



EeMAP

Energy efficient
Mortgages
Action Plan



CREATING AN ENERGY EFFICIENT MORTGAGE FOR EUROPE

Review of the impact of energy efficiency on probability of default



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TABLE OF CONTENTS

EXECUTIVE SUMMARY	4
1. Introduction	5
2. Effects of energy efficiency on probability of default	6
3. Effects of energy efficiency on buildings' cash flows and valuations	7
4. Do financial markets capitalize default risk?	8
5. Takeaways from the review	9
5.1 Costs and barriers	9
5.2 Recommendations relevant in the following WPs	9
6. Conclusion	10
7. Bibliography	10

EXECUTIVE SUMMARY

Buildings account for 40% of EU energy use, and it is estimated that the EU needs to invest around €100 billion annually in building renovations to meet its energy and climate goals. The EU has increased the amount of public funds available for energy efficiency, but the European Commission has indicated that there is a need to boost private energy investments – the EeMAP (Energy efficient Mortgages Action Plan) Initiative is intended to deliver a concrete, market-led finance solution to help bridge the gap.

Mortgage lenders have a clear interest in the state of the EU building stock. Mortgage loans are estimated to account for around a third of the total assets of the European banking sector. Investments in building performance improvements can help to free-up disposable income for borrowers through lower utility bills and can enhance property value. As a result, they can reduce credit risk, so they are a win-win for lenders, investors, consumers and climate.

Our Vision: *The EeMAP Initiative (www.energyefficientmortgages.eu) aims to create a European energy efficiency mortgage (EEM), to incentivise borrowers to improve the energy efficiency of their buildings or acquire highly energy-efficient properties. The incentives the EEM will offer borrowers (e.g. reduced interest rates and/or increased loan amount) aim to reflect the reduced credit risk of these loans.*

How does buildings' energy efficiency impact mortgage default risk? The answer to this question has the potential to unfold benefits to borrowers, lenders and investors alike. Thus, the objective of this document is to provide a glimpse into past works on this topic and to outline a guideline for best practice regarding future analyses.

In theory, mortgages on energy efficient houses should have lower risks relative to less efficient houses. The argument for this reasoning is that borrowers' savings from energy usage will result in more income available in case of emergencies or unexpected events. However, despite worldwide and decade-long efforts to implement (i) the energy efficiency regulation, (ii) the appropriate building technology and (iii) the efficiency measurement schemes, only little research has been conducted on the topic at hand. In order to gain some insights into this issue, this document explores the topic from three perspectives. First, it reviews the direct effect of energy efficiency on default risk. Second, it considers the potential indirect impact of energy efficiency on default risk via the cash flow channel, i.e., the association of energy efficiency with higher building rents and sale prices. And third, it reviews if investors demand lower risk premia for bonds with sustainability features.

To date, only three studies have attempted to measure the direct impact of energy efficiency on mortgage default risk. All three studies were conducted using housing data in the United States. Only one study employed residential mortgage data while the other two investigated commercial buildings. The outcomes are encouraging. All studies find evidence of a significant

reduction in default risk associated with energy efficiency. This effect is larger for more efficient homes. Thus, not only the energy efficiency label alone but also the degree of efficiency plays a substantial role. However, it is necessary to bear in mind that endogeneity issues could not be fully ruled out in these studies.

Key Message 1: *Studies find evidence of a significant reduction in default risk associated with energy efficiency. This effect is larger for houses that are more efficient.*

Default risk rises if declining cash flow prevents loan repayment or if decreasing property value produces negative net equity. In both cases, the attractiveness of the building—to prospective tenants as well as to potential buyers—plays a role. Thus, the impact of energy efficiency on a building's rent and valuation has the potential to reveal its effect on default risk via the cash flow channel. In fact, studies around the globe confirm that an energy efficiency label, as well as the degree of energy efficiency, is associated with a positive rent and price premium of residential and commercial buildings, thus, potentially contributing to lower cash flow risk.

In financial markets, lower default risk of debt is likely to translate into a lower risk premium required by investors, which in turn can potentially result in lower cost of debt for borrowers. Two recent studies document that in the bond market both energy efficiency and greenness factors in a broader sense are associated with higher prices and therefore lower risk premia. These results indicate that market participants favourably take into account sustainability features of bonds when assessing their risk of default.

Key Message 2: *Prospective homebuyers and debt investors, both perceive favourably energy efficiency labelling. This translates into higher building valuations and lower bond yields, respectively.*

The literature review in this document provides two important takeaways for future studies. First, researchers encountered in the past various obstacles during their data collection procedure. These hindrances should be addressed by data collectors and providers alike. Second, a correct model should be chosen cautiously as omission of important variables, such as building location or borrower income, could lead to biased results.

Key Message 3: *Reliable results on the effect of energy efficiency on default risk in Europe have yet to be produced. The key challenge consists in obtaining and aggregating the corresponding data. The EeMAP pilot phase is thus a crucial initiative.*

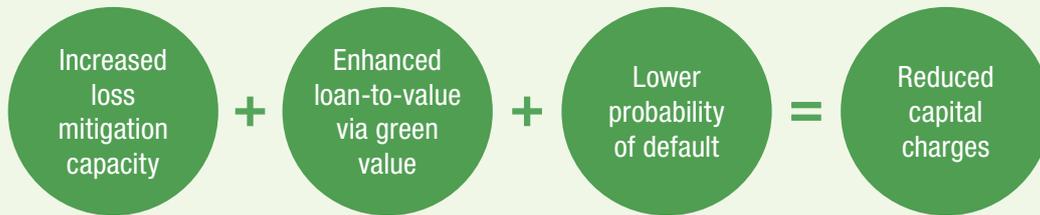
1. INTRODUCTION



EeMAP Energy efficient Mortgages Action Plan

The EU Horizon 2020 funded EeMAP Initiative aims to create a standardised energy efficient mortgage (EEM), that will incentivise building owners to improve the energy efficiency of their buildings or acquire an already energy efficient property by way of preferential financing conditions (reduced interest rates and/or increased loan amount) linked to the mortgage.

At the heart of the initiative is the objective to demonstrate that energy efficiency has a risk mitigation effect for banks.



Lower risks deliver a strong incentive for lenders and investors to enter the market and play a central role in driving climate action across Europe's building sector.

This report is one of a series of four produced by the EeMAP Initiative, which respectively review the state of play in relation to energy efficiency, valuation, finance and probability of default in the context of the EU's building stock. The reports are aimed at banks and other financial institutions interested in understanding how an EEM could be

established from the different perspectives of finance (both origination & funding), valuation and energy efficiency measurement.

Both new build and existing residential and non-residential buildings are within the scope of the work EeMAP is doing to establish an EEM, but the Initiative's central focus is how we create the biggest impact on Europe's climate goals by driving renovation across the residential building stock.

See: <http://energyefficientmortgages.eu/>

Over the last three decades, the building sector has witnessed a rapid growth in the implementation of energy efficient building technologies. In order to make such improvements comparable across buildings, energy efficiency components of a building have to be measured, evaluated and aggregated to an easily interpretable indicator, i.e., a rating. Currently, the landscape of rating schemes is quite diverse. For instance, in the United States, various energy efficiency certifications co-exist and compete with one another. In Europe, on the other hand, the information inherent in the energy performance certificate (EPC) varies across countries. And to add to the general diversity, in Germany, for instance, two definitions—an energy-consumption and an energy-demand perspective—co-exist under the same EPC label (see Weiss, Dunkelberg, and Vogelpohl, 2012). This provides a challenging research environment for the question at hand: how does buildings' energy efficiency impact mortgage default risk? The answer to this question has the potential to unlock benefits for borrowers, lenders and investors alike. Thus, this document aims to provide the reader with a glimpse into the past works conducted on this topic of interest, highlight the fact that most of the studies are US-based (and the need to cover this gap by providing more European-based studies) and to outline a guideline for best practice regarding future analyses.

The history of energy efficiency labels goes back to the early and mid-1980s when Alaska and California took the first steps to improve efficiency and affordability of housing in the United States (see Farhar, Collins, and Walsh, 1997). About a decade later, in 1995, the non-profit organisation Residential Energy Services Network (RESNET) took the initiative to develop the Home Energy Rating System (HERS)¹ and the governmental Environmental Protection Agency (EPA) introduced the ENERGY STAR certification program² for newly constructed single-family homes. During the same time, the government-owned National Renewable Energy Laboratory (NREL) initiated a pilot program that was intended to introduce a new financial product, the 'energy-efficient mortgage', and to link this product to a building's energy efficiency rating. Once the mortgages were distributed, the task was to evaluate the program. The evaluation phase intended, among other goals, also to analyse to what extent a link between buildings' energy efficiency and the mortgage probability of default exists (see Farhar, Collins, and Walsh, 1997; Farhar, 2000). The results from this analysis would have been the first of their kind. However, the study was either not conducted or not published, and the reasons for this remain unknown. Similarly, none of the published energy efficiency reports could provide a thorough analysis in the years thereafter. Data availability issues were reported as the main reason for this research gap (see, e.g., Hammon, 2005).

1 — A HERS index was introduced in 2006. It is normalized to the climatic zone, size, and type of the house. A HERS value of 100 corresponds to the current home built market standard. Most house scores fall between 0 to 150. The lower the number, the better, i.e., a net-zero-energy house scores a 0.

2 — An ENERGY STAR-rated house achieves typically a HERS rating of 85 or lower.

In Europe, Denmark and the UK were among the first countries to perform energy efficiency assessments of buildings in the 1970s and 1980s, respectively. In the early and mid-1990s, various European countries introduced mandatory energy efficiency requirements which were accompanied by the development and implementation of appropriate rating schemes. To name a few, in the UK, BREEAM and NHER were both introduced in 1990. In Ireland, ERBM was created in 1992 while in the Netherlands the energy performance of buildings was measured since the mid-90s. In 2002, the EPC was introduced as a requirement for European Union Member States by the Energy Performance of Buildings Directive. As a result, all Member States and some other European countries have established national building rating policies during the past two decades. Despite these initiatives, however, the usage of European energy rating information for research into the financial performance of property is rather rare. For this reason, the present document aims at summarising existing research findings and pointing out potential pitfalls with regard to previous analyses and data availability.

The rest of the document is organised as follows. Section 2 provides a review of extant studies that attempt to capture the direct effect of energy efficiency on mortgage default risk. Section 3 presents findings on the effect of energy efficiency on buildings' cash flows and valuations. Section 4 inspects if and to what extent the financial markets account for energy efficiency. Section 5 summarises the challenges faced by previous studies and proposes an outline for future analyses. Section 6 concludes.

2. EFFECTS OF ENERGY EFFICIENCY ON PROBABILITY OF DEFAULT

In the traditional loan origination business, the risk of applicants' default on consumer loans is generally assessed by employment of credit scores.

These scores represent the output of a statistical method that maps an applicant's characteristics to the probability he or she will default on the loan. The lender uses the forecast of an applicant's likelihood of default to determine the volume of credit granted and the interest rate charged. Typically, the input variables of a statistical model comprise behavioural, financial, and demographic information. These are usually supplemented by loan-specific characteristics, such as the loan-to-value ratio in the case of mortgage loans. The credit scoring methods are subject to ongoing refinements either through the introduction of new statistical and mathematical models or they are augmented by new variables or attributes. An important question for both the practitioners and academics alike is whether or not the inclusion of the mortgage-specific attribute termed 'energy efficient' or 'green' into the lender's scoring model provides any additional value. The theoretical argument is that mortgages on energy efficient houses should have lower risks relative to standard houses. The argument for this reasoning is that borrowers' savings from energy usage will result in more income available in case of emergencies or unexpected events. For instance, Burt, Goldstein, and Leeds (2010) argue that house ratings can predict accurately the annual energy costs which should translate into lower default risk. However, actual research on this topic is limited due to data availability issues. Only few studies have been conducted on this topic to date and all of them rely exclusively on residential and commercial mortgage data from the United States.

One of the most recent studies on the relationship between energy efficiency and the probability of default of residential mortgage loans was conducted by Kaza, Quercia, and Tian (2014). In their analysis, the authors employ information on about 71,000 loans for single-family, owner-occupied houses. The loans were originated between the years 2002 and 2010 in the United States and were used for purchase only. In the sample, all loans are accompanied by a HERS index score and about 35 percent of the houses are



ENERGY STAR-certified. The authors employ a hazard analysis and find that ENERGY STAR-rated houses are associated with a substantial and significant reduction of default and prepayment risk. *Ceteris paribus*, the results suggest that the probability of default of an ENERGY STAR-rated dwelling decreases by roughly 20 percent compared to a similar but non-rated house. In an additional analysis, the authors consider ENERGY STAR-certified homes only and examine the relative impact of energy efficiency on mortgage risk by utilising the HERS index information. The findings suggest that the degree of energy efficiency plays a substantial role: a marginal decrease in the HERS index implies a significant reduction in the likelihood of loan default. These findings suggest that even among ENERGY STAR-rated buildings differences prevail with mortgages on most energy efficient homes being the least likely to default. However, this evidence should be viewed with a certain amount of caution since the model may suffer from endogeneity issues. For instance, mortgage borrowers residing in energy-efficient dwellings may be financially better-off than those with less efficient properties. Furthermore, the authors did not employ a fully representative sample as important states, such as California, were excluded due to lack of data.

On another note, An and Pivo (2015) perform an analysis of the relationship between energy efficient buildings which hold an ENERGY STAR label, and the corresponding commercial mortgage default risk. The underlying loan sample is comprised of about 23,000 commercial mortgages that were originated between the years 2000 and 2012 in 17 Metropolitan Statistical Areas in the United States. The authors employ a standard Cox proportional hazard model and provide evidence that traditional default predictors do not fully reflect the financial benefits of energy efficiency. The findings suggest that ENERGY STAR-labelled commercial buildings are 20 percent less likely to default than their non-labelled counterparts. However, one should be cautious to generalise these findings since only a small fraction – 3.3 percent – of all loans in the sample is ENERGY STAR-rated.

A more recent commercial mortgage study was conducted by Wallace et al. (2017). Using a relatively small number of securitised commercial mortgages (around 1,900 in total), the authors evaluate the impact of buildings' actual energy efficiency on borrowers' default performance. The sample of loans covers the years 2000 to 2016 from six cities in the United States. Energy efficiency is measured by three different metrics: (i) site energy use intensity, (ii) source energy use intensity, and (iii) the ENERGY STAR score. The first two measures are approximated by (i) the total annual building energy consumption and (ii) the total amount of raw fuel that is required to operate a building per square foot. By controlling for loan underwriting characteristics, macroeconomic variables and the energy price gap, which is defined as the difference between forecasted and actual energy costs over the mortgage holding period, the authors document that energy efficiency, as measured by all three metrics, significantly mitigates default risk. They conclude that energy efficiency of buildings should be included in lenders' risk evaluation models at new mortgage originations.

Besides pure energy efficiency characteristics, studies have shown that buildings with higher sustainability scores are also less prone to default risk. By analysing relatively large datasets on residential and multi-family homes, Rauterkus, Thrall, and Hangen (2010) and Pivo (2013) observe that

sustainability features, such as buildings' location, transportation facilities (e.g., closeness to freeways, subways, work) or housing affordability, also play a significant role in borrowers' ability to repay their debt.

To summarize, the current literature on the direct relationship between energy efficiency and default risk is sparse and it focuses exclusively on the U.S. housing market. Moreover, only the study of Kaza, Quercia, and Tian (2014) employs residential mortgage data to investigate the impact of energy efficiency. The presented results are supportive of a significant and inverse relation between energy efficiency and mortgage default risk. However, each study suffers from data availability issues and further research on this topic, on (i) residential mortgages and (ii) European data, is highly encouraged.

3. EFFECTS OF ENERGY EFFICIENCY ON BUILDINGS' CASH FLOWS AND VALUATIONS

From a lender's perspective, default risk rises if declining cash flow prevents loan repayment or if decreasing property value produces negative net equity. In both cases, the attractiveness of the building – to prospective tenants as well as to potential buyers – plays a role. This aspect has been investigated in relation to energy efficiency and other sustainability features in various countries. The studies focus mainly on highlighting the differences between energy-efficient and non-energy-efficient buildings' cash flows and valuations. However, they do not explicitly investigate any effects on default risk. Thus, the relation between energy efficiency and default risk can only be inferred from these studies by deductive reasoning: if energy efficiency has a positive effect on cash flow risk, then, *ceteris paribus*, it will reduce default risk.

In the United States, various studies have been conducted at the state level over last decade. In Fort Collins, Colorado, Bloom, Nobe, and Nobe (2011) employ a balanced sample of 300 single-family homes that were sold between 1999 and 2005. Their findings suggest that the original sale price of an ENERGY STAR-rated home is higher than the price of a comparable non-ENERGY STAR-rated home. On average, ENERGY STAR-certified homes are valued USD8.66 higher per square foot than non-certified homes. Similarly, Kahn and Kok (2014) investigate single-family home sale transactions in California over the time period 2007 through 2012. Using a sample of over 1.1 million homes of which only 4,300 hold an energy efficiency certification, the authors find evidence that homes with a LEED³, GreenPoint⁴ or ENERGY STAR certification sell at a premium of 2.1%. In the commercial building universe, Eichholtz, Kok, and Quigley (2010) document that an otherwise identical commercial building with an Energy Star certification has a 3% higher rental rate per square foot while the selling price may be up to 16% higher.⁵

In Asia, Zhang, Liu and Wu (2016) document a positive relation between the Chinese Green Building Label⁶, which was introduced in 2008, and the sale price in the residential housing market. The relatively small sample of roughly 750 residential buildings yields an estimated average price premium of 6.9% among energy efficient homes compared to their non-labelled coun-

3 — Originally introduced in 2000, Leadership in Energy and Environmental Design (LEED) is a score-based certification program developed and subsequently refined by the U.S. Green Building Council. LEED assigns green buildings into four categories: Certified, Silver, Gold and Platinum.

4 — GreenPoint Rated is a green home certification program in California. It was introduced by a non-profit organization in 2006 at is closely aligned to California's energy code and green building requirements.

5 — Further evidence in the commercial building universe was provided by Fuerst and McAllister (2011), Eichholtz, Kok, and Yonder (2012) and Szumilo and Fuerst (2017). All three studies document a positive effect of energy efficiency on the rental and the sale price premium of buildings.

6 — The Chinese Green Building Label is the first informative national standard for green buildings introduced by the Chinese central government in 2008.

terparts. In Singapore, Deng and Wu (2014) document an energy efficiency price premium of 4.7% in the residential resale sector. In Japan, Yoshida and Sugiura (2015), observe a price premium for energy efficient residential buildings in Tokyo only two years after construction. However, Yoshida, Onishi, and Shimizu (2016) point out that Japanese office rent premiums are not directly associated with energy efficiency labels but they are rather affected by the actual reduction of the consumption of electricity and water.

In Europe, a growing number of econometric studies show that energy efficient buildings generate more cash flow and value in various countries. Brounen and Kok (2011) were the first to document that in Netherlands consumers capitalise the EPC information into the price of their prospective homes. By employing a large-scale dataset of around 177,000 housing transactions in 2008 and 2009, the authors find that houses receiving an A grade in terms of energy efficiency sell for a 10% price premium. Additionally, more energy efficient dwellings are listed in the sale market for a significantly shorter period of time than less efficient homes. These results are supported by the study of Chegut, Eichholtz, and Holtermans (2016) who analyze roughly 18,000 Dutch residential house transactions in the period between 2008 and 2013. They observe an energy efficiency price mark-up of 2.0 to 6.3 percent above the sale price of otherwise similar houses. In Sweden, Högberg (2013) investigates around 1000 single-family home transactions that took place in 2009 in Stockholm. Again, the results indicate that home buyers do take into account information available on energy efficiency and pay a price premium on more efficient dwellings. Similarly, Davis et al. (2014) find that energy efficiency is capitalised in the prices of private dwellings in Belfast, Northern Ireland. In Spain, de Ayala, Galarraga, and Spadaro (2016) observe a price-premium between 5.4% and 9.8% for energy efficient buildings. In the UK, Fuerst et al. (2015) investigate over 330,000 residential property sales that took place between 1995 and 2012. Once again, there is evidence of a positive relationship between energy rating and dwelling price. Additionally, the most recent LENDERS (2017) report suggests that monthly savings from fuel bills in more efficient homes can translate in GBP4,000 in additional mortgage financing. In other words, if a borrower of an energy efficient home decides not exhaust the full mortgage funds available to her, she will have more disposable income that she could use for repaying her debt and thus lowering her default risk. However, the European Commission (2017) report points out that this line of reasoning must not hold as a general rule. The reason for this is the so-called rebound effect. The rebound effect takes place when borrowers use their additional income to either consume more energy or spend it on other energy-intensive consumption goods.

Finally, Ankamah-Yeboah and Rehdanz (2014) conduct a meta-analysis of 30 published and unpublished studies relating to building energy efficiency certification from around the globe. They observe that energy efficiency is valued more in the sales market than in the rental market. The average global price premium is about 7.6 percent, weighted by each study's contribution. The effect is larger for non-residential buildings as opposed to residential. Furthermore, at the regional level Europe has the highest price premiums followed by the United States.

Extant studies provide empirical evidence that homebuyers worldwide recognize the contributory value of increased energy efficiency. They seem to require a larger discount for less energy efficient dwellings while capitalizing energy certifications into property value. These results indicate that energy efficient buildings might have a lower probability of default from a cash flow and property value perspective.

4. DO FINANCIAL MARKETS CAPITALIZE DEFAULT RISK?

In financial markets, lower default risk of debt is likely to translate into a lower risk premium required by investors, which in turn can potentially result in lower cost of debt for borrowers. Lenders can utilise the cheap refinancing opportunity by securitising their mortgage portfolios via corresponding financial products, such as mortgage-backed securities, green bonds or corporate bonds issued by REITs⁷. In particular, the latter two products are typically traded in the secondary market with observable market prices. Two recent studies employed this trading information in order to estimate the effect of energy efficiency on market risk premia.

Eichholtz et al. (2015) investigate the relationship between energy efficiency of commercial buildings and the associated risk premia required by the markets. For this purpose, the authors combine price data on corporate bonds issued by U.S. REITS with information on the underlying commercial building mortgages. The sample covers the period from 2006 to 2014 and includes about 3,300 mortgages from 143 REITs. In their analysis, the authors first assess the fraction of a REIT portfolio with either LEED and ENERGY STAR-certified buildings. They then investigate if a larger share of energy efficient buildings has an impact on bond spreads. The empirical findings provide evidence that a one-standard deviation increase in the LEED share in the portfolio leads to a significant decrease of bond spreads by 9 basis points. By accounting for different certification categories, the results further suggest that the extent of certification also plays a role. The spread discounts for Platinum-labelled LEED buildings are significantly larger than for Certified-labelled buildings.⁸ Additionally, in one of their previous studies, the authors find that REITs with a higher fraction of certified properties exhibit significantly lower systematic risk, as measured in terms of market betas (refer to Eichholtz, Kok, and Yonder, 2012).

In a recent study, Zerbib (2016) focuses on the worldwide issuance of green bonds. The green bond market is a relatively young financial instrument. The European Investment Bank issued the first green bond in 2007 and the definition of 'green' is very broad. A green bond can be collateralized by energy efficient mortgages but is not limited to this category. Environmentally sustainable and socially responsible projects also fall in the 'greenness' category. Despite this obvious imprecision for the purpose of this document, the analysis of Zerbib (2016) is the first of its kind and it provides guidance for future research. The author investigates the presence of a green bond factor and using a matching method, the author identifies the green bond premium as the difference in yields between a green bond and an equivalent synthetic conventional bond. The green premium is found to be negative, with the bond green rating being its main driver, i.e. the greener the bond is, the greater the negative premium will be.

Unfortunately, again both these studies focus largely on US empirical evidence. In fact, even Zerbib (2016) is characterized implicitly by this bias given that, on the worldwide level US is the country with the largest issuance of green bonds.

The above studies indicate that the debt market indeed capitalises any information that is associated with energy efficiency and greenness labelling. This observation is consistent with the large-scale meta-analysis of Friede, Busch, and Bassen (2015). In their study, the authors analyse more than 2000 empirical studies published since 1970 and show that environmental, social, and governance criteria have in roughly 90% of cases a non-negative relation on corporate financial performance. In fact, when differentiating

7 — A real estate investment trust (REIT) is a company whose sole activity is the management of a real estate portfolio.



between various asset classes, the findings are in particular supportive in the case of bonds and real estate.

5. TAKEAWAYS FROM THE REVIEW

5.1 COSTS AND BARRIERS

The review of extant literature reveals the challenges academics are facing all over the globe when studying the housing market. Despite the relatively large size of the housing sector, data availability issues are the core problem.

The authors list the following obstacles that they faced during data collection:

- Data sets lack information on specific physical building features that contribute to the level of energy efficiency
- Data sets are incomplete due to servicers' unwillingness to force borrowers to provide regular updates with regard to building characteristics
- It is close to impossible to obtain large datasets with standardised energy efficiency metrics that can be compared across building types and geographic regions.
- Privacy concerns lead to challenges in merging data sets, such as mortgage, borrower and building characteristics, thus, limiting the utilisation of information with regard to house location, borrower's income and employment status.

Due to the listed limitations, the majority of the studies cannot rule out endogeneity issues. Future studies will have to overcome these issues if they want to identify a clear causal link between energy efficiency and the likelihood of default.

5.2 RECOMMENDATIONS RELEVANT IN THE FOLLOWING WPS

To the best knowledge of the authors of this document, a European study investigating the effect of energy efficiency on the probability of mortgage default has not yet been conducted. The reasons for this research gap are numerous

and include but are not limited to those mentioned in section 3.1. Yet, given the rapid growth of interest in the topic at hand, it is likely that larger mortgage data sets that include borrower characteristics, which are supplemented by standardised energy efficiency attributes, will be compiled and made available for research purposes in the near future. Thus, the following takeaways from the literature review shall provide useful insights to researchers in this field.

Building on previous methodologies and experiences, a logistic regression or a hazard model can take the role of a baseline model in the analysis of default risk. A simple logistic model can take the following form:

$$\log \frac{\Pr(\text{default})}{1 - \Pr(\text{default})} = a + b_1 EE + b_2 \text{CONTROLS} + \varepsilon,$$

where the dependent variable, *default*, is a binary variable that is either equal to one in case of mortgage default and zero otherwise.

EE is a variable measuring energy efficiency. It can be defined in two ways:

- (i) *EE* is a binary variable that is equal to one if a building is energy efficiency-certified and zero otherwise, or
- (ii) *EE* is continuous numeric or ordinal variable that indicates the degree of a building's energy efficiency.

The definition of *EE* under (i) measures if energy efficiency labelling has any significant impact on default risk while (ii) intends to identify if the degree of energy efficiency plays substantial a role. *CONTROLS* can include but are not limited to building, borrower, and mortgage characteristics as well as macroeconomic variables:

- (i) Building: age, type, fuel type, location, occupancy rate, size
- (ii) Borrower: annual income, credit score, employment status, years at current residence, household size
- (iii) Mortgage: interest rate, loan type, maturity term, original loan balance, original loan-to-value ratio, prepayment restrictions, refinance incentive
- (iv) Macroeconomic variables: local unemployment rate, neighbourhood income

Most of the control variables are rather standard in the literature. The studies presented in section 2.1 discuss them in detail. However, the inclusion of the building location variable and its potential derivatives deserves special attention (see Burt, Goldstein, and Leeds, 2010). Building location and the associated transportation information play a significant role in borrowers' ability to repay their debt (see Rauterkus, Thrall, and Hangen, 2010; Pivo, 2013). As a simple example, high transportation costs due to a building's remote location might offset the cash flow generated from energy-efficient operation. Thus, energy efficiency could be falsely attributed to default risk by the model if a building's location efficiency information is omitted.

To summarise, the relationship between default risk and energy efficiency might be incorrectly identified if only traditional explanatory variables are employed in the analysis. Future researchers are advised to select carefully the explanatory variables in their analysis. In particular, buildings' location information might play a crucial role.

6. CONCLUSION

This review of existing literature finds support for the hypothesis that mortgages on energy efficient buildings are less risky than otherwise similar but less efficient properties. Additionally, there is evidence that more efficient buildings might have higher marginal rents and sell at higher prices, thus, contributing to lower cash flow risk. Also capital markets attribute lower yields to green and energy efficient financial products which might translate into more favourable default risk assessment by market participants and cheaper financing costs of debt.

The above findings, however, should be viewed with a certain degree of caution. The topic at hand is still under-researched and existing studies acknowledge endogeneity concerns.

In this respect, data availability is the key challenge to be addressed. The collection of larger data sets that are accompanied with standardized energy efficiency metrics across building types and geographic regions is of imperative importance and should be mobilised with the united effort of building rating associations, mortgage underwriters and the corresponding governmental agencies. The EeMAP Initiative takes the first steps in this direction by proactively bringing together a group of major mortgage lenders, energy utilities, valuers and organisations from the building industry and fostering a discussion with regard to the private financing of energy efficient dwellings. In particular, the forthcoming EeMAP Pilot phase is designed bridge the systemic lack of data highlighted in this and the other Reports. The pilot phase will group together key European lenders using common energy efficiency best practices – to be defined during the coming months under EeMAP - in their lending activities, and develop a comprehensive dataset allowing a deeper analysis of the impact of energy efficiency on credit risk and probability of default.

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EeMAP CONSORTIUM MEMBERS



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