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DETERMINING THE OPTIMAL INVESTMENT AMOUNT OF AN INTELLIGENT HOUSE - POTENTIALS OF INFORMATION AND TECHNOLOGY TO COMBINE ECOLOGY AND ECONOMY

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Abstract

Innovations in the field of information systems (IS) open up new possibilities to increase energy efficiency and carbon reduction. For this, real estate is an industry sector with remarkably high potential. Here IS are integrated into 'Intelligent Houses'. But many of these ecologically advantageous investments are not made yet, because they do not seem to be economically profitable. We therefore develop an IS-specific model to identify investment alternatives out of all ecologically advantageous investment alternatives which are also economically profitable. For this, we compare the investment amount with the achievable energy cost reduction and the raise of the buildings' resale returns. Out of all identified investments we determine the economically optimal investment amount. In this connection we put special emphasis on the valuation of risk and for the first time point out the applicability of Intelligent Houses as insurance against energy price volatility. Thus the quantity of all ecologically advantageous and economically profitable investments is enhanced as well as the economically optimal investment amount. IS' potentials to combine economy and ecology can thus be detected and made useable. An example illustrates how the model can be applied.

Keywords: Sustainability, Intelligent Houses, economic valuation, ecology and economy, Green IS, insurance, information systems, IS, investment.

1 Introduction

‘Even with modest UN projections for population growth, consumption and climate change, by 2030 humanity will need the capacity of two Earths to absorb CO₂ waste and keep up with natural resource consumption’ (World Wide Fund For Nature 2010, p.9). To counteract this trend and the concomitant pollution of our planet, technical innovations in various disciplines have been developed. Likewise, information systems develop such innovations. IS can be used to enhance the efficiency of business processes comprehensively over various economic sectors (Buhl and Laartz, 2008). In this way almost 7.8 GtCO₂e (billion tonnes (Gt) carbon dioxide equivalent) can be saved until 2020 based on the level of 2002. This reduction of carbon emissions would be five times as large as the whole carbon footprint caused by IS itself (The Climate Group 2008, p.6). One measure to reduce energy consumption and carbon emissions outstandingly strong is the application of IS in properties in so-called Intelligent Houses (also: ‘Smart Homes’ or ‘Green Buildings’). IS can be used as a tool for monitoring, feedback and optimisation at every stage of a property’s life cycle to raise energy efficiency. For example, intelligent building management systems can be used to run heating and cooling systems automatically according to tenant’s needs. Operatively coupled sensors in the whole building and its outer faces provide and transfer the necessary data by measuring adjacent climate information and thus contribute to lower the building’s overall energy consumption remarkably. Global carbon emissions can be lowered simply by using IS in properties (based on the level of 2002 until 2020) about 1.68 GtCO₂e and the global energy consumption of buildings about 15 % (The Climate Group 2008, p.6). Further IS innovations, which will be available for the first time in the future, could even raise the denoted savings. In this manner Intelligent Houses are a key enabler for energy efficiency. Although the ecological advantages of Intelligent Houses are evident, the investment rate to higher energy efficiency is currently only 1-1.5 % in non-residential buildings and actually only 0.07 % in residential buildings (Rottke, 2009). The use of IS in commercial or private properties should thereby be far lower. But which factors are opposed to the ecological contribution of IS at this point? Considering Intelligent Houses from an economic point of view, the following specifications appear:

Specification 1: The landlord-tenant-dilemma. Often, IS energy efficiency investments are not made because of the landlord-tenant-dilemma (The Climate Group, 2008). 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 an IS investment from the landlord (Bengtsson, 1998). The profitability of IS investments thus depends on the perspective.

Specification 2: Dependence on future energy price. The achievable energy cost savings depend on a property’s energy demand that can be reduced by an Intelligent House investment on the one hand, but also on the prevailing price for energy on the other hand. Thus, the overall advantageousness of investments in Intelligent Houses also depends on the future energy price (Atkinson et al., 2009).

Specification 3: Dependence on energy price volatility. IS investments reduce energy costs and (at the same time) its volatility, which originates from the volatile energy price (e.g. calculated standard deviation of oil was 0.33 (Schwartz 1997, p.937). Thus, the advantageousness of Intelligent House investments depends on the volatility of the energy price (Thompson, 1997).

However, there are more specifications of Intelligent House investments (see chapter 5), but the focus of this paper shall be on these three specifications only, because they are most relevant for our consideration. To the best of our knowledge, there are no established investment valuation methods that (adequately) consider the three focused specifications. However, the special economic potential of Intelligent House investments is founded on these characteristics. Furthermore, established valuation methods capture the specifications only qualitatively and / or are only applicable for a particular technology. A universally applicable, quantitative valuation method is not available. Many ecologically advantageous and economically profitable investments are thus not identified. To counteract, this paper will answer the following research question: How can Intelligent House investments be correctly evaluated economically and consequently contribute to use the ecological and economical potentials of IS? To answer this research question we describe the conflict between

ecology and economy of Intelligent Houses in chapter 3.1. In chapter 3.2 general assumptions and definitions that are necessary for a formal analysis are introduced. In chapter 3.3 we illustrate in an integrated risk and return consideration how to identify investments, which are ecologically advantageous and economically profitable at the same time. In chapter 3.4 the economically optimal investment out of all identified investments is determined. Subsequently we illustrate the practical applicability of the model with a practical example. We close with a summary of all results and a critical acclaim in chapter 5.

2 Literature review

IS in properties can contribute to energy efficiency already during the property's design and construction phase, e.g. through virtual construction methods. These IS methods are computer modeling techniques that support the construction process of a buildings from its initial modular design to its on-site construction and maintenance. In this way, IS can help to reduce costs, times and energy consumption during the construction (Murray et al., 2003). But IS can also be used during the use of the property to increase energy efficiency. IS can increase energy efficiency through teleworking and collaborative technologies to reduce need for office space (achievable carbon savings until 2020: 0.11 GtCO₂e), improved building design (0.45 GtCO₂e savings), building management systems (automatically controlled and adjusted heating, cooling, lighting and energy use; 0.39 GtCO₂e savings), voltage optimisation (0.24 GtCO₂e savings), automated heating, ventilation and air conditioning (0.13 GtCO₂e savings) and much more (The Climate Group 2008, p.40). The Climate Group (2008, p.9) estimates the achievable savings and states a globally IS-enabled saving potential of € 644 billion (between 2002 and 2020), of which € 216 billion can be saved by using IS in real estate. Kuckshinrichs et al. (2010) find even higher CO₂ abatement costs, which would raise the contemplated amount considerably. Of course, the denoted savings will only be fully realised if the IS measures are permanently used by the properties' tenants, i.e. the high potential of e.g. teleworking remains unused if the users do not accept and operate the provided technologies.

To integrate IS in properties the investment alternatives which are best to achieve the elected objectives have to be identified out of all existing alternatives. For this purpose, both the necessary investment payout and the value added need to be considered in order to reach an economical valuation. As mentioned above, an appropriate IS investment valuation method has to take into account the landlord-tenant-dilemma, the future energy price and its volatility and valuate investments quantitatively and as universally applicable as possible.

For this reason, research papers value investments that increase energy efficiency by measuring the hence emerging benefits solely on the basis of non-monetary utility values for environmental, social or economic benefits, e.g. Power (2008). These methods account for many different important factors and do not concentrate only on economical aspects. However, they are not quantitative and do not consider the importance of the future energy price (see *specification 2*) and its volatility (see *specification 3*).

Furthermore, decision-makers use so-called discounted-cashflow methods, which discount the investment's expected future cash flows with a discount rate to a present value (Gallinelli, 2008). In this way, the time-value of money is considered (which is very important for long-term investments). However, these discounted-cashflow methods do not measure or quantify an investment's risks, like the volatility of the energy price (see *specification 3*). Keown et al. (1994) recognise the special importance of risk for energy efficiency investments and suggest a basic approach to integrate risk into a discounted-cashflow valuation. They suggest the adaption of the discount rate depending on the height of the risk. Therefore a higher discount rate should be used for investments that have higher risk than a typical investment and a lower discount rate should be used for investments that have lower risk than a typical investment. However, this method is very inexact in measuring risk correctly. Johnson (1994) realises that the use of the adapted discount rate is broadly discussed in literature, but is not a satisfying way to adequately take risk into consideration.

Johnson (1994) furthermore reviews the relevance of classic economic models like the capital asset pricing model or the arbitrage pricing theory for energy technology investments. Despite some good propositions being made to incorporate risk, the author does not refer to the landlord-tenant-dilemma (see *specification 1*) nor to the actual application of the economic models taking into account the future energy price (see *specification 2*).

For this reason, a glance into other disciplines like architecture or material science is necessary. Bollatürk (2006) examines the optimum isolation thickness for building walls in the Journal of Applied Thermal Engineering and Al-Sallal (2003) compares polystyrene and fiberglass roof isolation in warm and cold climates in the Journal of Renewable Energy. These approaches consider the future energy price and are also quantitative. However, they do not consider risk either (see *specification 3*) and are only applicable for particular (non-IS) technologies.

Atkinson et al. (2009, p.2583) find that ‘the majority of existing research focuses on either the technical attributes of different low carbon solutions on small or large scales, or the macro-economic effects of carbon-reducing energy strategies’. These methods again are hence not adequate for our needs. For this reason, current valuation methods are not appropriate to value Intelligent House investments subject to their specifications named above or to determine the actual value of a sustainable building adequately (Rottke, 2009). Lützkendorf and Mrics (2008) criticise a lack of methodologies to connect the ecological component of an investment with its economical value. That is why a valuation method to identify ecologically advantageous and simultaneously economically profitable Intelligent House investments is developed in this paper followed by the determination of the economically optimal investment amount.

3 Planning of Intelligent House investments

Implementing each technically possible measure in line with an Intelligent House investment is not necessarily reasonable. First of all, we will identify all investments that are advantageous from an ecological perspective and profitable from an economical perspective. Building on that, we will determine the economically optimal investment amount.

3.1 Intelligent Houses in the conflict between ecology and economy

As shown in chapter 2, IS provide various measures to raise energy efficiency of properties. Each implemented measure creates ecological value, but also requires an investment payment. The potential of IS to lower carbon emissions and energy consumption is estimated at 15 % (The Climate Group 2008, p.6). To achieve this amount, all possible IS measures have to be implemented. However, it is unclear which of all measures shall be implemented. Each ecologically advantageous investment alternative is thus not necessarily profitable from an economic perspective. For this reason we will develop a tool to identify those investments out of all ecologically advantageous investments, which are also economically profitable, in the next chapters.

3.2 Assumptions and definitions

A property is rented and used by a tenant from time T_0 until T_I . 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 and 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 e.g. 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_I , the landlord sells the building and receives the resale return RR . The amount of RR can be seen as the net present value of all future achievable rental charges (the value of the land shall be disregarded at this point). Hence, it is irrelevant for our consideration whether the property is actually sold or not. In the following, we assume the resale of

the property in T_I for the sake of simplicity. The property's energy demand can be reduced with the help of an IS investment, which is determined by the amount of its necessary payout P , with $P \in [1; \infty[$. However, many energy saving measures of Intelligent Houses need energy for themselves. The net present value of these costs as well as further costs (e.g. for possible breakdown) shall be integrated in P . For reasons of simplicity, we consider energy costs which can be lowered permanently to a level of $EC_{new} < EC$ by reducing the energy demand from d to a permanent d_{new} . Moreover, the resale return RR can be raised to $RR_{new} > RR$. This coherence is verified by an empirical survey, assuming the demand for energy-efficient properties is on the rise because of the expected long-term increase of the energy price. Consequently, increased resale returns can be realised (Bienert, 2009). Furthermore, Rottke (2009) affirms that already today energy-efficient properties are rewarded by the market with higher prices. This coherence originates from expected strict future energy obligations, which cannot be complied with conventional buildings (Lützkendorf and Mrics, 2008). Moreover, the lifetime of energy-efficient properties is higher than the lifetime of conventional properties, so rental charges can be realised during a longer period of time (Kuckshinrichs et al., 2010). The necessary investment payout occurs in T_0 and has to be paid completely by the landlord at first. Though the landlord has the possibility to turn over a certain portion of the investment payout to the tenant (see next section). On account of this the basic rental charge rises to $RC_{new} > RC$.

Thus Intelligent Houses generate benefits for both tenant and landlord. However, both sides do not necessarily benefit from the investment to the same degree. That is why we want to dissolve the landlord-tenant-dilemma (see *specification 1*) by dividing the investment payout proportionally to the individual value added. In this way we can make sure that the value generated by the Intelligent House investment (respectively the realised savings) is divided evenly. Furthermore, both landlord and tenant have an incentive to participate in the investment, because they obtain their individual share of value / savings either way. In doing so we make sure a reasonable IS investment is made and are able to overcome a big IS investment barrier. We conclude the following assumptions:

- A.1: Landlord and tenant pay the necessary investment payout according to the proportion of their marginal willingnesses to pay. The portion of the tenant is divided over all periods of the letting and increases the basic rental charge in the form of a rent increase. At this, possible legal restrictions to the cost being turned over to the tenant shall be neglected.
- A.2: Landlord and tenant calculate with the identical risk-free discount rate i . For risk we account for in A.4.
- A.3: The energy price increases in the long run.

However, the consideration at hand not only accounts for the increase of the energy price, but for its short term volatility (see *specification 3*). For this purpose we assume normally distributed energy prices. As mentioned above, the energy costs are composed of the product of the energy prices at time t with the demand d and are thus normally distributed, too. The time-dependent, volatile energy costs can then be discounted to an expected present value of the cash flow μ , which is also normally distributed. Because of the energy price's volatility the calculated present value of the IS investment 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 cash flow. We measure this deviation with the variance σ^2 ($\sigma^2 > 0$). σ_E^2 shall be the variance of the energy price. To integrate measures for risk (σ^2) and return (μ), we use a preference function:

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

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

We assume risk-averse decision makers, i.e. the present value of the IS investment's cash flow is valued less, 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 upon the utility function $U(x) = -e^{2\alpha x}$ and is

compatible to the Bernoulli principle (Bernoulli, 1954). Its Arrow-Pratt characterisation of absolute risk aversion (Arrow, 1971) is -2α with $\alpha > 0$ modeling a risk-averse decision maker. The presented preference function was introduced by Freund (1956) and applied in many other papers on IS, e.g. by Fridgen and Müller (2009) and Katzmarzik et al. (2008).

3.3 Identification of ecologically advantageous and economically profitable investments

Out of all investments remaining after the ecological analysis, we want to identify those IS investments which are also economically profitable. For this, we have to analyse their economical characteristics. For this purpose we use a quantification with financial measurements in general, as well as with cash flows in particular. To ensure that we do not identify investments which generate only onesided benefits and which will not be made because of the landlord-tenant-dilemma, we take on the perspective of the landlord as well as the tenant. The economic consideration of the tenant is influenced by the rent increase on the one hand and by the achievable energy cost savings during the time of the letting on the other hand. For this, the future energy price is important (see *specification 2*). Considering the energy prices during the last decades, we observe strong increase. 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 exponentially in the forthcoming decades (Tucker and Patrick, 2007) and the consumption level of many nations will more and more reach western standards. Hence we can forecast a rising energy demand. On the other hand we recognise non-renewable energy sources to be finite. Because of the excess demand resulting sooner or later we can assume exponentially rising energy costs in the future. This forecast is supported by Buhl and Jetter (2009), who state that the price of each non-renewable resource – depending on the specific availability and demand – rises exponentially. One possibility to formalise the exponential rise of the energy price $P(t)$ is:

$P(t) = P_0 \cdot (1 + r)^t$. In this connection, 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 dependance of the energy price is implied by the exponent t . Moreover, we consider the energy price's short-term volatility (see *specification 3*). Resources and commodities are more and more subject to speculative transactions. Investments 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 of price volatility (Duffie et al., 1999). Considering this 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 costs), the reduced energy demand results in reduced volatility of the energy costs (Greene, 2008). Thus Intelligent Houses operate like an insurance: By paying a premium (rent increase) the insurance holder (tenant) can insure himself against the impact of a possibly occurring damage event (energy price volatility). The tenant's willingness to negotiate such an insurance and the amount of premium he is willing to pay depends upon his individual risk-attitude: Tenants who negotiate an insurance want to avoid (or lower) risk. They prefer to pay a certain amount of money (here the rent increase) rather than accepting an uncertain, more volatile payout. In this way, we can mentally divide the rental charge RC_{new} into three parts: The first part is the basic rental charge RC . The second part is the countervalue for the achievable energy cost savings. The third part is the insurance premium, which is the achievable risk reduction's value. This (over all periods of the letting) accumulated value IP equates to the difference of the second part of Bernoulli's preference

function before and after the investment: $IP = \frac{\alpha}{2} \cdot (d^2 - d_{new}^2) \cdot \sigma_E^2$. As mentioned in assumption A.4,

we assume risk-averse (and consequently insurance affine) decision makers (Bamberg and Spremann, 1981). For them, the risk-reducing effect of Intelligent Houses creates a value added and on that account their willingness to pay rises. Considering an exponentially rising energy price and its volatility, the tenant is willing to pay a maximum amount of money, which he is willing to pay in form of a rent increase. This amount is $I_{T,max}$:

$$(1) \quad I_{T,\max} = \sum_{t=1}^{T_1} \frac{EC_t - EC_{new}}{(1+i)^t} + IP = \underbrace{(d - d_{new})}_{\text{Energy demand reduction}} \cdot \underbrace{\sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t}}_{\text{Energy price at time } t} + \underbrace{\frac{\alpha}{2} \cdot (d^2 - d_{new}^2) \cdot \sigma_E^2}_{\text{Present value of insurance premium}}$$

This willingness to pay is compounded of the present value of the energy cost reduction over all periods of the letting plus the countervalue of the energy costs' volatility reduction subject to the individual risk-aversion. Taking on the perspective of the landlord, we have to consider the property's increased resale return and the necessary investment payout. The outcome of this is the landlord's maximal willingness to pay $I_{L,\max}$:

$$(2) \quad I_{L,\max} = \frac{RR_{new} - RR}{(1+i)^{T_1}}$$

$I_{L,\max}$ equates to the difference of the new and the old resale return, which is discounted to a present value. By summing up the two willingnesses to pay, we can claim the following condition (3) for the maximum overall investment amount, which has to be fulfilled by our favoured investment alternatives (in this connection we assume, that the property's resale return does not depend on the energy price and its volatility):

$$(3) \quad I_{\max} \leq I_{L,\max} + I_{T,\max}$$

$$I_{\max} \leq \frac{RR_{new} - RR}{(1+i)^{T_1}} + (d - d_{new}) \cdot \sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} + \frac{\alpha}{2} \cdot (d^2 - d_{new}^2) \cdot \sigma_E^2$$

By testing each investment to the condition (3) the amount of all considered IS investments will be reduced again. If the decision makers disregard the energy costs' volatility reduction (i.e. the insurance), the amount of ecologically advantageous and economically profitable investments would be much lower (i.e. the third addend of condition (3) would cease to apply). Figure 1 shows the impact of the insurance:

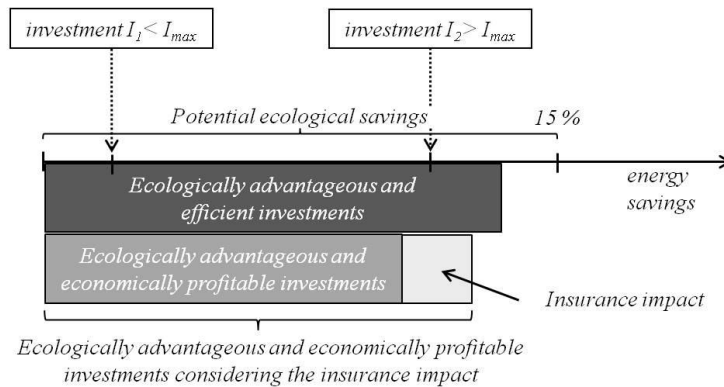


Figure 1. Ecological and economical classification of IS investments

In this example investment alternative I_1 is classified as ecologically advantageous and economically profitable. On the contrary, investment alternative I_2 will only be valued as economically profitable, if

the Intelligent Houses' ability to reduce risk like an insurance is considered. According to this, more IS investments generate benefits if the energy price is volatile, because IS can then be used to reduce this volatility like an insurance. As one can see, the maximal willingness to pay for an IS investment strongly depends on the duration of the letting. However, not the willingness to pay of one single tenant is decisive for the investment amount, but the sum of the willingnesses to pay of all tenants using the property and benefiting from the investment until T_I . Thus, the model at hand considers investments to be funded by more than one tenant. In this way, occurring differences in typical durations of lettings, e.g. between residential and commercial properties, are considered in the model. Yet, it is still indistinct how we can decide between different investments which all fulfill the ecological and economical requirements. For the ultimate decision we need to develop a quantitative optimisation model to identify the optimal investment amount in an economically substantiated way. An optimisation model of this kind shall be introduced and solved in the following chapter.

3.4 Determining the economically optimal investment amount

As stated in assumption *A.1*, landlord and tenant share the necessary investment payout according to the proportion of their marginal willingnesses to pay. Hence landlord and tenant can be considered as a unity and the rental charge can be disregarded. Evaluating all cashflows and risks of the landlord-tenant unity with Bernoulli's preference function we come to the following objective function to be optimised:

$$(4) \quad \Phi(\mu, \sigma) = \Phi(\mu(I), \sigma(I)) = \Phi(I) = -I + \Delta d(I) \cdot \sum_{t=1}^{T_I} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} + \frac{\Delta RR(I)}{(1+i)^{T_I}} + \frac{\alpha}{2} \cdot \Delta \sigma^2(I)$$

The first addend of the objective function is the necessary investment payout, which incurs in T_0 and whose optimal amount has to be determined. The second addend corresponds to the achievable energy cost savings that can be increased in subject to the investment amount. The third addend equates to the additional achievable resale return, which rises in dependence on the investment amount. The last addend corresponds to the volatility reduction of the energy costs weighted with the risk aversion parameter α and which can also be increased with the investment amount. To solve the optimisation problem at hand, we have to analyse the course of the functions for $RR(I)$ and $d(I)$.

At this point a special characteristic of IS becomes evident: Investments in IS can – compared to e.g. architectural investments – be sized more precisely within certain ranges. Imagine a decision maker with limited financial resources who wants to spend a certain amount of money on his property's energy efficiency. He only has enough money to either a) thermally insulate half of the roof using architectural measures or b) invest in IS to integrate chips and controllers for BMS (building management systems) in half of the property's area. Needless to say, insulating half of a property's roof would not induce an appreciable contribution to energy efficiency since the property would still lose heat energy through the non-insulated part of the roof, i.e. making only half the investment does not lead to 50 % savings. The IS measure however can also be integrated partly, e.g. only in certain (separate) parts of the property. This way these parts of the property contribute fully to energy efficiency, so that this investment can actually facilitate 50 % of the achievable savings. The scalability of the IS measure can even be increased by selecting not only certain parts of the building for the integration of chips and controllers, but also selecting certain functional ranges like management of only heating, heating and ventilation or heating, ventilation and air conditioning. The interrelations between the investment amount in IS and its positive effects are hence, at least in certain prevailing ranges, approximately continuous. We account for this IS characteristic and therefore model the interrelations between investment amount and energy demand and resale return in a continuous time model with scalable-at-will IS investment amounts.

As mentioned above, the resale return rises with the investment amount. Due to many properties' value drivers like location, age or condition, one cannot assume that an IS investment can raise the resale return of a property infinitely. Hence we can conclude that the investment's effect declines.

Thus we can conclude a strictly monotone increasing ($\frac{\partial RR}{\partial I} > 0$), concave ($\frac{\partial^2 RR}{\partial^2 I} < 0$) course of the function for RR (starting from the resale return without any IS investment RR_0). This coherence can be formalised exemplarily for $I \geq 1$ (as assumed in the following) as: $RR(I) = RR_0 + s \cdot \ln I$. The parameter s determines the inclination of the resale return curve. The higher s we choose, the more an IS investment raises the building's resale return. Hence the achievable raise of the resale return with an IS investment is $\Delta RR(I) = RR_{new} - RR = RR_0 + s \cdot \ln I - RR_0 = s \cdot \ln I$. The second element of the objective function describes the development of the property's energy demand $d(I)$ depending on the investment amount. As mentioned above, the energy demand decreases permanently when the IS investment amount rises ($\frac{\partial d}{\partial I} < 0$). At this point, we use a linear relation between the energy demand and the investment amount in the relevant region. One possible function for this is $d(I) = d_0 - v \cdot I$. d_0 is the property's energy demand in the initial state, i.e. without any IS investment. v determines the curve's inclination and equates to the marginal energy demand of the property: If the investment amount is raised about one monetary unit, the energy demand of a property drops permanently about exactly v units. The achievable permanent energy demand reduction is: $\Delta d(I) = d - d_{new} = d_0 - (d_0 - v \cdot I) = v \cdot I$. It is important that these coherences are technology-dependent. It is self-evident that an IS investment for the integration of an intelligent energy management system has a different impact on a property's energy demand and its resale return than an investment of the same amount to integrate an intelligent commissioning 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 will cover a general case to illustrate the basic interdependencies. Our model can be tailored arbitrarily to specific IS measures by simply adapting the course of the functions. We hence claim our model to be universally applicable for IS measures. To sum up, we can formalise the induced effects of an IS investment in properties to raise energy-efficiency depending on the investment amount as follows:

$$(5) \quad \Phi(I) = -I + v \cdot I \cdot \sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} + \frac{s \cdot \ln I}{(1+i)^{T_1}} + \frac{\alpha}{2} \cdot (d_0^2 - (d_0 - v \cdot I)^2) \cdot \sigma_E^2$$

A mathematical analysis shows that the objective function is strictly concave in the domain (e.g. $I > 1$) and reaches its maximum at the investment amount

$$(6) \quad I^* = \frac{-1 + v \cdot \sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} + \alpha \cdot v \cdot d_0 \cdot \sigma_E^2 + \sqrt{\left(1 - v \cdot \sum_{t=1}^{T_1} \frac{P_0 \cdot (1+r)^t}{(1+i)^t} + \alpha \cdot v \cdot d_0 \cdot \sigma_E^2\right)^2 + 4 \cdot \frac{s}{(1+i)^{T_1}} \cdot \alpha \cdot v^2 \cdot \sigma_E^2}}{2 \cdot \alpha \cdot v^2 \cdot \sigma_E^2}.$$

Consequently, (if $I^* \geq 1$, which we assume) it is reasonable to raise the investment amount up to I^* . Below this investment amount, an elevation of the investment sum leads to a higher resale return increase, energy cost reduction and reduction of the energy cost's volatility than the necessary payout. In contrast, the positive effects above the investment amount I^* in fact exceed the incidental payouts, but disproportionately high capital expenditure is necessary. Figure 2 shows these coherences:

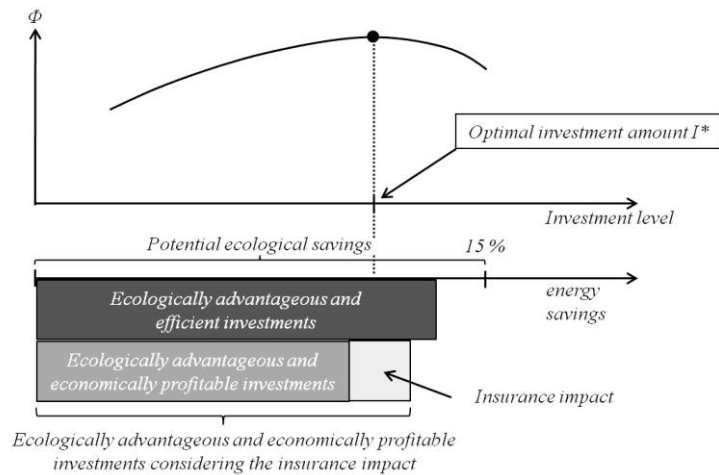


Figure 2. Course of the preference function (exemplary)

By comparing the computed optimal investment amount to the optimal investment amount of a risk-neutral decision maker we can show that the optimal investment amount considering energy price increase and volatility (see *specifications 2 and 3*) is always higher than assuming a non-volatile energy price. Considering the energy price accurately will not only lead to a higher amount of ecologically advantageous and economically profitable investments, but also to an increase of the actual optimal investment amount. By using the presented model, IS' initially mentioned high potentials to reduce the energy demand and the carbon footprint of properties can be utilised far better. The model's application and benefits shall now be illustrated in the following example.

4 Example of use

A building society wants to design a block of offices under construction in an energy-efficient way. The company wants to use the high potentials of IS. For this example we assume the following facts to be given: The duration of the letting after the completion of the property is 30 years ($T_I=30$). 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 IS investment starting from an amount of 1,000,000 monetary units (MU) in a form that can be described by the following function: $RR(I) = 1000000 + 10000 \cdot \ln I$. The property's demand for domestic fuel oil can be lowered about 0.06 l p.a. with each invested MU starting from a basic demand of 3000 l p.a.. Hence we can conclude the following coherence for the energy demand: $d(I) = 3000 - 0,06 \cdot I$. We assume an energy price increase of 7 % p.a with an initial price of $P_0=0,85$ MU/l. The volatility is assumed to be $\sigma_E^2=0,006$. For the parameter of risk-aversion we assume $\alpha=1$. Considering the insurance impact of Intelligent Houses, we recognise that all investment alternatives with an investment amount of at most 74,554.4 MU fulfill the condition (3) and are thus ecologically advantageous and economically profitable. If the company disregards the insurance impact of Intelligent Houses, only those investments with a necessary payout of at most 49,799.4 MU are ecologically advantageous and economically profitable. Alternatives with a higher necessary payout are hence ignored by risk-neutral decision makers in the further decision process. We can determine the position of the optimal investment amount through mathematical optimisation. Considering the insurance impact of Intelligent Houses we determine an optimal investment amount of $I^*=18,748$ MU. An example for an IS investment at this amount is the installation of an intelligent building management system in an adequately large building that runs heating and cooling systems according to tenants' needs and that is operatively coupled to temperature sensors in the whole building and its outer faces. If the company disregards the energy price's volatility, the optimal investment amount is only 4,604 MU. Considering

the insurance impact of IS clearly raises the optimal investment amount and energy demand and carbon footprint can be reduced remarkably. Taking into account energy volatility as illustrated, the economical and ecological potential of IS can be utilised far better than with existing financial valuation methods used today. The application of our model will hence countervail the prevailing structural underinvestment degree.

5 Summary and outlook

IS innovations can generate a valuable ecological and economical contribution. Intelligent House investments lower a property's energy costs permanently and raise its resale return at the same time. Moreover, the energy cost's volatility can be reduced and the tenant is thus insured against energy price volatility. This paper shows how these effects can be evaluated correctly by identifying all ecologically advantageous and economically profitable investments. To choose the economically optimal investment alternative, we developed a formal model. We showed that the amount of all ecologically advantageous and economically profitable investments as well as the optimal investment amount can be increased by considering the insurance effect of Intelligent Houses. Nevertheless several assumptions and resulting conditions of this paper have to be examined critically. First of all, Intelligent Houses have more than the mentioned three specifications which might be of importance too, e.g. the lack of incentives for energy companies to encourage energy-efficiency, the lack of common IS standards to enable interoperability of building management systems or the long time period necessary in the building sector to adopt new technologies (The Climate Group 2008, p.44). Since we put our focus exclusively on the mentioned three specifications, the consideration of other specifications can be next steps for research. Second, the resolution of the landlord-tenant-dilemma may not be possible in each case in practise due to possibly existing legislative reasons (e.g. German landlords can only pass on 11 % p.a. of the costs of energy efficient refurbishment measures to the tenant). In that case, the identified amount of ecologically advantageous and economically profitable investments is likely to sink. Third, the model at hand considers tenant and landlord as a collaboratively optimising unity. The outcome of individually optimising parties could be subject to further research (e.g. by using game theory). Fourth, we developed a continuous time model, which is only applicable for IS investment due to their high scalability. The model is so limited to the range of high scalable IS investments yet. The model is thus not transferable to other (non-IS) measures and is, just like the modelling of dependencies between IS and non-IS measures and the consideration of more complicated scenarios (e.g. house-to-grid technologies), subject to further research. Anyhow, developing our model and concentrating on IS makes sense for us, since the relevance of other disciplines like architecture or material science for saving energy and reducing the carbon footprint is self-evident, whereas the ability of IS as enabler is yet unknown to many decision makers. Even in the current political debate and in the media, the focus is mostly limited to improved insulation materials or double glazed windows. Furthermore, the collecting and consolidation of data as well as the valuation of investments and the generation of incentive systems are IS key issues. For this reason, the discipline of IS should continue to extend the evaluation of its own methods thus revealing its high potentials.

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