Discussion Paper

The "Insurance Effect": How to increase the Investment Amount in Green Buildings – A Model-Based Approach to reduce the Energy Efficiency Gap

by

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THE "INSURANCE EFFECT": HOW TO INCREASE THE INVESTMENT AMOUNT IN GREEN BUILDINGS –A MODEL-BASED APPROACH TO REDUCE THE ENERGY EFFICIENCY GAP

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Abstract

Real estate is an industry sector with high potential to increase energy efficiency. However, many of the existing green building investment opportunities (GBIO) are not utilized because economic valuation tools are complex and oftentimes difficult to understand. For this reason, we develop a formal, but comprehensible bottom-up model to determine the optimal investment amount from an economic perspective, placing particular emphasis on the descriptive valuation of risk, and point out the applicability of GBIO as insurance against energy price volatility. We also give examples of the model's potential application. Our work shows that considering the insurance effect will increase the optimal investment amount and that certain investment amounts lead to both economic and ecological benefits in properties and property portfolios. Our findings can be used for a comprehensible enhancement of existing valuation methods and tools to reduce the energy efficiency gap (EEG). They constitute a quantitative basis for the adaption of laws to counteract the current underinvestment in the real estate sector.

Key words: energy efficiency gap, energy price risk, green building, investment valuation

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1. Introduction

To protect against the consequences associated with global warming, European Union – similar to other economic regions – aims to significantly reduce the current energy consumption. This goal is related to a reduction of greenhouse gas emissions by at least 20% until 2020 and by at least 80% until 2050 compared to 1990 levels (European Union, 2011). To achieve this, a variety of measures to increase energy efficiency is required. From a scientific perspective – and based on Hirst and Brown (1990) – a large number of publications refers to energy efficiency (Gillingham et al., 2009; Patterson, 1996) and especially the energy efficiency gap (e.g. Allcott and Greenstone (2012); Jaffe and Stavins (1994); Koopmans and te Velde (2001)). The development and application of measures to increase energy efficiency is emphasized both from an economic perspective as well as for reasons of climate change. Furthermore, the existence of an energy efficiency gap (EEG) – defined as "the difference between the amount of energy that households and business currently consume and the amount they 'should' consume, relatively to (…) the optimal level" (Klemick and Wolverton, 2013) – is unanimously confirmed. This gap (resulting in the energy paradox) is attributable to the existence of various barriers, which – based on classifications schemes of Gillingham et al. (2009) and Levine et al. (1994) – can be categorized as follows:

Existing *price distortions*: The majority of environmental and (long-term) social costs – summarized as "external costs" – are not included in the observable market price of energy. Furthermore,

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also state intervention (e.g. taxes and subsidies) influence the market price of energy. These distortions complicate conclusions about the ‘real’ height of the EEG, which is also dependent on energy prices (Levine et al., 1994).

Information problems: A variety of information problems also influences the EEG. In addition to the lack of information (e.g. on current energy consumption patterns and ways to reduce this consumption) (Levine, 1994), the *principle-agent problem* is particularly important: In the context of investments in green buildings this problem occurs, if one party (the landlord) chooses the level of investments in energy efficiency measures, but the energy bills are paid by the other party (the tenant) (Brown, 2001; Jaffe et al., 2005). In general, information problems lead to an underinvestment in energy efficiency (Gillingham et al., 2009; Jaffe and Stavins, 1994).

Transaction costs: In our context, transaction costs can be defined as costs of gathering, assessing and applying information on the characteristics and performance, making decisions as well as enforcing contracts relating to the purchase and installation of technologies, which reduce the energy demand of a building (Hein and Blok, 1995; Levine et al., 1994). The existence of transactions costs (which increase the total cost of energy efficiency measures) results in lower – and/or later – investments in energy efficiency measures than it would be assumed from a purely neo-classical perspective (Golove and Eto, 1996).

Capital market imperfections: Especially in capital intensive industries like the real estate business, liquidity constraints complicate the quantification of the ‘real’ EEG. Limited access to financing for energy-efficient investments is resulting in underinvestment and therefore in an increasing EEG (Gillingham et al., 2009).

In current literature, the existence of these barriers (and the difficulties resulting from their quantification) (Golove and Eto, 1996; Hein and Blok, 1995) lead to disagreements over the actual extent of the EEG. One of the main reasons for this it that different scales are used: To demonstrate the problems related to the quantification of the EEG, Jaffe and Stavins distinguish (already in 1994) between the “economist’s economic potential”, the “technologist’s economical potential” (which, in comparison, is higher than the first scale), the even higher “hypothetical potential” and the “narrow social optimum” and the “true social optimum”. To illustrate these differences, we refer to Cullen and Allwood (2010), who argue that – from a purely technical perspective – the global demand for energy could be reduce by almost 90%, if energy conservation devices were entirely employed. In contrast, other authors like Allcott and Greenstone argue that „the actual magnitude of the EEG is small relative to the assessment from engineering analyses“ (2012). No matter how big the EEG actually is – it plays an important role in scientific discussions on real estates (Jakob, 2006; Myers, 2014; Shove, 1999; Wilson and Dowlatabadi, 2007). The real estate sector is one of the largest consumers of energy and is responsible for approximately 40% of global energy use (Pinkse and Dommisse, 2009) and 40% of all carbon emissions (Apgar, 2009). Energy consumption of properties is responsible for more than 30% of global final energy demand and one-third of energy-related CO_2 emissions and is feared to increase by further 33% until 2050 (compared to 2005) in a sub-optimal scenario (Global Energy Assessment, 2012). A study by the McKinsey Global Institute (2007) revealed that the largest potential for reducing energy demand and the negative effects on the environment (commonly quantified in the emission of CO_2 equivalents, $CO_{2\text{-eq}}$) lies in the real estate sector. Existing technologies could be integrated into so-called “green buildings”, thereby increasing energy efficiency by 35% (WBCSD, 2007). Although the ecological advantages of green buildings to significantly improve their $CO_{2\text{-eq}}$ footprint are evident (Edwards and Naboni, 2013; Teng and Wu, 2014) and even net zero energy (NZE) buildings are possible from a technical perspective (Kibert, 2014), the investment rate in higher energy efficiency is only 1–1.5 % in non-residential buildings and only 0.07% in residential buildings (Rottke, 2009). These figures demonstrate the existence and high relevance of EEG especially in the real estate sector.

Various strands of research try to reduce the EEG in the building sector. So, for example, a macro-economically oriented strand examines the impact of government programs to increase energy efficiency (Abadie et al. 2012; Clinch and Healy, 2001; Dixon et al., 2010; Hull et al., 2009). Another line of research evaluates and ranks the variety of technical devices, which are available for energy efficiency measures in the real estate sector, in terms of their economical appropriate use (Jakob, 2006; Kobos et al., 2006). This includes tools such as MAKRAL and RETScreen: The International Energy Agency (2001) uses a detailed and technology-specific linear programming approach to connect individual energy use to macroeconomic effects. In this way, an optimal combination of technologies can be determined, which holds energy service demands stable while minimizing energy system total costs. Software-based solutions like RETScreen provide the opportunity to compare different technologies with regard to their energy generation, savings, life cycle costs, emission reduction, financial figures and technology-specific risks.

Against this background, it is *not* our goal, to correctly determine the actual amount of the EEG in the real estate sector, *nor* to quantify or integrate the effects of market failures (like the above-mentioned energy price distortions, information problems including principle-agent problems between landlord and tenant, transaction costs, capital market imperfections) or behavioral failures (Gillingham et al., 2009), *nor* to develop a selection algorithm to classify or rank specific technical devices in terms of their ability to reduce the EEG. Rather, we first develop a rudimentary optimization model, by which we quantified an "optimal investment amount in green buildings" in the setting of rented buildings and building portfolios. In the context of focused abstraction – and without loss of generality – only a potential trade-off between the two factors "ecologic potential savings" and "economic investment amount" (necessary to attain the first factor) is modelled. On the basis of this basic model, we want to formally derive the impact of the so-called „insurance effect" in the second part of this paper. The insurance effect describes the effect that reduced energy demand leads to reduced volatility of energy costs – an added value to risk-averse tenants, who can use GBIO as insurance against the impact of a possible damage event (energy price volatility) by paying a premium (rent increase). Correctly integrating this effect an *increase* of the initial optimal investment amount in green buildings can be derived. We would like to point out that factors such as the location of the property, its age, the original level of its technical equipment, etc. are consciously disregarded in our model-theoretic considerations. These factors, in reality, play an important role in determining the optimal level of investment in EEG. However, our paper primarily focuses on the "insurance effects" and its consequences on the investment level.

Since the "insurance effect" can be worked out even without additional factors (such as location, etc.), we have decided to abstract from these effects. In the main part of the paper, we will show that it is possible to reduce the EEG if this insurance effect is taken into account, which in fact is a novelty in the scientific discussion of the EEG. It should be noted that the further use of the term "optimal" *only* refers to the model-theoretic considerations outlined in this paper, as potential market and behavioral failures (already discussed in the first part of the introduction) remain unattended. Against this background, the 'model-theoretic optimum' differs from the 'real' optimal level of investments in green buildings. Since the existence of an EEG can be regarded as proved and since the gap is likely to be even greater if the already discussed failures are included, the model-theoretic optimality considerations lead in the right direction (i.e. towards the 'real live optimum').

Existing literature, which refers to EEG in the context of the real estate sector, only sporadically addressed uncertainty and the associated risks to the EEG. If uncertainty/risk is focused, it is for example related to uncertainty about future government intervention (such as support programs and subsidies or stricter regulations to internalize external effects) (Hirst and Brown, 1990), uncertainty about the future energy price (Bristow and Kennedy, 2010), weather-related uncertainty effecting different amounts of future energy use (Wang et al., 2012), uncertainty on the energy usage patterns of tenants (Silva and Ghisi, 2014) or uncertainty about the actual long-term impact of new (and unproven) devices (Mills et al., 2006).

In existing publications, often one of these risks is considered in detail and quantified, but without model-based referring to its effective implication. Furthermore, most existing literature does not address, that investments in the real estate area are – caused by the capital intensity for the landlord – characterized by a specific type of risks, which prohibits conventional beta pricing. Thus, an isolated consideration of the investment's idiosyncratic risk – on the basis of established capital market-theoretical methods – is not possible.

We will focus in detail on this issue and its impact on our modelling approach in section 3.1.1. If risk is discussed in existing publications, it is often restricted to the statement, that due to risks, *less* measures to increase energy efficiency are useful or can be performed (Hirst and Brown, 1990; Szabó et al. 2010; Thompson, 1997); an increase of risk leads – so it is concluded – (analogous to other market imperfections) to an *increase* of the EEG in the real estate sector.

Extending our above-mentioned basic model, we will be showing in the second part of the paper, that, as a result of uncertainty about the future energy price and unlike the above-mentioned common integration of risks, *more* measures to increase energy efficiency are meaningful. By working out this insurance effect, which is new and so far unconsidered both in scientific discourse and business, a contribution to the future reduction of the EEG in real estate sector can thus be brought off.

We believe that the capability of energy efficiency investments to work as an insurance against energy price volatility is a comprehensible benefit, which should be used by means of awareness-raising and informative actions, which are needed to accomplish behavior / social change (Vedung, 1998). As a consequence, our approach may contribute to counteract the energy efficiency gap by overcoming associated barriers like uncertainty and, first and foremost, information gaps (Hirst and Brown, 1990). To illustrate our approach, the paper is structured as follows: In section 2, we develop our formal valuation model with regard to specific characteristics of GBIO and determine the optimal economic investment amount under certainty in section 3. In section 4, we show the impact of the insurance effect when the landlord has a real estate portfolio with several tenants. We use an example to illustrate the model's practical applicability in section 5 and conclude with a summary of results as well as directions for future research in section 6.

We would like to point out that we already used some of the assumptions and the modeling approach of section 2 and 3 in an earlier version of the paper (Buhl et al., 2011). This paper builds upon our preliminary groundwork and extends it significantly with regard to the modeling of property portfolios (section 4), the demonstration of the model's practical applicability (section 5) and inferable results (section 6). Furthermore, this significantly extended version of the paper contains a comprehensive review of existing literature regarding the energy paradox, EEG investments and uncertainty (section 1).

2. Model development

As already outlined in the previous section, it is our main goal to derive the impact of the so called "insurance effect" on the investment level in rented green buildings. To achieve this, we will only derive a rudimentary optimization model in the following section. By implication, we do not focus on the potential market or behavioral failures already outlined in the introduction. To set up our optimization model and to work out the insurance effect in the second part, only the following characteristics of green buildings are required:

Characteristic 1: Achievable energy cost savings depend on a property's energy demand (that can be reduced by green building investment opportunities [GBIO]) on one hand, and on the prevailing price for energy on the other hand. Thus, the benefits of GBIO depend on future energy prices (Atkinson et al., 2009).

Characteristic 2: GBIO reduce energy costs and, at the same time, volatility, which originates from the volatile energy prices. As we will point out, GBIO reduce risk and operate like insurance. Thus, the profitability of GBIO depends on the volatility of energy prices (Thompson, 1997) and the insurance effect.

Characteristic 3: If a portfolio of properties is considered, the advantage of GBIO also depends on energy price correlations, which affect the overall portfolio risk.

Although more special characteristics of GBIO might take effect as investment drivers (cp. the discussion of market failures like energy price distortions, information problems including principle-agent problems between landlord and tenant, transaction costs, capital market imperfections or behavioral failures in the introduction), the focus of this paper is on these three characteristics only. According to the model setting of the present paper, an investment in green building technology is planned to be performed in a first step. Depending on the investment amount, the question arises, which single measure (or which set of measures) is most suitable to increase energy performance of the building from a purely technical perspective.

As it is elaborated in the main part of the paper, the application of these technical measures also increases the resale value of the building. In turn, the improved energy performance leads to a reduction of the future energy consumption of the building. From an ecological perspective, this results in a reduction of damage induced by the consumption of energy. Although the negative impact of energy consumption relates to many different dimensions (e.g. consumption of finite energy sources, environmental pollution, climate change), it is commonly normalized and aggregated to CO_2 equivalents ($CO_{2\text{-eq}}$). Therefore, it stands for reason to measure ecological effects in terms of $CO_{2\text{-eq}}$ emission reductions in the context of our paper.

We do not consider other possible ecological impacts of GBIO in the following. In addition to these environmental aspects, reduced power consumption leads to a reduction in energy costs for the users of the property. In addition, the insurance effect can be observed. Its implications for landlord and tenant and their willingness to conduct the respective investment in green buildings is the main focus of our work and will be discussed in detail in chapter 5. Since it is the aim of the present article to examine ecological and economic impacts of investments in green building technologies, we will consciously not consider or evaluate technical performance criteria of single technical measures, which are available to improve the energy performance of buildings.

Thus, it is not the aim of the paper to examine the (dis)advantages of possible individual measures from a technical perspective, nor to make an optimal decision selection from various available technologies. Fig. 1 may help to summarize and clarify our model setting: As we will point out, available approaches in literature are appropriate to address the listed characteristics, but do not focus on the risk reducing insurance effect of GBIO. We believe that this insurance effect can be a comprehensible figure, which can be used to inform decision makers about the (thereby increasing) benefits of GBIO. Vyas and Cannon (2008) state, "The current information stream has become polluted with advocacy and lobbying rather than useful metrics." In this vein, the "major challenge to make home buyers aware of the advantages of clean technologies and to inform them about the exact consequences of adoption" is difficult to master (Pinkse and Dommisse, 2009).

In order to meet this challenge, this paper will develop a bottom-up model putting special emphasis on the insurance effect of GBIO. Based on our model setting (see Fig. 1) we will therefore derive purposeful assumptions to answer the following research question: How can GBIO in rented properties and property portfolios be correctly evaluated and how does this affect the valuation of the ecological contribution of the real estate sector and contribute to overcome the energy efficiency gap?

Thus, we aim at providing an awareness-raising and applicable instrument for consumers in order to accomplish social change leading to higher investment rates in GBIO. Since this paper focuses only on investment valuation, we do not consider the resolution of the landlord-tenant dilemma (for this purpose, see, e.g., Schleich and Gruber, 2008). In order to incentivize technology adoption, bottom-up models evaluate the benefits of energy efficiency technologies. Bottom-up models are disaggregated representations of the energy-economy system considered of "prime importance to support the most suitable design of policies by assessing whether they are capable of achieving the impacts that would justify their implementation" (Mundaca et al., 2010).

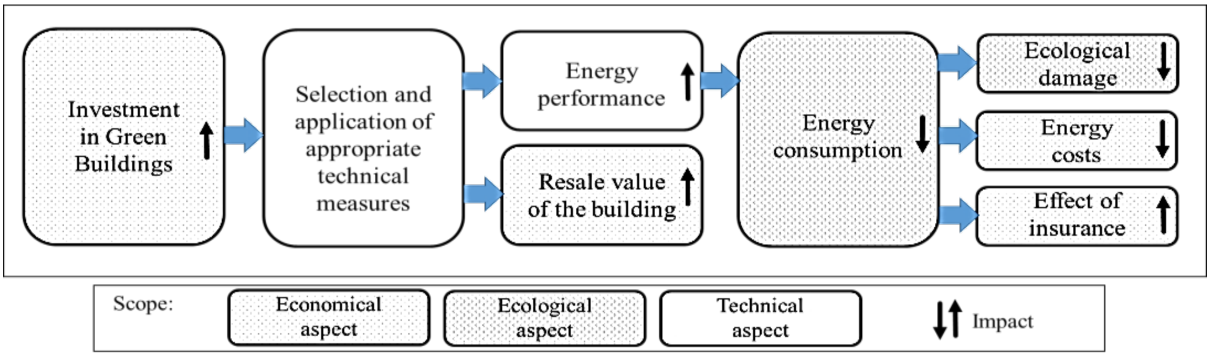

Fig. 1. Investment in green buildings and its economic and ecological results

However, bottom-up models are also criticized to lack the ability to portray both broader macroeconomic effects (Rivers and Jaccard, 2006) and microeconomic decision-making by businesses and consumers when selecting technologies. In this vein, it has long been argued that bottom-up models provide only "an unrealistic portrait of microeconomic decision-making frameworks for technology choice" (Mundaca et al., 2010). Despite the criticism, bottom-up models can be used to describe current and prospective competition of energy technologies in detail on the supply and on the demand side. In fact, also the aforementioned McKinsey study (McKinsey Global Institute, 2007) is based on a bottom-up approach arguing that macroeconomic phenomena are "really nothing more than the sum of demand from hundreds of microeconomic sectors".

Thus, bottom-up models can provide valuable insights in radically different technology futures and enable decision making which may help to take full advantage of the benefits of energy efficiency technologies in general, and GBIO in particular (Hourcade et al., 2006). Gallinelli (2008) uses a discounted-cash-flow approach, which discounts an investment's expected future cash flows using a discount rate to reach a present value. In this connection, Keown et al. (1998) recognized the particular importance of risk for energy-efficiency investments and suggested a basic approach to integrate risk into a discounted-cash-flow valuation. They suggested the adaption of the discount rate depending on the height of the risk. However, Johnson (1994) realizes that the use of the adapted discount rate is broadly discussed in literature, but is not a satisfying way to take risk into consideration adequately.

2.1. Key rationale

The potential of green buildings to lower carbon emissions and energy consumption is estimated to be 35% (WBCSD, 2007). In order to achieve this amount, all possible GBIO have to be implemented. This might be advantageous from an ecological perspective, but not necessarily from an economic perspective. For a meaningful combination of ecological and economic perspectives (cp. Figure 1), we develop a quantitative optimization model to identify the economical optimal investment amount. Investing this amount of money will lead to economical optimal and at least ecologically advantageous results. In the framework of our model the optimal (private) investment amount in green buildings is derived. This single, private investment simultaneously contributes to reach the overall economic optimum while being ecologically advantageous.

2.2 Main definitions and assumptions

We consider a setting with a property being rented and used by a tenant from time T_0 until T_1. The tenant pays a constant periodic basic rental charge (excluding energy costs) at the specific amount *RC* to the landlord. Furthermore, the tenant has to pay energy costs *EC* to a gas/electricity supply company, which is necessary for the property's operation. These energy costs are the product of the property's energy demand *d* and the effective energy price at time *t*, *P(t)*. Additional expenses like, for example, expenses for water supply are irrelevant for this analysis and are not considered. The landlord receives the periodic basic rental charge *RC* from the tenant. At the end of the letting in T_1, the landlord sells the building and receives the resale return *RR*. The amount of *RR* can be considered the net present value of all future achievable rental charges (as already motivated in the introduction, the value of the land and other factors like location, condition or technical equipment of the building shall be disregarded at this point shall be disregarded at this point). Hence, it is irrelevant for our consideration whether the property is actually sold. In the following account, we assume the resale of the property in T_1 for the sake of simplicity. The property's energy demand can be reduced with the help of a green building investment, which is determined by the amount of its necessary investment payout *I*, with $I \in [1;\infty[$. However, many energy-saving measures of green buildings require energy themselves. The net present value of these costs, as well as further costs (e.g., for possible breakdown) is integrated in *I*. The property's energy costs can be lowered permanently through GBIO to a level of $EC_{after} < EC_{before}$ by reducing the energy demand from d_{before} to d_{after}. Moreover, the resale return *RR* can be raised to $RR_{after} > RR_{before}$. This relationship is verified by an empirical survey, assuming that the demand for energy-efficient properties is on the rise because of the expected long-term increase in energy prices. Consequently, increased resale returns can be realized (Bienert, 2009). For our model, we assume a diminishing marginal resale return.

The necessary investment payout occurs in T_0 and has to be paid completely by the landlord initially, although the landlord has the possibility of turning over a certain portion of the investment payout to the tenant (see next section). On account of this, the basic rental charge rises to $RC_{after} > RC_{before}$.

Thus, GBIO generate economic benefits for both tenant (energy cost reduction) and landlord (resale return increase). However, these benefits are not necessarily equally high. Often, energy-efficiency investments are not made because of the above-mentioned landlord-tenant dilemma (The Climate Group, 2008), that is, the landlord decides on the investment amount, but only the tenant benefits from the resulting energy cost savings. In contrast, tenants do not have the right to claim GBIO from the landlord. Since this paper focuses on the derivation of the "insurance effect", we can consider the landlord and tenant as *one* and do *not* analyze the division of the investment amount. At this point, game theory can provide some important directions for research, for example, as done by Bengtsson (1998) and also the WBCSD (2009) drill on this in their simulation study. To proceed, the following assumptions are considered necessary for further analysis:

A.1: Landlord and tenant decide on the investment amount *together* and evaluate GBIO according to their willingness to pay.

A.2: Landlord and tenant calculate with the identical risk-free discount rate *i*.

A.3: The energy price increases in the long run.

2.3 Objective function

Energy prices have increased sharply during the last few decades. The price for light fuel oil increased from ~8€ ct/l in 1970 to 80€ ct/l in 2008 (i.e., ~6.2% p.a.). Furthermore, the world population will continue to rise (Tucker, 2007), and the consumption level of many nations will approach Western standards. Hence, we can forecast a rising energy demand. Because of the inevitable excess demand, we can assume exponentially rising energy costs in the future. This forecast is supported by Buhl and Jetter (2009), who stated that the price of each non-renewable resource, – depending on the specific availability and demand, rises exponentially. One possibility to formalize the exponential rise of the considered energy price *P(t)* is $P(t) = P_0 \cdot (1+r)^t$. Here, P_0 is the energy price in its initial state in T_0. The parameter *r* is the periodical growth rate of the energy price compared to the previous period. The time dependence of the energy price is implied by the exponent *t*. We obtain the objective function through pretest-posttest study, that is, by comparing all cash flows of the landlord-tenant unit after GBIO, CF_{after}, to all cash flows before any investment, CF_{before}, and maximizing the (positive) difference between the two. This maximal difference is obtained through optimization of the objective function Eq. (1).

$$\begin{aligned} \Delta CF(I) &= CF_{after}(I) - CF_{before} = \\ &= -I + \sum_{t=1}^{T_1} \Delta EC(I) + \frac{\Delta RR(I)}{(1+i)^{T_1}} = \\ &= -I + \Delta d(I) \cdot \sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} + \frac{\Delta RR(I)}{(1+i)^{T_1}} \end{aligned} \qquad (1)$$

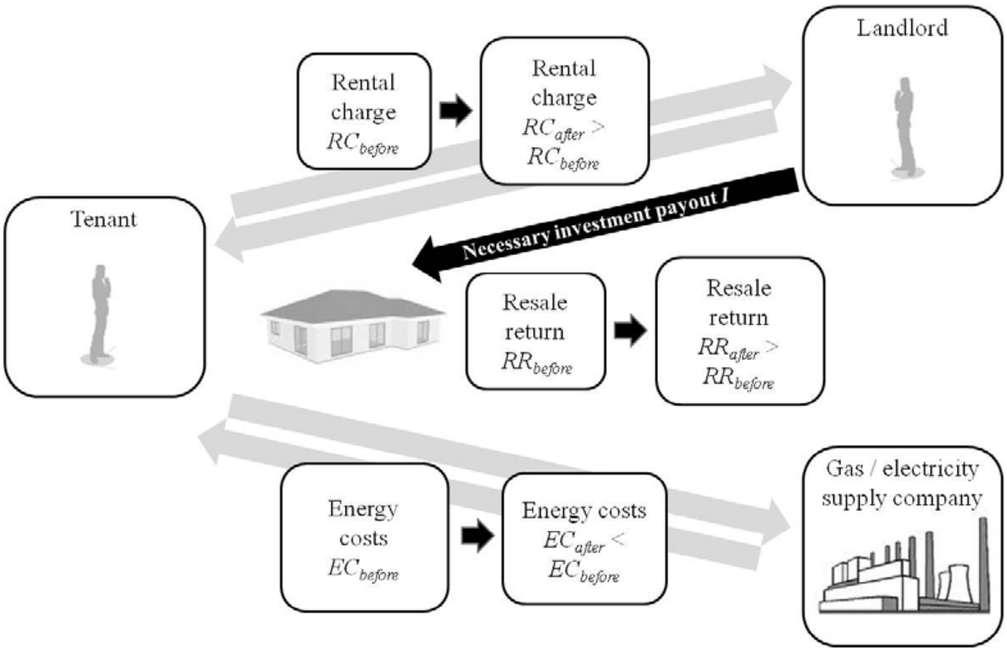

Fig. 2. Impact of GBIO on the considered cash flows

As mentioned above, the resale return rises with the investment amount. One cannot assume that GBIO can raise the resale return of a property linearly. Hence, we can assume that investments’ effects decline. Thus, we can use a strictly monotone increasing ($\frac{dRR_{after}}{dI} > 0$), concave ($\frac{d^2RR_{after}}{d^2I} < 0$) course of the function for RR_{after} (starting from the resale return without any GBIO RR_{before}). This can be formalized exemplarily for $I \geq 1$ as $RR_{after}(I) = RR_{before} + s \cdot \ln I$. The parameter s determines the inclination of the resale return curve. The higher s we choose, the more GBIO increase the building’s resale return. Hence, the achievable increase of the resale return with GBIO is $\Delta RR(I) = RR_{after} - RR_{before} = (RR_{before} + s \cdot \ln I) - RR_{before} = s \cdot \ln I$. The second element of the objective function describes the development of the property’s energy demand $d_{after}(I)$ depending on the investment amount. As mentioned above, the energy demand decreases permanently when the investment amount rises ($\frac{dd_{after}}{dI} < 0$). At this point, we use a linear relation between energy demand and investment amount in the relevant region. One possible function for this is $d_{after}(I) = d_{before} - v \cdot I$. d_{before} is the property’s energy demand in the initial state, that is, before any investment. v determines the curve’s inclination and equates to the marginal energy demand of the property: If the investment amount is raised by one monetary unit, the energy demand of the property falls permanently by approximately v units. This observation is in line with Christen et al. (2002), who found that the energy-efficiency gain of GBIO has a linear connection with the hence emerging costs. Note that our model also allows for negative energy demand, which can be realized with sufficiently high investment amounts and energy generation devices, such as solar panels. It is important that these relationships are technology-dependent. It is self-evident that an investment for the integration of a modern roof insulation material has a different impact on a property’s energy demand and its resale return than an investment of the same amount to integrate an information system-based heating and air-conditioning management system. Furthermore, properties have individual cost functions, which are determined by specific prevailing conditions (Atkinson et al., 2009). We approach this problem by using only generic functions that encompass a general case to illustrate basic interdependencies. Our model can be tailored to specific GBIO by simply adapting the course of the functions. To sum up, we can formalize the induced effects of GBIO in properties to raise energy efficiency using Eq. (2).

$$\Delta CF(I) = -I + v \cdot I \cdot \sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} + \frac{s \cdot \ln I}{(1+i)^{T_1}} \qquad (2)$$

Setting the objective function’s first derivative to 0 and verifying the second-order condition shows that the objective function is strictly concave in the domain and reaches its maximum at the investment amount.

$$I^*_{RiskNeutral} = \frac{s}{(1+i)^{T_1}} + v \cdot \sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} \qquad (3)$$

Consequently, it is reasonable to raise the investment amount up to $I^*_{RiskNeutral}$ Eq. (3). Below this investment amount, an elevation of the investment sum leads to a higher resale return increase and energy cost reduction than the necessary payout. In contrast, the positive effects above the investment amount $I^*_{RiskNeutral}$, in fact, exceed the incidental payouts, but disproportionally high capital expenditure is necessary. These relationships are depicted in Fig. 2 (like before, we assume the potential of green buildings to lower carbon emissions and energy consumption to be 35% (WBCSD, 2007)).

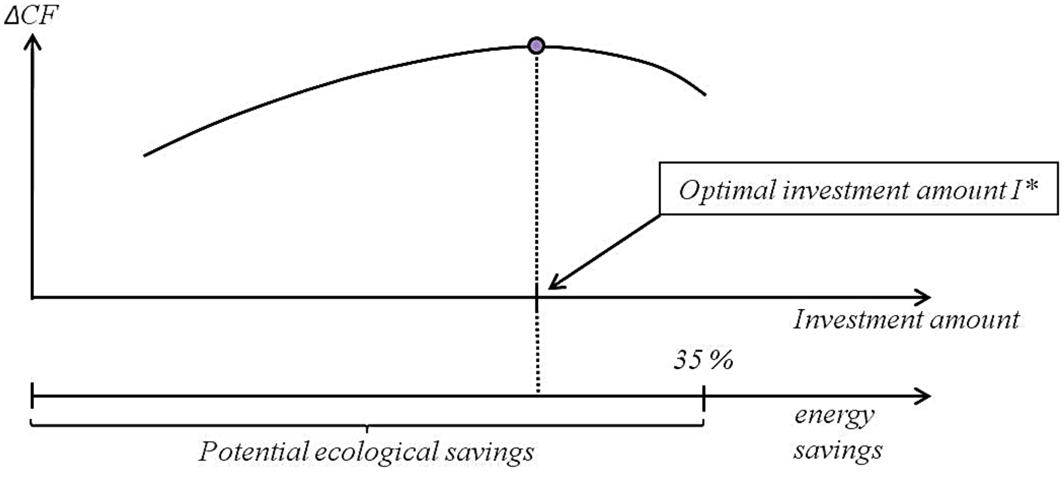

Fig. 2. Course of the objective function (exemplary)

3. Optimal investment amount under uncertainty

Resources and commodities are ever more subject to speculative transactions. Investment in commodity indexes increased by a factor of 20 from US $13 billion in 2003 to US $260 billion in 2008 (Masters, 2008). As shown by Shiller (1981), increased speculation and trading of commodities and energy sources cause an increase in price volatility (Duffie et al., 1999). Other sources of uncertainty, for example, a volatile resale return due to market price changes, are irrelevant for our consideration and are thus excluded. In order to account for energy price volatility, the following assumptions and definitions are necessary.

3.1.1. Assumptions and definitions

For this consideration, we assume normally distributed energy prices. As mentioned above, the energy cost savings are composed of the product of the energy prices at time t with the demand reduction Δd and are thus normally distributed, too. Then, the time-dependent, volatile energy savings can be discounted to an expected present value of the savings, which is also normally distributed. Because of the volatility of energy prices, the calculated present value of the energy cost savings is volatile, too. Here, we interpret the volatility of the present value as the possible positive or negative deviation of the present value from the expected present value of the savings. We measure this deviation with the variance σ^2 ($\sigma^2 > 0$). σ_E^2 is the variance of the energy price. In order to integrate measures for risk (σ^2) and return (μ), we use a preference function:

A.4: The risk-adjusted value of the investment is determined by both parties with Bernoulli's theory of expected utility (Bernoulli, 1954) and the preference function Eq. (4):

$$\Phi(\mu,\sigma) = \mu - \frac{\alpha}{2} \cdot \sigma^2 \tag{4}$$

We assume risk-averse decision makers, that is, the present value of the investment's cash flow is valued lower if its variance is higher (assuming a fixed expected value μ).

The risk-adjusted value corresponds to a preference function, which is developed according to established methods of decision theory and integrates an expected value, its deviation, and the decision maker's risk aversion. This preference function is based on the utility function $U(x) = -e^{2\alpha x}$ and is compatible to the Bernoulli principle (Bernoulli, 1954). The Arrow-Pratt characterization of absolute risk aversion (Arrow, 1971) is -2α with $\alpha > 0$, modeling a risk-averse decision maker. It seems reasonable for us to choose this approach to adequately include energy price risks in our specific context: While risks of other investments can usefully be quantified by established approaches derived from capital market theory, which help to differentiate between market and project specific risks, this is not the case for the investor/landlord in the context of real estate. Investments in real estate use up a very *large part* of a private investor's capital. Since it is not possible in this case to diversify the market risk, individual pricing of risk by means of a preference functional appears to be appropriate. This approach is consistent with Johnson (1994), who draws attention to boundaries of established investment theories – like the capital asset pricing model (CAPM) and arbitrage pricing theory (APT) – in the context of energy technology choices and rather proposes variations of the net present value (NPV).

Considering energy price volatility in our valuation, we discover a particular effect: Taking into account the rules of linear transformation of random variables (in our consideration, the present value of the energy savings), the reduced energy demand results in reduced volatility of the energy costs (Greene, 2008). Thus, green buildings operate like insurance: By paying a premium (rent increase), the insurance holder (tenant) can insure himself against the impact of a possible damage event (energy price volatility). The tenant's willingness to negotiate such insurance and the amount of premium he is willing to pay depends on his individual risk attitude:

Tenants who negotiate insurance want to avoid (or lower) risk. They prefer to pay a certain amount of money (here, the rent increase) rather than accept an uncertain, more volatile payout. In this manner, we can mentally divide the rental charge RC_{after} into three parts: The first part is the basic rental charge RC_{before}. The second part is the counter value for the achievable energy cost savings. The third part is the insurance premium, which is the value of the achievable risk reduction (Buhl et al., 2011). This (over all periods of the letting) accumulated value equates to the difference of the second part of Bernoulli's preference function before and after the investment. As mentioned in *A.4*, we assume risk-averse (and consequently insurance-affine) decision makers (Bamberg and Spremann, 1981). For them, the risk-reducing effect of green buildings creates added value.

3.1.2. Optimization model

Valuating all cash flows and risks of the landlord-tenant unit before and after GBIO with Bernoulli's preference function, we obtain the new objective function to be optimized Eq. (5):

$$\begin{aligned}
&\Delta\Phi(\mu,\sigma) = \Phi_{after}(I) - \Phi_{before} = \\
&\Phi(\mu_{after}(I), \sigma_{after}(I)) - \Phi(\mu_{before}, \sigma_{before}) = \\
&= \mu_{after} - \frac{\alpha}{2} \cdot \sigma^2_{after} - (\mu_{before} - \frac{\alpha}{2} \cdot \sigma^2_{before}) = \Delta\Phi(I) = \\
&= -I + \Delta d(I) \cdot \sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} + \frac{\Delta RR(I)}{(1+i)^{T_1}} + \frac{\alpha}{2} \cdot \Delta\sigma^2(I)
\end{aligned} \tag{5}$$

The first three terms are similar to Eq. (2) in our consideration under certainty. The last term corresponds to the volatility reduction of the energy costs weighted with the risk-aversion parameter α and that can be increased with the investment amount.

To sum up, we can formalize the induced effects of GBIO in properties under consideration of risk as shown in Eq. (6).

$$\Delta\Phi(I) = -I + v \cdot I \cdot \sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} + \frac{s \cdot \ln I}{(1+i)^{T_1}} + \frac{\alpha}{2} \cdot \\ \cdot (d_0^2 - (d_0 - v \cdot I)^2) \cdot \sigma_E^2 \qquad (6)$$

The objective function is strictly concave in the domain again and reaches its maximum at the investment amount in Eq. (7).

$$I^* = \frac{-1 + v \cdot \sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} + \alpha \cdot v \cdot d_0 \cdot \sigma_E^2}{2 \cdot \alpha \cdot v^2 \cdot \sigma_E^2} + \\ + \frac{\sqrt{\begin{aligned}&(1 - v \cdot \sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} + \alpha \cdot v \cdot d_0 \cdot \sigma_E^2)^2 \\ &+4 \cdot \frac{s}{(1+i)^{T_1}} \cdot \alpha \cdot v^2 \cdot \sigma_E^2\end{aligned}}}{2 \cdot \alpha \cdot v^2 \cdot \sigma_E^2} \qquad (7)$$

By comparing the computed optimal investment amount considering the insurance effect to the optimal investment amount of a risk-neutral decision maker, we can see that the optimal investment amount considering energy price volatility is always higher than assuming a non-volatile energy price. Considering the energy price and the insurance effect accurately will consequently lead to an increase of the actual optimal investment amount. Consequently, valuating GBIO correctly will lead to economic decisions that will generate more benefits also from an ecological perspective.

4. Addressing the ‘insurance-effect’ in multiple properties

In this section, we transfer our presented analysis to an approach with multiple properties and analyze how the insurance effect takes effect in building portfolios.

4.1.1. Assumptions and definitions

Now assume a landlord with $n \geq 2$ properties i and multiple tenants. The landlord and his tenants together decide on the investment amount to be spent on GBIO. For this, they need to determine the overall optimal investment amount $I^*_{overall}$ for the entire property portfolio as well as the optimal allocation of this investment amount to each property. If we consider the properties to be supplied by different energy sources (e.g., gas, oil etc.) and compare their prices, we discover a special characteristic: There are similarities in the prices, for example, for domestic fuel oil and domestic gas in the past. Many drivers for energy prices, such as global demand or inflation, are present across all energy sources. As theoretical and empirical research affirms (Da Silva, 2007), energy prices are not independent of each other, but are correlated, that is, they are systematically associated with each other (Eydeland and Wolyniec, 2003). In order to accurately determine the optimal investment amount for a property portfolio, we have to account for the impact of energy price dependencies on the overall risk and the manner in which it is affected by GBIO. If energy price dependencies were disregarded, the computed optimal investment amounts would not account for possible diversification effects and would consequently be false. For this reason, we want to adapt our model and add the following assumption:

A.5: All n properties are supplied by energy sources whose prices depend on each other. The measurement for the energy price dependencies is the correlation coefficient k_{ij}. We consider these correlations coefficients to be given. All other possible dependencies among the properties are disregarded.

As mentioned above, energy price dependencies affect the overall volatility of a property portfolio. According to Keown et al. (2008), the overall variance of a portfolio is determined by summing up the stand-alone risks of each property σ_i and considering the dependencies between the energy prices with the help of the correlation coefficient. Hence, the overall energy costs’ variance of a property portfolio (without any GBIO) is shown in Eq. (8)

$$\sigma^2_{overall} = \sum_{i=1}^{n} \sum_{j=1}^{n} \sigma_i \sigma_j k_{ij} \qquad (8)$$

If we consider the properties being supplied by energy sources whose prices do not show perfect positive correlation (i.e., $k_{ij} = [-1;+1[$), we can see that the overall property portfolio’s variance is smaller than its variance with perfect positive correlation ($k_{ij} = +1$). This risk-reducing effect is called the diversification effect and can be interpreted in the following manner: If the considered properties are supplied by the same energy source, k_{ij} equals +1 since an energy price is always fully positively correlated with itself. If this energy price increases, the overall payouts for energy will then increase in equal proportion since energy costs only depend on one stochastic factor. However, if the landlord and tenants decide on properties supplied by different energy sources, k_{ij} is likely to take on a value of $k_{ij} = [-1;+1[$, that is, the energy prices will not show perfect positive correlation with each other. If one of the energy prices increases, the payouts for energy will then increase in a smaller proportion since the risk of a possible price increase is diversified on multiple stochastic factors. Consequently, the resulting overall portfolio risk is lower than the aggregate stand-alone risks of the properties.

Since the stand-alone risks of each property of a portfolio codetermine the value of the portfolio's diversification effect, GBIO also indirectly affect the value of the diversification effect. As a well-grounded investment valuation has to account for all investment-caused consequences on financial figures, we need to consider the investment's effect – as well as the insurance effect – on the value of the diversification effect in our valuation, too.

4.1.2. Optimization model

Eq. (9) is the objective function for multiple properties accounting for all aforementioned GBIO-caused effects:

$$\begin{aligned}
&\Delta\Phi_{overall}(\mu,\sigma)=\Phi_{overall,after}(I_i)-\Phi_{overall,before}=\\
&=\Phi(\mu_{overall,after}(I_i),\sigma_{overall,after}(I_i))-\\
&\Phi(\mu_{overall,before},\sigma_{overall,before})=\Delta\Phi_{overall}(I_i)=\\
&=-\sum_{i=1}^{n}I_i+\sum_{i=1}^{n}\left(\Delta d_i(I_i)\cdot\sum_{t=1}^{T_{1,i}}\frac{P_{0,i}\cdot(1+r_i)^t}{(1+i)^t}+\frac{\Delta RR_i(I_i)}{(1+i)^{T_{1,i}}}\right)+\\
&\frac{\alpha}{2}\cdot\Delta\left(\sum_{i=1}^{n}\sum_{j=1}^{n}\sigma_i^2(I_i)\sigma_j^2(I_j)k_{ij}\right)
\end{aligned} \tag{9}$$

This function consists of the following terms: The negative sum of the investment amounts in each property (first term) and the sum of the achievable energy cost savings and resale return increases for each property (second term). Additionally, the third term considers the individual risk reductions for each property as well as the investments' effect on the value of the diversification effect.

In order to obtain the overall optimal investment amount as well as the individual optimal investment amounts for each property, this objective function has to be optimized. At its maximum, the necessary (but not sufficient) conditions shown in Eq. (10) are fulfilled.

$$\frac{d\Delta\Phi_{overall}(I_i)}{dI_i}=0 \tag{10}$$

For the verification of the second-order condition, we test the Hessian matrix to be negatively definite in the domain. Since the multiple unknown decision variables cannot always be separated, an explicit solution for the objective function cannot always be determined. However, a numerical solution of the optimization model at hand with a limited number of properties can be computed in most cases.

The authors made several model calculations and compared the calculation results of the presented model to results of calculations disregarding the impact of diversification. In this manner, we ascertained that the overall optimal investment amount of a portfolio under consideration for the diversification effect can be higher or lower than the optimal investment amount disregarding price dependencies. If the diversification effect is raised by GBIO, another potential of green buildings becomes visible: In certain cases, GBIO positively affect the value of the diversification effect and are consequently able to reduce the overall risk in a property portfolio in two ways: reducing the stand-alone risks of each property due to energy demand reduction and reducing the portfolio risk due to a positively affected diversification effect. Consequently, a correctly conducted economic valuation will lead again to an increased overall optimal investment amount and to a higher ecological contribution to energy efficiency. Despite not computing higher overall optimal investment amounts in all cases, it is evident that the high economic and resulting ecological potential of GBIO only becomes visible, if risk is considered correctly.

5. Example of potential application and results

A building society wants to design a block of offices in an energy-efficient manner. Therefore, the company wants to exploit the high potential of GBIO. For this example, we consider the following situation: The duration of the letting is 30 years ($T_1 = 30$). The company receives a one-time resale return for the property after 30 years and calculates (like their tenants) with a discount rate of $i = 3\%$. The resale return can be raised by an energy-efficiency investment, beginning from an amount of 1,000,000 monetary units (MU) in a form that can be described by the following function: $RR_{after}(I)=1000000+10000\cdot\ln I$. The property's demand for domestic fuel oil can be lowered by approximately 0.06 l p.a. with each invested MU starting from a basic demand of 3000 l p.a. Hence, we use the following relationship for the energy demand: $d_{after}(I)=3000-0.06\cdot I$. We assume an energy price increase of 7% p.a. with an initial price of $P_0 = 0.85$ MU/l. We determined the optimal investment amount to be 4,604 MU. Hence, the company should invest exactly this amount to maximize its economic profit and thus contribute to energy efficiency. Investing more than the computed optimal amount is advantageous from an ecological perspective, but not from an economic perspective. In order to account for risk and determine the optimal investment amount from an economic viewpoint under uncertainty, we simply assume the energy price to be volatile ($\sigma_E^2 =$ 0,006). For the parameter of risk aversion, we assume $\alpha = 1$. All input values are summarized in Table 1.

Considering risk and the insurance impact of green buildings, we determine an optimal investment amount of $I^* = 18{,}748$ *MU*. Considering the insurance impact clearly raises the optimal investment amount and energy demand, and thus the carbon footprint can be reduced much more. The company in this example will save 37.5% of its periodic energy demand if it chooses the optimal investment alternative, whereas the company would only save 9.2% of energy if it disregarded the insurance impact and conducted a valuation under certainty.

Table 1. Input values for the example with one property

$T_1=30$	$i=3\ \%$	$r=7\ \%$	$RR_{after}(I)=1000000+10000\cdot\ln I$
$P_0=0{,}85$ MU/l	$\sigma_E^2=0{,}006$	$\alpha=1$	$d_{after}(I)=3000-0{,}06\cdot I$

Table 2. Input values for the example with n=2 properties

$T_{1,1}=30$	$\alpha=1$	$n=2$	$RR_{after,1}(I_1)=1000000+10000\cdot\ln I_1$
$T_{1,2}=30$	$k_{12}=0{,}5$	$i=3\ \%$	$RR_{after,2}(I_2)=3000000+30000\cdot\ln I_2$
$P_{0,E}=0{,}85$ MU/l	$\sigma_E^2=0{,}006$	$r_E=7\ \%$	$d_{after,1}(I_1)=3000-0{,}06\cdot I_1$
$P_{0,F}=0{,}6$ MU/u	$\sigma_F^2=0{,}009$	$r_F=5\%$	$d_{after,2}(I_2)=5000-0{,}03\cdot I_2$

Imagine the building society together with their tenants planning to invest in GBIO for $n = 2$ properties. Both properties are under possession of the building society and used by their tenants. Property *1* is the familiar block of offices. All given input values remain unmodified. Property *2* is a production site for commercial uses. All input values given are summarized in Table 2.

We can determine an optimal investment amount for property *1* of $I_1^* = 41{,}064$ MU and for property *2* of $I_2^* = 74{,}529$ MU. By summing up the two optimal investment amounts, we obtain the overall optimal investment amount $I_{overall}^* = 115{,}593$ MU. Compared to a consideration without price dependencies, we can observe significantly different results: In the current example, the overall optimal investment amount is only *65,121 MU* if energy price dependencies are disregarded. Here, the consideration of energy price dependencies leads to a further increase in the optimal overall investment amount. Hence, we could model-based show that an accurate economic valuation raises the ecological contribution again.

As already stated in the introducing section, it is not the aim of this fictional example, to determine the optimum level of investment in devices to reduce energy consumption in green buildings (for which we once again refer to the application of established tools). Instead, we focus on deriving the relevant cause-effect relationships particularly resulting from the effect insurance: If this – as shown in our numerical example – is taken into consideration, there is an increase in the optimal level of investment.

6. Conclusions

In the first part of this paper, a rudimentary optimization model is developed to determine the optimal investment amount in green building investment opportunities (GBIO). We also show that investments in green buildings are appropriate up to a certain level (which can be identified, if the presented model is applied) from an economic as well as from an ecological perspective. Without focusing on an exact quantification of the EEG and potential market or behavioral failures, it is also shown that the (model theoretic) optimal investment amount can be increased by considering the so called “insurance effect” of green buildings. The model-theoretic conception of this effect (and the impact on the EEG) is a novelty in the scientific literature, which is examining the energy efficiency gap in the real estate sector. Furthermore, we pointed out that a diversification effect is a further possible benefit of GBIO in property portfolios. Of course, a theoretical model gives only limited information about real world impacts. Thus, it cannot be concluded with certainty that planning tools and businesses considering the insurance effect lead to a practical reduction of the EEG in every case. The practical effectiveness of the insurance effect must be proven in real world settings, for example in pilot test versions of planning tools which may give insight about user acceptance and the actual EEG impact of GBIO investments considering the insurance effect.

Moreover, several assumptions and conditions of this paper have to be examined critically, which opens up possibilities for further research. First, the landlord-tenant dilemma might be an investment barrier and identified economical and ecologically meaningful investments are not being made because landlord and tenant are not willing to share the investment amount.

Furthermore, existing legislation can impede reasonable investments if the investment amount cannot be divided equitably (e.g., German landlords can only pass on 11% p.a. of the costs of certain energy-efficient refurbishment measures to the tenant). In that case, it is possible that the investment amount to be spent is limited. Second, it is obvious that the value (and thus the resale return) of properties depends on many more factors than the investment amount of GBIO and energy price dependencies (e.g. location, condition, technical equipment). A model integrating these factors should be the subject of further research.

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