Energy Efficiency Financing:
A review of risks and uncertainties

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Abstract

Over the last 30 years, a growing body of literature has identified five interrelated barriers to energy efficiency (EE) investment, including market, institutional, technical, motivational, and financial barriers. Of these, financial barriers pose a significant hurdle in mobilizing private capital for EE projects. The factors involved range from market-specific (e.g. lack of appropriate financing vehicles or debt instruments, regulatory risks, volatile energy prices), investor-specific (e.g. risk aversion, behavioral bias, perceived lack of collateral), to project-specific barriers (e.g. high initial costs, long payback periods, uncertainty of technology). In other words, investors remain skeptical of EE projects due to a number of risks and uncertainties specific to EE investments. While a substantial body of literature exists concerning these risks, efforts to summarize, integrate and synthesize the key findings across studies have failed to keep pace, especially from a third-party investor's perspective. The aim of this paper, therefore, is to conduct a comprehensive review of published research on the associated risks and uncertainties in EE investments. In doing so, this paper provides researchers, financial institutions, practitioners and policymakers with a deeper understanding of what those risks are, how they are accounted for in financial models, and where further research may be necessary.

Keywords: Energy efficiency financing, Investment risks, Market barriers

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1 Introduction

Concern about climate change and greenhouse gas emissions has brought about renewed attention to energy conservation in recent years. Experts and governments have emphasized the importance of an energy efficient economy through both policy recommendations and implementation. However,

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despite technological advancements and the apparent cost effectiveness of efficiency improvements, the rate of energy efficiency (EE) investment remains relatively stagnant due to a phenomenon known as the ‘energy efficiency gap’. This gap refers to the difference between levels of investment in technically feasible EE measures that appear to be cost effective and the levels that actually occur (Hirst and Brown, 1990; Jaffe and Stavins, 1994). In other words, it is the existence of unexploited investment opportunities that appear economically sound at current prices. Over the last 30 years, a growing body of research has sought to investigate the key factors underlying the gap, culminating in the identification of a number of barriers and market failures said to contribute to the inadequacy of the market.

These barriers can be classified into five, interrelated categories, namely a) classical market failures, such as imperfect information, split incentives, and transaction costs; b) institutional, such as a lack of supportive government policy or coordination, conflicting guidelines or standards; c) technical, such as low rates of innovation or inadequate technology; d) motivational, such as bounded rationality or conflicting values; and, e) financial barriers, such as hidden costs, access to capital, lack of appropriate financial products, consumer heterogeneity, volatile or artificially low energy prices, and uncertainties.[1] Of these, financial barriers pose a significant hurdle to mobilizing (private) capital for EE projects and particularly hinder the development of viable financial instruments specialized for EE projects.

The factors associated with financial barriers generally boil down to a number of risks and uncertainties that result in skeptical investors applying higher than usual discount rates to EE investments. This further amplifies the scarcity of appropriate financail products on the market.[2] Nevertheless, there is a general consensus that third-party financing is a feasible mechanism to accelerate investment and market growth. And while a substantial body of literature exists concerning financial barriers to EE investment and their associated risks, efforts to summarize, integrate and synthesize the key findings across studies have failed to keep pace.

The aim of this paper, therefore, is to conduct a comprehensive review of published research on the associated risks in EE investments. In doing so, this paper provides researchers, financial institutions, practitioners and policymakers with a deeper understanding of what those risks are, how they are accounted for in financial models, and where further research may be necessary. Hence, this review is concerned with the following research questions: a) What are the risks and uncertainties typically attributed to EE financing? b) How are those risks accounted for in financial models? and c) What innovative financing models or schemes have been identified in the literature?

Following a brief description of the review method, the remainder of this paper is organized as such: First, the key findings are presented in five subsections, according to a classification system developed for the review. Within each subsection, the appropriate risks and uncertainties are identified and defined, along with the relevant literature. Next, recent advancements in financial modeling and risk assessment in relation to EE investments are discussed. Subsequently, innovative financing models and schemes that have already been implemented are examined in relation to how they deal with the risks. Finally, some concluding remarks are presented.

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[1] For thorough discussions on the EE gap and the barriers which cause them, see especially Blumstein et al. (2000); Golove and Eto (1996); Jaffe and Stavins (1994); Ruderman et al. (1987); Sorrell et al. (2004); Sutherland (1996).

[2] The EE gap concept implies that there is an implicit discount rate for EE investments which can be compared to the interest rates offered by other, non-EE investments that investors are purchasing. The difference between these rates is offered as evidence of inadequacies in the function of the EE market (see esepcially Golove and Eto, 1996; Hausman, 1979; Ruderman et al., 1987).

2 Review Method

A systematic search of the academic literature was conducted using a number of bibliographic databases in the social, economic and financial sciences (e.g. ScienceDirect, JSTOR, SpringerLink). Search keywords used include *energy efficiency investment*, *energy efficiency financing*, *energy efficiency risk*, *energy efficiency market*, and variants thereof. Publications from non-academic or non-governmental institutions (e.g. IEA, OECD), national research laboratories and institutes (e.g. LBNL, DIW Berlin), and proceedings from energy-related conferences (e.g. IAEE, ECEEE Summer Study) were also examined.

The search was confined to studies conducted in European and North American countries, written in English, and published since the late 1970s. Studies from non-Western countries were excluded due to potentially significant differences in the barriers private investors face in developing countries (i.e. unstable governments, lack of trust in the financial system, corruption). Studies conducted before the 1970s were also excluded due to developments in financial regulations in North America and Europe over the past four decades that may have an impact on the generalizability of this review. That said, a vast majority of the studies included were published since the early 2000s; those prior to this provided mostly theoretical or historical background material.

Table 1: Risks attributed to energy efficiency financing.

Risks	Manifested as	Key literature
Economic and Financial	Construction cost increases, interest rates, volatile energy prices, payment default	An and Pivo, 2017; Kaza et al., 2014; Meier and Eide, 2007; Mills et al., 2006; Tuominen and Seppänen, 2017
Behavioral and Operational	Behavioral biases, rebound effect, faulty operation, unexpected consumption pattern	Guerra Santin, 2013; Haldi et al., 2017; Linares and Labandeira, 2010; van Raaij and Verhallen, 1983a,b
Measurement and Verification	Poor data quality, inconsistent measurement, modeling errors	Kromer, 2007; Lee et al., 2015; Meyers and Kromer, 2008; Xia and Zhang, 2013
Contextual and Technology	Poor project design, installation delays, insufficient information on facility, poor equipment design, poor performance	Hu and Zhou, 2011; Lee et al., 2015; Mills et al., 2006; Stevens et al., 2018
Regulatory	Changes in grant/subsidy programs, unfavorable financial regulation, conflicting guidelines, changing regulation on financial markets	Hu and Zhou, 2011; Kaminker and Stewart, 2012; Langlois-Bertrand et al., 2015; Stevens et al., 2018

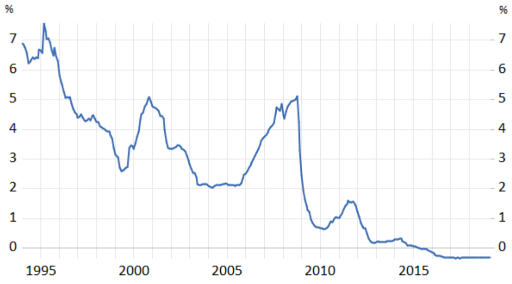
3 Risks in Energy Efficiency Financing

Risks associated with EE investment can be classified into five broad but often interrelated categories, namely a) economic and financial, b) behavioral and operational, c) measurement and verification, d) contextual and technology, and e) regulatory risks.[3] Following Mills et al. (2006), risks can be further classified as either *project intrinsic* (and therefore controllable) or *extrinsic* (uncontrollable). Stevens et al. (2018), on the other hand, classifies risks as either *quantifiable* (e.g. financial) or *non-quantifiable* (e.g. regulatory). For the purpose of this review, however, a simplified classification is sufficient because the additional dimensions suggested can easily be discussed within the different categories as they are presented. Table 1 presents a summary of the key findings. Each risk category includes examples of how that type of risk may manifest itself in EE-related investments and the relevant studies concerned. The remainder of this section discusses the risks organized according to the categories defined above.

3.1 Economic and financial risks

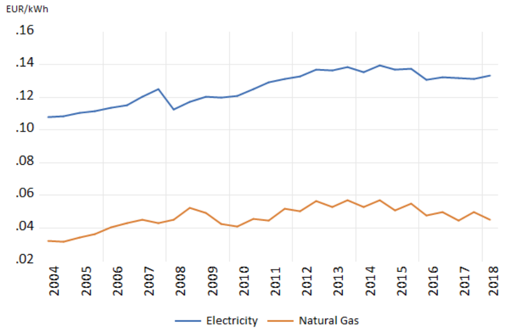
Economic and financial risks are mostly extrinsic and include volatile fuel prices, uncertainty in demand charges, fluctuating interest rates, and loan default risks (Mills et al., 2006). Despite the extrinsic nature of these risks, a number of them can be managed by means of contracting or some other hedging mechanisms. Fluctuations in interest rates, for example, can lead to uncertainty in the cost of capital. Figure 1 demonstrates such fluctuations in the 3-month Euribor rate since 1995 (a crucial benchmark for a range of EUR-denominated financial products, such as mortgages) and the drastic effect a financial crisis can have on interest rates. To hedge against these fluctuations, Stevens et al. (2018) suggest opting for long-term fixed interest rates rather than floating rates. Borgeson et al. (2014), on the other hand, suggest public funding schemes may be used to subsidize interest rates to below market price and guard against such risks.

Figure 1: Euribor 3-month historical close in the Euro area (% per annum).



Source: European Central Bank

Figure 2: Development of energy prices for households in the Euro area – bi-annual data.



Source: Eurostat

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[3] This classification system was adapted from those found in Mills et al. (2006), Hu and Zhou (2011), and Lee et al. (2015)

Fluctuations in energy prices (and energy taxes) affect the life cycle cost of an EE project and, likewise, the expected returns of the investment. If energy prices increase drastically, or contrary to the assumptions underlying the investment decision, the expected energy savings will vary. As shown in Figure 2, average annual energy prices for the European Economic Area have steadily increased since 2004; moreover, the seasonality effects are more pronounced for natural gas prices. Thompson (1997) and Stevens et al. (2018) suggest long-term energy price fixing in order to hedge against this type of uncertainty, when available. Tuominen and Seppänen (2017), however, postulate that price risks can not only be reduced by a meaningful amount through EE improvements, but that the monetary value of this reduction can be calculated and compared to other financial instruments that insure against unexpected price hikes (e.g. risk insurance).

Literature concerning loan default risks relating to EE investment appears limited. Most studies are concerned with the mortgage loan default rate of EE-certified buildings. An and Pivo (2017), for example, find that green buildings (e.g. LEED- or ENERGY STAR-certified)[4] carry 34% less default risk, *ceteris paribus*, in the commercial mortgage-backed securities market in the US. Moreover, Kaza et al. (2014) find that higher levels of EE correlate to even lower rates of default in the US residential sector. Such findings have potentially positive implications for the development of EE financing products: borrowers seeking loans for EE improvements may pose less credit risk, at least to mortgage-backed loans, making them more attractive to primary lenders and secondary investors.

3.2 Behavioral and operational risks

Behavioral and operational risks can manifest as unexpected consumption patterns, faulty operation or improper maintenance of equipment, and negative utility from time-consuming maintenance or usage. The causes of these risks are often attributed to systematic behavioral biases, a so-called rebound effect, or energy-related behavior patterns. A number of prominent studies concerned with the specific behavioral factors influencing energy consumption originate in behavioral economics or psychology. Some of the more influential and cited works include van Raaij and Verhallen's (1983a) behavioral model for household energy use and Costanzo et al.'s (1986) social-psychological model.

Such models allow for the identification and analysis of energy-related behavior patterns to predict household energy consumption. Van Raaij and Verhallen (1983b), for example, defined five patterns of household energy use, between which the consumption behavior was significantly different from the 'average' consumer.[5] Given the differences between the clusters on a socio-demographic level, the results of such studies help inform not only energy policy but also risk analysis. Examples include Haldi et al.'s (2017) advanced modeling framework to predict the scope and effects of behavioral diversity in building occupants, Lee and Malkawi's (2014) agent-based model for simulation, and Stragier et al.'s (2012) standardized scale to measure EE behavior in multifamily buildings. Frederiks et al. (2015) presents a comprehensive review of socio-demographic and psychological predictors of residential energy consumption.

The so-called rebound effect is often discussed in relation to EE investment. The concept posits that increases in EE can lead to lower prices for energy services and potentially to a substantial increase in demand for such services, resulting in lower-than-expected savings (Haas et al., 1998).

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[4] See https://www.energystar.gov and https://new.usgbc.org/leed for more information about these programs.

[5] The authors identified five clusters of behavior, or patterns, namely *conservers*, *spenders*, *average*, *warm* and *cold*. The conservers use less energy, while spenders use more energy than the average group. Both warm and cool users (so named based on their indoor temperature preferences), use less energy than the average group.

Studies over the years reveal a possible range somewhere between 5 and 130%, depending on the country, sector, and aggregation level of the data used (for reviews of these studies, see especially Greening et al., 2000; Linares and Labandeira, 2010).[6] The relevance of these findings, however, are highly context-dependent and, it should be noted, that, when the effect is lower than 100%, a net reduction in energy demand is still realized. There are a number of particularly noteworthy studies in the area. Guerra Santin (2013), for example, employs behavioral models based on that developed by van Raaij and Verhallen to show that occupants of EE dwellings tend to prefer higher indoor temperatures and to ventilate less, compared to occupants of less EE dwellings. Other prominent studies include Herring (2006), Copiello (2017), Haas et al. (1998), Webber et al. (2015), and Hens et al. (2010).

3.3 Measurement and verification risks

As the return on investment from any EE project will likely be the energy savings, financial institutions and investors would require an accurate assessment of the achieved savings. Therefore, cost effective measurement and verification (M&V) is essential for achieving long-term energy savings (Kromer, 2007). However, the potential risks can manifest as poor data quality, inconsistency of data collection, level of verifiability, and modeling errors. The International Performance Measurement and Verification Protocol (IPMVP) is often discussed in the literature as a guideline for mitigating M&V risks (see especially Kromer, 2007; Meyers and Kromer, 2008).

To that end, Xia and Zhang (2013) present a mathematical description for M&V problems so that 'scientific rules behind existing M&V practices are discovered, and M&V option selection and M&V plan development in M&V practices are also guided by scientific principles.' Other possible mitigation solutions include improved model validation, and proper metering (e.g. smart metering) (Kromer, 2007; Lee et al., 2015). Vine et al. (2006), however, note that the development of an infrastructure and process for conducting rigorous M&V takes time and needs the active participation of many stakeholders.

3.4 Contextual and technology risks

Contextual and technology risks involve unpredictable negative externalities or uncertainties related to the technical specifications of the project. Stevens et al. (2018) and Mills et al. (2006) identify contextual risks as insufficient information about the facility, installation delays, and extreme weather conditions or changes. Insufficient information about the facility (e.g. house, apartment building, factory) is perhaps the most obvious risk related to EE installations. While a full audit and project assessment prior to the start of the project would limit such risks, acquiring complete and accurate data on a building is often difficult. Similarly, installation delays relate to the removal of existing equipment and the installation of new equipment, which is typically done during specific working hours and therefore exposed to time delays. The environmental risks include uncertainties about the adaptability of the installed technology to changing climate conditions (Kaminker and Stewart, 2012).

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[6] The rebound effect is usually measured as an elasticity of energy demand with respect to EE, so that: at 0% the reduction in energy demand corresponds to the increase in EE; larger than 0% but lower than 100% indicates a net reduction in energy demand but lower than the corresponding increase in efficiency; and larger than 100% there is a backfire effect, with the increase in EE resulting in a net increase in energy demand and negating the savings.

Lee et al. (2015), Mills et al. (2006), and Hu and Zhou (2011) describe technology risks as uncertainty in the lifespan of the installed equipment, suboptimal performance of the equipment, and improper system selection. Such risks can lead to delays in project completion, require a readjustment of the expected energy savings, or have higher non-monetary costs associated with the project (e.g. time lost for maintenance, negative utility). The level of risk depends greatly on the maturity of the technology selected and the reputation of the manufacturer (Kaminker and Stewart, 2012). Given that contextual and technology risks are more project-specific than those discussed thus far, most references to them are within the context of risk mitigation, contracting, or risk transfer (e.g. Mathew et al., 2005; Mills, 2003).

3.5 Regulatory risks

Regulatory risks are associated with the (negative) effects of changes in government policies. Langlois-Bertrand et al. (2015) propose a comprehensive framework for identifying institutional-political (i.e. regulatory) barriers to EE investment. Their framework includes three categories, namely political obstruction, conflicting guidelines, and lack of policy coordination. Examples of these include adjustments in energy rating standards, revision of building codes, stricter climate change mitigation policies, reduction or cancellation of grants, subsidies or other public funding programs (Hu and Zhou, 2011; Stevens et al., 2018). Other risks include failure to implement supportive policies for energy services or an EE market, changing regulations on financial markets, as well as economic, regional and industrial development policies.

Institutional investors may face additional hurdles from financial regulation rules governing pensions funds and insurance companies. Kaminker and Stewart (2012) note, for example, that some international accounting and funding rules may inadvertently discourage institutional investors from investing in longer-term, illiquid or riskier assets. The risk of changing regulation is difficult to account for in financial models, as they are non-quantifiable and exogenous (Stevens et al., 2018).

4 Accounting for Risk in Financial Modeling

The most significant risk factors attributed to EE investments have been discussed in relation to financial barriers. How then, are these risks accounted for in risk assessment or investment decision-making models? Studies originating from a range of disciplines, including finance, behavioral economics, and organizational management, have attempted to address this question. Much of the literature focuses on the implicit discount rate applied by investors and modeled using some adaptation of existing financial (e.g. capital asset pricing model) or behavioral models (e.g. cumulative prospect theory). In the following, the most prevalent studies on risk assessment, mitigation or investment decision-making in EE projects are discussed.

The dominance of the discount rate in the literature stems from the empirical work of Dubin and McFadden (1984), Hausman (1979), and Ruderman et al. (1987). In their seminal work, discount rates for the adoption of energy efficient appliances were found to range between 20 to 800% – rate that were significantly higher than those applied to non-EE options of the same price. Howarth and Sanstad (1995) argue that high discount rates 'constitute *prima facie* evidence of market failures' that are the cause of the EE gap introduced in Section 1. Attempting to explain this phenomenon, Thompson (1997) postulates that investors' (i.e. consumers') attitudes toward risk are accounted for incorrectly when discounting is applied to an investment decision. Rather than deciding whether or not to invest in an asset with an uncertain future benefit stream, he posits consumers are actually choosing between two future cost streams, each of which is uncertain. However, as discussed in Jackson (2010), there is 'no single satisfactory methodology… to determine the appropriate risk-adjusted discount rate' to employ in financial models.

To demonstrate the complexity of the discount rate, Schleich et al. (2016) introduced a comprehensive framework that distinguishes three broad categories of factors involved, namely a) preferences, notably over time, risk, loss, debt and the environment; b) predictable (ir)rational behavior, such as bounded rationality, rational inattention, and behavioral biases; and c) other external barriers to EE. Investment evaluation studies, therefore, often attempt to go beyond the fundamentals of the capital asset pricing model. Thompson (1997), for example, reformulates the traditional net present value (NPV) method to discount two future cost streams separately and then subtract their sums in order to calculate the true present value (i.e. savings) of an EE investment project. Thompson's equation is shown below, where V'_S is the present value of savings; t is the time period up to the time horizon of the investment (T); P_t is the price of fuel in period t; F_C is the amount of fuel used with the current capital equipment, and F_N is the fuel amount used with the new or improved capital equipment; and r is the discount rate.

$$V'_S = \sum_{t=1}^{T} \frac{P_t F_C}{(1+r)^t} - \sum_{t=1}^{T} \frac{P_t F_N}{(1+r)^t}$$

Other scholars attempt to go beyond the traditional NPV method. Menassa (2011), for instance, augments NPV with option pricing theory to develop a framework for single or multi-phase investment evaluation by establishing 'an analogy between investment in sustainable building retrofits and perpetual American options.' Atkinson et al. (2009) expands on Thompson's method to develop a financial model that uses 'discounted cash flow analysis over a long-term cost period to represent the full lifespan of a building.' Häckel et al. (2017) analyze the influence of behavioral biases on EE investment decisions using cumulative prospect theory. Jackson (2010) extends the traditional Value-at-Risk model to more accurately account for risks in EE projects. Clinch and Healy (2001), Jakob (2006), and Morrissey et al. (2013) employ cost-benefit analysis to demonstrate how energy savings, environmental benefits, and health and comfort improvements may be assessed in EE projects. Diakaki et al. (2010) present a multi-objective optimization method for decision-making that accounts for the multiple and usually competitive objectives in EE investments (i.e. energy consumption, financial costs, environmental performance, etc.).

Risk transfer is often discussed in relation to insurance or actuarial pricing of EE projects. Mills (2003), for example, suggests an energy-savings insurance scheme in order to transfer and spread risk over a large pool of EE projects. This is similarly supported through actuarial pricing of EE project suggested in Mathew et al. (2005) and further developed in Mills et al. (2006). However, this requires a high-level of standardization of EE projects as well as accurate M&V in order to be viable – two things severely lacking from the EE market, thus far. Moreover, these studies are focused specifically on the energy service company sector and energy performance contracting (discussed more in Section 5), rather than on private capital investors.

A number of econometric studies examine the contextual characteristics of energy demand, the results of which help inform risk assessment and financial models. These studies typically vary in the method of analysis, country of interest, building sector (e.g. residential, industry), building types (e.g. multifamily apartment buildings, public buildings), fuel source (e.g. natural gas), energy use (e.g. space heating, cooking, lighting), and so on. Examples include Rehdanz (2007) for residential space heating in Germany, Hill (2015) for overall energy expenditures in Austria, Baker et al. (1989) for electricity in the UK, Dubin and McFadden (1984) in the US, and Wood et al. (2012) for Australia. While not specifically focused on the risks of EE investments, these studies provide useful insight into the effect socio-economic, demographic, regional and building characteristics have on energy demand that can be used to inform financial risk assessment models. For example, Hill (2015) finds that detached and semi-detached buildings in Austria increased energy expenditures by 33 and 31%, respectively, and buildings built before 1919 were 15% more costly.

5 Innovative Financing Models

A number of successful, innovative financing models have been developed and implemented in recent years, especially in the European Union and the United States. The most prominent of these models is the energy service company (ESCO), particularly in the public and industrial building sectors. While a full discussion of an ESCO and its role is beyond the scope of this review, it can be briefly defined as a commercial business providing a broad range of energy solutions, including designs and implementation of energy saving projects, retrofitting, energy conservation, as well as risk management. The main characteristics of an ESCO is the guarantee of savings and/or provision of the same level of energy service at lower cost; remuneration is typically tied directly to the energy savings achieved (i.e. technical and financial risk is on the side of the ESCO); and arrangement of financing for the operation of an energy system through the guarantee of savings. The most common model of financing is an energy performance contract (EPC), which uses the stream of income from the cost savings to repay the costs of the project, including costs of the investment.

The most important characteristic for our purposes is the (financial and technical) risk transfer through guaranteed reductions in energy demand and tying the remuneration directly to the energy savings achieved. How this is calculated, however, is typically proprietary and rarely shared for academic studies. Vine (2005), Bertoldi and Boza-Kiss (2017), and Marino et al. (2011), however, provide comprehensive reviews and analyses on the ESCO market, particularly for Europe.

Various configurations of the ESCO-EPC model exist in practice. Bullier and Milin (2013), for example, provide a critical inventory of traditional and alternative financing models and report on third-party investment schemes which disconnect the burden of debt from the building owner and attach it to the building itself through programs in the US, UK, France and Bulgaria. The Energies POSIT'IF scheme in France and the BgEEF program in Bulgaria are both based on the ESCO model; the latter is in combination with specialized finance vehicles that allow for refinancing of the projects. Schlein et al. (2017) similarly present analyses of third-party EE financing from Europe, North America and Asia, including a survey of the most critical barriers and recent examples of success in those regions.

The EU-sponsored project CITYnvest examined 24 financing models from 11 EU countries.[7] In the final report (Vanstraelen et al., 2015), they identified four financing models (or funding vehicles) used to provide funding for EE projects. These included financial institutions (i.e. banks, utility funds), ESCO financing, program delivery unit (PDU), and investment funds. Many of the EE programs examined in the project used a combination of these models to fund EE investments in various sectors. Examples include the SUNShINE (Save your bUildiNg by SavINg Energy) project in Latvia in which a forfeiting fund purchases the future receivables from an ESCO, allowing the

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[7] See http://www.citynvest.eu/ for more information on this Horizon 2020 project.

ESCO to take on new loans; Energiefonds Den Haag in the Netherlands which finances projects through a revolving fund; and SPEE Picardie in France, which incorporates third-party financing based on gains through savings on heating bills. A fifth funding vehicle identified in the project is crowd-funding, or citizens financing, such as the Brixton Energy Co-op program in London, UK.

Several studies have also examined the ESCO model as a potential template for the development of a specialized EE financing instrument, or the securitization of energy savings. While Peretz (2009) has shown that EE investments are comparable to the potential returns of standard corporate bonds and equity securities, an SEE Action (2015) report postulates that creating financial instruments that are tied to EE savings may provide several advantages, including lowering the cost of capital and increasing the demand for expert knowledge (i.e. specialized intermediaries), potentially translating into lower interest rates for consumers and an increase in demand for EE investments. The report further outlines the aspects of EE asset class creation and the involvement of the secondary capital market. To that end, Bevington (2013) presents a framework that uniquely combines the responsibilities of owners, lenders and contractors into interlocking obligations, or a so-called 'iron triangle' that insures a successful outcome for each stakeholder. The author also suggests looking closer at collateralized debt obligations (CDO) as a possible pathway toward developing a specialized EE asset class. Jackson (2010) also suggests that Value-at-Risk analysis provides a well-accepted framework for facilitating securitization.

6 Conclusions

This paper presents a comprehensive review of published research on the associated risks inherent in EE investments. These studies reveal that an investor faces a number of extrinsic and intrinsic risks that can be classified into five categories: economic and financial; behavioral and operational; measurement and verification; contextual and technology; and regulatory risks. Literature focused on how risk is accounted for in financial modeling is also discussed. The studies surveyed originate from various academic fields, including finance, economics, management, and behavioral economics. Finally, innovative financing models already implemented in the market are presented.

What is clear from the literature is that most studies do not take the perspective of a third-party investor, but rather that of an investor who is also the decision-maker (e.g. a homeowner, building owner, business owner). Third-party financing, nevertheless, is a viable mechanism to increase investment in the EE market. Moreover, more research is needed to define the potential role of institutional investors (e.g. pension funds, insurance companies), investigate appropriate pathways to securitization, and the development of a secondary capital market for EE investments.

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