784 - 22.195	854 - 14.646	854 - 5.773		
D	4.784 - 26.221	2.372 - 18.138	854 - 11.784			
C	854 - 22.200	854 - 13.196				
B	854 - 9.860					

The National Energy Atlas (RVO) also calculated the average energy savings from transitions in EPC-labels. Table 3 shows that savings increase with larger transitions. Based on the investments costs however, the yearly energy savings show a very long payback period. House owners possibly need more prospects of return in order to agree with investing. Therefore, premiums on house prices as a result of such investments could be part of the decision-making, yet only if house owners are aware of such potential. It should however be noted that these numbers are averages, based on one type of dwelling in an average situation. Especially table 3 contains averages without deviation intervals. In reality, the Net Present Values (NPVs) of upgrades vary strongly by technology (Das et al., 2021). Apart from climate zones which are less relevant for the case of The Netherlands, factors such housing size and thermostat setpoints are important in determining the NPV (Das et al., 2021).

TABLE 3: AVERAGE SAVINGS IN ENERGY COSTS PER LABEL TRANSITION (IN €, YEARLY) (RVO, 2022)

EPC-Label	A savings	B savings	C savings	D savings	E savings	F savings
G	219	189	171	154	112	64
F	214	183	140	105	43	
E	197	179	125	58		
D	192	160	78			
C	176	115				
B	134					

4. DATA & METHODS

Data in this study is gathered at the Dutch Land Registry Office, Het Kadaster, and uses three separate datasets. Dataset A functions as the main data for the hedonic analysis, and consist of all home-owner transactions in the Netherlands, during the period between January 2015 and September 2022 in which, among other variables, housing prices, energy labels and buyer information are stated. The second dataset, referred to as Dataset B, contains the entire Dutch housing stock from the period January 2012 until January 2022. This Dataset B reveals information on EPC labels, both from home-owner occupied dwellings and houses owned by housing institutions and institutional investors. A third dataset, Dataset C, consists of information on all label shifts that took place between 2018 and 2022, in which the entire stock of January 2018 is compared to the entire stock of January 2022. Based on these three datasets, the next section aims to draw an image of the current situation regarding the development of EPC labels and their distribution in the Dutch housing market in order to reveal trends and other potential notables. Before using the data, a process of data cleaning took place, which is further elaborated on in section 4.2.

4.1 Context

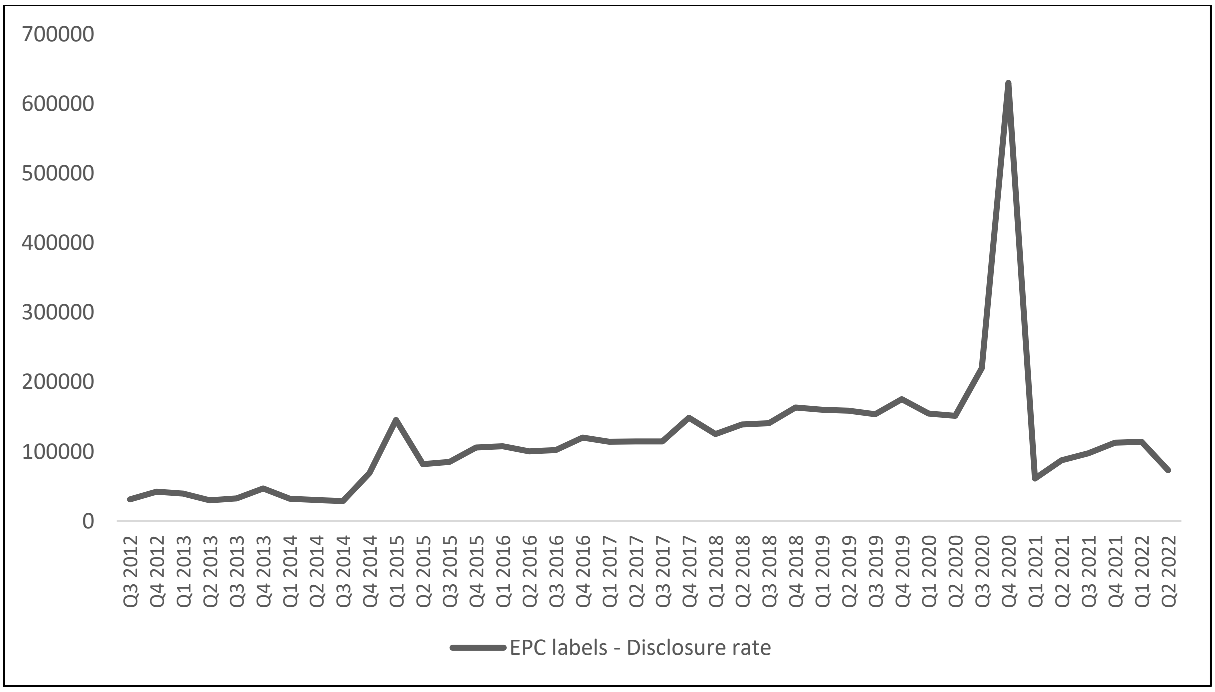


Figure 3. Number of disclosed EPC labels in the Netherlands between 2012 and 2022 (Het Kadaster, Dataset B)

In the Netherlands, EPC labels need to be disclosed with the Dutch Enterprise Agency, Rijksdienst voor Ondernemend Nederland (RVO), after which such are registered at the Kadaster, the Dutch Land Registry and Mapping Agency. Figure 3 shows the disclosure of the labels between 2012 and 2022. A very vast peak is visible between the fourth quarter in 2020 and the first quarter of 2021. This peak can be linked to the policy change in January 2021 mentioned earlier, after which the determination of the EPC label became more strict, and therefore more expensive for homeowners. The peak is in all probability caused by homeowners that ought to secure their 10-year valid EPC label before costs for applying rose.

4.2 Data collection

In order to find the valuation of EPC labels in housing prices, data from the Dutch Kadaster is used. A dataset from all transactions by home-owners between January 2015 and September 2022 is collected, in which transaction price, location, EPC label, as well as their registry dates and other housing characteristics e.g. building year and size are present.

Figure A1 in the Appendix contains the sample distribution of the transaction price, construction year, dwelling size and zipcode. These distributions are based on the data of home-owner dwellings sold between January 2015 and September 2022, attached with an EPC label. This research excludes homes that were constructed before 1900. Outliers based on the sample distribution of size and price are eliminated according to upper and lower boundaries set at the 1^{st} and 99^{th} percentile. Both for transaction price and dwelling size, the data is transformed to the natural logarithm, in order to distribute the data more normally, as is often done in comparable research (Brounen and Kok, 2011; Aydin et al., 2017; Kholodilin et al., 2017). This selection leads to a sample of over 1.2 million home-owner dwellings transacted with an EPC between 2015 and 2022. Due to noise in the data regarding building years, all observations in which the energy label is registered before the corresponding construction year are removed from Dataset A. These objects are mostly demolished rebuilt houses of which the energy labels are erroneous.

As discussed, data in this study is provided by Het Kadaster, and is confidential since the observation are on an individual level by zipcode and address attached by owner names. In order to receive the datasets, a non-disclosure agreement is signed, after which the data is only made available on a laptop lend by the organization. The data will therefore not be used for other purposes than that of this study. Furthermore, the research is performed by, and from the viewpoint of, a student writing a master’s thesis which should be taken into account when measuring the results.

Several studies acknowledge the potential of selection biases caused by missing EPCs. Since the data used in this study entails all house transactions that took place in the investigated time period (2015-2022), selection bias will form no issue. However, since the determination process of EPC labels changed during the time period of this research, and the fact that there are still several observations without attached EPC labels in the dataset, potential discrepancy could be present. It is worth mentioning that the EPC labels cannot be ensured fully accurate. Up until 2021, home-owners were able to self-determine their labels. Since the labels are valid for 10 years, these labels are still present in the dataset.

Another limitation to this study is the absence of certain housing characteristics such as number of rooms, which is often added in comparable literature (Hyland et al., 2013; Kholodilin et al., 2017; Khazal and Sønstebø, 2020), as well as for example the presence of a balcony (Kholodilin et al., 2017; Khazal and Sønstebø, 2020). Het Kadaster has no information on such specific housing characteristics other than construction year and total size. Because the explorative power is still high, it is not considered problematic, yet it is worth mentioning as it has proven to be of impact on the transaction prices.

4.3 Methodology

For the investigation of the price influence of energy efficiency in the form of EPC labels, a standard hedonic real estate valuation framework as conducted by Rosen (1974) is used. This is in line with most of the studies mentioned in table 1 (Brounen and Kok, 2011; Cajias and Piazolo, 2013; Hyland et al. 2013; Högberg, 2013; Fuerst et al. 2016; Aydin et al. 2017). As explained in the second chapter, the logarithm of transaction price of owner-occupied properties is in this case the result of several explanatory locational as well as physical variables, including the variable of interest, the EPC label:

$$1)\quad \text{Log}(TransactionPrice_{it}) = \alpha + \delta EPC_i + \varphi \text{Log}(DwellingSize)_i + \sum_{c=1}^{C} \beta ConstructionYear + \sum_{b=1}^{B} \mu BuildingType + \sigma Zipcode_i + \lambda_1 UrbanizationLevel_n + \gamma TransactionYear_{it} + \varepsilon_{it}$$

where α and β are estimated coefficients for the control variables, β, μ, and are multiple hedonic housing characteristics such as size and age, and δG_i is the quality of the EPC label. λ_n contains neighborhood specific effects, γ controls for the transaction year, and ε_i contains the error term which holds the value of unobserved characteristics.

4.5 Control variables

Malpezzi (2003) provides a comprehensive summary on hedonic price models in real estate appraisal, in which several variables have proven to be important predictors of property prices. This study controls, as far as possible within the data availability, for the most following frequently tested features:

Size and type of the dwelling: Almost all studies include dwelling size as explanatory variable for the (transaction) price (Kholodilin et al., 2017). In this paper, dwellings size is captured using total living space in square meters. Furthermore, the same studies generally differentiate dwelling types. This study particularly controls for potential effects if the dwelling type is an apartment, a corner house, a semi-detached house, a detached house or a terraced house.

Building attributes: Dwelling age is often associated with a certain 'natural' quality of housing, as houses built in different decades can be characterized by certain architectural designs, construction techniques and materials as well as aspects of urban planning affecting the quality of life in the houses (Kholodilin et al, 2017). Therefore, to account for architectural design differences, this research includes a measure of building age, being the year of construction divided in several year groups.

Amenities: A common variable to control for accessibility effects is the distance to the city center, as well as the endowment with local amenities (Kholodilin et al., 2017). Due to absence of such variables in the dataset, the five levels of urbanization as created by the Dutch Central Statistics Office are added to the dataset. By using the address density, the 'Centraal Bureau voor Statistiek' (CBS) distinguishes the following five categories: extremely urbanized, strongly urbanized, moderately urbanized, hardly urbanized and not urbanized (CBS, 2022).

Lastly, the model in equation (1) includes a variable of transaction year in order to account for the macroeconomic factors that could influence home prices over time, as is also done by Aydin et al. (2017).

4.4 Descriptive statistics/analysis

TABLE 4: DESCRIPTIVE STATISTICS

Variable	N	Median/%	Mean	Std	Min	Max
House transaction price						
Total price (€)	1,262,345		301357	146986.8	90000	985037
Price per sqm (€/m²)	1,262,345		2571.656	1173.121	305.2805	20543.48
Period of construction%						
1900-1920	71,214	5.64				
1921-1940	147,205	11.66				
1941-1960	127,479	10.10				
1961-1980	367,002	29.07				
1981-2000	334,652	26.51				
2001>	214,793	17.02				
Building type (%)						
Apartment	315,560	25.00				
Corner House	181,866	14.41				
Semi-detached House	140,461	11.13				
Terraced House	464,697	36.81				
Detached House	159,761	12.66				
EPC Label (%)						
A	246,859	19.56				
B	198,086	15.69				
C	356,384	28.23				
D	172,480	13.66				
E	123,387	9.77				
F	88,183	6.99				
G	76,966	6.10				
Year of Transaction						
2015	104,056	8.24				
2016	147,786	11.71				
2017	173,488	13,74				
2018	165,529	13.11				
2019	174,870	13.85				
2020	191,376	15.16				
2021	184,970	14.64				
2022	120,270	9.53				
Hierarchical location						
Zip Code	1,262,345		4703.973	2452.812	1011	9999
Municipality Code	1,262,281		743.5894	600.8588	14	1991
Urbanization Level	1,261,256					
Extremely urbanized	246,490	19.54				
Strongly urbanized	286,515	22.72				
Moderately urbanized	156,655	12.42				
Hardly urbanized	184,071	14.59				
Not urbanized	387,525	30.73				
Other Housing Attributes						
Size of the property	1,262,345		122.101	43.86404	44	309
Number of observations	1,262,345					

Table 4 reveals the descriptive of all relevant variables included in the dataset. The transaction prices for dwellings is represented are in euros, containing a mean value of 301,357 and a mean square meter price of 2,572, which is in line with the values in comparable studies (Brounen and Kok, 2011; Kholodilin et al., 2017). After creating the histogram, visible in Appendix Figure A1, it becomes notable that both transaction price and dwelling size in square meter are left-skewed, and are therefore transformed into a natural logarithm similar to most other studies using hedonic analyses.

Multicollinearity between the independent variables is tested using a correlation matrix, attached in the appendix (table A3). As expected, correlation between the EPC label and construction year is highest. However, since none of the independent variables show higher correlation than 0,8, multicollinearity is considered not to be of issue in this study.

5. RESULTS AND DISCUSSION

This section on results and discussion further looks into the data and provides a data analysis on the current stage of the Dutch EPC labels and its implementation. After this, the above mentioned hedonic model is conducted and discussion with regards to previous literature is given.

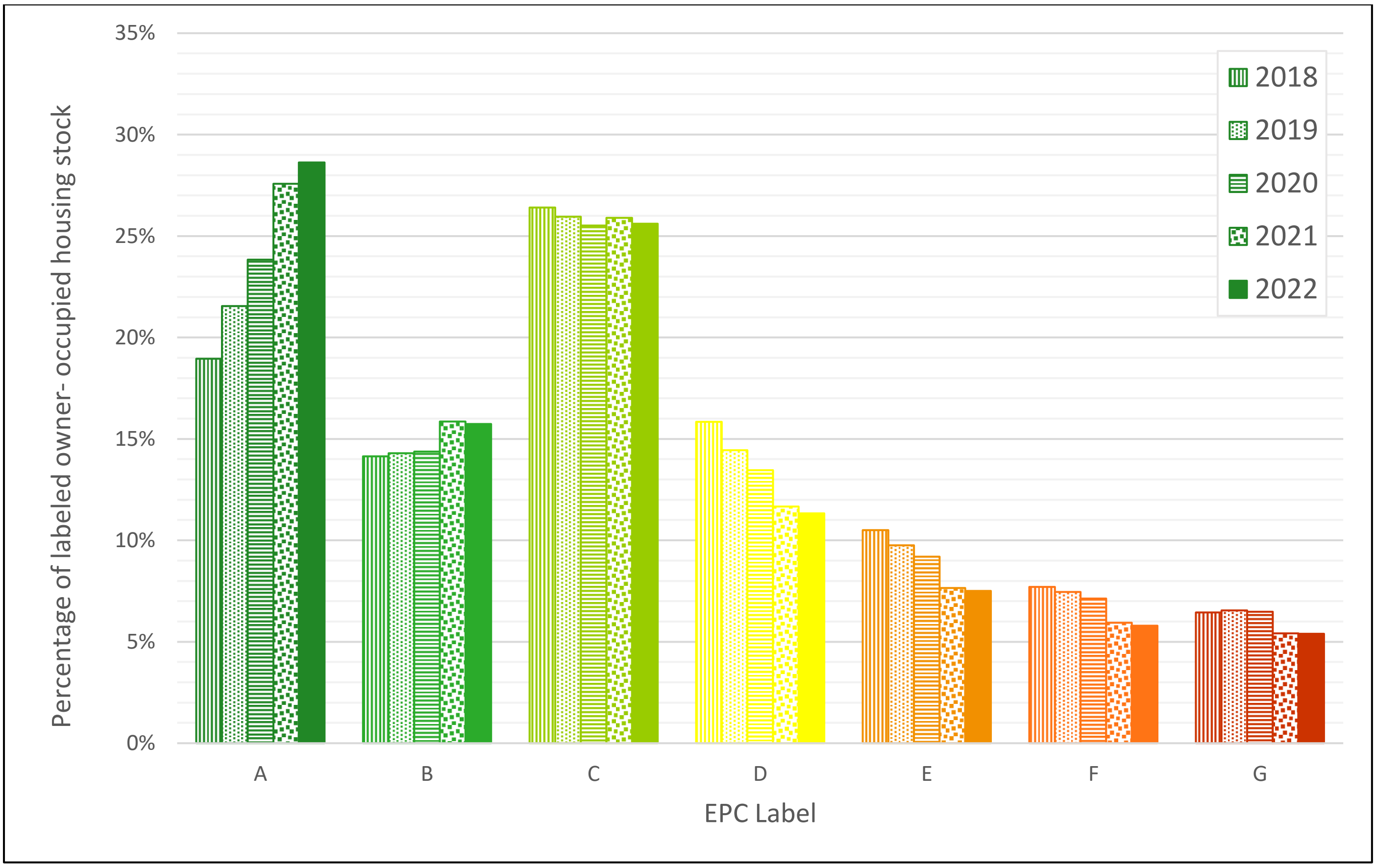


Figure 4. The distribution of EPC labels throughout the registered labelled owner occupied housing stock in the Netherlands from 2018 to 2022 (Het Kadaster, Dataset B (n=4,558,812)).

The registration of the EPC labels led to the distribution of labelled housing stock as is shown by figure 4. It becomes visible that the share of the green labels A and B is growing, whereas the medium labels C, D and E, as well as the worse label F are decreasing in proportion. The A- or B-labelled stock increased from a total of around 33% to a total of approximately 43% in 2022. Remarkable however, is the persistence of the G-labelled share of the housing stock. Note, however, that this figure is only representing the labelled housing stock, and that more than half of the Dutch owner-occupied housing stock is not yet attached with a label. In 2018. 21% of the owner-occupied houses was attached with a label, where this is increased to 41% in 2022.

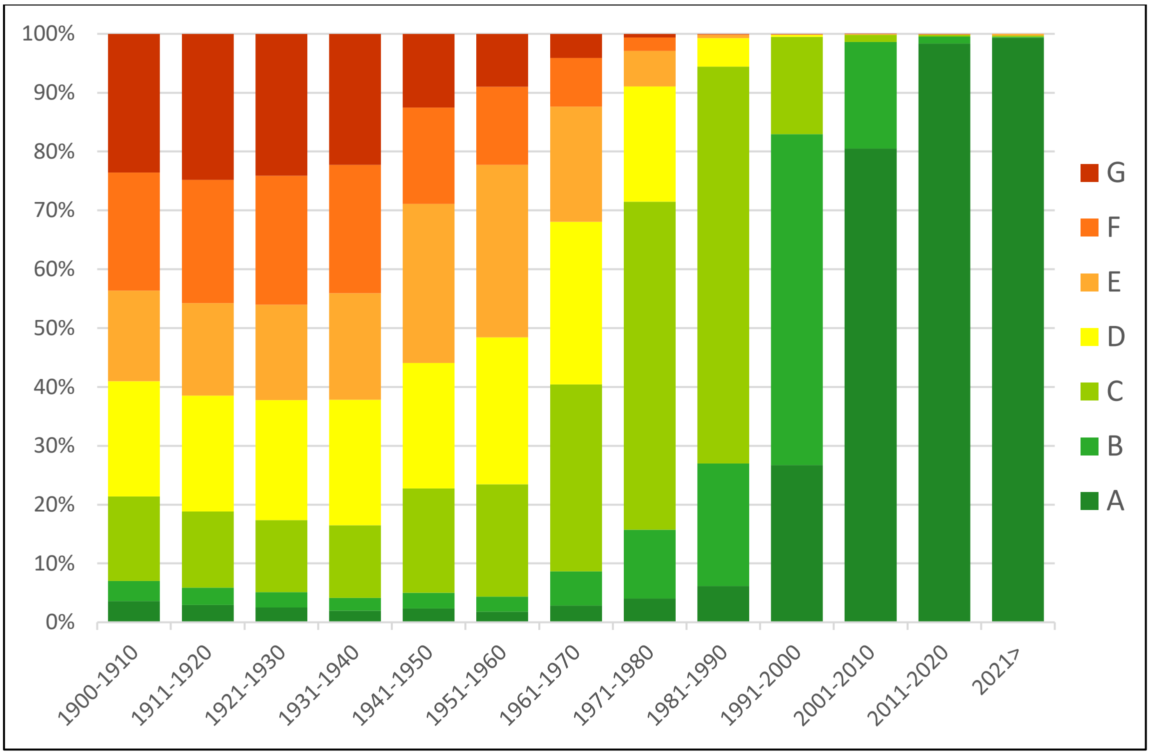


Figure 5. EPC distribution of sold dwellings per building age category (Het Kadaster, Dataset A (n=1,262,295))

Figure 5 shows the distribution of EPC labels among the several building year categories. When looking at the dispersion, the expectation of correlation between building year and EPC label arises, since the newer transacted houses represent only green labels, whereas the older transacted houses are attached with lower scoring labels in half of the cases. Multicollinearity between the year of construction and the EPC may cause a bias when controlling for it in the OLS regression later on. In the results section, this problem will be looked further into.

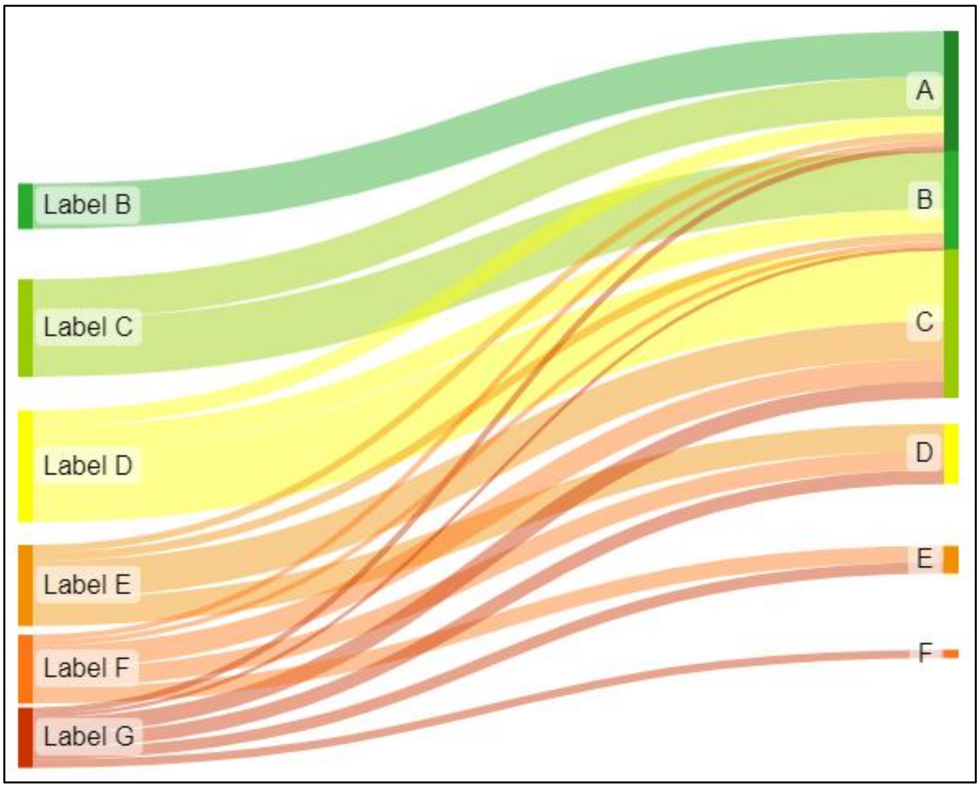


Figure 6. A Sankey Diagram mapping the upward flow of EPC labels in 2018 to EPC labels in 2022, owner-occupied housing stock (Het Kadaster, Dataset C (n=78,136)).

More important for the Dutch energy transition are the label shifts in the Netherlands. Such shifts partially reveal actions by home-owners to improve their energy performance. Figure 6 shows all registered label shifts in the Netherlands that have taken place between 2018 and 2022. Almost 80,000 houses registered an energy efficiency improvement over the last four years. Mostly, energy improvements results in smaller steps, visible for example at the large share of shifts between D-labelled houses to a C-label, as well as the share of G-labelled houses to E and D. However larger steps, e.g. from G to C or from E to A and B, are also evident. Notice that, whereas a large amount label shift is present and registered here, an unknown yet expected large amount of energy efficiency improvements is not registered due to an already valid EPC label at the date of transaction. Since 2021, costs for determining the EPC label increased, leading the incentive for home-owners to do so to decrease if not necessary, for example when the shift is expected to be insufficient for the house price to increase. The same holds for houses that are not transacted between 2018 and 2022.

Figure 7. Quarterly Price Development, mean Real House Price, adjusted to inflation using consumer expenditure index (OECD, 2022) (Het Kadaster, Dataset A (n=1,262,295)).

The real house price is a ratio using the nominal mean prices in Dataset A, quarterly adjusted for the Dutch consumers' expenditure form the OECD national accounts database. Figure 7 shows the development of these real house prices, divided per EPC label. It becomes visible that the dispersion of the labels according to their price level was rarely in line with the corresponding EPC score up until 2020, whereas this seems to change to a more towards EPC distributed price dispersion nowadays. Even though greener lines were highest ever since 2015, the medium labels C, D and E now reach higher real prices than the formerly higher priced low labels F and G.

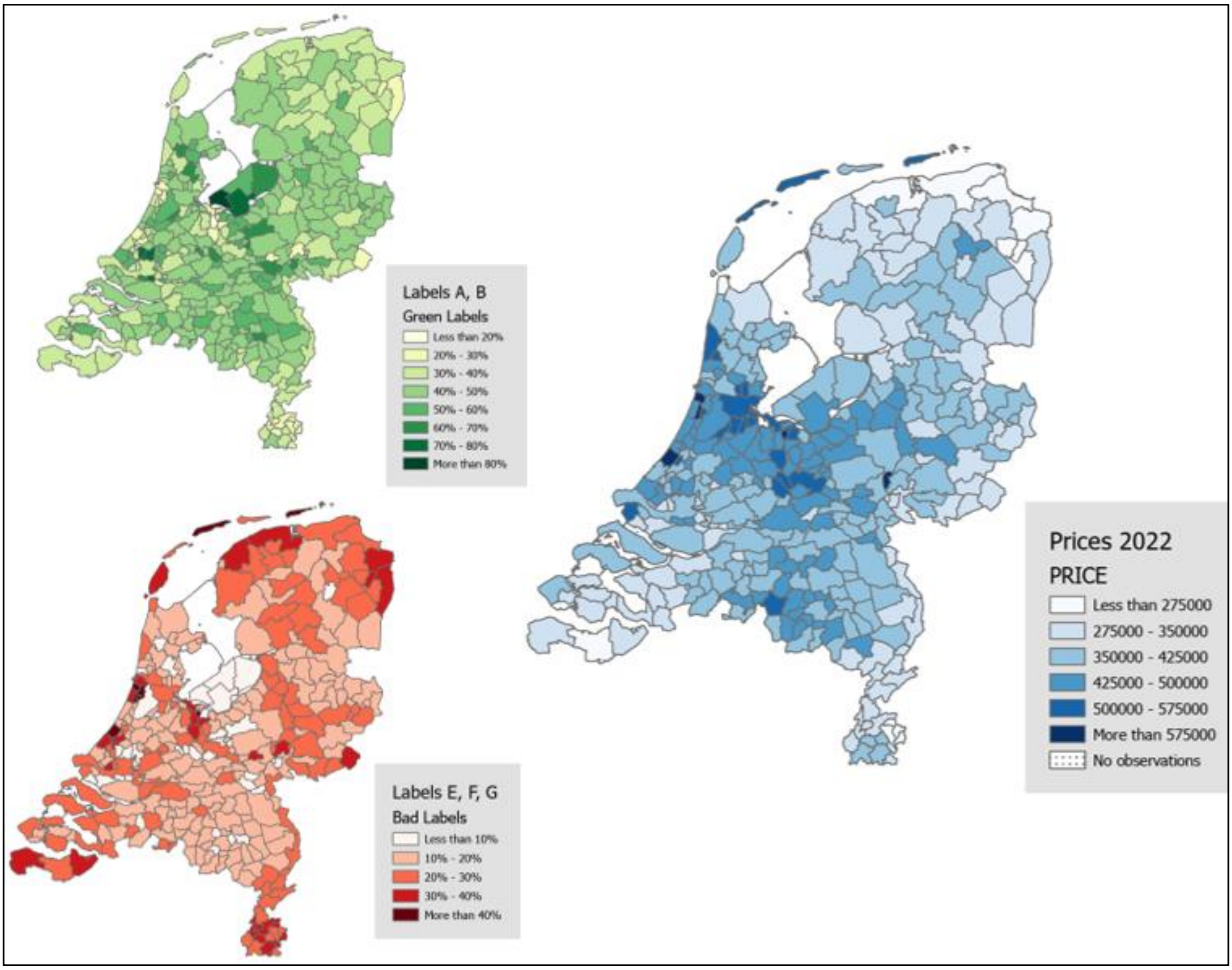


Figure 8. Spread of green and bad labels in the Netherlands in 2022, accompanied by the spread of mean transaction prices in the same year.

Figure 8 is a graphic display of the spread of both green and non-green EPC labels throughout the Netherlands in 2022, as well as the average transaction prices per municipality in the same year. Whereas a clear green centre of the map (Labels A,B), added by an almost white coloured centre below (Labels E, F, G), is visible at province of Flevoland, this part of the map is not as strongly highlighted in the map revealing prices. However, the darker red parts of the border regions in the Netherlands in the north and south (Labels E, F, G) align with the lighter municipalities showing lower house prices. It is to be questioned whether there is relationship between the two.

TABLE 5: RESULTS HEDONIC PRICE MODEL FOR ALL TRANSACTIONS AND SUBSAMPLE OF LABELLED-ONLY TRANSACTIONS

	1) Labelled transactions	2) Labelled transactions	3) Total transactions	4) Total transactions
VARIABLES	ln_price	ln_price	ln_price	ln_price
Reference	*Non-green*		*Non-green*	
Green (A or B)	0.0399***		0.0422***	
	(0.000798)		(0.000766)	
Reference		*C*		*C*
A		0.0625***		0.0438***
		(0.000895)		(0.000866)
B		0.0482***		0.0396***
		(0.000690)		(0.000709)
D		-0.0290***		-0.0191***
		(0.000707)		(0.000728)
E		-0.0469***		-0.0345***
		(0.000823)		(0.000839)
F		-0.0723***		-0.0570***
		(0.000953)		(0.000966)
G		-0.140***		-0.125***
		(0.00104)		(0.00105)
No Label				-0.0471***
				(0.000650)
Reference	*1981-2000*	*1981-2000*	*1981-2000*	*1981-2000*
1900-1920	-0.0870***	-0.00173	-0.0892***	-0.0296***
	(0.00108)	(0.00120)	(0.001017)	(0.00110)
1921-1940	-0.0674***	0.0201***	-0.0689***	-0.00867***
	(0.000875)	(0.00103)	(0.000834)	(0.000938)
1941-1960	-0.108***	-0.0462***	-1.1135***	-0.0719***
	(0.000852)	(0.000966)	(0.000809)	(0.000883)
1961-1980	-0.114***	-0.0800***	-0.1159***	-0.0931***
	(0.000631)	(0.000693)	(0.000610)	(0.000652)
2001>	0.0674***	0.0643***	0.0715***	0.0776***
	(0.000895)	(0.000891)	(0.000846)	(0.000845)
Reference	*Terraced House*	*Terraced House*	*Terraced House*	*Terraced House*
Apartment	-0.0469***	-0.0472***	-0.0535***	-0.0526***
	(0.000698)	(0.000692)	(0.000664)	(0.000660)
Corner House	0.0512***	0.0587***	0.0501***	0.0556***
	(0.000622)	(0.000618)	(0.000604)	(0.000601)
Semi-detached House	0.143***	0.153***	0.142***	0.149***
	(0.000745)	(0.000740)	(0.000722)	(0.000718)
Detached House	0.298***	0.314***	0.293***	0.306***
	(0.000798)	(0.000798)	(0.000768)	(0.000768)
Reference	*2015*	*2015*	*2015*	*2015*
2016	0.0405***	0.0408***	0..0446***	0.0417***
	(0.000903)	(0.000893)	(0.000798)	(0.000793)
2017	0.103***	0.102***	0.1079***	0.103***
	(0.000876)	(0.000866)	(0.000776)	(0.000773)
2018	0.173***	0.171***	0.177***	0.172***
	(0.000884)	(0.000874)	(0.000791)	(0.000788)
2019	0.228***	0.225***	0.236***	0.228***
	(0.000875)	(0.000866)	(0.000793)	(0.000792)
2020	0.290***	0.286***	0.297***	0.288***
	(0.000861)	(0.000852)	(0.000783)	(0.000786)
2021	0.397***	0.392***	0. 406***	0.395***
	(0.000867)	(0.000858)	(0.000794)	(0.000798)
2022	0.502***	0.495***	0.510***	0.497***
	(0.000948)	(0.000939)	(0.000894)	(0.000900)
Zipcode	Yes	Yes	Yes	Yes
Urbanization level	Yes	Yes	Yes	Yes
Constant	9.039***	9.079***	9.037***	9.075***
	(0.00417)	(0.00414)	(0.00394)	(0.00392)
Observations	1,261,186	1,261,186	1,514,031	1,514,031
R-squared	0.757	0.763	0.747	0.751

Note: Dependent variable is log of transaction price. Standard errors in parentheses with *** , **, * indicating significant at 1%, 5% and 10%, respectively.

Table 5 reports four separate specifications of the OLS regression, containing the subsample of labelled-only transactions twice in column 1 and 2 (N=1,261,186), and the whole sample in column 3 and 4 including non-labelled dwellings as well as labelled dwellings. (N=1,514,013). A second breakdown is made visible in the table regarding the treatment of the EPC-variables. Both estimations for the all separate EPC-labels in the two datasets, as well as a grouping by 'Green' (labels a and b) and 'Non-Green' (all other labels) are shown. The model estimated here explains 76 percent of the natural logarithm price variation when using the subsample, and 75 percent for the whole dataset in the third and fourth column. Apart from the year category '1900-1920' in the second column regression, all estimates are significant at a 99% confidence level.

When looking at the coefficients of the control variables, the estimates are in line with the earlier summarized and reported literature both in sign and magnitude. Table 5 only contains the presence of control variables. Detailed estimates of these control variables can be found in Appendix Table A1.

As by multiple similar studies, the value of energy labels in general is assessed by distinguishing high-quality labels from low-quality labels in the full sample (Chegut et al., 2016; Khazal and Sønstebø, 2020). After this, the subset of labelled dwellings only is used to investigate the effect of each energy efficiency level in more detail.

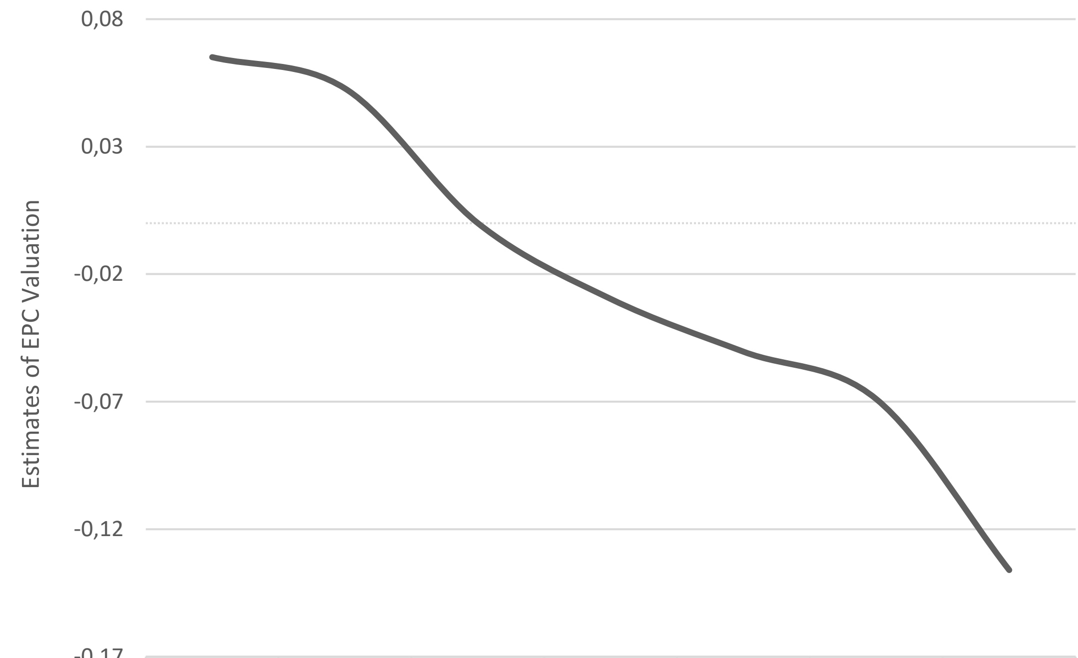
Non-labelled dwellings in the total dataset still have, even though unknown, a certain energy efficient score varying from A to G if those were labelled today. Thus, if the label itself would not affect the price, it would be expected that the estimate for houses without a label reaches at least the same price as the lowest rated dwellings (F- or G-labels) (Khazal and Sønstebø, 2020). When comparing the non-labelled coefficient to all other EPC ratings, column 4 reveals that both the estimates for F and G-labelled houses are lower than those of houses without a label. Whereas Khazal and Sønstebø (2020) find significant lower estimates for houses with labels, signalling the impact of the labelling on prices, this effect cannot be found here. Following the same line of reasoning, these results suggest that houses without a label are valued over houses with the worst labels F and G. However, this idea is expected to fade out, as selling a house without an EPC-label is impossible nowadays.

The dependent variable is the natural logarithm of transaction price. Coefficients will therefore need to be transformed into percentage-based price effects, using the following equation:

$$2)\quad \Delta P_{\%} = ((EXP(\beta_x X_i) - 1) * 100$$

To look into the effect of each EPC label on transaction prices in more details, the subsample in column 1 and 2 is used. The findings in the model then suggest that dwellings with an EPC-label A and B respectively transact for a 6,4% and a 4,9% percent higher price than a dwelling attached with label C. Houses with more energy inefficient labels, D, F and G, trade for discounts of 2,9%, 4,6% and 13,1% respectively when considering only labelled houses in column 2. This results in corresponding marginal price increases of €19,287 and €14,766 for the average A and B dwellings in the sample. When looking at figure 2 in the contextual framework, the general average costs needed for investing in reaching these efficiency levels (A and B) are similar to estimated savings. Figure 8. shows the linear prediction of log prices per

EPC label, in which the price premiums for greener labels, as well as the discount for labels less energy efficient than label C become visible.



	A	B	C	D	E	F	G
EPC valuation	0,065	0,053	0	-0,030	-0,050	-0,069	-0,136

Figure 8. Valuation per EPC label, estimated from regression 1 in column 2 of table 5 (equation 1).[1]

5.1 Starters vs. non-starters

Thus far, the overall effect of EPC on transaction prices is investigated, in which the potential heterogeneity among several buyer groups is still neglected. Using the information on starter indications available in the data, it is however possible to further explore whether or not starters capitalize EPC labels equally as seasoned buyers. As the literature review reveals, both generational characteristics and financial constraints linked to FTBs might be potential factors influencing the valuation of EPC. In the Netherlands, this group of first-time buyers is mostly referred to as *starters* in the housing market, and contains the people who enter the housing market for the first time. It is assumed that the opposite group has bought a house a least once before, and therefore this study refers to this group as *non-starters*.

Table A2 in the Appendix shows the summary statistics for starters and non-starters. Note that while the proportions of both A- and B labelled houses are higher among seasoned buyers, the medium labels C- D- and E- are more present for starters. This is to a larger extent visible in figure 9. below.

[1] Calculated as: Estimates table 5, 'A-label: column 2) Labelled transaction, row 'A'.'

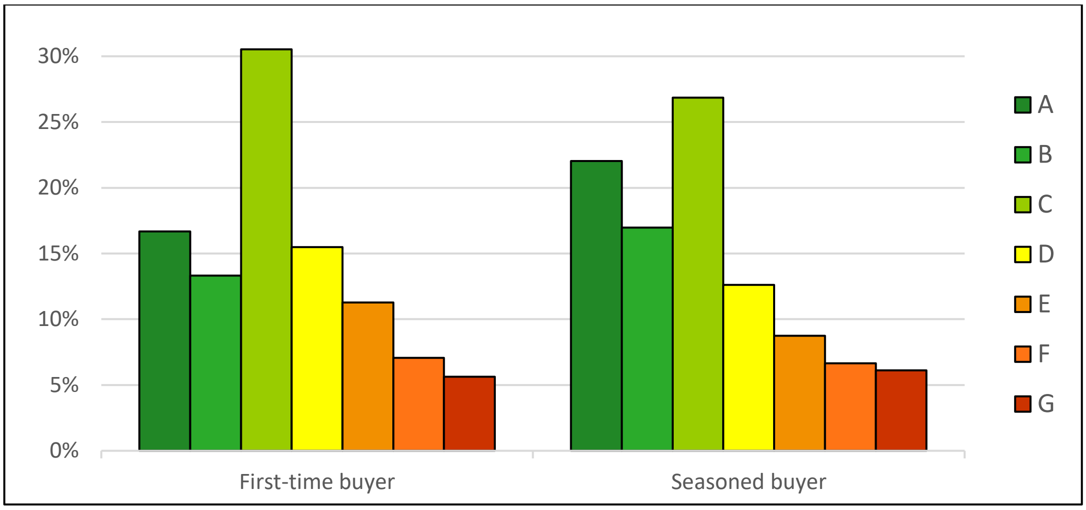


Figure 9. Distribution of labels among transactions of starters and non-starters between 2015 and 2022.

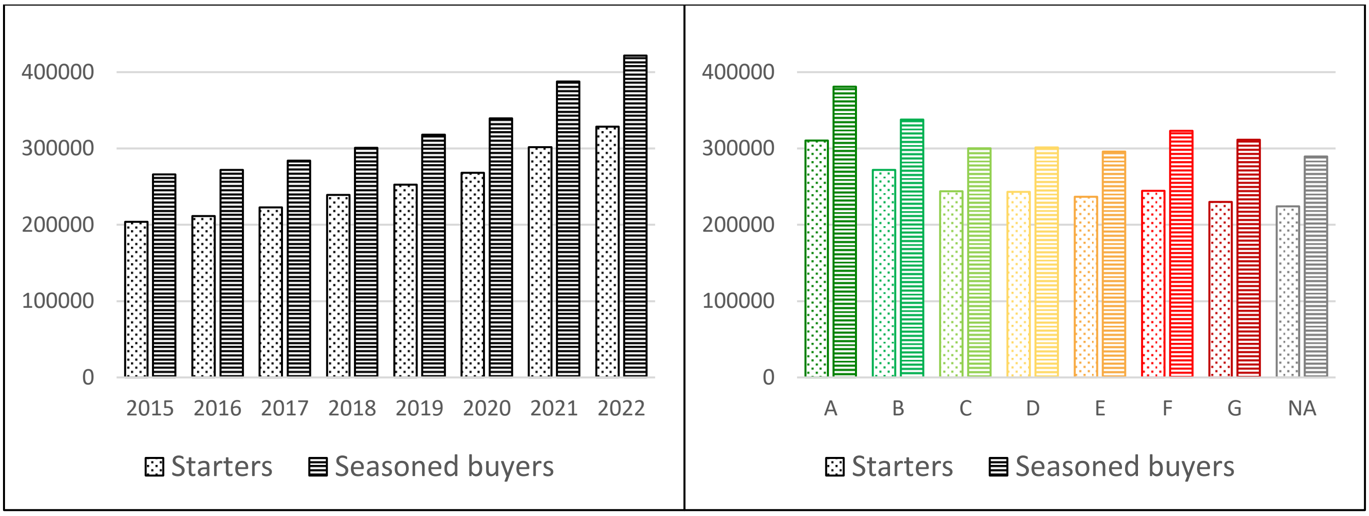


Figure 10. Average transaction prices (€) of houses for staters and non-starters over time (2015-2022), and by EPC label.

Figure 10 reveals that the yearly average transaction prices are higher for seasoned buyers than for starters over time. Added to that, the figure shows that the distribution pattern is rather similar for both groups.

To analyse any potential inequality in the relationship between EPC label and house prices for starters versus seasoned buyers, a re-estimation of the hedonic equation (1) is conducted, as is also done by Khazal and Sønstebø (2020). By including a dummy variable – being the value one if the buyer is a starter and 0 if non-starter - overall heterogeneity can be controlled for. The addition of interaction terms tests whether the two groups have an equal valuation of EPCs (Khazal and Sønstebø, 2020). Table 6 reports the estimation. For this, the following equation 3 is used.

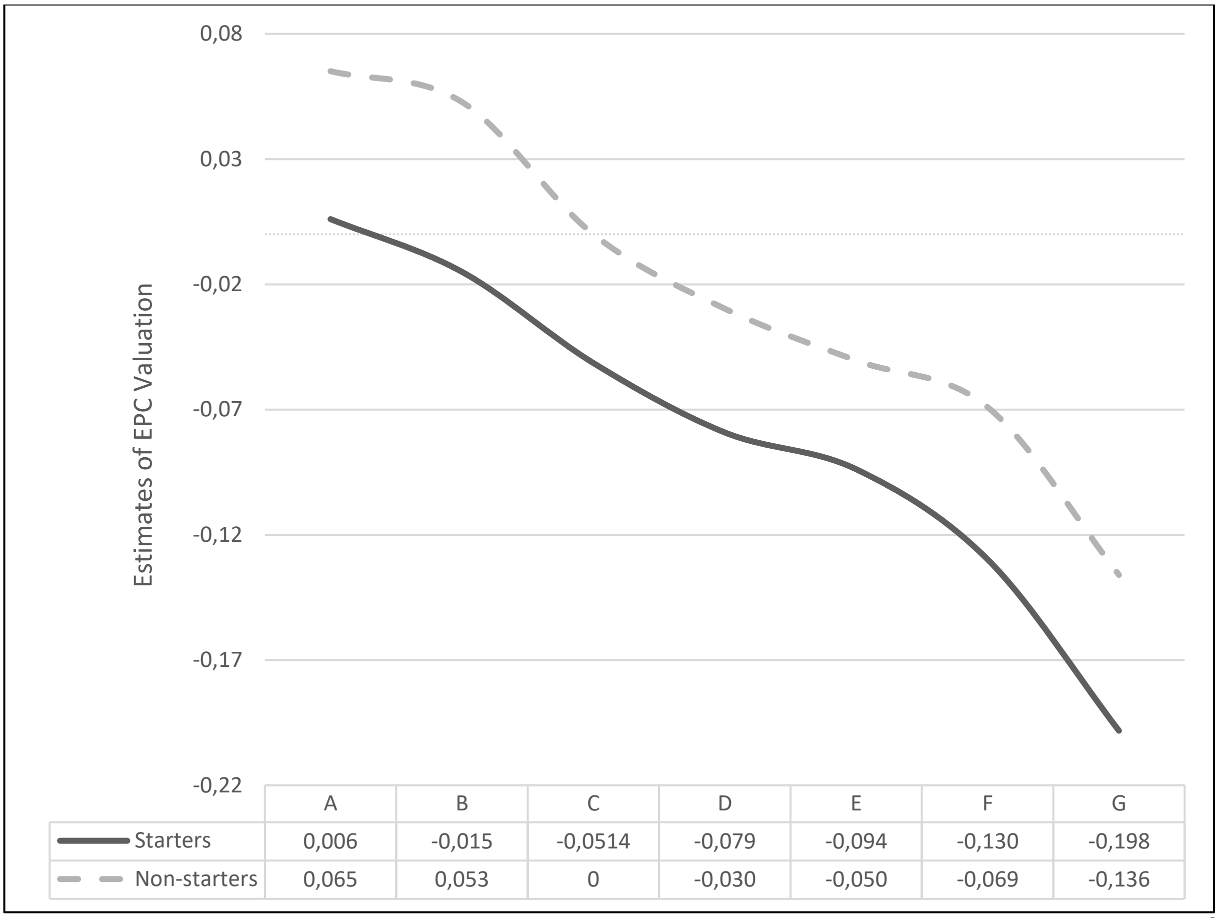
$$3) \quad \text{Log}(TransactionPrice_{it}) = \alpha + \delta EPC_i + \varphi \text{Log}(DwellingSize)_i + \rho FTB + (\delta EPC_i * \rho FTB) + \sum_{c=1}^{C} \beta ConstructionYear + \sum_{b=1}^{B} \mu BuildingType + \sigma Zipcode_i + \lambda_1 UrbanizationLevel_n + \gamma TransactionYear_{it} + \varepsilon_{it}$$

TABLE 6: RESULTS OF INTERACTION EFFECTS FOR HETEROGENEITY BETWEEN STARTERS AND NON-STARTERS

VARIABLES	1) Buyer Type ln_price
Reference	*Non-starter*
Starter	-0.0514***
	(0.000766)
Reference	*C*
A	0.0651***
	(0.000979)
B	0.0528***
	(0.000820)
D	-0.0297***
	(0.000881)
E	-0.0504***
	(0.00102)
F	-0.0690***
	(0.00115)
G	-0.136***
	(0.00123)
(A*Starter)	-0.00766***
	(0.00123)
(B*Starter)	-0.0164***
	(0.00131)
(D*Starter)	0.00197
	(0.00132)
(E*Starter)	0.00799***
	(0.00148)
(F*Starter)	-0.00938***
	(0.00171)
(G*Starter)	-0.0108***
	(0.00183)
Controls	Yes
Constant	9.039***
	(0.00417)
Observations	1,261,186
R-squared	0.757

Note: Dependent variable is log of transaction price. Standard errors in parentheses with *** , **, * indicating significant at 1%, 5% and 10%, respectively. All variables from the first equation (1) are included in the model, yet not reported in this table (Controls)

As in line with the average transaction prices in figure 10, a visualization of the linear prediction by table 6 (equation 3) shows higher prices for non-starter buyers, compared to the group of starters. This visualization is shown by figure 11 below. Note that this difference does not vary across EPCs.

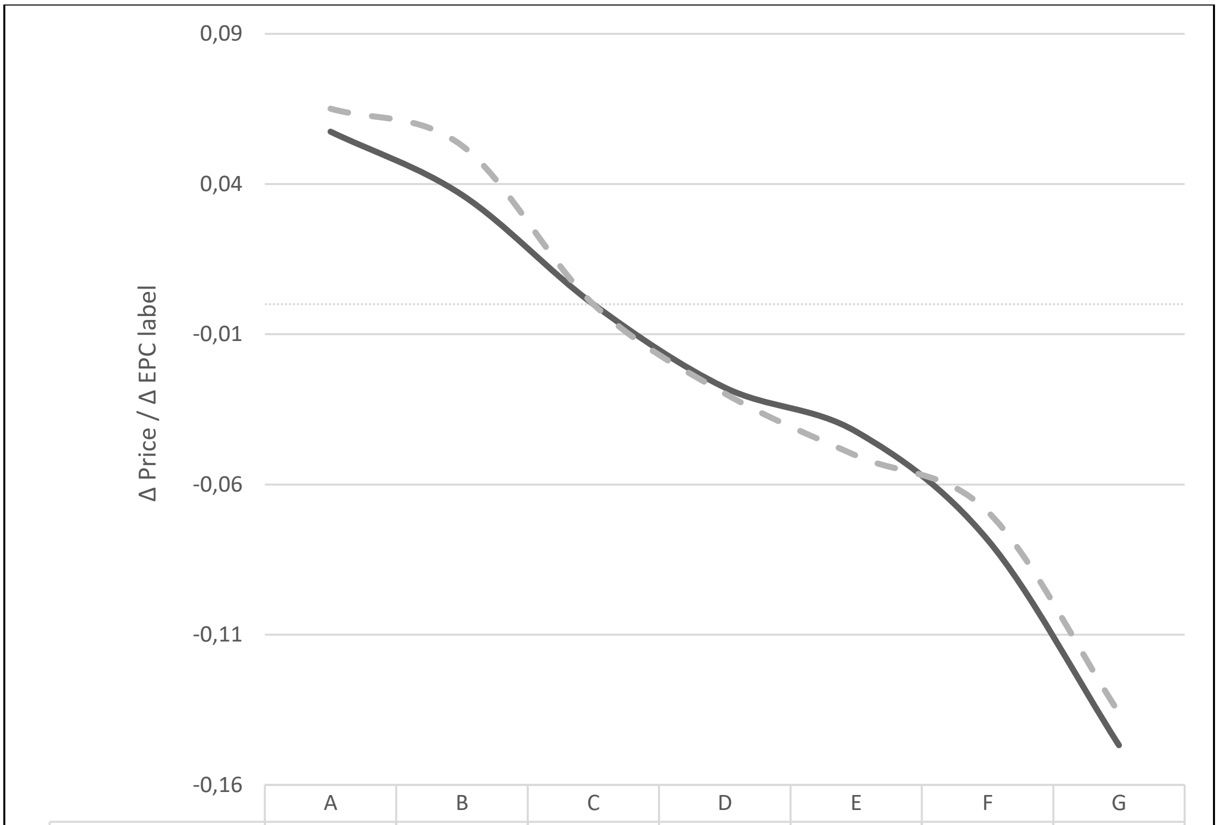


	A	B	C	D	E	F	G
Starters	0,006	-0,015	-0,0514	-0,079	-0,094	-0,130	-0,198
Non-starters	0,065	0,053	0	-0,030	-0,050	-0,069	-0,136

Figure 11. Linear Prediction: Heterogeneity in valuation of EPCs (Note: non-starters and label C are used as reference group)[2]

Following the same pattern as figure 8, prices are higher for greener EPCs (A and B), and lower for less energy efficient labels (D, E, F and G) compared to the C-label. However, in order to compare willingness-to-pay of starters versus non-starters, the marginal effects need to be graphed. Whereas the lines in figure 11 seem to follow a similar pattern, overlapping the lines by graphing the marginal effects (figure 12) shows, to a small extent, heterogeneity.

[2] Calculated as: Estimates table 6, 'A-label starters: ((-0,0514)+0,065+(-0,008))', 'A-label Non-starters: (0,065)'



	A	B	C	D	E	F	G
Starters	0,057	0,036	0,000	-0,028	-0,042	-0,078	-0,147
Non-starters	0,065	0,053	0,000	-0,030	-0,050	-0,069	-0,136

Figure 12. Marginal effects based on EPC label (Note: non-starters and label C are used as reference group)[3]

Figure 12, as well as the estimates in table 6, reveal that starters are to a lesser extent willing to pay for greener EPCs (A and B), compared to non-starters. Therefore, there is heterogeneity, yet the difference is small and mostly profound for the EPC labels A and B (between 0,8% and 1,6%). This difference, however, is significant at a 99% significance in statistic terms. For the other labels, the results are more inconclusive. The estimates for label D are insignificant. When looking at label E, the line for starters goes up, whereas that of non-starters continues to descend. A link to expectations in prior research cannot be found here. Therefore, this anomaly is hard to explain, yet there may for example be a relation to unobservable housing attributes that influences the price differently for starters than for non-starters.

The heterogeneity found for starters can to some extent be linked to prior research. As is explained in the third chapter, the twofold expectations from literature suggest that starters are less able to realize their demands on the housing markets as a result of budget constraint, yet from a generation perspective, put more emphasis of greenness and energy efficiency. The budget constraint becomes visible in figure 11, since transaction prices in general are higher for non-starters than for starters. The higher expected importance for green dwellings is however not shown is these results. On the contrary, non-starters pay more for the most energy efficient dwellings than starters. A closer look into the estimates reveals that this premium is between 0,8% for a label B dwelling and 1,6% for A-labelled houses. On an average house price of around €300.000, this is calculated as a premium of €4800 maximum in economic terms.

As Fergonara et al. (2019) noticed, the G level, and potentially the F-level as well, need to be considered with special attention due to the possibility of self-certifying the dwelling, at least for a certain period. Following the budget constraints mentioned before, it is likely that starters may not have the means to do so, leading their willingness-to-pay

[3] Calculated as: Estimates table 6, 'A-label starters: (0,065+(-0,008))', 'A-label Non-starters: (0,065)'

for a house that needs self-certifying to be lower. Added to this, Burbank and Keeley (2014) claimed Generation Y to tend to buy houses that are renovated or required minimum renovation. These results therefore require more exploration in order to find true reasons for the found lower willingness-to-pay for energy inefficient houses among starters.

5.2 Heterogeneity among several building types

As with buyer types, heterogeneity between several building types is expected as a result of the literature review in the third chapter. In summary of the review, this is due to the degree of ability to self-upgrade the dwelling, as well as the ability to keep track of one's own energy use. Based on the label distribution of sold dwellings, graphically displayed in figure 13 below, similar expectations are drawn. A hint of importance for greener labels among multi-family dwellings, in this case apartments, corner houses and terraced houses, is visible as the share of green labels is far larger than that of less energy efficient labels. The same line of reasoning, where a buyer is less able to fully self-upgrade, as well as to individually and independently set up energy usage costs can be applied here.

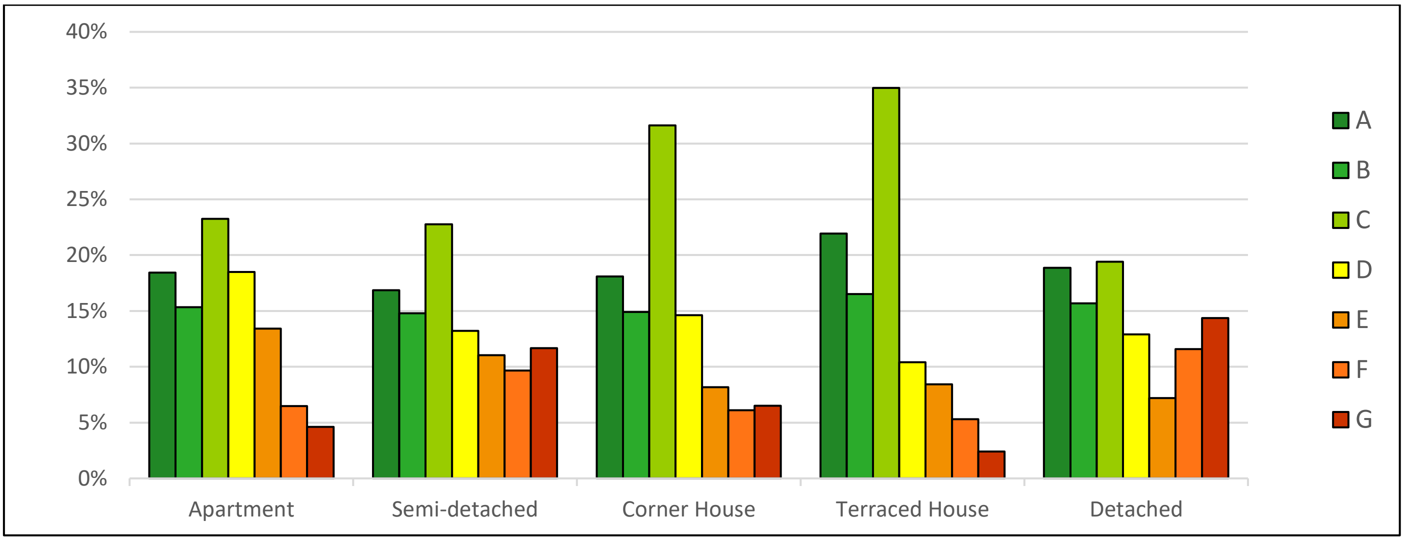


Figure 13. EPC distribution of sold dwellings per dwelling type

A similar method to that of section 5.1 is used to reveal potential heterogeneity per each building type. For interpretation purposes, interaction between building type and 'greenness' is added to the basic regression in equation 1. Greenness is related to the EPC label, as a dwelling is considered green when the EPC label is A or B, and considered non-green with EPC labels C, D, E, F and G. By including a dummy variable – being the value one if the building is a green and 0 if non-green - overall heterogeneity can again be controlled for. This results in the following equation:

$$4)\quad \text{Log}(TransactionPrice_{it}) = \alpha + \delta Green_i + \varphi \text{Log}(DwellingSize)_i + (\delta Green_i * \sum_{b=1}^{B} \mu BuildingType) + \sum_{c=1}^{C} \beta ConstructionYear + \sum_{b=1}^{B} \mu BuildingType + \sigma Zipcode_i + \lambda_1 UrbanizationLevel_n + \gamma TransactionYear_{it} + \varepsilon_{it}$$

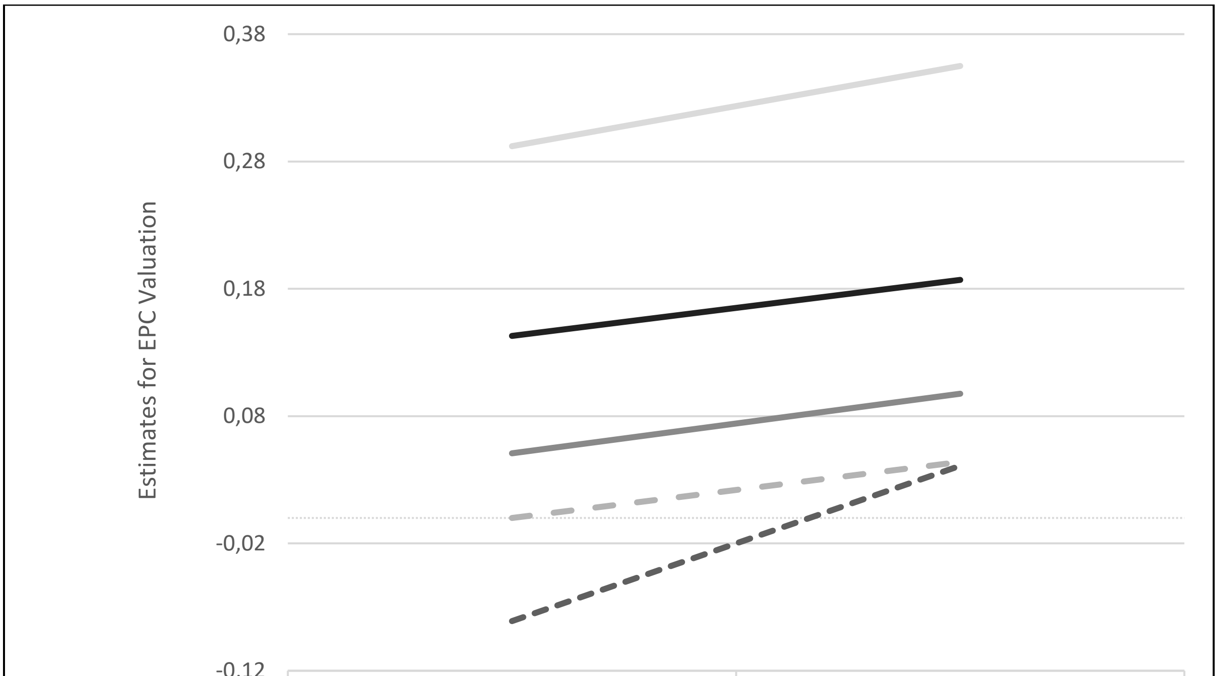
The relationship between building type and a dwelling's 'greenness' using equation 4 is explored in table 7 below.

TABLE 7: RESULTS OF INTERACTION EFFECTS FOR HETEROGENEITY

VARIABLES	1) Buyer Type ln_price	2) Building Type ln_price	3) Transaction Year ln_price
Reference	*Non-green*	*Non-green*	*Non-green*
Green	0.0679***	0.0444***	0.0672***
	(0.000706)	(0.000827)	(0.00156)
Reference	*Non-starter*		
Starter	-0.0512***		
	(0.000520)		
(Green*Starter)	-0.0124***		
	(0.000885)		
Reference	*Terraced House*	*Terraced House*	*Terraced House*
Apartment	-0.0589***	-0.0806***	-0.0503***
	(0.000695)	(0.000824)	(0.000694)
Corner House	0.0500***	0.0508***	0.0524***
	(0.000617)	(0.000764)	(0.000620)
Semi-Detached House	0.137***	0.143***	0.143***
	(0.000739)	(0.000894)	(0.000741)
Detached House	0.288***	0.292***	0.298***
	(0.000795)	(0.000948)	(0.000795)
(Green*Apartment)		0.0774***	
		(0.00114)	
(Green*Corner House)		0.00239*	
		(0.00129)	
(Green*Semi-Detached House)		-0.000679	
		(0.00148)	
(Green*Detached-House)		0.0181***	
		(0.00139)	
Reference	*2015*	*2015*	*2015*
2016	0.0381***	0.0407***	0.0402***
	(0.000895)	(0.000897)	(0.00110)
2017	0.0985***	0.103***	0.104***
	(0.000869)	(0.000870)	(0.00107)
2018	0.168***	0.172***	0.173***
	(0.000877)	(0.000878)	(0.00107)
2019	0.223***	0.228***	0.229***
	(0.000868)	(0.000869)	(0.00107)
2020	0.284***	0.290***	0.291***
	(0.000854)	(0.000855)	(0.00105)
2021	0.395***	0.397***	0.399***
	(0.000859)	(0.000861)	(0.00106)
2022	0.500***	0.501***	0.497***
	(0.000939)	(0.000941)	(0.00117)
(Green*2016)			0.000831
			(0.00192)
(Green*2017)			-0.00393**
			(0.00185)
(Green*2018)			-0.00283
			(0.00187)
(Green*2019)			-0.00457**
			(0.00185)
(Green*2020)			-0.00478***
			(0.00182)
(Green*2021)			-0.00848***
			(0.00182)
(Green*2022)			0.00909***
			(0.00198)
Controls	Yes	Yes	Yes
Constant	9.039***	9.049***	9.038***
	(0.00417)	(0.00415)	(0.00418)
Observations	1,261,186	1,261,192	1,261,192
R-squared	0.757	0.761	0.760

Note: Dependent variable is log of transaction price. Standard errors in parentheses with ***, **, * indicating significant at 1%, 5% and 10%, respectively. All variables from the first equation (1) are included in the model, yet not reported in this table (Controls)

When just looking at the estimates of the linear regression in table 7, column 2, two conclusions can be drawn regarding transaction prices per building type. Figure 14 shows the graphic view of these conclusions. Firstly, there can be said that prices are higher for a higher level of greenness, for all building types. Compared to non-green dwellings of the same building type, all categories show higher prices for green dwellings. Secondly, prices are lower for apartments compared to terraced houses, yet higher for the building types corner house, semi-detached house and detached house. The price difference between apartments and terraced houses disappears for green houses. Worth mentioning, the estimates for semi-detached dwellings are insignificant and should therefore be interpreted with caution. In addition, these differences in prices cannot be related to the greenness of the dwelling.



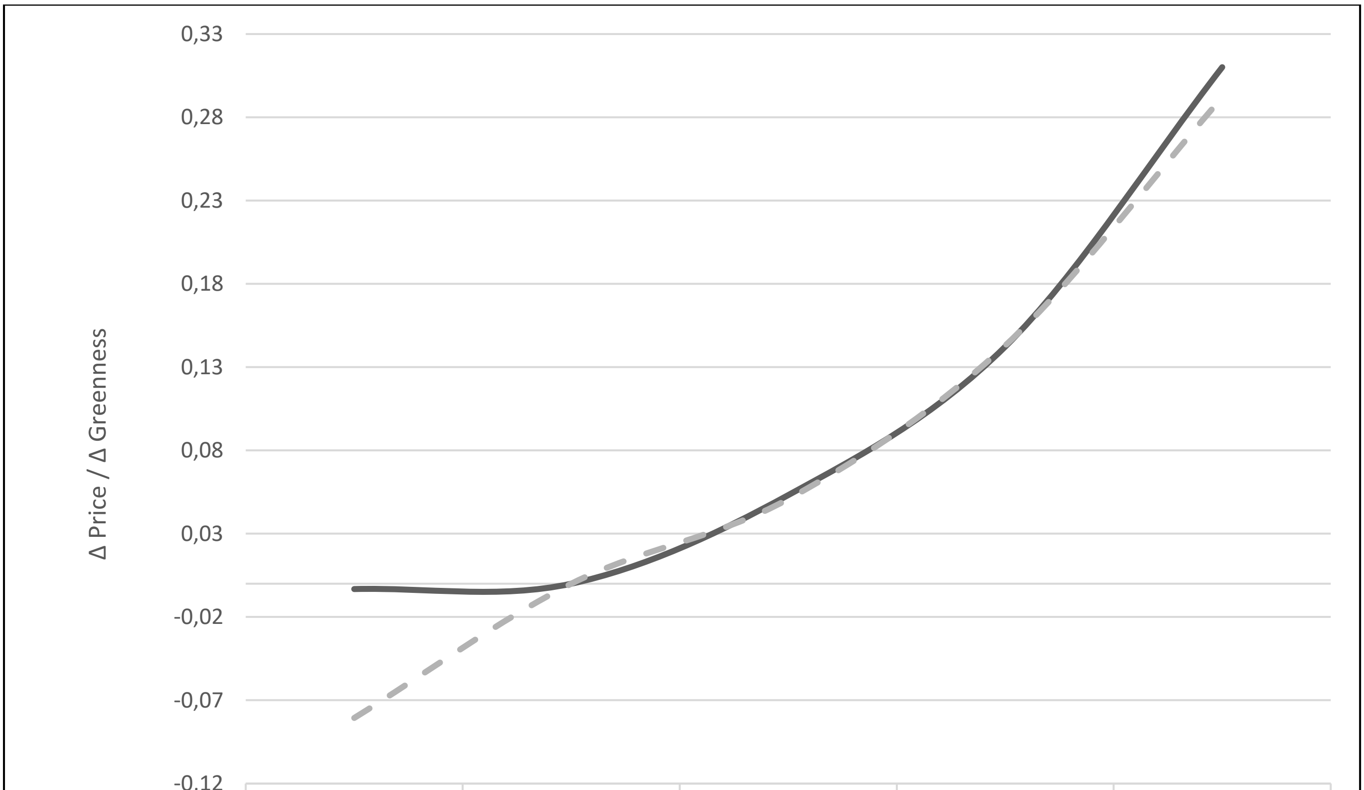
	Non-Green	Green
Apartment	-0,081	0,041
Terraced	0	0,044
Corner	0,051	0,098
Semi-detached	0,143	0,187
Detached	0,292	0,355

Figure 14. Linear Prediction: Heterogeneity in valuation of Greenness per building type (Note: Non-Green and Terraced House are used as reference group)

Figure 15 below reveals the marginal price effects per building type, making it possible to determine the differences related to greenness. The same results are visible, where corner houses, semi-detached houses and detached houses transact at higher prices. Non-green apartments sell at lower prices than terraced houses, whereas green apartments show similar values. Remarkable in this graph, is the separation between the green and non-green line for apartments. There can be concluded that buyers of apartments are more willing to pay for greenness than buyers of other building types. To a lesser extent, the same applies to buyers of detached houses. These results are not visible for corner houses and terraced houses, and inconclusive regarding semi-detached houses due to the insignificance of the estimates.

For apartments, the higher value for already green dwellings is in line with the above mentioned prior research expectations, since buyers might be less able to self-upgrade or influence the total building's energy usage, making them value already present greenness more than for other building types.

For detached houses, the expectations were opposite to the result. As detached houses are mostly single-family dwellings, a slightly higher valuation is remarkable. Assumptions regarding the higher incomes of occupants of detached houses, and their ability to self-upgrade or cope with higher utility bills can be made here, yet further research might be necessary to fully draw conclusions on this outcome. Another possibility would be that there are unobservable variables that influence the results, for example regarding farmhouses on a larger estate or historic homes. Further research potentially enriches these results when including more housing characteristics or estate information.



	Apartment	Terraced House	Corner House	Semi-detached House	Detached
Green	-0,003	0,000	0,053	0,142	0,310
Non-green	-0,081	0,000	0,051	0,143	0,292

Figure 15. Marginal Price Effects per building type: Non-Green vs. Green (Note: Non-Green and Terraced House are used as reference group)

The estimates in table 7 can be translated into price premium percentages using equation 2. This reveals the following green price premiums per building type: 12,2% for apartments, 4,7% for corner houses, 4,4% for terraced houses, 4,4% for semi-detached houses (insignicant) and 6,3% for detached houses. Thus, the premium for a green apartment is the apartment category is larger than that of green premiums in other building types.

5.3 Social Housing and housing affordability

Comparing the owner-occupied label shifts to those of social housing institutions, a different image is formed. In Appendix Figure A2 and A3, two similar graphs to Figure 3 and Figure 5 are stated, where a Sankey-diagram and a distribution of only transactions by housing institutions are shown. Whereas home-owners mostly make smaller label shifts, by increasing only one or two levels, housing institutions invest in measures that increase the labels by larger shares, mainly from G to A. As figure A2 shows, most of the label shifts done by housing institutions lead to an increase of at least two label levels. Half of the of improved label A houses used to be attached by a EPC label of D or lower. This particularly shines a different light on housing affordability in relation to the energy transition and the payment of utility bills regarding social housing renters and those not able to buy a house. It is a contradiction with expectations in the literature regarding the split incentive problem. Institutional investors mostly do not directly benefit from reduction in utility bills. When they rent out their investment properties, without including the energy bill in the total rent price, a potential reduction in the energy bill would benefit the renter instead of the owner. This split incentive problem may lower the willingness to invest in energy efficiency for institutional investors, since the benefits appear elsewhere, but the investment costs cannot always be charged (Kahn et al., 2014). März et al. (2022) acknowledge this landlord-tenant dilemma. Their research results show a price premium for energy efficiency, yet insufficient, resulting in investments in energy efficiency not being attractive for landlords from an economic perspective. The risk of investments costs being higher than the gains from the market through reduced vacant periods or higher net rents is substantial. Added to this, investments in other apartment features, such as a fitted kitchen or an extra toilet, led to significantly better refinancing on the rental market in the period 2012 – 2019 (März, 2022). Due to data limits regarding transaction prices of housing institutions (institutional buyers often buy combined housing units, concealing the true house price of each units) it is beyond this study to look further into this contradiction. The contradiction in the data and expectations from literature is however interesting and worth mentioning in the light of housing affordability and energy poverty which is more relevant to this housing sector.

6. CONCLUSION

Based on the contextual framework and the literature review, the implementation of EPC labels in the Dutch housing market is expected to reduce carbon emissions as well as energy consumption by inducing involved actors, e.g. home owners, to invest in improving the energy efficiency. This study is first to draw an image of the current improvement stage the Dutch housing market is in, as well as effect of EPC labels on most recent transaction prices for the entire Dutch housing market, adding to the already large amount of literature regarding to this topic. Furthermore, as to the current knowledge, this research is first to analyze heterogeneity concerning buyer types as well as building types, by applying an hedonic regression model on a strongly representative dataset of over 1.2 million observations over the whole of The Netherlands between 2012 and 2022, made available by Het Kadaster.

A contextual analysis shows a growing share of green labels in the Netherlands, from a green share of 33% in 2015 to a total of 43% in 2022. The total share of medium labels is decreasing as a result. However, the worst label, G, is persistent in its share of the total owner-occupied housing stock, responsible for around 6%. A distribution of the sold dwellings reveals that the less energy efficient houses are mostly represented by older dwellings, constructed between 1900 and 1950. Of these houses, certain characteristics match aesthetic preferences of a large share of house buyers, potentially revealing the persistency in G-labelled transactions. More importantly for the energy transition, a Sankey diagram shows the current upward flow of EPC labels between 2018 and 2022. Mostly smaller steps, increasing 1 or 2 levels of EPC labels are evident, yet the larger shifts are also present. A total of almost 80,000 label shift is registered. However, incentives to register label shift are insufficient for home-owners leading to a smaller amount of label shifts registered than actually present in The Netherlands.

When looking at the price developments of EPC labels, it seems to be assumable that whereas the distribution of house prices was not according the green-to-red scale considering their prices at the starting point in 2015. However, in 2022, the dispersion of higher labels attached to higher priced houses and vice versa is more common. The spread of green (and red labels), corresponding to higher (and lower) prices throughout the Netherlands is on the other hand less visible, apart from border regions that might show lower prices for several other reasons as well.

The hedonic regression model reveals price premiums of 6,4% and 4,2% compared to C-labelled dwellings for A- and B-labels respectively. This is in line with similar prior research (Brounen and Kok, 2011; Fuerst et al., 2015; Chegut et al., 2016). The overall pattern that became visible shows price premiums for EPC labels more energy efficient than C-labelled dwellings, as well as increasing discounts the more energy inefficient the dwelling is, compared to the C-base level. Particularly interesting is the higher valuation of A- and B-labelled houses and their higher price premiums compared to the other labels, where both A- and B-labels receive similar high transaction prices after which the prices strongly decline with lower energy efficiency.

To a small extent, this study finds heterogeneity in the EPC price valuation between starters and non-starters, where non-starters are willing to pay more for A- and B-labelled dwellings than starters. In line with the expectations from previous literature, this might be related to the financial barriers for entering the housing market that this buyer group of starters is facing. The A- and B-labelled, and therefore more energy efficient houses, might be part of the housing preferences that starters are not able to fulfill as a result of these barriers. Stronger heterogeneity is also found for the several building types. As was expected from prior research, the multi-family building type apartment shows higher price premiums for a greener dwelling than shown by other building types, in which fragmented ownership is less common. A higher valuation can also be found among detached houses, which is remarkable and of which reasons are still unknown. More research on this topic would therefore be necessary.

A limitation mentioned in this study is the absence of housing characteristics that are often associated with upgrading a dwelling, such as a new kitchen or bathroom. Such housing characteristic upgrades could be done simultaneously with energy efficiency improvements, affecting the transaction price in a matter unrelated to energy efficiency. With the absence of such variables, these combined upgrades cannot be controlled for. Future research would be benefitted by, if possible, including upgraded housing characteristics that are of impact on the house price.

Another limitation in this study coincides with the validity of EPC labels. Dutch EPC labels are valid for ten years, and there is little to no incentive to update existing labels in case of a housing transactions since updates are expensive, and energy improvements might be visible without attached label). Up until 2021, home-owners were able to (partly) compose the label attached their label using an online form. As a result, such self-determined EPC labels are still valid, and the current EPC label distribution does not show the full picture.

This study fails to fully control for unobserved locational effects in a way that a repeat sales analysis would be able to. However, based on the above-mentioned notion that there is little incentive to update an existing EPC label, observations that entail a label shift as well as a price shift are scarce for the time period 2015-2022. This is expected to change over the next years, when the 10-year validity will expire, generating more of such observations. At this moment, a repeat sales analysis with this population data was too early, yet future research should focus on the repeat sales method in order to tackle unobserved location fixed effects.

The results stated above might be useful for policy implications, especially for energy efficiency programs in the energy transition strategy. As is shown, energy efficiency is to some extent capitalized in the housing market, apart from the benefits it has on utility bills and societal costs of energy inefficiency. If uncertainty regarding the costs and benefits of undertaking investments in a greener dwelling are a result of an unknown value of this capitalization in transaction prices, public awareness on this topic could make a difference in inducing households to make their dwelling more sustainable. When households are more informed on both the direct (lower utility bills) and indirect returns (higher sales price), their benefits might be higher than expected. Especially when looking at the heterogeneity for first-time buyers, where this buyer group does not value A- and B-labels as much as more seasoned buyers, this might have implications for policy programs with starters as their target audience. The consequences of higher utility bills, compared to the higher price of greener dwellings might be an important issue to raise public awareness about, for FTBs in particular looking at the barriers they already face when entering the housing market.

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APPENDIX: FIGURES

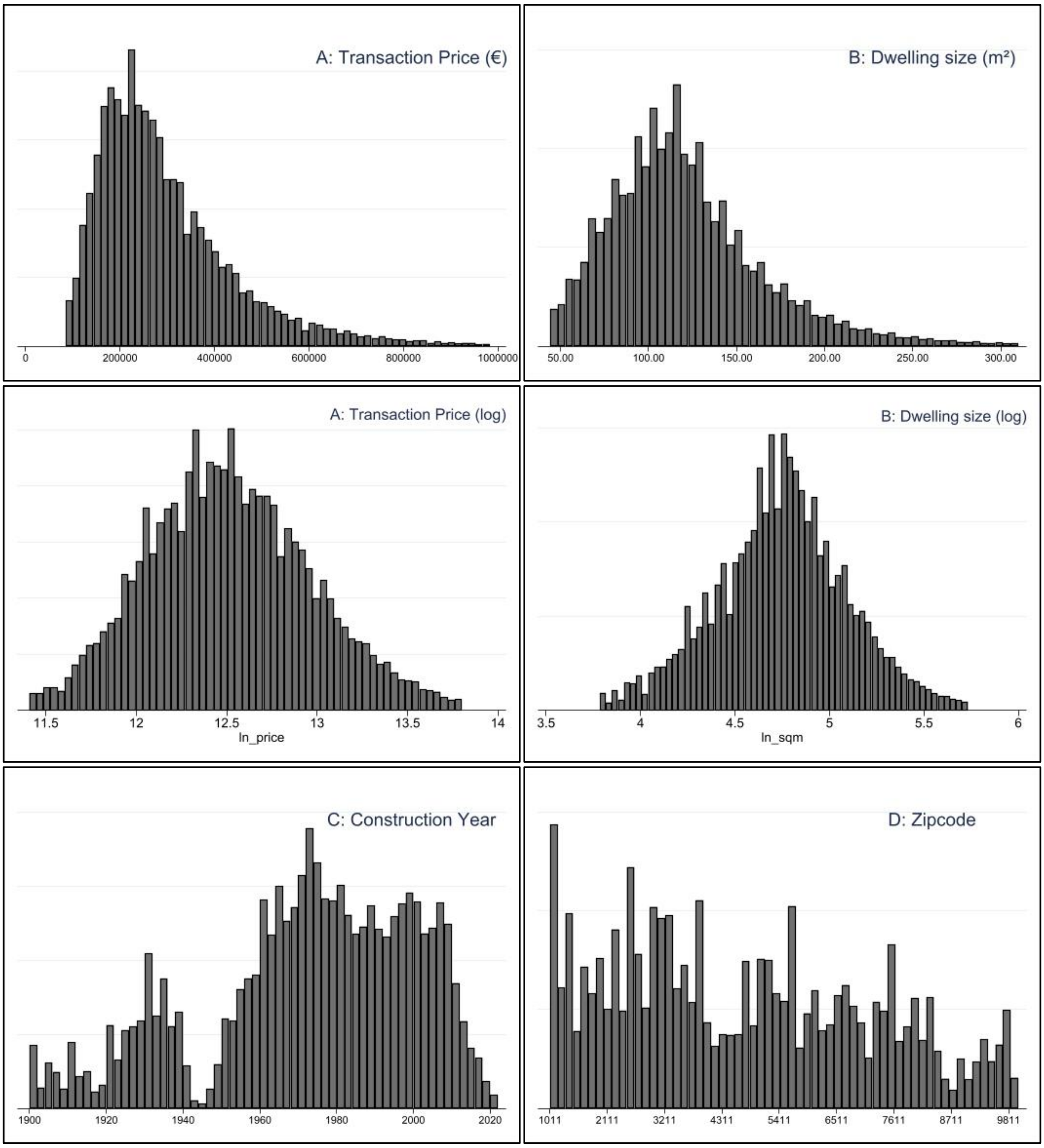

Figure A1. Sample distribution of Transaction Price, Dwelling size, Construction Year and Zipcode

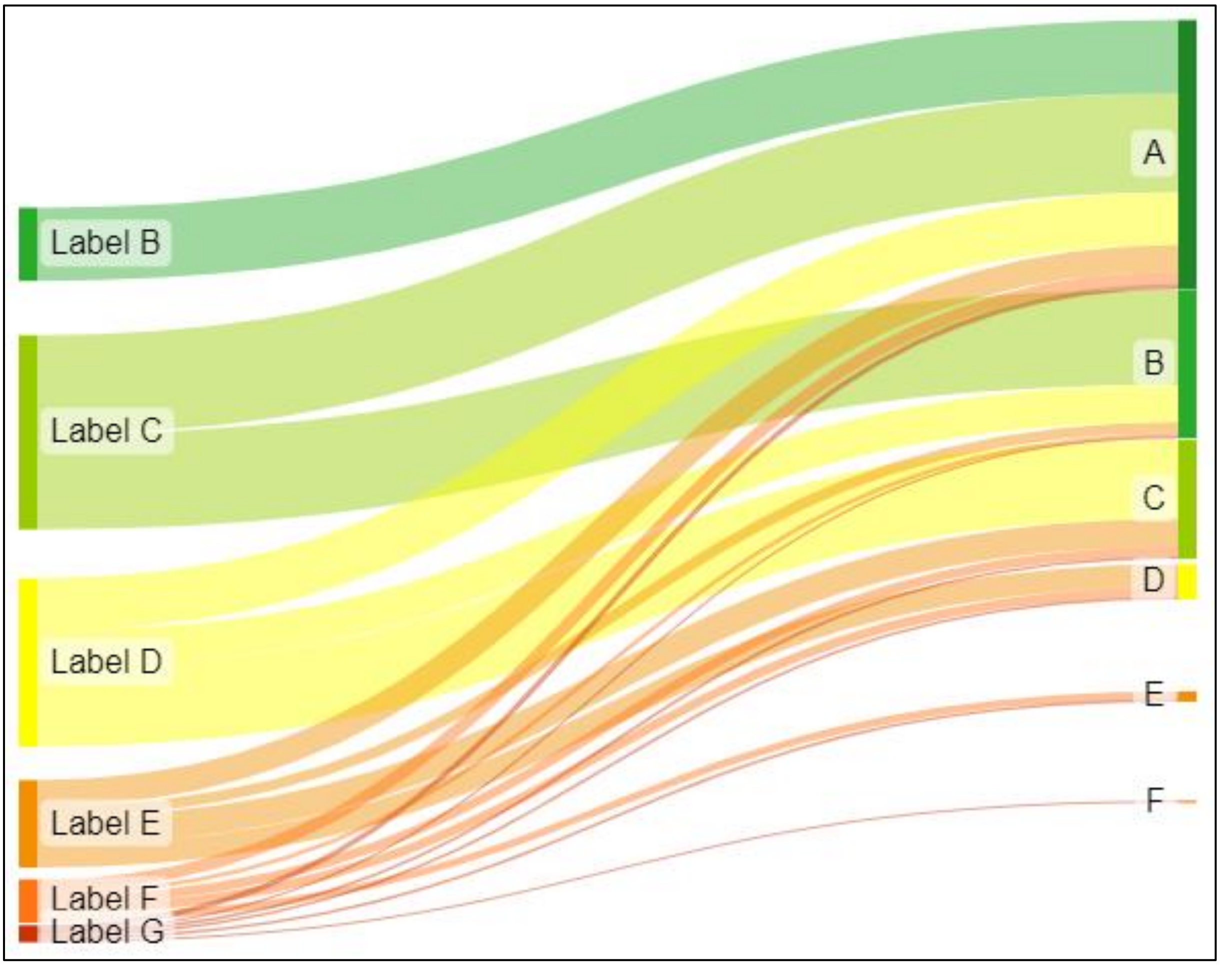

Figure A2. A Sankey Diagram mapping the upward flow of EPC labels in 2018 to EPC labels in 2022, housing institutions (Het Kadaster, Dataset C (n=635,112)).

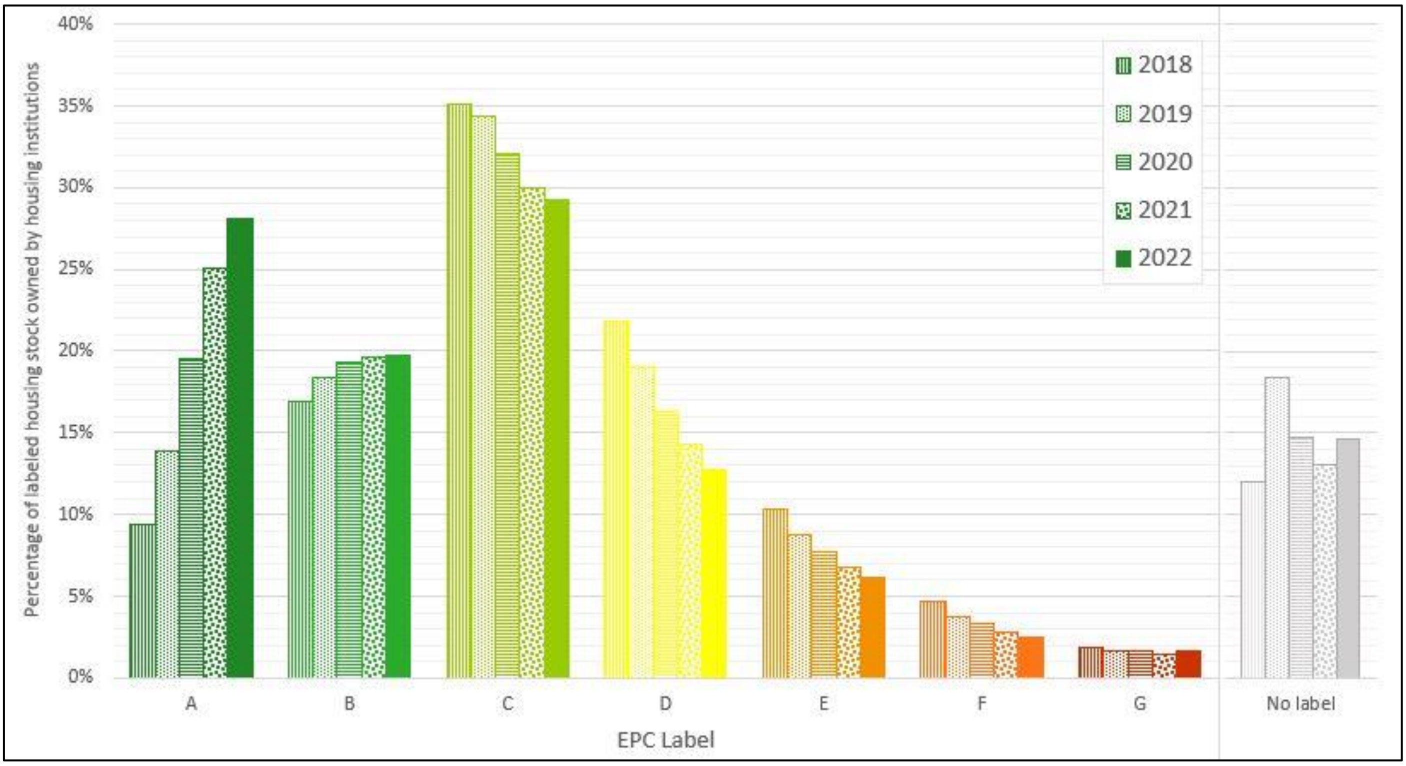

Figure A3. The distribution of EPC labels throughout the registered labelled housing stock owned by housing institutions in the Netherlands from 2018 to 2022 (Het Kadaster, Dataset B (n=1,931,992)).

APPENDIX: TABLES

TABLE A1: RESULTS HEDONIC PRICE MODEL FOR ALL TRANSACTIONS AND SUBSAMPLE OF LABELLED-ONLY TRANSACTIONS

VARIABLES	1) Labelled transactions ln_price	2) Labelled transactions ln_price	3) Total transactions ln_price	4) Total transactions ln_price
Reference	*Non-green*		*Non-green*	
Green (A or B)	0.0399***		0.0422***	
	(0.000798)		(0.000766)	
Reference		*C*		*C*
A		0.0625***		0.0438***
		(0.000895)		(0.000866)
B		0.0482***		0.0396***
		(0.000690)		(0.000709)
D		-0.0290***		-0.0191***
		(0.000707)		(0.000728)
E		-0.0469***		-0.0345***
		(0.000823)		(0.000839)
F		-0.0723***		-0.0570***
		(0.000953)		(0.000966)
G		-0.140***		-0.125***
		(0.00104)		(0.00105)
No Label				-0.0471***
				(0.000650)
Reference	*1981-2000*	*1981-2000*	*1981-2000*	*1981-2000*
1900-1920	-0.0870***	-0.00173	-0.0892***	-0.0296***
	(0.00108)	(0.00120)	(0.001017)	(0.00110)
1921-1940	-0.0674***	0.0201***	-0.0689***	-0.00867***
	(0.000875)	(0.00103)	(0.000834)	(0.000938)
1941-1960	-0.108***	-0.0462***	-1.1135***	-0.0719***
	(0.000852)	(0.000966)	(0.000809)	(0.000883)
1961-1980	-0.114***	-0.0800***	-0.1159***	-0.0931***
	(0.000631)	(0.000693)	(0.000610)	(0.000652)
2001>	0.0674***	0.0643***	0.0715***	0.0776***
	(0.000895)	(0.000891)	(0.000846)	(0.000845)
Reference	*Terraced House*	*Terraced House*	*Terraced House*	*Terraced House*
Apartment	-0.0469***	-0.0472***	-0.0535***	-0.0526***
	(0.000698)	(0.000692)	(0.000664)	(0.000660)
Corner House	0.0512***	0.0587***	0.0501***	0.0556***
	(0.000622)	(0.000618)	(0.000604)	(0.000601)
Semi-detached House	0.143***	0.153***	0.142***	0.149***
	(0.000745)	(0.000740)	(0.000722)	(0.000718)
Detached House	0.298***	0.314***	0.293***	0.306***
	(0.000798)	(0.000798)	(0.000768)	(0.000768)
Reference	*2015*	*2015*	*2015*	*2015*
2016	0.0405***	0.0408***	0..0446***	0.0417***
	(0.000903)	(0.000893)	(0.000798)	(0.000793)
2017	0.103***	0.102***	0.1079***	0.103***
	(0.000876)	(0.000866)	(0.000776)	(0.000773)
2018	0.173***	0.171***	0.177***	0.172***
	(0.000884)	(0.000874)	(0.000791)	(0.000788)
2019	0.228***	0.225***	0.236***	0.228***
	(0.000875)	(0.000866)	(0.000793)	(0.000792)
2020	0.290***	0.286***	0.297***	0.288***
	(0.000861)	(0.000852)	(0.000783)	(0.000786)
2021	0.397***	0.392***	0. 406***	0.395***
	(0.000867)	(0.000858)	(0.000794)	(0.000798)
2022	0.502***	0.495***	0.510***	0.497***
	(0.000948)	(0.000939)	(0.000894)	(0.000900)
Reference	*Not urbanized*	*Not urbanized*	*Not urbanized*	*Not urbanized*
Extremely urbanized	-0.0107***	-0.0103***	-0.00477**	-0.00491**
	(0.00253)	(0.00250)	(0.00242)	(0.00240)
Strongly urbanized	-0.00952***	-0.00929***	-0.00641***	-0.00686***
	(0.00211)	(0.00209)	(0.00204)	(0.00202)
Moderately urbanized	-0.0207***	-0.0204***	-0.0204***	-0.0200***
	(0.00223)	(0.00221)	(0.00215)	(0.00213)
Hardly urbanized	-0.00570***	-0.00719***	-0.00515**	-0.00587***
	(0.00218)	(0.00216)	(0.00210)	(0.00208)
Log square metres	0.684***	0.671***	0.683***	0.674***
	(0.000812)	(0.000808)	(0.000768)	(0.000765)
Zipcode	Yes	Yes	Yes	Yes
Constant	9.039***	9.079***	9.037***	9.075***
	(0.00417)	(0.00414)	(0.00394)	(0.00392)
Observations	1,261,186	1,261,186	1,514,031	1,514,031
R-squared	0.757	0.763	0.747	0.751

Note: Dependent variable is log of transaction price. Standard errors in parentheses with *** , **, * indicating significant at 1%, 5% and 10%, respectively.

TABLE A2: DESCRIPTIVE STATISTICS STARTERS INDICATION / GREENNESS

Variable	N	Median/%	Mean	Std	Min	Max
House transaction price						
Total price (€)	1,262,345		301357	146986.8	90000	985037
Price per sqm (€/m²)	1,262,345		2571.656	1173.121	305.2805	20543.48
Period of construction%						
1900-1920	71,214	5.64				
1921-1940	147,205	11.66				
1941-1960	127,479	10.10				
1961-1980	367,002	29.07				
1981-2000	334,652	26.51				
2001>	214,793	17.02				
Building type (%)						
Apartment	315,560	25.00				
Corner House	181,866	14.41				
Semi-detached House	140,461	11.13				
Terraced House	464,697	36.81				
Detached House	159,761	12.66				
EPC Label (%)						
A	246,859	19.56				
B	198,086	15.69				
C	356,384	28.23				
D	172,480	13.66				
E	123,387	9.77				
F	88,183	6.99				
G	76,966	6.10				
Greenness						
Green	443,681	35,25				
Non-green	812,385	64,75				
Year of Transaction	1,262,281					
2015	104,056	8.24				
2016	147,786	11.71				
2017	173,488	13,74				
2018	165,529	13.11				
2019	174,870	13.85				
2020	191,376	15.16				
2021	184,970	14.64				
2022	120,270	9.53				
Hierarchical location						
Zip Code	1,262,345		4703.973	2452.812	1011	9999
Municipality Code	1,262,281		743.5894	600.8588	14	1991
Urbanization Level	1,261,256					
Extremely urbanized	246,490	19.54				
Strongly urbanized	286,515	22.72				
Moderately urbanized	156,655	12.42				
Hardly urbanized	184,071	14.59				
Not urbanized	387,525	30.73				
Other Housing Attributes						
Size of the property	1,262,345		122.101	43.86404	44	309
Buyer Type	1,256,066					
Starter	454,211	36,16				
Non-Starter	801,855	63,83				
Number of observations	1,262,345					

TABLE A3: CORRELATION MATRIX: ALL REGRESSION VARIABLES

	Starter	Greenness	Dwelling Size	Transaction Year	EPC	Zipcode	Urbanization Level	Construction Year	Building Type
Starter	**1**								
Greenness	**-0.0901**	**1**							
Dwelling Size	**-0.2542**	**0.1746**	**1**						
Transaction Year	**0.0012**	**0.0343**	**-0.0006**	**1**					
EPC	**0.0588**	**-0.7620**	**-0.1528**	**-0.0416**	**1**				
Zipcode	**-0.0453**	**-0.0052**	**0.2302**	**0.0203**	**0.0079**	**1**			
Urbanization Level	**-0.0704**	**-0.0038**	**0.2266**	**0.0106**	**0.0023**	**0.2784**	**1**		
Construction Year	**-0.0716**	**0.6290**	**0.1464**	**-0.0175**	**-0.7585**	**0.0293**	**0.0460**	**1**	
Building Type	**-0.0757**	**0.0355**	**0.4935**	**0.0096**	**-0.0328**	**0.2094**	**0.2215**	**0.0155**	**1**