Leskinen, Niina; Vimpari, Jussi; Junnila, Seppo

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Using real estate market fundamentals to determine the correct discount rate for decentralised energy investments

Niina Leskinen*, Jussi Vimpari, Seppo Junnila

Department of Built Environment, School of Engineering, Aalto University, P.O. Box 11000, Otakaari 4, Espoo, Finland

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ABSTRACT

Decentralised renewable energy production (on-site energy) is potentially more profitable than commonly believed, especially in urban areas characterized with well-functioning real estate markets and low property yields. Traditional calculation methods, such as the levelized cost of energy, ignore the value on-site energy production can create to property owners through capitalizing the decreased energy costs. Past research has found that these methods are very sensitive to the discount rate, whose selection is very difficult. Evaluating the profitability of on-site energy as part of the underlying property has two major benefits: property yields, defined by real estate markets, can be used as accurate discount rates and economic value created to the property owner is quantified. To justify the use of property yields, risk profiles of energy and property investments are compared in this paper. Subsequently, a theoretical framework of on-site energy investment risks is created and demonstrated with geographical information system analysis modelling the profitability of rooftop photovoltaics in all buildings in the city of Vantaa, Finland. The findings question the traditional way of equalising the discount rates of on-site energy investments in larger geographical areas and suggest that property yields can be used as discount rates for on-site energy investments.

1. Introduction

Decentralised renewable energy production (i.e., building-specific energy solutions, such as rooftop photovoltaics {PVs} and heat pumps), hereafter termed on-site energy, offers cities and real estate owners a great possibility to enhance sustainability. On-site energy production enables built environments, which account for roughly 40% of energy use and carbon emissions (International Energy Agency, 2018), to produce at least a part of the required energy and to increase the share of renewable energy, as many on-site energy technologies use renewable energy sources (Pepermans, Driesen, Haeseldonckx, Belmans, & D'haeseleer, 2005). The combination of urbanisation, growing electricity demand and an urgent need to transition from fossil fuels to renewables, supports on-site energy production (Allam, 2019). Similarly to energy efficiency investments (Christersson, Vimpari, & Junnila, 2015; Popescu, Bienert, Schützenhofer, & Boazu, 2012; Szumilo & Fuerst, 2017), the profitability of on-site energy production should be considered from real estate owners' perspective. As on-site energy production decreases the underlying property's operating expenses (by cutting energy bills), the value of the property increases, as suggested by property appraisal standards (International Valuation Standards Council, 2017). According to the International Energy Agency (IEA) (International Energy Agency, 2019), the cost savings of on-site energy production could amount to 30 % on average based on savings in transmission and distribution. On-site energy production could potentially help to reduce expensive peak loads (Jurasz & Campana, 2019) and protect against rising energy prices and taxes. In addition to savings in operating expenses, many property investors may also see additional indirect economic benefits. Increased sustainability may appeal to tenants and increase the occupancy ratio or rent level and, consequently, the value of the buildings (Eichholtz, Kok, & Quigley, 2010; Fuerst, 2015; Fuerst & McAllister, 2009; Fuerst & McAllister, 2011a, 2011b). Although this paper focuses on direct economic benefits, real estate owners might also see further value in on-site energy production, such as protecting the environment (Chmutina, Wiersma, Goodier, & Devine-Wright, 2014). These benefits form the so-called customer value, where particularly the economic benefits drive the profitability of on-site energy investments. These elements, if properly understood by both the real estate and energy industries, create a strong economic incentive to increase capital flows to building-integrated energy solutions. This benefits both real estate owners by increasing their business opportunities and cities by radically increasing the possibilities to finance the required energy revolution.

Traditional calculation methods for evaluating the profitability of

* Corresponding author.
E-mail address: niina.leskinen@aalto.fi (N. Leskinen).

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on-site energy production, such as the levelized cost of energy (LCOE),[1] have ignored how real estate owners evaluate their investments and how on-site energy production can create value for them. The LCOE method has been criticised in prior works, particularly over the concern that it is very difficult to choose the correct discount rate (Branker, Pathak, & Pearce, 2011; Hernández-Moro & Martínez-Duart, 2013; Joskow, 2011; Lind et al., 1982). The selection process has even been accused of being arbitrary (Breyer, 2019). As part of investment decision analyses, an investor estimates future income and costs, and discounts the cash flows to the present with an appropriate discount rate reflecting relevant risks. The discount rate has a significant effect on profitability especially in long-term investment, which has been noted in earlier research. For instance, Darling, You, Veselka and Velosa (2011) used Monte Carlo analysis to simulate a probability distribution for LCOE values in solar energy (also employing probability distributions in the input parameters) and found that the discount rate was by far the most important factor affecting LCOE. Ondraczek, Komendantova and Patt (2015) note that when capital cost variation between countries is taken into account, the LCOE of solar energy may actually be lower in more northern countries than in equatorial countries with excellent solar irradiation.

Although the importance of financial conditions has been recognised, the typical approach so far has been to select a country-specific or regional discount rate for each energy production method (e.g., (International Energy Agency, 2015; Noothout et al., 2016; Ondraczek et al., 2015). We claim that equalising discount rates within countries is not a sufficiently granular approach. Unlike traditional country-specific energy discount rates, property discount rates vary considerably even within smaller areas and between property types. Evaluating the value of on-site energy production as part of a property's cash flow and using the property yield as the discount rate take into account the variation of profitability in a more precise way and thus reveal the customer value of on-site energy production. This paper continues the work of Vimpari and Junnila (2017; 2019), who first introduced the idea of applying property yields when analysing the profitability of on-site energy investments. However, they have assumed that property investment risks are equivalent to on-site energy production investment risks. This paper instead questions this assumption and sets to study the issue. There is a need to examine and compare the individual risk components (reflected in the discount rates) of property and energy investments more comprehensively in an on-site energy investment context. This paper inclusively considers all related risks and carefully examines whether the property yield can actually be used as the discount rate in the economic analysis of on-site energy investments.

This paper is structured as follows. First, to understand the risks of on-site energy investments, we examine the risks related to energy and real estate investments. The theoretical framework for the risks of on-site energy investments is then created and empirically demonstrated. We have chosen rooftop PVs for our empirical analysis, which have enormous potential to produce renewable on-site energy (Defaix, van Sark, Worrell, & de Visser, 2012; Ram et al., 2019). Using geographical information system (GIS) analysis, the empirical part of this paper describes from the real estate investor's perspective at what point on-site energy production becomes profitable in all the buildings in the city of Vantaa, Finland. Finally, a discussion and conclusions are presented.

According to our analysis, using property yields as discount rates in evaluating the profitability of on-site energy investments has several advantages over the traditional country-specific approach. The value of on-site energy investments can be better understood when the value created through location is incorporated into the profitability analysis through location-dependent property yields. Furthermore, the property yield is determined by the well-functioning and active real estate transaction market, and it contains an assessment of many risks that are otherwise hard to quantify separately. Our results suggest that property yields reliably reflect the risks of on-site energy investments. Thus, they can be used as the discount rate in evaluating the profitability of on-site energy. Taking into account the value created for individual property owners, we show that the profitability of on-site energy can vary substantially even within a small area, not merely between countries, as traditionally believed in the energy industry.

2. Risk of energy and real estate investments

The risks of any investment are reflected in the required rate of return used as a discount rate: the greater the risks, the greater the required return. We will first briefly explain the general concept of the required rate of return. We will then further discuss risk premiums, which represent part of the required rate of return in energy and real estate investments.

2.1. Required rate of return

Any investment can be seen as an exchange of current capital for a future income stream and future capital value. Because a sum of money receivable in the present is more valuable than the same amount in the future, the time value of money is acknowledged by discounting. In the discount factor, $1/(1 + \mathrm{R})^t$, the discount rate R represents the required rate of return, and t represents the number of years.

According to Fisher's famous theory of interest (Fisher, 1930), the required rate of return comprises three factors. First, an investor has to be compensated for postponing current consumption and tying up the invested money. Due to lost liquidity, the investor requires at least a risk-free rate of return on the money. Second, inflation will over time decrease the purchasing power of the money, and the investor requires compensation for that. Third, the money could be partly or entirely lost, and therefore the investor needs a reward to compensate for the added risk. Risk, defined as variance in actual return compared to expected return (Damodaran, 2002), is included in the required rate of return. The riskier the investment, the higher the risk premium. The required rate of return can be expressed as follows:

$$\mathrm{R} = R_f + \mathrm{i} + R_p$$

R = required rate of return R_f = the real risk-free rate of return R_p = the risk premium (compensation for additional risk) i = compensation for expected inflation

In the real estate industry, the discount rate that reflects the required rate of return is called the property yield.[2] The property yield would be equal to the required rate of return if there was no growth or depreciation (Baum & MacGregor, 1992), but income is typically assumed to grow in the long run, as rental agreements commonly allow the owner to raise rents at the same rate as inflation. A higher growth rate of income leads to a higher value of the property. Thus, the growth rate of rents is deducted from the required rate of return. The decrease in an ageing property's ability to generate rental income and capital value compared to an equivalent new property is termed depreciation (Hoesli & MacGregor, 2000). Depreciation is an essential element in real estate, as it affects all properties to at least some extent. The greater

[1] LCOE represents the full life-cycle costs of an energy system per unit of produced electricity.

[2] To be exact, this is called initial yield in the real estate industry. For the sake of clarity, we refer to initial yield as property yield. The term *yield* is used as a measure of return to describe the relationship between income and the value of an investment. Two types of yield—total return and current income per capital value—are commonly used in all investment classes, with the exact terminology varying between industries. In the real estate industry, those yields are called equated yield and initial yield. Equated yield measures total return calculated as internal rate of return, and initial yield is the ratio of current income and present value (of the real estate). Initial yield is often called the capitalisation rate (cap rate) in real estate research.

the depreciation, the lower the value of the property. Thus, depreciation is added to the required rate of return. The property yield is extracted from market data (transactions or valuations) and represent the ratio of current income to the present value of the property; thus, it corresponds to the price-to-earnings ratio in the stock market.

Property yield (Y) = net operating income (NOI)/present value (V)

Considering both growth and depreciation, property yield can be written as follows[3] (for the full mathematical derivation of property yield components, see (Baum & MacGregor, 1992)):

$$Y = R_f + i + R_p - G + d$$

Y = Property yield R_f = Risk-free return R_p = Risk premium i = inflation G = expected growth rate of rents d = depreciation

The risk premium is specific to each individual investment (Baum & MacGregor, 1992). In the next two sections, the risk premium is examined in both energy and real estate contexts. Understanding the risk premiums of both investment classes is essential in constructing a risk profile of on-site energy investments.

2.2. Energy risk premium

Based on prior research (Burger, Graeber, & Schindlmayr, 2007; International Energy Agency, 2007, 2015; Noothout et al., 2016), the components of the energy risk premium can be grouped into two main categories and several subcategories, which are summarised in Table 1.

Political and technological risks have a significant effect on an energy investments' cash flow and have therefore drawn much attention in research papers. The political risk premium increases with greater political uncertainty and the proximity in time to a policy change. Because the value of the waiting option increases as the time of the political change approaches, frequent small changes are more harmful to investors than larger infrequent changes. Technological improvements may have a major impact on initial investment costs, operating costs or the efficiency of production, but the degree and pace of the changes are typically very hard to predict. Some technology reforms make old solutions outdated and inefficient, and it is also possible for improvements in one sector to adversely affect the economics in another. Desired technological development, however, creates uncertainty from the investor's perspective, especially in terms of timing. Investors who expect a significant drop in the investment cost can profit by postponing the investment and waiting for the cost to drop.

2.3. Real estate risk premium

Combining the instructions of the Royal Institution of Chartered Surveyors (2010) and empirical research on the topic, the real estate risk premium comprises market- and project-specific risks[4], shown in Table 2.

Many of the real estate risk subcategories culminate in the macro and micro location of a property. The more central or appealing the location, the less risky the property, as the probability and length of vacancy decreases and the probability of attracting creditworthy tenants (with desired lease structures) increases. Properties with appealing locations enjoy higher rental levels and rental growth, as well as higher investor demand decreasing illiquidity. The less risky the property, the less intensive and more predictable the management it requires, enhancing the predictability of ownership and management costs. Furthermore, an appealing location decreases the risk of obsolescence or at least increases the possibilities and probability of profitable renovations or refurbishment.

3. Risk of on-site energy investments

Having covered the risk premiums of energy and real estate investments, we proceed to discuss the risk profile of on-site energy investments. The first part considers the risks related to on-site energy investments, comparing the suitability of energy and real estate risk-assessment practices. The second part demonstrates the theory in practice, using data on all buildings located in the city of Vantaa, Finland.

3.1. Risk of on-site energy investments: Theoretical framework

The first and perhaps most easily defined component of on-site energy's risk profile is the risk-free rate of return. The suitable risk-free rate is chosen based on the investment horizon, which is long in both energy and real estate investments. Given the long investment horizon, the 10-year government bond serves well to represent the risk-free rate in on-site energy investments. Inclusion or exclusion of inflation as a separate component follows from the choice of nominal or real cash flows. Irrespective of the chosen approach, the inflation rate used for investments within one country generally does not vary by investment type.

On-site energy investments are quite illiquid, as they are a fixed part of the underlying building. If the underlying property is sold, the on-site energy investment is also sold as a part of the transaction. Therefore, the illiquidity risk premium must be included in on-site energy investments as in the underlying property. General macroeconomic risks should also be taken into account when assessing the risks of on-site energy investments. The property yield suitably reflects these risks. As in any other energy investment, the risk premium of on-site energy requires an assessment of demand and counterparty credit risks. The demand risk is taken into account in the property yield, as it encompasses the vacancy risk of the underlying property. Investors consider counterparty credit risk when examining the types and credit ratings of tenants as part of their risk analysis. The counterparty credit risk of on-site energy is accordingly incorporated into the property yield.

Policy risk is an important divergence in the risk of energy and real estate investments. In the energy sector, policy risks have garnered much attention, while stable property rights are a pillar of modern society, and one of the most important market selection criteria for property investors (Falkenbach, 2009). Accordingly, political risks are not a grave concern in the real estate industry. On one hand, the risk-free rate captures some of the risk associated with the stability and reliability of a country and its investment atmosphere. On the other hand, energy and real estate investments are regulated by different sets of laws, and—what is most noteworthy—the energy sector is very sensitive to changes in the political environment. Politicians can make decisions favouring some energy production methods over others, and the changes can be unpredictable. Because of a combination of increasing electricity demand and climate-change mitigation, however, the share of renewable energy is expected to increase through actions taken independently by local governments and due to the implementation of international agreements.

Real estate risk premium is affected by the location, type, age, condition and renovation status of the property, while the energy risk premium does not consider any of those factors. We argue, however, that these factors are also relevant for evaluating on-site energy

[3] Property yield is often simplified to Y = R_f + R_p - G. Baum and MacGregor (Baum & MacGregor, 1992) note that, in the real estate sector, the practice is to use a nominal framework instead of a real framework in cash flow analysis, meaning that inflation is included in the cash flows. Thus, the risk-free rate also needs to guarantee nominal risk-free return and includes compensation for inflation. This means that, in the above equation, R_f + i simplifies to R_f. In addition, Hoesli and MacGregor (Hoesli & MacGregor, 2000) mention that depreciation is often deducted from the growth rate, whereupon the growth rate becomes a net rate and (-G + d) simplifies to (-G).

[4] Project-specific risks are usually called property-specific risks in real estate research. In order to facilitate the comparison of risks between property and energy investments, we have chosen to use the term project-specific risks.

Table 1
The risk premium of energy investments.

Type	Risk	Description
Market risks	Macroeconomic	Risks associated with business cycles and fluctuations in general capital market variables, as well as changes in fiscal policy, exchange rates, availability and cost of human resources and financing (Awerbuch & Sauter, 2006; International Energy Agency, 2007, 2015).
	Energy demand	Energy demand is strongly linked to aggregate industrial output representing business cycles (Thoma, 2004).
	Input and output price risks	Fluctuating energy prices are also an important source of uncertainty in energy investments as uncertainty affects input and output prices (International Energy Agency, 2015).
	Political risks	Political risks include uncertainty regarding environmental regulations and policies that require or encourage the installation of cleaner technologies (and alter energy demand), uncertain carbon prices and governmental energy policies (such as those concerning general legal and regulatory frameworks for trade), investment and electricity markets, taxation, energy subsidies and market reforms. In some regions, geopolitical conditions, and international regimes on climate-change mitigation are relevant risk factors (Blyth & Yang, 2007; Blyth et al., 2007; Fuss, Szolgayova, Obersteiner, & Gusti, 2008; Fuss, Johansson, Szolgayova, & Obersteiner, 2009; International Energy Agency, 2003; International Energy Agency, 2015; Ishii & Yan, 2004).
Project-specific risks	Project management risks	Construction, documentation, administrative risk related to licensing (lead time and the number of permits needed), grid connection (process and lead time), political risk at the local level and the availability of financing for the specific project, as well as social acceptance risk. (International Energy Agency, 2015; Nazari, Maybee, Whale, & McHugh, 2015; Noothout et al., 2016)
	Technological risk	Technological risks include risks associated with development of technologies (impacting the timing of an investment) and technology-specific operational risks regarding output quantities, adequate human resources, investment and operating costs, technological degradation and safety (Fuss & Szolgayová, 2010; International Energy Agency, 2015; Murto, 2007).
	Legal risks	Documentation/contract risk, jurisdictional risk. (International Energy Agency, 2007).

Table 2
Real estate risk premium.

Type	Risk	Description
Market risks	Macroeconomic risks	General capital market variables reflecting macroeconomic conditions, such as the risk-free interest rate, the term spread of interest rates reflecting expected inflation and stock market price-to-earnings ratios, consumption per capita and international capital flows, explain variations in property yields (Ambrose & Nourse, 1993; Chervachidze, Costello, & Wheaton, 2009; Froland, 1987; Ling & Naranjo, 1997; McAllister & Nanda, 2015; Oikarinen & Falkenbach, 2017).
	Illiquidity upon sale	Properties are rather illiquid compared to other investment types, such as bonds and stocks, and there is no public marketplace for selling individual properties. Sales processes are long and resource-intensive (Shilling, 2002).
	Local property market risks	Location heterogeneity, diversity of the local employment base, mix of public and private tenants, normalised vacancy rate, level of office space absorption, employment-growth stability, rent levels and rental growth rate, greatly explain the time variation of property yields (Hendershott & MacGregor, 2005b, 2005b; Sivitanidou & Sivitanides, 1999b, 1999b; Wheaton, 1999).
	Locational, economic, physical and functional depreciation	Depreciation is caused by the physical deterioration or obsolescence of a building or site. Building-specific deterioration, linked to the passage of time, includes wear and tear through use or environmental factors. By contrast, obsolescence is linked not to the passage of time but to a decline in utility, meaning that the property can no longer meet the demands of tenants. In the risk premium, uncertainty is related to estimating the possible values of depreciation (Hoesli & MacGregor, 2000; Pinder & Mansfield, 2008).
	Political risks	Political risk arises when governments unexpectedly change the logic by which investors operate, through interventions such as barriers to capital flows, changing tax regulations, added exchange controls or even expropriation (Cashman, Harrison, & Seiler, 2016; Lee, 2001).
Project-specific risks	Covenant risk	An investor needs to assess the creditworthiness of the tenants, i.e., how likely they are to meet the agreed rental payments. Good tenant diversification (tenant mix) may decrease the risk (Chaney & Hoesli, 2015).
	Vacancy risk	Failure to re-let is expressed as vacancy risk. A property's attractiveness to prospective tenants, including location and building flexibility, determines the probability and length of future vacancy. (Royal Institution of Chartered Surveyors, 2010)
	Lease structure risk	There is uncertainty related to future lease structures, such as lease breaks and options, the timing and method of rent reviews and the question of how to divide operating costs and capital expenditure between the property owner and the tenants (Royal Institution of Chartered Surveyors, 2010).
	Costs of ownership	Uncertainty related to the costs that are the owner's responsibility affect the risks of properties (Royal Institution of Chartered Surveyors, 2010).
	Location	The more central or appealing the location, the less risky the property, which is confirmed in several studies (Alonso, 1964; Hendershott & Turner, 1999; Janssen, Söderberg, & Zhou, 2001; Netzell, 2009; Ricardo, 1821; Saderion, Smith, & Smith, 1994).
	Property type	Office, retail, industrial, logistics and apartments have different risk profiles. (Ambrose & Nourse, 1993; Hendershott & Turner, 1999; Sivitanides, Southard, Torto, & Wheaton, 2001).
	Age, condition, renovation status	Age, condition and renovation status affect the risks of properties (Chaney & Hoesli, 2015; Janssen et al., 2001; McDonald & Dermisi, 2009; Netzell, 2009; Saderion et al., 1994).

investments. There is greater risk in installing rooftop PVs, for instance, on older properties that have not been renovated. Location and type of property have been neglected in current on-site energy investment evaluation methods, ignoring a major part of the value to the property owner. Applying the same discount rate (property yield) as in the underlying property, a significant part of the value of on-site energy production is created through location, and the value is heavily dependent on the location of the underlying building. This is demonstrated in the next section.

Technological risk, highly relevant in renewable on-site energy production, is not taken into account in property yields. New technologies are riskier from an operational point of view than conventional ones, as discussed earlier. However, the International Valuation Standards (International Valuation Standards Council, 2017) suggest that the value of any permanent technical building component depends on its ability to affect the underlying property's net cash flow. In that sense, on-site energy production should not be considered separately from the property investment. If some of the risks of on-site energy are already considered in the underlying property's cash flows (e.g., operational risks can be reflected in the cash flow by adding excess cost reserves), they should be excluded from the risk premium of the discount rate (property yield) to avoid a double accounting of risk (Royal Institution of Chartered Surveyors, 2010). Although the effect of on-site energy production, as well as some of its technological risks, is included in the underlying property's net cash flow, investors may feel that there is still uncertainty in their estimates. Accordingly, they might increase the risk premium. This also applies to technological degradation.

In an environment of declining investment costs, waiting may be more valuable than investing. For example, technological development has been relatively rapid in PVs. The learning rate (i.e., the cost reduction per every doubling of cumulative installed capacity) is a common measure of technological development. Several studies report that the learning rate of PVs is around 20% (Fraunhofer, 2019; Rubin, Azevedo, Jaramillo, & Yeh, 2015; Samadi, 2018). Considering these relatively high historical learning rates, investors are likely to anticipate continued declining costs in future. However, declining costs are not relevant in the assessment of the risk premium, as they affect only the optimal timing of the investment. If the investment is profitable with current prices, declining investment costs will not change that. However, it may be even more profitable to invest later, as investment costs decline.

The growth of net income is relevant in both energy and real estate investments. Rents are typically tied to the consumer price index (CPI), which differs from the growth rate of electricity prices. The effect of evolving electricity prices on the value of on-site energy production is taken into account in the operating expenses of the underlying property. If electricity price growth was not considered in the cash flow analysis, relying on property yield underestimates the value of an on-site energy investment for the property owner. This is because the growth rates of electricity prices have been greater in the long run than that of the CPI. For instance, average annual growth of inflation was 1.6% between 2000–2018 both in Finland and in Germany, while energy prices grew 5.7% on average per year in both countries (Destatis Statistisches Bundesamt, 2018, 2019; Statistic Finland, 2019a, 2019b). The higher the electricity price, the more profitable the on-site energy investment for the property owner. In that sense, on-site energy works as a hedge against rising electricity prices. As (the majority of) the produced energy can be consumed on-site, the property owner also avoids the transfer fees and taxes that form a significant part of the total electricity bill (Eurostat, 2019).

Two types of depreciation—deterioration and obsolescence—affect the real estate risk premium, while only deterioration (often referred to as technological degradation in the energy sector) is relevant in energy investments. This technological degradation of on-site energy production is included in the underlying property's cash flows in operating expenses and need not be reflected by the property yield. Furthermore, the lifecycles of properties and on-site energy production technologies are rather long, and in that sense technological degradation can be assimilated (Vimpari & Junnila, 2017). Obsolescence, in turn, applies only to real estate. Obsolescence can in theory be diversified away by investing in diverse property types in various locations (Hoesli & MacGregor, 2000), and accordingly it should be ignored by property yields. Table 3 summarises the risks of on-site energy investments.

According to our analysis, using the property yield as the discount rate in on-site energy investments has several advantages over the traditional approach of selecting a country-specific discount rate when evaluating on-site energy investments. First, the property yield can be extracted from the real estate markets, which are very active. Second, it contains an assessment of many relevant risks, such as demand, counterparty credit risk, age and condition of the property, that can otherwise be very hard to quantify. Third, using the property yield as the discount rate reveals the otherwise hidden customer value. A comparison of the energy and real estate risk premiums in an on-site energy investment context reveals that it is reasonable to use the property yield as the discount rate when assessing the value of on-site energy. Political and risks related to new technologies are the most important divergences between the risks of (on-site) energy and real estate investments, increasing the risks associated with on-site energy compared to those of properties. Political risks are to some extent included in the property yield, while new technology risks are not. However, the relevant technological risks can mostly be reflected in cash flows and need not be included in the property yield. The faster growth of electricity prices than the growth of rents, as well as absence of obsolescence in on-site energy investments, decrease the difference between the risks of properties and those of on-site energy production. Adding a premium reflecting additional risks on top of the property yield may be justifiable.

3.2. Risk of on-site energy investments: Visualisation

The risks of energy investments are traditionally evaluated from country- and technology-specific perspectives that equalise the investment risks in relatively large areas for each energy production method (e.g., International Energy Agency, 2015; Noothout et al., 2016; Ondraczek et al., 2015). Fig. 1 illustrates this traditional way of thinking. We, however, claim that the profitability of on-site energy between areas and even adjacent buildings is non-uniform, as property yields depend on the individual characteristics of each property. Employing property yields as discount rates reveals the variation in the profitability of on-site energy production.

To reveal the variation of profitability, we analyse each property individually with the help of GIS analysis. This analysis is based on the same data that was used by Vimpari and Junnila (2019) in their research, where a detailed description of the methodology and data used can be found. In their study, the return of rooftop PVs was calculated separately for 89 000 buildings in the Helsinki Metropolitan Area (comprising the cities of Helsinki, Espoo, Kauniainen and Vantaa) by combining several datasets from both public and private sources. The value of on-site energy production for self-consumption is the sum of spot price, taxes and distribution fees, while surplus production only receives the spot price. Accordingly, the economically optimal system size maximizes the net present value of the investment:

$$\text{NPV} = -\ \text{CAPEX} + \sum_{1}^{t} \frac{(E_{se}{*}P_{se} + E_{su}{*}P_{su}){*}(1-d) - OPEX)t}{(1+y)t}$$

Where, Table 4 explains the variables.

The calculated current and projected return for every individual rooftop allows for estimating when rooftop PV becomes profitable from property owners' perspective. Rational property owners will adopt rooftop PV, when the return of PV exceeds that of the underlying property (property yield). The year in which rooftop PVs become profitable in each property is termed the adoption year. The present study has combined this data with open source GIS data (Avoindata.fi., 2019) to demonstrate visually how the profitability of rooftop PVs develops in various parts of Vantaa. First, we analyse the whole city of Vantaa to demonstrate our theoretical approach at the city level. We then focus on a single district in Vantaa to show how the profitability varies at a more detailed resolution.

3.2.1. The city of Vantaa

The first map demonstrates the diffusion of rooftop PVs in various areas of Vantaa. For the sake of clarity, we have chosen only one property type, retail, for this demonstration. The dark blue symbol indicates properties for which the installation of PVs is profitable by

Table 3
Comparative risks of real estate, energy and on-site energy risks. Property yield is comprised of the following elements: Y = $R_f + i + R_p - G + d$, as explained in section 2.1. In the third column, '+' means that the risk is greater in on-site energy than in real estate, '- 'that the risk is less than in real estate and '=' that the risk components are equal for both investments.

	Risks	On-site energy risks	+ / - / = compared to real estate
Risk-free rate + inflation, $R_f + i$		Given the long investment horizon, the 10-year government bond represents the risk-free rate.	=
Risk premium, R_p: Market risks	Macroeconomic risk	Macroeconomic risks need to be included in the risk premium of on-site energy investments. Given the co-location, macroeconomic risks are identical.	=
	Illiquidity	On-site energy production investment as a permanent building component will be sold as part of the property; therefore, the same illiquidity risk premium applies to on-site energy investments as to the underlying property.	=
	Local real estate market risks	Represents risks associated with energy demand in on-site energy investments and with the availability of financing.	=
	Policy risk	Policy risks are an essential part of on-site energy investments. Policy risks are greater in (on-site) energy than in real estate investments.	+
Risk premium, R_p: Project-specific risks	Covenant risk	Covenants risk, known as counterparty credit risk in the energy industry, must be included in the on-site energy risk premium. As (the vast majority of) the produced energy is consumed on site, the covenant risk of the underlying property represents the counterparty credit risk in on-site energy investments.	=
	Vacancy risk	As the majority of on-site energy production is consumed on site, the vacancy risk of the underlying property suitably represents the risks associated with energy demand in on-site energy investments.	=
	Lease structure risk	Changing lease structures must be considered in on-site energy production. Property owners, who are responsible for properties' operating expenses, directly and immediately benefit from on-site energy production. In the long run, property owners will gain the benefits of on-site energy production (as higher rents) in lease structures where tenants are responsible for operating expenses, similarly to other green property investments (Reichardt, 2014).	=
	Age, condition, renovation status	There is a greater risk in installing on-site energy in older/unrenovated buildings than in newer/renovated ones. Therefore, these characteristics of the underlying property need to be reflected in the risk premium of on-site energy investments.	=
	Cost of ownership and management	Similarly to other permanent buildings components, on-site energy production does not affect the risks of ownership and management costs.	=
	Location	On-site energy investments are permanent building components and a significant part of their value is created through location, as in the underlying property. The location-dependent part of the value is the same for properties and related on-site energy investments.	=
	Technological risks: Operation risk of new technology	Risks related to the operation of new technologies is important in on-site energy investments. They are not accounted for in the property yield. However, risks related to the operation of new technology can be reflected in the in the operating expenses of the underlying property.	+
	Technological risks: Risk of declining costs in new technology	Declining costs affect only the optimal timing of an investment. If the investment is profitable with current prices, declining investment costs will not change that. It only means that the investment will be even more profitable later.	+
Growth, G		The growth of electricity prices needs to be included in the on-site energy risk premium, as inflation does not entirely capture the growth. The growth of electricity prices has historically been greater than that of rents (usually tied to the CPI), and thus the property yield underestimates this component.	–
Depreciation, d	Deterioration	Deterioration, usually referred to as technological degradation in energy investments, is included in the operating expenses (part of the cash flows) of the underlying property. Technological degradation of properties and on-site energy production can be assimilated due to the long lifecycles of both.	=
	Obsolescence	Non-existent in on-site energy investments, but relevant in properties. In theory, property yields should ignore obsolescence as it is an unsystematic risk that can be diversified away by investing on diverse property types in various locations.	–

2020. Fig. 2 clearly shows that rooftop PVs become profitable first in the established retail areas with the lowest retail property yields: Myyrmäki, Aviapolis, Tammisto, Tikkurila and Porttipuisto. Myyrmäki is one of the older retail areas in Vantaa, with good accessibility by both car and train. One of the bigger shopping centres in Finland, Jumbo, is located in Aviapolis, attracting numerous visitors to the area. The vast number of visitors has enabled business opportunities for specialty and big box retail near the shopping centre and in Tammisto. Tikkurila is the administrative centre of Vantaa. The attraction of Porttipuisto is its IKEA department store, which generates possibilities for other retailers as well. The findings of this city level analysis can be reduced to a rule of thumb: The more appealing the location, the lower the property yields and the sooner the adoption of PVs becomes profitable.

If the discount rates were chosen according to the traditional country-specific approach, investing in rooftop PVs in the presented location would most likely be seen as unprofitable. For instance, one of the largest energy companies in the Nordics, Fortum, uses 10.0% as a target return on capital (Fortum, 2018), while the return of rooftop PVs varies between 5.2% and 9.2% in the area. This means that none of the locations would be profitable. By contrast, the property yields in the

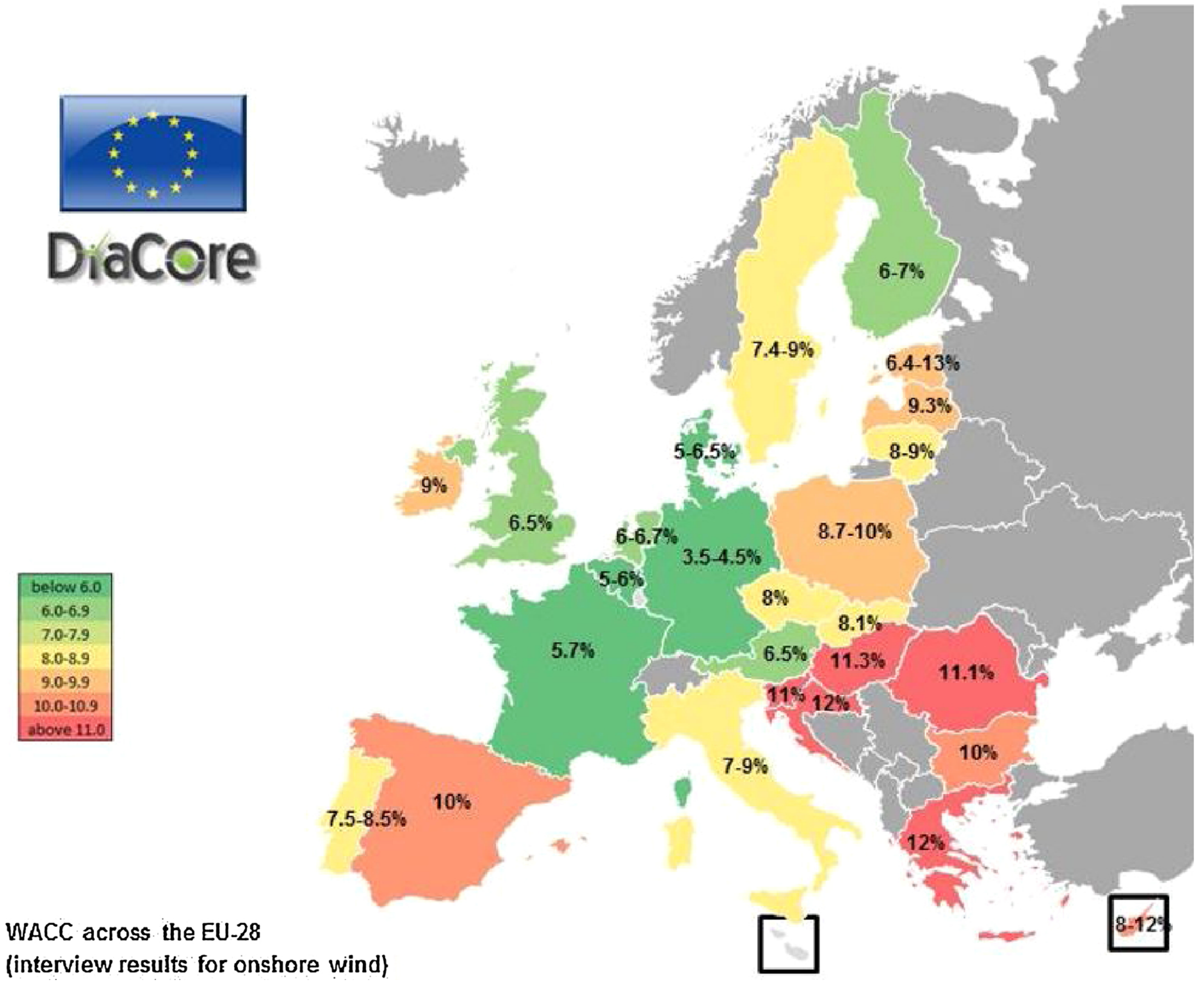

Fig. 1. The risk of energy investment is typically evaluated from country- and technology-specific perspectives. The map demonstrates this traditional way of thinking and shows the weighted average cost of capital[5] across the EU-28 for onshore wind (Noothout et al., 2016). The traditional way of evaluating the profitability of energy investments ignores customer value.

area vary from 4.2% to –11.8%, which makes some of the locations profitable already. Our analysis takes into account the value created for individual property owners, which makes investing in rooftop PVs already profitable for many of the properties in the first year analysed (2019). Investing in on-site energy production decreases the operating expenses of the underlying property, and the property owner also avoids paying energy taxes and transfer fees. It is not merely the savings that are relevant but particularly the value created through capitalising the savings. Our analysis indicates the year (adoption year) when the yield of rooftop PVs becomes the same or higher than that of the underlying property. When the yields are the same, the property value increase is the same as the investment cost of the rooftop PV system. When the rooftop PV yield is higher than the underlying property yield, the property value increase is higher than the investment costs, i.e., the investment creates added value for the property owner. The larger the difference, the larger the added value created.

3.2.2. *The Aviapolis area*

We will now focus on one area, Aviapolis, located near the airport, to show that the profitability also differs between properties even in a small area, as Fig. 3 shows. In the Aviapolis area, property yields are lowest in apartments, and, accordingly, PVs are already profitable in the vast majority of buildings in the first year of the analysis. In reality, it is doubtful whether the owners of residential properties will behave according to the results of our analysis. The value-added perspective is more suitable to commercial properties, which are professionally managed and regularly appraised using discounted cash flows. Furthermore, according to current legislation, apartment buildings receive no tax benefit from on-site energy production, unlike commercial buildings.

In this area, office yields are quite stable, as the vast majority of the office stock is very similar, comprising modern, recently constructed business parks with good services for tenants. However, there is a slight difference in the adoption year in some of the office buildings, which is explained by differences in age and available roof area. Industrial property yields are higher than other property yields in the area. Accordingly, rooftop PVs become profitable later for these properties than for other property types. The industrial properties located closest to the airport have the lowest yields in the area and the earliest adoption year for rooftop PVs.

To summarise, we have shown that the profitability of rooftop PVs can vary even in adjacent buildings. We have used the average estimated market property yield for each property type. The individual investment characteristics of each property, such as the length of lease agreements, the type and quality of the tenants and the technical

[5] Depending on the capital structure of a project, either the equity cost of capital or the weighted average cost of capital is most often used as the discount rate (Berk & DeMarzo, 2007).

Table 4
Description of data used to evaluate the profitability of rooftop PV in all buildings located in city of Vantaa. A detailed description of data and methodology can be found in Vimpari and Junnila (2019). This study combines the described data with open source GIS data to visualize the variation in profitability of rooftop PV in the city of Vantaa.

Data	Description
Technical building data	Property identifiers, construction year, number of floors, floor area, heating type and type of use.
Available roof area, *ARA*	Roof size is approximated by dividing the floor area by the number of floors. Available roof area for PV was then calculated by using coefficients 0.15, 0.175, 0.2 and 0.3 for residential, office, retail and logistics buildings respectively, based on previous research.
Rooftop PV system size	System size = (floor area/number of floors)*ARA*(1/6) (The constant 1/6 is derived from the fact that 1 kWp requires approximately 6 sqm of roof area with current technology)
Electricity consumption	Electricity consumption was estimated for each building type from real energy consumption data provided by the local energy company.
Electricity production, E_{se} & E_{su}	837 kWh/kWp based on real hourly irradiance data in the city of Vantaa and previous research. Electricity production for self-consumption (E_{se}) and surplus (E_{su}) are separated, for more information see Electricity prices below.
Electricity prices, P_{se} & P_{su}	The average Nordpool hourly spot price for Finland. Expected annual increase of electricity prices is 2.5 %. Relevant taxes and distribution costs are calculated separately. The value of on-site energy production for self-consumption (P_{se}) is the sum of spot price, taxes and distribution fees, while surplus production (P_{su}) receives only the spot price.
Operating expenses, *OPEX*	Varying between 13.5-19.5 EUR/kWp/year in commercial properties depending on the size of the PV system, 24 EUR/kWp/year in residential buildings due to value added tax.
Capital expenditure, *CAPEX*	Varying between 900-1300 EUR/kWp in commercial buildings depending on the size of the PV system, 1600 EUR/kWp in residential buildings. Yearly decline in capital expenditure is assumed to be 3 % based on previous research.
Economic lifecycle, *t*	30 years based on previous research.
Annual degradation, *d*	0.5 % based on previous research.
Property yield, *y*	Market information of property yields taking into consideration property type, age and location of properties.

condition, affect the determination of the property yield, as explained in 2.3. This means that there would be even more variation in the profitability of PVs between the properties than is presented here. The results also clearly show the importance of location; the more central or appealing the location, the more profitable are rooftop PVs, as property yields decrease along with declining risks. Applying property yields, which capture the value of location, in the profitability analysis of on-site energy implies that on-site energy is more profitable in appealing urban locations than in remoter ones.

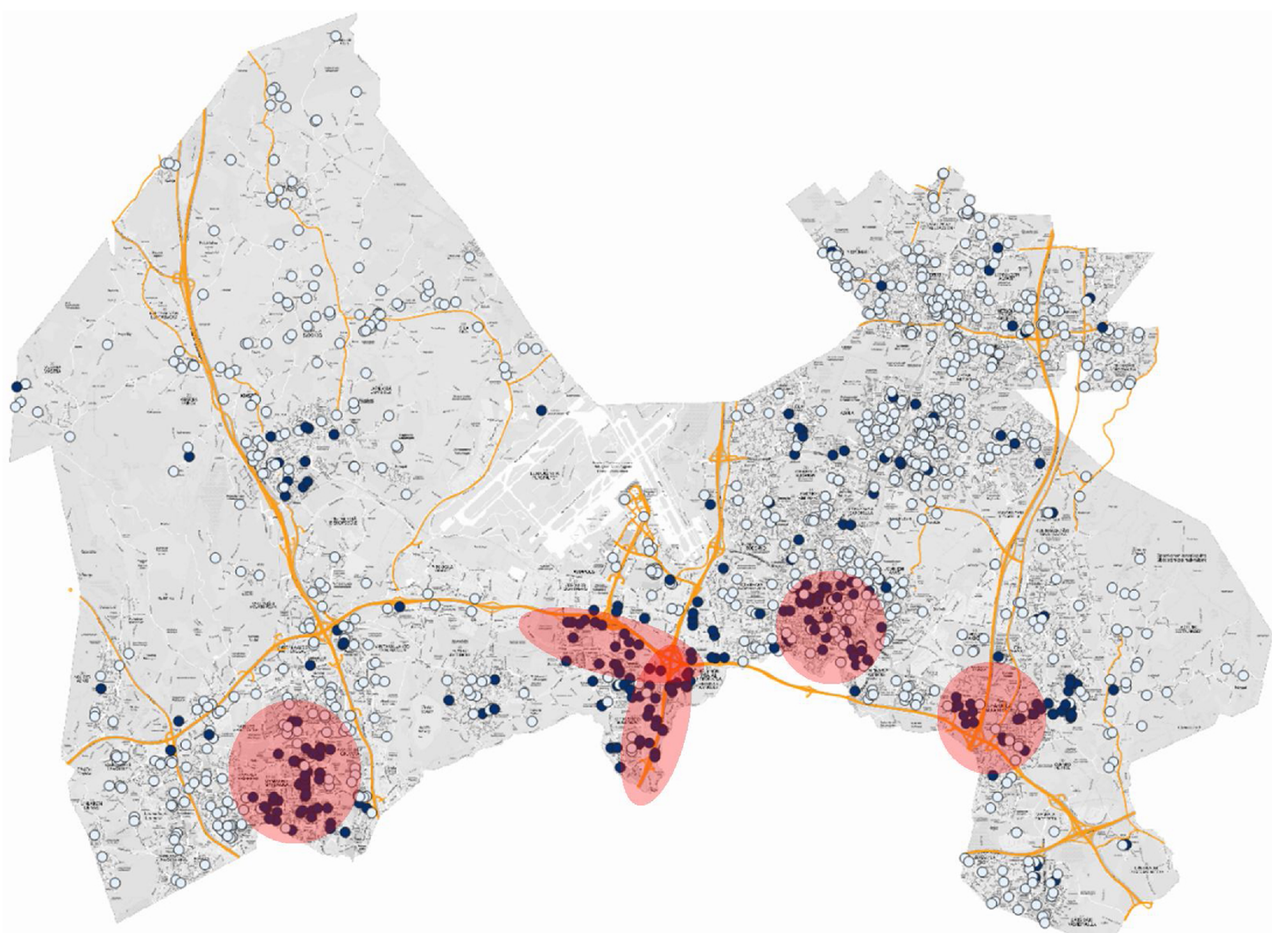

Fig. 2. The dark blue symbol indicates the retail properties for which rooftop PVs become profitable in 2020. These areas are the well-established retail areas of Myyrmäki, Aviapolis, Tammisto, Tikkurila and Porttipuisto along the main traffic routes. The more attractive the location, the lower the property yields and the sooner rooftop PVs become profitable. The light blue symbols mark the retail properties for which rooftop becomes profitable later than 2020.

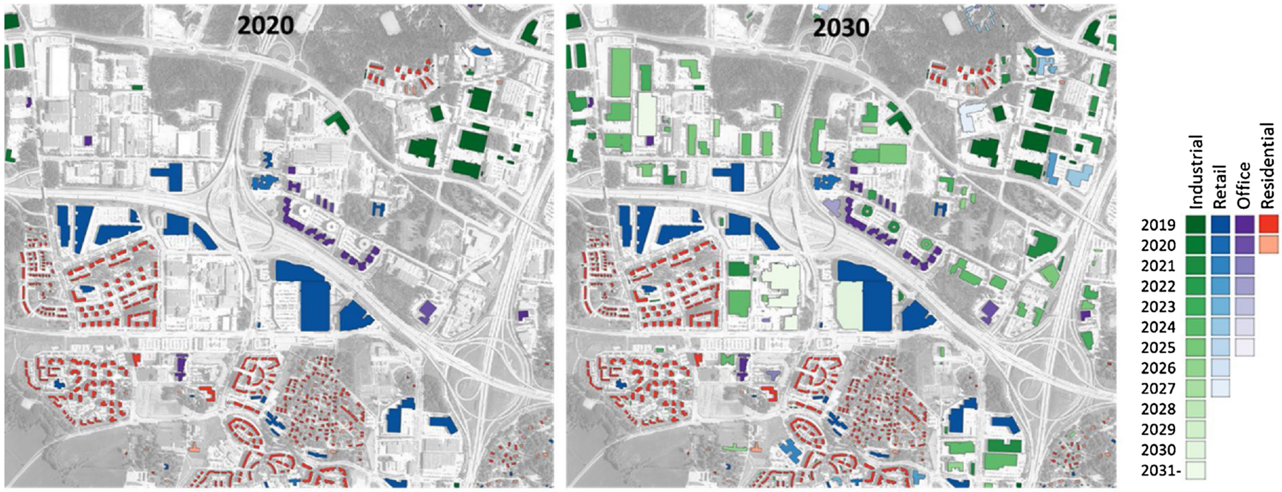

Fig. 3. Adoption years for PVs in various property types in the Aviapolis area in 2020 (left) and 2030 (right). The darker the colour, the sooner rooftop PVs become profitable.

4. Discussion

This study examined the use of property yields in evaluating the profitability of on-site energy production. Based on prior research, a theoretical framework was built to evaluate the risk of on-site energy investments from a real estate perspective. Our results indicate that property yields reliably reflect the risks of on-site energy investments. Using property yield as the discount rate offers several benefits. First, property yields are derived from easily available market information based on actual property transactions. Second, property yields reflect risks, that may otherwise be hard to quantify separately, well. Third, property yields reveal the otherwise hidden customer value that is created to property owners through capitalisation of decreased operating expenses. However, property yield does not fully include the new technology and political risks of on-site energy production (see Table 3 for detailed description). Therefore, adding a risk premium that reflects these additional risks on top of property yield may be justifiable. However, the faster growth of electricity prices compared to rental growth rate, as well as the absence of obsolescence in on-site energy investments, decrease the needed risk premium.

We show that the profitability of rooftop PVs can vary even in adjacent buildings. We claim that the traditional way of equalising the discount rates of on-site energy within one country is not a sufficiently granular approach to evaluating on-site energy investments, as it ignores the value created by location. This spatial value can be incorporated into the profitability analysis only by using location-dependent property yields as discount rates. In the real estate industry, both macro- and micro-location drive the risks of an investment, rather than solely the output of an investment (rental income). The more central or appealing the location, the less risky the property investment and the lower the property yield. Applying property yields in the profitability analysis of on-site energy investments suggests that on-site energy production is more profitable in appealing urban locations than in remoter ones.

The property industry will most likely accelerate investment in on-site energy production when it becomes more familiar with the presented value-creation logic. According to this value-creation mechanism, investments in on-site energy production increase the value of properties in areas where the property yields are lower than the on-site energy yields, so rational investors are probably willing to consider on-site energy production. Furthermore, our analysis only indicates the year in which adding on-site energy production to the underlying building becomes profitable. It does not quantify the created value, which can be a significant multiple of the rooftop PVs' investment cost. This encourages real estate owners to pursue these investments. It is important for the energy industry to understand how one of their most important customer groups, property owners, evaluates on-site energy investments. Rather than seeing on-site energy production as a threat, the energy industry should see on-site energy investments as a new, interesting business area and as an opportunity to develop services to property owners.

Urban planning, mentioned as an important means to achieve renewable energy future (Adil & Ko, 2016; Vandevyvere & Stremke, 2012), should encourage developers and property investors to examine the potential of on-site energy production as part of permitting processes. Cities could exploit the methodology presented in Vimpari & Junnila (2019) and this paper to identify and visualise the districts and property types where on-site energy production could potentially be profitable from property owners' perspective. In these areas developers may be recommended or required to consider on-site energy production by the means of urban planning procedures. The usefulness of GIS in has been noted in several urban planning tasks, such as identifying potential sites for decentralised renewable energy, recognising land constraints and calculating availability of roof areas for PV (Manfren, Caputo, & Costa, 2011; Van Hoesen & Letendre, 2010; Voivontas, Assimacopoulos, Mourelatos, & Corominas, 1998; Wiginton, Nguyen, & Pearce, 2010). Our approach adds also the perspective of property market information and economic viability to the analysis.

In addition to technology-specific support, both financing and adequate financial instruments are becoming increasingly important in ensuring the future deployment of solar energy (Fea, 2017). As demonstrated in this paper, considering the contribution of on-site energy production investment to the underlying property's cash flow offers potential as a financial instrument for the deployment of solar power production. Real estate is one of the more important investment classes, and a huge amount of capital is seeking new investment opportunities. According to calculations by the international real estate advisor Savills (2016), the real estate sector stores approximately 60% of national, corporate and individual wealth in the world, a total of over USD 200 trillion. The professional real estate market is also very active. In 2018, for example, the volume of global real estate transactions amounted to approximately USD 1000 billion (CBRE, 2019), whereas global investments in renewables were approximately USD 280 billion (Renewable Energy Policy Network for the 21st Century, 2018), and those in PVs were USD 160 billion (Jäger-Waldau, 2018). A global energy system based solely on renewable energy by 2050 would require investments worth USD 67 trillion, of which 70% would be in solar energy (Ram et al., 2019). Increasing awareness of the value-creation mechanism of on-site energy investments would encourage the vast amount of capital present in the real estate industry to flow into renewable energy investments. Furthermore, debt financiers could potentially finance these investments under the same conditions as the underlying properties, which would increase the availability and attractiveness of debt finance for renewable energy production. The underlying properties could also serve as collateral. More financing with better terms and conditions would further accelerate the renewable revolution in the built environment.

In this paper, the presented customer value was based solely on an economic assessment of decreased operating expenses, but property owners, especially professional investors, might see further value in on-site energy production. Investing in sustainability enhances the green reputation of buildings and typically leads to an increase in net cash flow. These changes increase the value of the building through the green signalling effect [e.g., Fuerst, Oikarinen, & Harjunen, 2016] and related cash flow parameters [e.g., Christersson et al., 2015; Fuerst & McAllister, 2011b, Reichardt, 2014, Holtermans & Kok, 2019; Reichardt, Rottke, & Zietz, 2012]. Furthermore, they potentially even lower the overall risk of the property, leading to a decrease in property yield [e.g., McGrath, 2013; Miller, Spivey, & Florance, 2008], which typically affects the value more than improved cash flow parameters. Arguably, the property yield decreases as renewable on-site energy production reduces the risk of rising operational expenses that are caused by uncertain conventional energy price development and the possible internalisation of negative externalities. Thompson (1997) argued as early as the 1990s that investing in energy efficiency lowers the overall risk of investors' portfolios, as energy-efficiency benefits are high when fuel prices are high. High fuel prices tend to lower the overall market return, so the value of energy-efficiency investments moves in the opposite direction. Bhattacharya and Kojima (2012) also considered renewable energy investments from a portfolio-theory perspective, albeit on a national level. The writers note that when different energy production methods are compared, the comparison should not be done solely from a production cost perspective. Instead, the analysis should be based on the contribution of diverse energy production forms to the overall risk of the portfolio. Adding renewable energy to the portfolio might increase production costs but decrease the risk (and hedging costs) of fuel price volatility. A similar logic may be applicable to individual property owners' 'energy portfolio'; on-site renewable energy would work fairly well as a hedge against rising conventional energy prices and, accordingly, decrease property yield. Furthermore, entire cities or areas may enhance their sustainable image by encouraging property owners to examine and actualize the possibilities of on-site energy production, which could lead to a reduction in areal property yield levels.

Despite the economic and other benefits of on-site energy, the current adoption rate is quite low. For rooftop PVs, some 8% of the potential is currently in use in Europe. The approximation is based on Defaix et al., 2012 estimation of the potential amounting to around 951 GW and the installed capacity of PVs amounting to 114 GW, of which rooftop PVs represent approximately 64% (SolarPower Europe, 2018). At least three explanations of the low adoption rates in professionally managed properties can be identified. First, although on-site energy investments add value to underlying properties, the value is quite low in absolute terms. Scare resources are more worth, for instance, in managing the income side of the property. Second, the value added is theoretical for as long as the investor holds the property or unless an objective surveyor approves the decreased operating expenses in the appraisal. Recognising the value in these situations usually requires historical evidence, which naturally will not help the decision-makers in the investment-decision phase. Third, real estate investors may lack the expertise to understand the technological aspects of on-site energy investments and may overestimate the related risks. In spite of the profitability, an insufficient understanding might lead to negative investment decisions.

As the data used in the empirical analysis are the same as in Vimpari and Junnila (2019), the same limitations also apply to this study. In addition to the limitations that those authors Vimpari and Junnila (2019) mention, property yields in practice vary more than the general market data used in our empirical analysis implies. This means that if the individual characteristics of each property were taken into account in the property yield, the adoption rates would vary even more between properties than was presented. Furthermore, the net present value analysis employed in our empirical analysis extinguishes the value of waiting, which is important in the face of rising electricity prices, political instability and technological progress. This value could be captured by real option analysis. Fleten, Maribu and Wangensteen (2007) are among the few to research the profitability and optimal investment strategies of decentralised renewable energy production from the property owner's perspective. According to their analysis of on-site wind power, an optimal investment strategy under uncertain electricity prices is to invest only when the electricity price is considerably higher than the net present value breakeven price if an investor has the possibility of postponing the investment and can choose between mutually exclusive capacities. Their real option analysis revealed the value in waiting, as a rising electricity price raises the net present value of the investment in the future. However, the writers note that there are several investment strategies in the case of modularity. Modularity applies poorly to on-site wind power, but in the case of solar energy it might be an attractive alternative and thus might advance the optimal time for investing compared to on-site wind power. Our empirical analysis supports the claim of Fleten et al. (2007) that the adoption of rooftop PVs has not been as fast as analysis would indicate and that investors seem to wait longer than a profitability analysis would suggest.

This paper presents a new way of thinking about on-site energy discount rates and adds to the research on the economic viability of on-site energy. Further research could attempt to quantify the size of the risk premium, which investors currently seem to add on top of the property yield. It would also be important to research how real estate investors evaluate on-site energy investments in practice and demonstrate the value creation mechanism for instance using case studies with discounted cash flow analysis. The added value, which is created to property owners through on-site energy production, in different areas and property types could also be potentially quantified using statistical analysis. Furthermore, it would also be interesting to interview professional property investors weather they see other benefits, such as enhancing the green reputation of their properties, on top of the presented economic value. The perspective of debt financiers also demands more attention to find out whether banks could offer debt financing for on-site energy investments as a part of underlying properties' debt with the same conditions and using properties as collaterals. The purpose of this paper was to shed light on investment decision analysis, especially how to choose the correct discount rate. When conducting cash flow analysis in practice, different stochastic models may improve the accuracy of estimations and understanding of different outcomes (Cano, Moguerza, & Alonso-Ayuso, 2016). These models could be further improved by applying our approach to choose the correct discount rate.

5. Conclusions

The results of this paper indicate that evaluating the economic profitability of on-site energy solely from a country-specific perspective is not a sufficiently granular approach. We show that the profitability can vary even between adjacent buildings when the value created to individual property owners is taken into account. This spatial value can be incorporated into the profitability analysis of on-site energy production by using location-dependent property yield as a discount rate. Our results indicate that property yields reliably reflect the risks of on-site energy investments and are the only way to reveal the otherwise hidden customer value. However, property yield reflects the political and new technology risks of on-site energy production only to some extent. Therefore, adding a premium on top of the property yield might be justifiable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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