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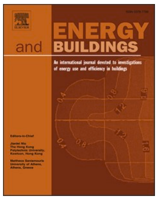

Energy efficiency practices: A case study analysis of innovative business models in buildings

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ABSTRACT

Over the last two decades, the European Union has significantly improved its legal framework for building energy efficiency. New mandatory standards have led governments to adopt incentive measures that, in turn, encourage the growth of innovative entrepreneurial practices. This study analyzes emerging business models that capitalize on energy efficiency in the building industry. Thirty-seven energy efficiency projects – either retrofit or new construction, supported exclusively by innovative business models featuring the presence of an individual contractor – in five Central and Western European countries are considered. Data is collected on property characteristics, business environment, and energy efficiency measures. Using the Rough Set approach, the analysis identifies core attributes that associate or differentiate the case studies. They include building ownership, energy-related services to be provided to the users, and the duration for which the contractor must be involved. Additionally, other attributes – such as the types of retrofit work, investment costs, access to monetary incentives, and expected payback period – allow us to identify the cases representing best practices for each innovative model. There remain open questions concerning where the boundary between different business models lies and long-term economic self-sustainability, regardless of the availability of incentives.

1. Introduction

This study deals with a somewhat disregarded topic, namely, the role played by innovative business models (BMs) in pursuing building energy efficiency targets. The aim is to showcase the best practices in the European Union's (EU) energy policy framework, on which the remainder of this introductory section focuses along with the other underlying premises of the study. To that end, a case study analysis is performed, relying on a multi-attribute technique suited for dealing with complete or incomplete information, both quantitative and qualitative in nature. The methodology is further detailed in Section 3, while Section 4 presents the thirty-seven case studies identified across five Central and Western European countries and the data concerning three primary domains: property characteristics, entrepreneurial environment, and energy-related works. The innovative aspects of this work lie in the comprehensive examination of innovative BMs in the literature and an effort to identify their closest applications, as well as in the analysis of commonalities and distinguishing elements in those applications so as to cluster them according to various success levels.

1.1. Ten years and more of Directive 2010/31/EU on the energy performance of buildings

Energy efficiency in general – and building energy efficiency, specifically – is a current, prominent issue that started attracting attention many years ago [32,41]. The oil shocks of the seventies raised awareness of the energy issue, with new regulations and standards adopted by several countries shortly after [30,31,46,87,120,127]. While the focus was essentially on energy saving at the beginning, it later shifted to energy performance and energy efficiency of several sectors, including the building industry, bearing in mind environmental and climate impacts as well [33,121].

Concerning the EU, the recently adopted European Green Deal (EGD) (European [43,53] sets a framework of long-term targets for the member countries and their economies, which imply structural changes in the energy, manufacturing, building, and transportation industries. A few meaningful keywords, such as climate neutrality and decarbonization regarding production and consumption processes, can describe those ambitious aims. While mainly covering environmental issues, the EGD has energy-side implications, especially on how energy is generated by

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different sources, how it is supplied to end-users, and how firms and households use it. Also, and more focused on the building industry, the recast of the Energy Performance of Buildings Directive (EPBD) will set stringent mandatory standards – meaning zero emission standards – for new buildings by 2030 and for existing ones by 2050. Besides, it sets a range of provisions to increase the renovation rate of existing buildings [76]. However, all this is not novel at all, as it represents the last step of a two-decade-long evolution in the regulatory framework, the previous milestones of which are Directive 2002/91/EC, its recast in Directive 2010/31/EU, and its amendment in Directive 2018/844/EU [79]. Especially, Directive 2010/31/EU includes substantial amendments to the 2002 Directive, which rest on three pillars. The first is the methodology to identify cost-optimal levels of building energy performance [9,68], encompassing the construction phase (upfront costs), operation phase (maintenance and management costs – energy costs and savings, especially), and disposal stage (disposal costs or residual value). It builds on the inverse relationship between construction cost and operating cost while trying to improve the energy performance: the former is bound to increase, and the latter is likely to decrease, so the total cost is expected to show a somewhat parabolic shape. Therefore, allowing for the comparison of different energy measure packages, the methodology leads to identifying a cost-optimal area encompassing those measures that maximize the energy performance and minimize the global cost in the building life cycle [131]. The second pillar refers to the concept of minimum energy performance requirements to be established for new and existing buildings, in the case of large renovation of building units and elements, and for the installation, replacement, or upgrade of systems [130]. The third pillar – although significant differences among the EU member countries characterize its implementation [77] – paves the way for further strengthening the mandatory certification system of building energy performance, which is meant to stimulate transparency in the building industry and the real estate market [4].

1.2. *Incentive policies and measures*

Overall, the contents of the regulations mentioned above have been implemented by EU countries and translated into a variety of command-and-control tools at first, but mostly incentive policies and measures later. As the players deal with several market barriers and information asymmetries in the implementation of building retrofit, incentives play a significant role in overcoming them [2,24,63,108].

Building on a wide corpus of studies [61,62,116,123] – and complementing them with the information in the Odyssee-Mure database,[1] below is a tentative classification of the policies adopted in the EU countries (Fig. 1). Aside from the energy performance certificates and other regulatory instruments such as building codes and standards, three main clusters are as follows: financial incentives[44,82,83,110], both direct, such as grants and subsidies, and indirect, as tax rebates [6,21,20,124]; in-kind incentives, such as tradable assets and securities [15]; behavioral incentives[59], namely, behavioral stimuli and knowledge transfer[10]. Besides, the literature identifies a variety of innovative tools proposed by private financial institutions, including on-bill finance and energy-efficient mortgages, which have the potential to reduce the need for government subsidies and simultaneously open up additional private sources of funding for renovations. Especially, energy-efficient mortgages can apply to both new construction and extensive refurbishment projects due to features such as long repayment periods and low interest rates. The literature has already suggested classifications of energy incentive policies [13,35]. One of these distinguishes the financial instruments in non-repayable rewards, debt financing, and equity financing, also clustering them according to their degree of innovativeness[12,14]. It is worth noticing that the first two clusters identified here are elsewhere denoted as price instruments or economic incentive instruments[82,110]. At the same time, the third cluster is referred to as information instruments or information, education, and training measures[10,35].

1.3. *Underlying hypothesis of this study*

The hypothesis underlying this study is that the innovations in the regulation and the related incentive-focused policies and measures have led, in turn, to the birth and rise of innovative entrepreneurial models for sustainable buildings [28,39,58]. Those models are explicitly meant to exploit the business opportunities – and their effects on revenue generation and profit growth – offered by the tools designed to stimulate the green transition (Fig. 2).

Under the framework above, this work lies on the assumption that further developments of those innovative entrepreneurial models [27,54]are required to pursue the goals set in the EGD [53,121,128], especially to double the building renovation rate by 2030 [7,104], as stated in the priority topics of the European Climate Pact. The research questions we address here can be expressed as follows. What lesson can we learn from the innovative entrepreneurial approaches and BMs developed in the building industry during the last decade? What are likely to be identified as the success factors and the most successful models, which thus can be regarded as best practices? This study tries to answer these questions by examining 37 case studies across five Central and Western European countries: Belgium, France, Germany, Spain, and The Netherlands. Collected data refers to three domains: the property subject to refurbishment, the works meant to improve energy performance, and the entrepreneurial environment. Land and building characteristics are considered to describe the property, along with information concerning the ownership status. All the works related to thermal insulation, heating and cooling systems, windows and frames, mechanical extract ventilation systems, and renewable energy sources are analyzed as far as improving energy performance is concerned. The entrepreneurial environment variables account for the adopted BM, the involved public and private players, and the relationships they establish. Data is processed using the multidimensional approach of the Rough Set Theory, which allows for the identification of a series of somewhat vague and partly overlapping clusters according to the primary characteristics of the case studies.

2. Literature review

In this section, a perusal of the literature is presented. The review is divided into four parts. First, we deal with the broad definition of BMs, as found in studies related to the building industry. Secondly, we focus on characterizing the BMs meant explicitly to pursue sustainability goals. Thirdly, we turn to some specific BMs whose adoption has been stimulated by the Directives on building energy performance and the related incentive policies and measures. Lastly, we address the different risk allocation profiles of those BMs.

2.1. *Cornerstones of a business model*

According to the Cambridge Business English Dictionary [29], a BM is “a description of the different parts of a business or organization showing how they will work together successfully to make money.” Therefore, it can also be described as the plan – or the intangible medium, if you will – by which a company promotes its products and services to reach the target customers and, more broadly, the reference community [132].

Based on previous studies [8,78,91,118,134], a review focusing on the development of sustainable BM archetypes [19]identifies three cornerstones of each BM: value proposition, value creation and delivery, and value capture (Fig. 3). Value proposition refers to the reasons why a company introduces and uses a specific entrepreneurial organization to

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[1] See: https://www.measures.odyssee-mure.eu/policy-mapper-efficiency-tool.html#/ (accessed 31.07.2023).

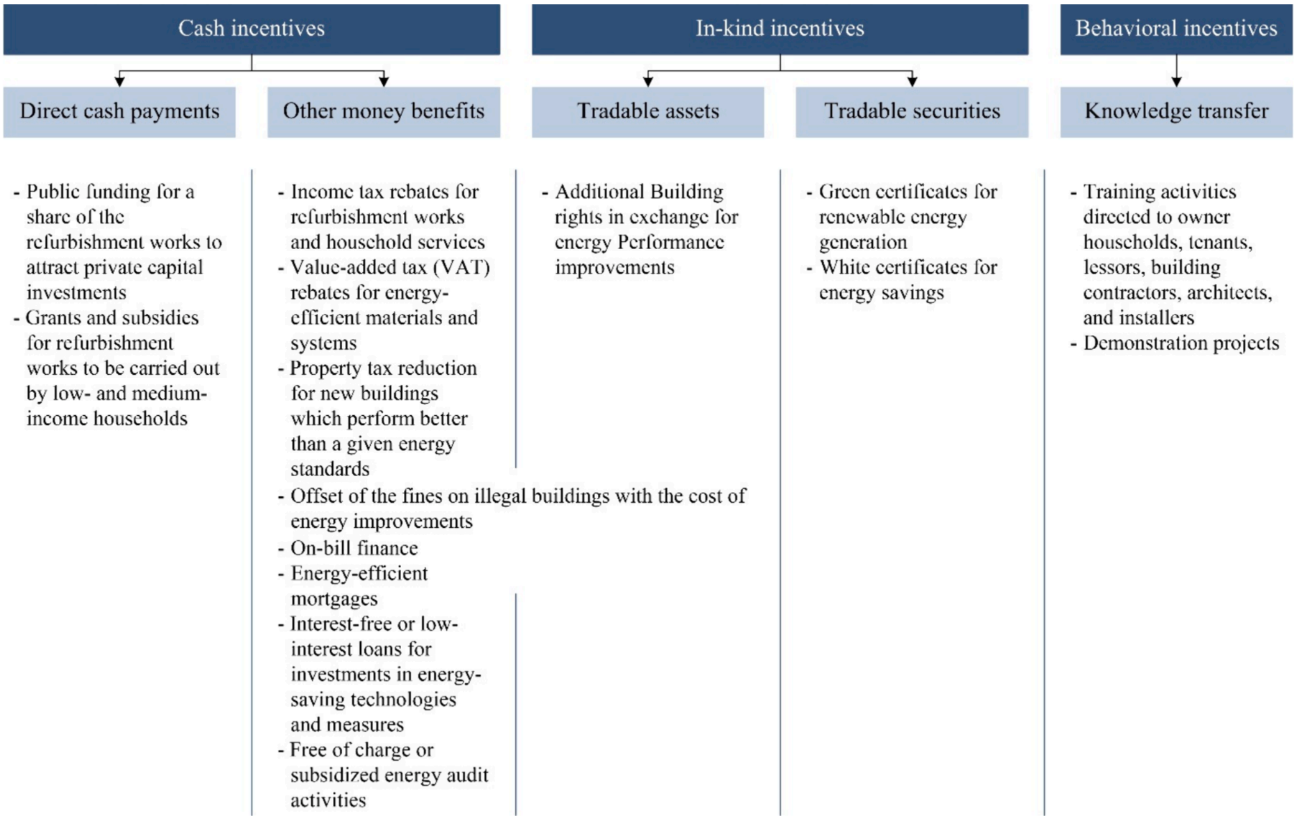


Fig. 1. A tentative classification of incentive tools and measures.

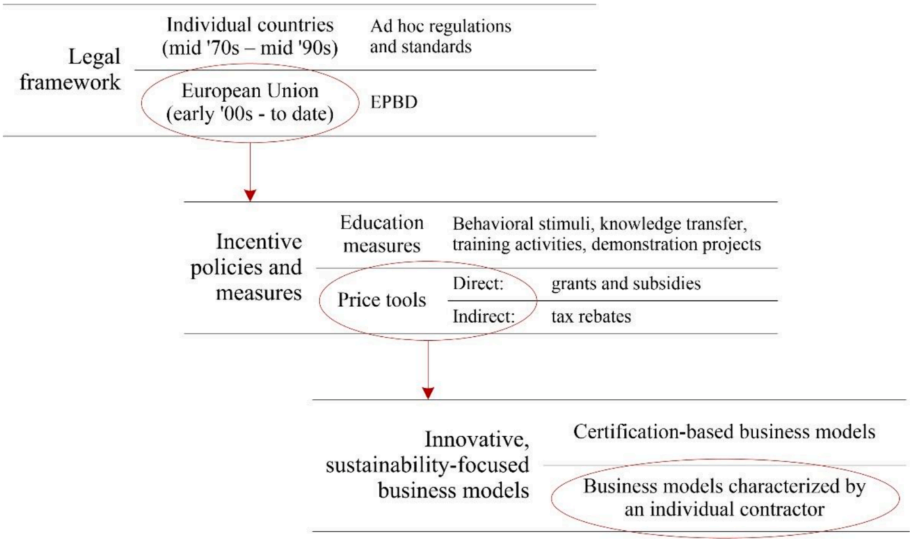


Fig. 2. Underlying premise: legal framework, incentive policies and measures, innovative business models.

produce its goods and services, mainly including the benefits it can deliver to the users, ensuring at the same time an adequate balance between costs and revenues to pursue the goal of profit maximization. The second element – value creation and delivery – involves all the procedures that support production and sales – such as order processing and fulfillment, inventory management, customer support, and so forth – to meet customers' expectations in terms of need satisfaction as well as business owners' expectations in terms of profit-making. The third element – value capture – means how the value generated is translated into revenue streams and later retained by the company or redistributed to the shareholders.

It is worth mentioning that other studies divide some key aspects into distinct subsets (Fig. 3). For instance, the second element – namely, value creation and delivery – is sometimes referred to as the supply chain on the one hand and customer interface on the other hand [25]. That means drawing a line between the relationships established with the supplier and the relationships that involve the customers [23,132]. In addition, the third element – that is, value capture – can be clustered into two activities: financial modeling is the former, and governance modeling is the latter [25].

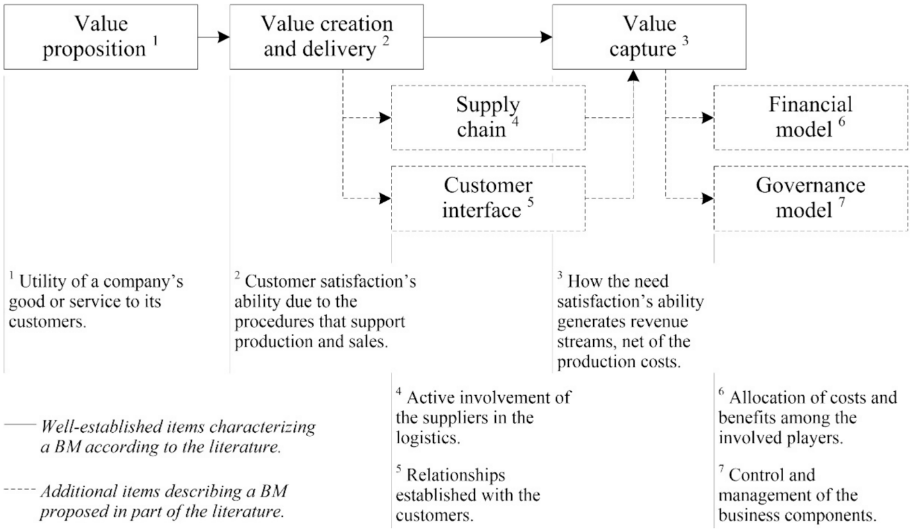


Fig. 3. Cornerstones of a business model.

2.2. Sustainability-focused business models

A BM focused on sustainability issues can be distinguished from a generic one according to three crucial aspects: the intended goal, the value creation process and outcomes, and the involved players. Taking for granted that profit maximization is the aim of all entrepreneurial ventures, the will to reduce and mitigate (at least some of) the negative impacts on the environment and society characterizes only a subset of them [74,75,133]. While value creation is the ability to make money from the products brought to market, in a sustainability-focused BM, it also implies manufacturing goods with longer life cycles and lower negative externalities [132]. Lastly, taking a sustainability view entails adopting longer production chains [19,89,122,133]where the relationships with and among the stakeholders are reshaped, shifting from a traditional unidirectional structure to a circular and open format [42], and a greater exchange of information and knowledge between the players occurs [5,132]. The literature classifies the BMs committed to sustainability based on technological, social, and organizational aspects [19]. Technological-driven sustainable BMs focus on maximizing material and energy efficiency, renewable energy use, and value creation from waste.

2.3. The One-stop shop, energy performance contracting, (Managed) energy services agreement, and other business models

This subsection deals with some sustainability-focused BMs; the primary three of them are as follows: One-stop shop (OSS), Energy performance contracting (EPC), and (Managed) energy services agreement (MESA). They all share the value proposition, namely, enabling building energy refurbishment by providing a comprehensive bundle of related goods and services so that the customers can experience lower energy bills as well as more livable, more comfortable, and healthier housing. They rather differ in aspects of customer interface as far as value creation and delivery are concerned and revenue streams in the financial model as far as value capture is concerned (Table 1).

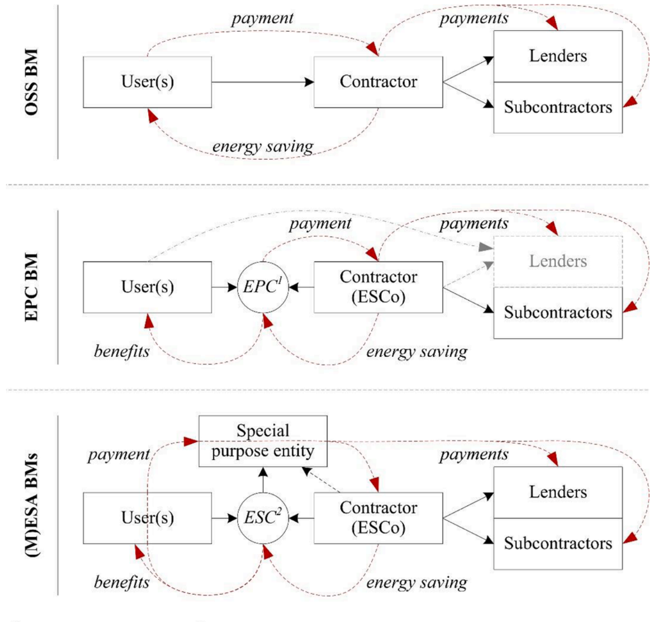
One-stop shop (OSS) is a common locution in several fields. It is used to mean the integrated offer of products, services, or solutions by a private entity to its customers or by a public body to its users. It identifies a BM making its way into the building industry, too, especially for refurbishment works, as the adoption of the Directives on the Energy Performance of Buildings has favored it. The distinguishing feature of the OSS BM (Fig. 4) is the presence of an individual contractor who performs the following tasks: interacts with the customers to fulfill their needs; provides them with the information required to define the project and carry out the work; identifies the suppliers of specific goods and services, including financial services; takes care of the payment flows; bears the responsibility for discrepancies between expected and actual results [12,14,25]. The boundaries of the contractor action include establishing relationships with a few consultants, which support the customers in the planning process, the financing decisions, and the energy audit [12,14,22]. Cases and applications of public-driven and private-driven OSS [94]have been identified in the Scandinavian countries [80]and in Western European countries [7,73], especially France and Belgium [37]. Recent studies show that the acceptance of the OSS BM is likely to grow according to the age, education level, and income level of the prospective customers [18,80,93].

A BM derived from the OSS one features the presence of a private partner – mostly an Energy Service Company (ESCo) – playing the role of the individual contractor [3,48,117,125]. The ESCo is responsible for the energy performance of those works and provides guarantees to the customers. The contractor then recovers capital expenditure by directly benefiting from energy saving, representing its primary income flow [72,92]. The costs and energy savings allocation among the involved parties may change based on the agreed energy service contract [65,81,85]. Concerning the latter, it is usually shaped according to different financial models: Energy performance contracting (EPC) [26,47,72,109,119](Fig. 4) and Energy supply contracting (ESC) [26,47,114], the first of which is the most commonly used in the building industry. Depending on the energy-saving distribution and risk allocation, the literature identifies four EPC contract subtypes: guaranteed saving, shared saving, without guaranteed savings, and the so-called chauffage one [72,81,117]. The topic of ESCOs requires some clarification. The establishment and rise of these entities predate the incentive measures discussed here, and their functioning is sizably independent of public subsidies [16,11]. Additionally, ESCOs employing the EPC BM only focus on renovating buildings, particularly large public ones, and primarily carry out projects likely to generate a return on investment in the short to medium term.

When the relationships between the involved parties – particularly between customers and the contractor – are regulated under the ESC framework, another class of sub-models can be recognized. In order to identify it, the literature uses the acronym (M)ESA, which stands for (Managed) energy services agreement [25,26,36]). The (M)ESA BM combines the responsibility born by the contractor – usually an ESCo, again – for the energy performance ositivet works with an energy supply contract. Furthermore, it often features the establishment of a special purpose vehicle [17]; thus, a legal entity where the subcontractors can be involved and that plays as the interface for the customers [60] or, put

Table 1
Key features of three sustainability-focused business models.

		OSS BM	*EPC BM*	*(M)ESA BM*
Value proposition		Enabling building energy refurbishment by providing a comprehensive bundle of related goods and services so that the customers can experience lower energy bills as well as more livable, more comfortable, and healthier housing.		
Value creation and delivery	*Supply chain*	The company handles all the relationships with the suppliers of intermediate goods and services.	The company handles all the relationships with suppliers of intermediate goods and services, and occasionally financers.	The company handles all the relationships with partners, financers, and suppliers of intermediate goods and services.
	Customer interface	The customers are provided with energy consultancy and auditing services, refurbishment works, and energy-efficient installations.	The customers are supplied with retrofit measures and performance guarantees, often with energy management and monitoring services, occasionally with loans.	The customers get efficiency-related works, management of buildings and facilities, performance guarantees, and energy supply and management.
Value capture	*Financial model*	Upfront costs are offset by means of public funds when available and money borrowed from lenders.		
		The customers pay for the goods and services provided as work progresses. Customers benefit from energy savings.	The revenue streams are based on energy savings allocated between the contractor and the customers.	The revenue streams are based on energy savings, which are allocated between the contractor and the customers, and energy selling.
	Governance model	Coordination and management activities are taken care of by an individual contractor.		The contractor and its partners may establish a special purpose entity.



¹ Energy performance contract; ² Energy supply/service contract.

Fig. 4. Comparison between OSS, EPC, and (M)ESA BMs concerning the players' arrangement and relationships.

differently, a subsidiary of the contractor that is useful to perform separate transactions with subcontractors and customers (Fig. 4) as well as isolate financial risk. Concerning the latter aspect, it seems straightforward to identify a resemblance with the so-called risk-fence role played by the special purpose vehicles in public–private partnerships. Though primarily used for the energy retrofit of commercial buildings and public properties, a few large-scale interventions in the residential sector are reported across Central and Western European countries, signally for social housing [25].

The recent literature identifies almost a dozen more BMs focusing on building energy efficiency [25,26,109,119]; among the others, it deserves mentioning the Turnkey contract (TKC) BM [56,86,90]. The term turnkey refers to a contract wherein an individual contractor prearranges all the necessary resources – premises, equipment, supplies, and so forth – to bring a project – of a facility, building, or–plant – to a fully operational state [84]. This definition closely resembles the distinguishing feature of the OSS BM; besides, turnkey solutions can be embedded in EPC-like BMs [69]. Nonetheless, there are a few differences that are worth bearing in mind. Firstly, while the OSS BM is specially meant to deal with renovation, refurbishment, and retrofit, the TKC BM is mainly adopted in new construction projects and does not include subsequent maintenance. Secondly, in the OSS BM, professional advisors assist the customers to ensure that the planned works best suit their needs; instead, in the TKC BM, the customers only set the required output and the expected performance, while the contractor is fully responsible for design development and implementation. Lastly, TKCs are usually awarded following a call for tenders. Once awarded the contract, the contractor must appoint a project manager who acts as the interface with the subcontractors and customers. Payments for TKCs are most likely to occur on a lump-sum basis or as work progresses, and the work must be carried out by a fixed deadline.

2.4. Risk allocation profile of the sustainability-focused business models

Aside from the commonalities and dissimilarities described above, the various classes of BMs are characterized by subtle differences in risk allocation. While supply risk – namely, risk-bearing as far as the retrofit or new construction works are concerned – usually lays on the shoulders of the contractor, demand risk – that is to say, risk-bearing as far as energy management and consumption are concerned – is sometimes shared – in part, at least – between customers and the contractor [52,70,126] (Fig. 5). In the OSS BM, the customers benefit from energy saving and – separately – make payment(s) to the contractor. Thus, the saving (as inflow for the customers) and the price (as outflow from the same customers) are not interlinked. –ontrariwise, in the E–C and (M) ESA BMs, t–e repayment for the contractor directly stems from the savings achieved with the energy retrofit works. Hence, increasing performance and achieving a high level of energy saving is crucial as the contractor's gain depends on them.

3. Method

We aim to find out the best practices among a few dozen case studies described by variables belonging to several domains. As those variables are both quantitative and qualitative, as they are an incomplete characterization and representation of the case studies, and as they sometimes include imprecise, vague, or even noisy information, we find it profitable to process the data using Rough Set (RS) Theory, which was introduced by Polish mathematician Z. Pawlak in 1982 [95,98–99,100,113]. Therefore, we can roughly describe the class of best practices and the other groups of case studies, where the approximation comes from considering and investigating a complex phenomenon and also dealing with imperfect information and missing data [49,67].

Objects and attributes are the two essential elements of an information system, which can be represented using a table where the former ones are positioned in the rows and the latter ones in the columns. Let us denote a generic object by x and the set of attributes used to describe it in the information system by A. Row-column intersections of the table mentioned above feature the values $a(x)$ taken by each object for each attribute. A rough set of the analyzed objects can be defined by identifying two other sets, the lower and upper approximation, respectively, of the rough set itself.

Let us suppose that, based on their attributes, the two objects x and y belong with certainty to a group, for instance, because they share the same value for all those A attributes. To paraphrase the words of Z. Pawlak, those objects are indiscernible – or indistinguishable, if you will – and bound in an indissoluble relationship as they share the very same information for the same set of attributes [95–96]. The indiscernibility relation $xI(A)y$ is, hence, one of the key concepts in RS Theory. It can be used to identify the lower approximation set $\underline{P}X$:

$$\underline{P}X = \{x|[x]_P \subseteq X\} \tag{1}$$

Let us also assume that a few other objects may or may not belong to that collection, as they share the same values for some attributes but not all. Uncertainty is another crucial concept in RS Theory, which refers to the inability to define whether or not an object is included in a set: it might, according to part of the attributes, or it might not, according to other features. It can be used to identify the upper approximation set $\overline{P}X$:

$$\overline{P}X = \{x|[x]_P \cap X \neq 0\} \tag{2}$$

Here, we consider both the lower- and upper-approximation set to be crisp – or conventional, if you will – as in the standard RS theory version [96]. The difference $\overline{P}X - \underline{P}X$ identifies the so-called boundary region [97]. In other words, on the one hand, the lower-approximation set includes all the objects that belong to the rough set with a probability equal to 1 while, on the other hand, the upper-approximation set includes the objects that belong to the rough set with a non-zero probability (Fig. 6).

Let us denote the ratio between the number of elements in lower- and upper-approximation sets by $\alpha_P(X)$ [96], which is also a measure of the accuracy of the set representation:

$$\alpha_P(X) = \underline{P}X/\overline{P}X \tag{3}$$

with $0 \leq \alpha_P(X) \leq 1$. If $\overline{P}X = \underline{P}X$, then the upper-approximation set and the lower-approximation set include the same objects, the boundary region is empty, and $\alpha_P(X) = 1$; hence, there is a perfect approximation. Usually, the number of objects that indeed belong to the set ($\underline{P}X$) is lower than the number of those that possibly belong to it ($\overline{P}X$), which means $0 \leq \alpha_P(X) < 1$, and the set is roughly definable, so it is essentially vague.

RS analysis has been applied primarily in engineering, computer, and medical sciences; later, it has also made its way into other research fields, such as urban planning and building energy efficiency. In addition, RS and its extensions are often associated with the twofold purpose of multiple-criteria decision-making and multiple-criteria decision support: to explain decisions as far as the underlying circumstances and

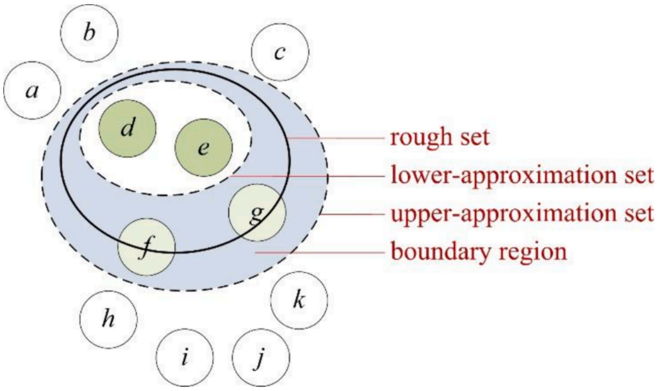


Fig. 6. Representation of a rough set.

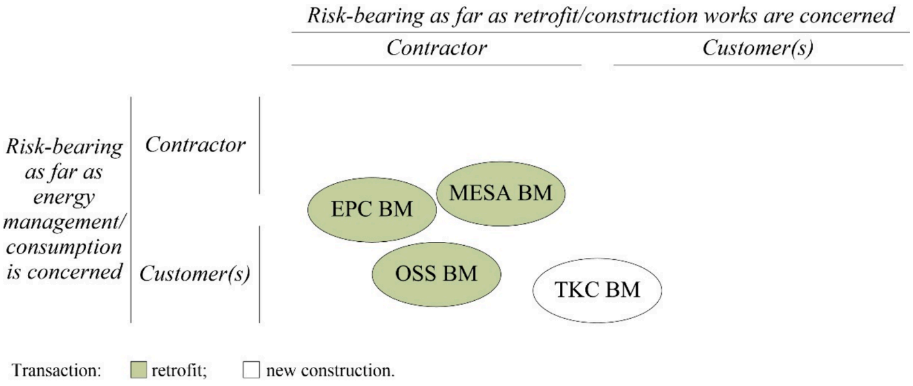


Fig. 5. Comparison between OSS, EPC, (M)ESA, and TKC BMs concerning risk allocation.

determinants are concerned and to recommend how a decision should be made given specific circumstances [50–51,112].

Concerning urban planning, a study focusing on a multi-actor approach for projects involving the use and revitalization of Dutch urban land [88]is worth mentioning. RS analysis is applied to case studies of urban development plans involving public–private partnership (PPP) transactions, aiming to identify the key drivers of the success or failure. Various kinds of PPP forms are also analyzed in a publication on the characterization of urban models in Italy [115]. Another work in urban planning tackles the issue of waste-to-energy plants' and landfills' locations[1], compared based on several demographic and environmental attributes.

Regarding building energy efficiency, RS has been used in a few studies to improve energy consumption monitoring and energy efficiency prediction in buildings supplied with district heating [64], to examine conflicts amongst objectives in green buildings projects [111], to identify the success factors of energy-efficient social housing built or refurbished through a PPP scheme [31], for the automatic reconfiguration of photovoltaic systems in the attempt to minimize the adverse effects of shading and, thus, maximize their performance [38], to perform a reduction of redundant variables influencing building energy consumption so as to reveal the critical factors [71].

The analysis below is performed using the software ROSE2 [105,106], developed by the IDSS (Intelligent Decision Support Systems) Laboratory at the Poznan University of Technology. It features a package for "rule induction" based on RS Theory – essentially a sorting and classification technique – which requires distinguishing between condition attributes (A^C) and decision (or evaluation) attributes (A^D) [101]. An analogy can be established with statistical analysis, with each A^C playing the role of independent variables, while each A^D represents a dependent variable, even though the distinction between condition and decision attributes does not always imply a causal relationship. Examples of rules are as follows:

$$\left(A_1^C = a_p\right) \wedge \left(A_2^C = a_q\right) \wedge \left(A_3^C = a_r\right) \Rightarrow \left(A_1^D = a_t\right), \{x_i, x_j\} \tag{4}$$

$$\left(A_1^C = a_p\right) \wedge \left(A_3^C = a_r \vee a_s\right) \Rightarrow \left(A_1^D = a_t\right), \{x_i, x_j, x_k, x_l\} \tag{5}$$

Hence, if the first three condition attributes A_1^C, A_2^C, and A_3^C take on the values a_p, a_q, and a_r, respectively, then we can expect the first decision attribute A_1^D to be equal to a given value a_t, and the two objects x_i and x_j are included in the set. Also, if the value of the first condition attribute A_1^C is a_p and the third decision attribute alternatively takes on the two values a_r and a_s, then the first decision attribute A_1^D is equal to a_t, and the four objects x_i, x_j, x_k, and x_l are included in the set. It is straightforward to see the resemblance between the rules in Eqs. (4)-(5) and the definition of lower- and upper-approximation sets as in previous Eqs. (1)-(2).

4. Case studies

Below is a workflow diagram describing the steps of the case study analysis and their respective inputs and outputs (Fig. 7). Projects of energy retrofit or new energy-efficient constructions carried out using innovative business models are identified using a wide range of sources: reports and deliverables drafted under the framework of EU-funded projects (for instance, STUNNING[2] – SusTainable bUsiNess models for the deep ositiven of buIldiNGs, BEEM-UP[3] – Building Energy Efficiency for Massive market Uptake, E2REBUILD[4] – Industrialized energy efficient retrofitting of resident buildings in cold climates, and EXCESS[5] – ositive user-Centric Energy ositive houseS); research articles [40,57,102,103], conference papers [45,55,107], and book chapters [66]; technical reports concerning projects, construction site activities, and energy audits; information sheets published by industry monitors; online collaborative platforms and open information portals aimed at collecting and sharing information on sustainable building projects. Data is collected concerning 37 case studies across five Central and Western European countries: Belgium, France, Germany, Spain, and The Netherlands (Fig. 8, Table 2). It is observed that most case studies are located in regions with Continental and Atlantic climates, while only few cases fall under the Mediterranean climate zone. This variation in climate zones is reflected in the primary use of different building materials, such as reinforced concrete for the Continental climate and bricks for the Atlantic one. Besides, differences arise concerning the building typology. The Belgian, Dutch, and German cases include uses other than residential. Apartment buildings are ordinary in the French and German cases. Most cases consist of multi-family buildings, while terraced, semi-detached, and detached houses are rare.

The information gathered for each case study can be clustered into three domains (Table 3): characteristics of the adopted BM, features of the properties where energy-efficiency measures are taken, and aspects of the performed efficiency-related works.

The first domain includes data concerning the kind of BM used, the public or private nature of the property ownership, the type of project developer, whether or not other players are involved, whether incentive measures such as subsidies and tax rebates are used, type and duration of the works, and amount of the investment.

OSS and TKC are the most represented BMs, while the (M)ESA one is absent in the analyzed case studies. The EPC BM is predominant when private non-profit building owners appoint consulting firms as project developers (Fig. 9). Incidentally, in some cases, the specific BM setting deviates slightly from expectations. For instance, in a couple of them, a consortium of contractors or several contractors are appointed simultaneously instead of an individual contractor and multiple subcontractors. Nonetheless, some distinctive features of the analyzed BMs can still be recognized. Also, two critical players are essentially missing: ESCos, as far as contractors and project developers are concerned, and energy suppliers, about subcontractors. Even though ESCos are largely underrepresented, there are a few cases where consultancy firms play similar roles, at least concerning the energy-related activities needed to carry out the project. Investment costs vary between a minimum of 30 thousand and a maximum of nearly 60 million Euros; the average investment is 7 million, while the median equals 3.2 million Euros. Unit investment costs are often in the ranges of 300 to 650 Euro/m2 (27 % of the case studies), 650 to 900 Euro/m2 (14 %), 1,000 to 1,550 Euro/m2 (30 %), and 2,000 to 2,900 Euro/m2 (16 %), with the highest unit cost reaching 3,390 Euro/m2. Economic incentives are used in about half the cases (18 out of 37), but the actual amount of public funds is available only for a part of them (11 out of 18). Average subsidies are equal to 1.3 million Euros, with a median value of 644 thousand Euros. In a demonstration project, grants cover up to 98 % of the investment, but they mostly range between 5 % and 43 %. Two additional variables are considered and used as decision attributes in the analysis, along with BM and the use of incentives. They are as follows: allocation of the energy savings between ownership and developer and expected payback period,[6] although data is often missing, as the information about savings allocation and the payback period is unknown for several case studies.

The second domain is meant to provide an overview of the leading property features: its size, meaning the net floor area, the construction year, the building typology and construction materials, both the energy

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[2] See: https://renovation-hub.eu/ (accessed 09.08.2023).

[3] See: https://cordis.europa.eu/project/id/260039 (accessed 09.08.2023).

[4] See: https://cordis.europa.eu/project/id/260058 (accessed 09.08.2023).

[5] See: https://positive-energy-buildings.eu/ (accessed 09.08.2023).

[6] The available data refers to the simple payback period; hence, merely the ratio between savings and investment costs (net of capital grants). Considering the discounted payback period – thus accounting for the time value of money – would lead to higher payback values.

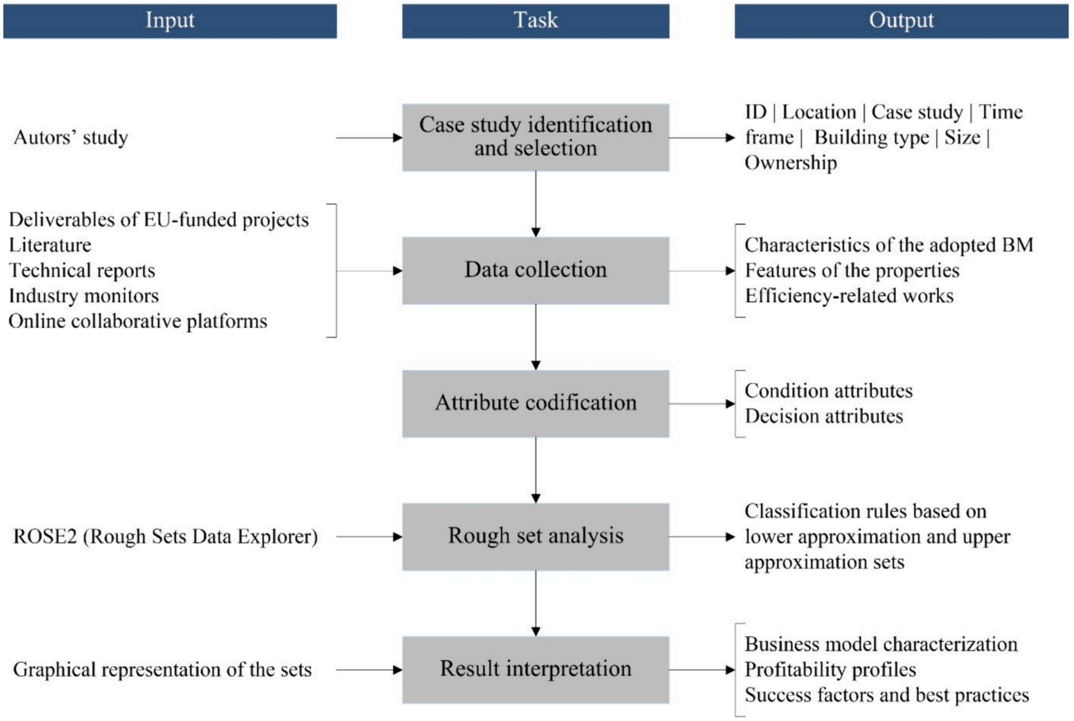

Fig. 7. Case study analysis workflow diagram.

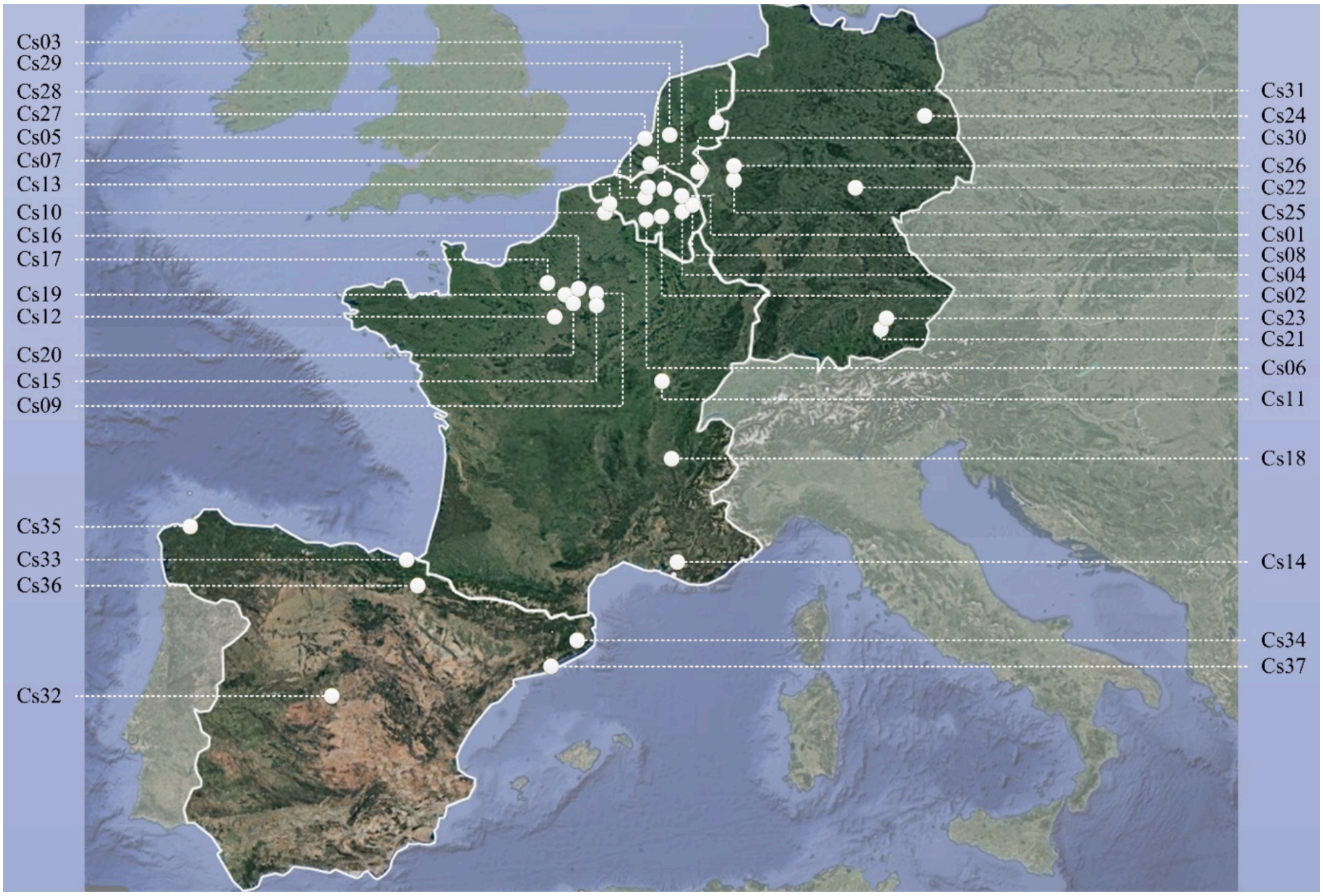

Fig. 8. Location of the case studies.

Table 2
Main features of the case studies.

ID	*Location*	*Case study*	*Time frame*	*Building type*	*Size (m2)*	*Ownership*
Cs01	Hoeselt (BE)	De Sociale Energiesprong	2021	Semi-detached	445	Cordium (social housing company)
Cs02	Namur (BE)	Nouveau Centre Perex	2017–19	Office building	7,884	SPW Mobilité et Infrastructures
Cs03	Averborde (BE)	Uitgeverij Averbode	2013–14	Office and warehouse	5,800	Uitgeverij Averbode
Cs04	Liège (BE)	Uliège Institute of Botany	2015–19	University building	9,000	Université de Liège
Cs05	Bruxelles (BE)	Rue Belliard, 65	2014–18	Office building	5,134	AXA REIM Belgium
Cs06	Charleroi (BE)	Cité du Centenaire	2016–17	Multi-family	3,420	La Sambrienne (public housing company)
Cs07	Bruxelles (BE)	Avenue Lousie, 120	2010–12	Office building	2,948	Gilt Investments
Cs08	Herstal (BE)	Pivert II	2016–18	Multi-family	7,510	Société Régionale du Logement de Herstal
Cs09	Paris (FR)	Cotentin Falguière	2013–14	Multi-family	3,338	ICF Habitat (part of SNCF Immobilier)
Cs10	Hem (FR)	Hem Energiesprong	2018–19	Detached houses	787	Vilogia
Cs11	Nuits-Saint-Georges (FR)	Rue Jean Mermoz, 8	2007–10	Multi-family	2,054	SCIC Habitat Bourgogne
Cs12	Rambouillet (FR)	Résidence La Vénerie	2020	Multi-family	13,350	Copropriété La Vénerie
Cs13	Wattrelos (FR)	Rénovation EnergieSprong	2020–22	Terraced houses	14,654	Vilogia
Cs14	Aix-en-Provence (FR)	Jas de Bouffan	2016–19	Multi-family	56,000	ESH Famille & Provence
Cs15	Paris (FR)	Résidence Desnouettes	2020–21	Multi-family	12,343	Copropriété Desnouettes
Cs16	Saint-Germain-en-Laye (FR)	Ru de Buzot	2016–18	Multi-family	9,138	Copropriété Ru de Buzot
Cs17	Mantes-la-Jolie (FR)	Tour Neptune	2021–22	Multi-family	6,935	Copropriété Neptune
Cs18	Bourgoin-Jallieu (FR)	Résidence Maréchal Leclerc	2010–11	Multi-family	2,369	Alpes Isère Habitat (formerly Opac 38, Office Public d'Amenagement et de Construction)
Cs19	Plaisir (FR)	Résidence Gabrielle	2020–22	Multi-family	21,271	Copropriété Gabrielle
Cs20	Les Clayes-sous-Bois (FR)	Résidence La Vigneraie	2018–20	Multi-family	30,609	Copropriété La Vigneraie
Cs21	Munich (DE)	Weiterbauen	2010–14	Multi-family	3,323	GWG Städtische Wohnungsgesellschaft München mbH
Cs22	Erfurt (DE)	Max-Liebermann-Straße, 24	2010–11	Multi-family	380	private owner(s)
Cs23	Munich (DE)	Parklogen Schwabing (former Funkkaserne)	2015–17	Multi-family	4,067	LIP Ludger Inholte Projektentwicklung GmbH
Cs24	Berlin (DE)	Newtonprojekt Adlershof	2016–18	Multi-family	1,085	Wohneigentümergesellschaft Newtonprojekt
Cs25	Wuppertal (DE)	Variowohnen Wuppertal	2020	Student housing	4,230	Hochschul-Sozialwerk Wuppertal A.ö.R.
Cs26	Bochum (DE)	Wohnheim Siepenfeld	2017–19	Multi-family	6,626	AKAFÖ Akademisches Förderungswerk A.ö.R.
Cs27	Delf (NL)	Van der Lelijstraat	2011–13	Multi-family	9,124	Woonbron
Cs28	Roosendaal (NL)	De Kroeven Roosendaal	2010–11	Terraced houses	5,320	AlleeWonen
Cs29	Utrecht (NL)	Flat met toekomst (zero-on-the-meter)	2017–20	Multi-family	4,000	Mitros
Cs30	Venlo (NL)	Stadskantoor Venlo	2012–16	City hall	13,500	Gemeente Venlo
Cs31	Almelo (NL)	Stadhuis Almelo	2013–15	City hall	20,409	Gemeente Almelo
Cs32	Madrid (ES)	Entrepatios Las Carolinas	2018–20	Multi-family	1,404	Cooperativa Entrepatios
Cs33	San Sebastián (ES)	Villa Eulieta	2016–17	Multi-family	354	private owner(s)
Cs34	Girona (ES)	Carrer Nou	2016–17	Multi-family	678	MBD Real Estate Group
Cs35	La Coruña (ES)	Parque Ofimático	2011–16	Multi-family	13,633	Sociedade Cooperativa Galega de Viviendas Parque Ofimático
Cs36	Pamplona (ES)	Edificio Thermos	2016–17	Multi-family	2,239	Promociones Las Provincias
Cs37	Barcelona (ES)	Nena Casas	2017–18	Detached house	300	private owner(s)

rating band and the energy performance index before the works, and whether or not the works are part of an urban redevelopment project.

Most cases involve multi-family buildings (62 %), while terraced houses, commercial buildings, and community services are almost equally represented in the remaining cases. Concrete (73 %) and bricks (19 %) are the most common construction materials. Property size varies between 300 and 56,000 square meters of net floor area; the average size is about 8,250 m2, while the median is approximately 5,150 m2. A couple of properties date back to the first half of the last century, while most of the cases feature properties built during the fifties and the sixties (38 %) and between the seventies and the nineties (24 %).

The third domain focuses on the adoption of energy-efficiency measures. It includes a series of binary variables concerning building cladding and insulation, ventilation, heating and cooling systems, photovoltaic and solar thermal systems, and rainwater harvesting systems.

The common denominator with most of the case studies is the joint intervention on the building envelope – including replacing windows and frames and adding insulation layers – and the heating system. Since that leads to creating a well-insulated home environment, installing a mechanical ventilation system is often featured, too (Fig. 10, upper-left corner). Also relatively standard is the installation of photovoltaic systems (Fig. 10, center-right panel) and, to a lesser extent, solar thermal systems (Fig. 10, center-left panel). Incidentally, using photovoltaic (PV) energy seems comparatively easier in new construction than in retrofit (installation of PV panels is featured in 82 % of the cases concerning newly built efficient houses and offices – namely, 9 out of 11 – while it is featured in only 31 % of the refurbishment cases – that is to say, 8 out of 26). The opposite holds true regarding solar thermal (ST) energy (ST systems are used in 9 out of 26 refurbishment cases – namely, 35 % – but only in 1 out of 11 new construction cases – that is, 9 %). Nevertheless, the figures above do not control for potential confounders such as case study location, building orientation, roof shape, and so forth. Finally, far less common are cooling and rainwater harvesting systems.

As an effect of the works mentioned above, several cases are characterized by the shift from the D to the B energy rating band and, to a lesser extent, from the D to the A rating band (Fig. 11). There are a few cases where the efficiency works allow just for minor improvements in the energy need, there it can be seen that the energy rating band shifts from C to A, from D to C, and even from E to D. In the retrofit cases, 243 and 212 kWh/m2 y are the average and the median energy performance index before the works, respectively. Those figures fall to 77 and 75 kWh/m2 y once the energy refurbishment is done.

Table 3
List of the analyzed attributes.

Domain	*ID*	*Variable*	*Categories*
Business model	BM *	Business model	1: OSS; 2: EPC; 3: (M)ESA; 4: TKC
	OW	Building ownership	1: public body or semi-public organization (including local public and social housing authorities); 2: private non-profit entity (natural persons, housing cooperatives and associations); 3: private for-profit company
	PD	Project developer	1: ESCo; 2: construction company; 3: architecture studio, engineering firm, or financial consulting firm
	EP	Energy provider	(binary) 1: involvement of an energy supplier
	OP	Other players	(binary) 1: involvement of actors other than PD and EP
	IM *	Incentive measures	(binary) 1: use of subsidies or tax rebates
	TW	Type of work	1: retrofit; 2: building enlargement and retrofit; 3: new construction
	DW	Duration of the works	1: less than a year; 2: one to three years; 3: more than three and up to ten years
	IC	Investment costs	1: <1mln Euros; 2: 1-3mln; 3: 3-5mln; 4: 5-10mln; 5: 10-20mln; 6: >20mln
	UC	Unit costs (per m2 of net floor area)	1: <650 Euros/m2; 2: 650–999; 3: 1,000–1,499; 4: 1,500–1,999; 5: 2,000–3,000; 6: >3,000
	ES *	Allocation of energy savings	1: nearly equal distribution between PD and OW; 2: most of the savings go to OW
	PB *	Payback period	1: less than ten years; 2: ten to twenty years; 3: more than twenty years
Property features	FA	Property size (net floor area)	1: ≤500 m2; 2: 501–2,000; 3: 2,001–8,000; 4: 8,001–12,000; 5:12,001–20,000; 6: ≥20,000
	CY	Construction year	1: earlier than the 1950 s; 2: 1950 s and 1960 s; 3: 1970 s to 1990 s; 4: 2010 s; 5: 2020 s
	BT	Building typology	1: detached, semi-detached, and terraced house; 2: multi-family building; 3: commercial; 4: other (community services)
	CM	Construction material	1: bricks; 2: concrete; 3: wood; 4: steel
	UR	Urban renewal	(binary) 1: the project contributes to the renewal of urban community spaces in the neighborhood
	RBb	Energy rating band before the works	1 to 7: A to G
	EPIb	Energy performance index before the works	1: 100–149 kWh/m2 y; 2: 150–162; 3: 163–195; 4: 195–207; 5: 208–229; 6: 230–280; 7: 281–339; 8: 340–359; 9: ≥359
Efficiency measures	Rba	Energy rating band after the works	1 to 7: A to G
	EPIa	Energy performance index after the works	1: ≤19 kWh/m2 y; 2: 20–38; 3: 39–52; 4: 53–71; 5: 72–79; 6: 80–91; 7: 92–149; 8: 150–159; 9: ≥159
	CI	Building cladding and insulation	(binary) 1: efficiency measures related to cladding and insulation
	WF	Windows and frames	(binary) 1: replacement of windows and frames
	HS	Heating system	(binary) 1: replacement of the heating system
	CS	Cooling system	(binary) 1: installation of a cooling system
	VS	Ventilation system	(binary) 1: installation of a mechanical ventilation system
	PV	Photovoltaic	(binary) 1: installation of a photovoltaic system
	ST	Solar thermal	(binary) 1: installation of a solar thermal system
	RH	Rainwater harvesting	(binary) 1: installation of a rainwater harvesting system

* Decision attributes

5. Results

According to the recognizable rough sets, the OSS BM (Fig. 12, upper panel **a**) is essentially tied to public ownership of the buildings (OW = 1), while project developers are either construction companies (PD = 2) or, to a lesser extent, consultancy firms (PD = 3). In this regard, it can be seen as a newly added partnership form to the realm of public–private partnerships. Properties undergoing retrofit are concrete (CM = 2), medium-sized (FA = 3), multi-family (BT = 2) outdated buildings, mostly built during the 1950 s and 1960 s (CY = 2). The retrofit works usually take longer than a year but no longer than three years (DW = 2), and, most importantly, the unit costs are low to moderate (UC = 1,2,3), namely, mostly below 650 or in the range of 650 to 999 Euros per square meter.

The intervention strategy (Fig. 12, lower panel **b**) always involves the addition of insulation layers to the building envelope, almost always the replacement of windows and frames (WF = 1), the installation of a more efficient heating system (HS = 1), and the use of a mechanical extract ventilation system (VS = 1), and seldom the adoption of renewable energy sources to generate electrical power or domestic hot water. It deserves to be pointed out that the previous characterization of the OSS BM refers to most of the cases belonging to it – namely, twelve out of sixteen – but not all. Four additional observations have little in common with the above description; thus, they share little information with the other cases.

The EPC BM (Fig. 13, upper panel **a**) has a pretty clear characterization as far as building typology and construction material are concerned. All the cases but one are either detached, semi-detached, and terraced brick houses or multi-family concrete buildings. A remarkable difference with the OSS BM concerns ownership. No more public bodies or semi-public organizations, but private non-profit entities – including housing cooperatives and associations – own most of the properties. Also, using architecture studios, engineering firms, or financial consulting firms as project developers is pretty standard. The rough sets for the EPC BM (Fig. 13, upper panel **a**) bring other noteworthy specificities to light. Most of the involved properties were not characterized by abysmal energy performance at the beginning, as witnessed by the rating bands C, D, and E before the retrofit projects were carried out (RBb = 3,4,5). It implies that they did not need to undergo deep retrofit. Also, several cases resort to modular, off-site manufactured elements (Cs01, Cs13, and Cs28, for instance), which are then readily deployed and installed rather than cast in place. Perhaps all this helps explain why low unit costs are incurred in several cases (UC = 1).

A further difference with the OSS BM lies in the adopted energy efficiency measures (Fig. 13, lower panel **b**). Again, almost all cases share the addition of insulation layers, replacement of windows and frames, and substitution of the heating system, often along with the installation of a mechanical ventilation system (VS = 1). Regardless, by contrast with the OSS BM, the use of solar thermal energy is a common trait for a few case studies (ST = 1), and all of them share the installation of photovoltaic panels (PV = 1).

The recognizable rough sets also offer an interesting reading concerning the relationships of the OSS and EPC BMs with the use of incentive measures – especially in the form of grants and subsidies – and with the economic viability of the case studies – as expressed by the payback period when available (Fig. 14). Monetary incentives (IM = 1) are used in more than half of the projects but are more common in the cases belonging to the EPC BM rather than in the OSS BM cases. The use

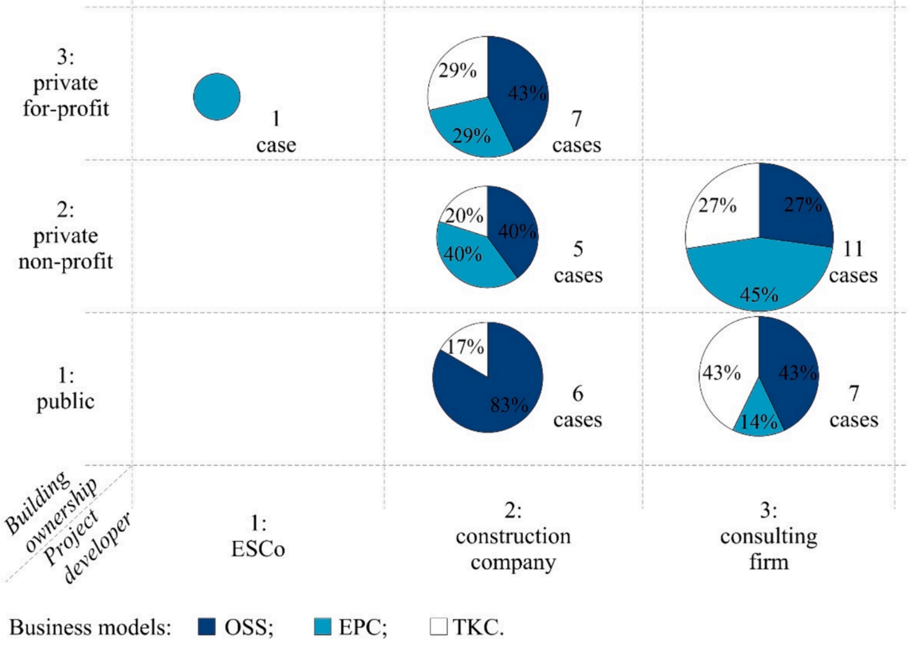

Fig. 9. Breakdown of business models by building ownership and project developer.

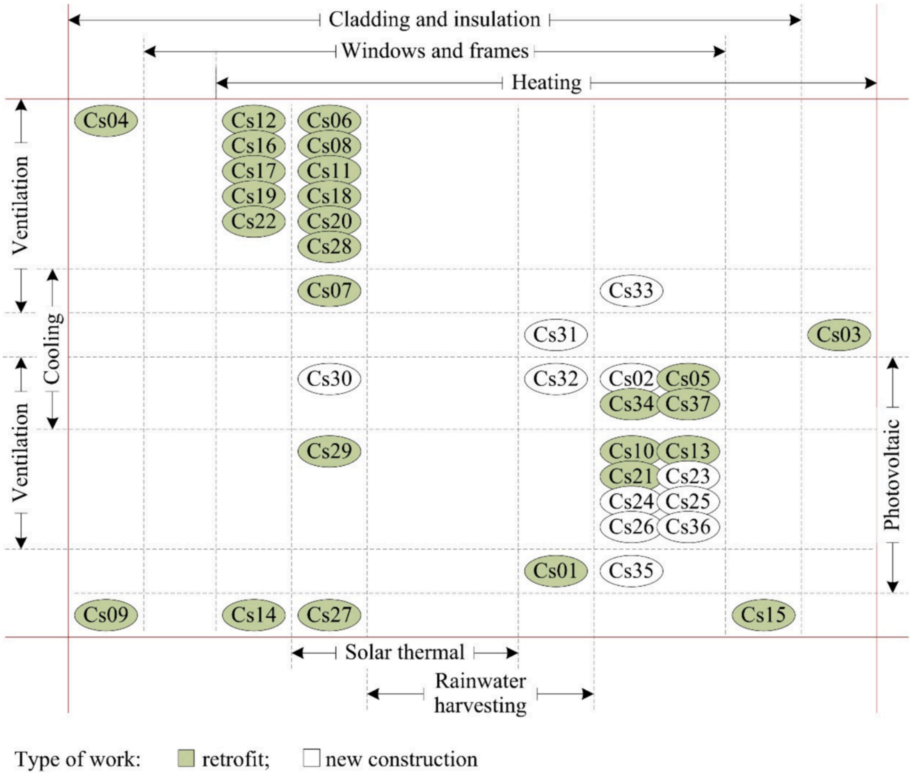

Fig. 10. Combinations of energy efficiency-measures.

of monetary incentives is seemingly independent of the unit investment costs. One would expect the access to grants and subsidies to be distinctive of more expensive projects. On the contrary, it turns out to be ordinary for the case studies where unit investment costs are moderate (in the range of 650 to 999 Euros per square meter, UC = 2) and even low (below 650 Euros per square meter, UC = 1). Surprisingly, incentive measures tend to be less used as unit investment costs increase (for instance, in the range of 1,000 to 1,499 Euros per square meter, UC = 3). In addition, although data on the actual amount of grants paid is available for barely a third of the case studies, there is no clue that the share of investment costs covered by monetary incentives is somewhat related to the investment costs. The information about the expected payback period, available for only half of the case studies, also suggests a potential decoupling between investment costs and economic viability. Shorter payback periods mainly characterize cheaper projects, regardless of the availability of monetary incentives (see the light blue area in

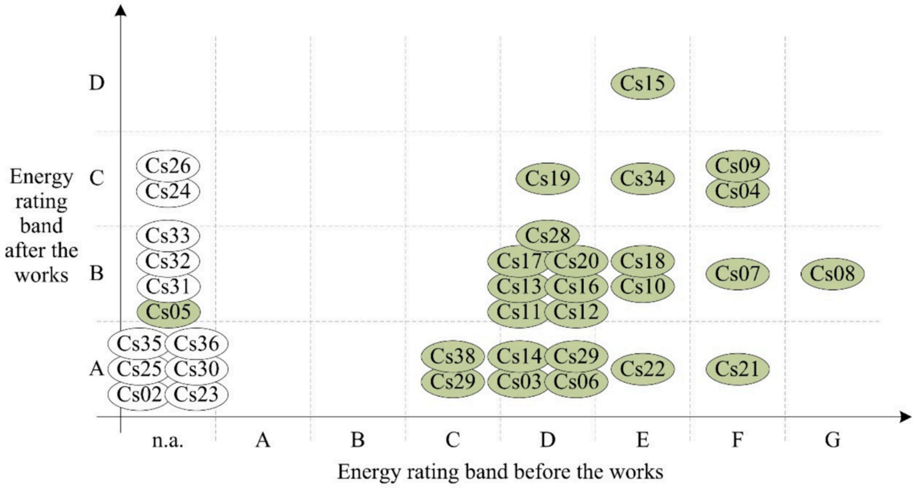

Fig. 11. Changes in the energy rating bands before and after the works.

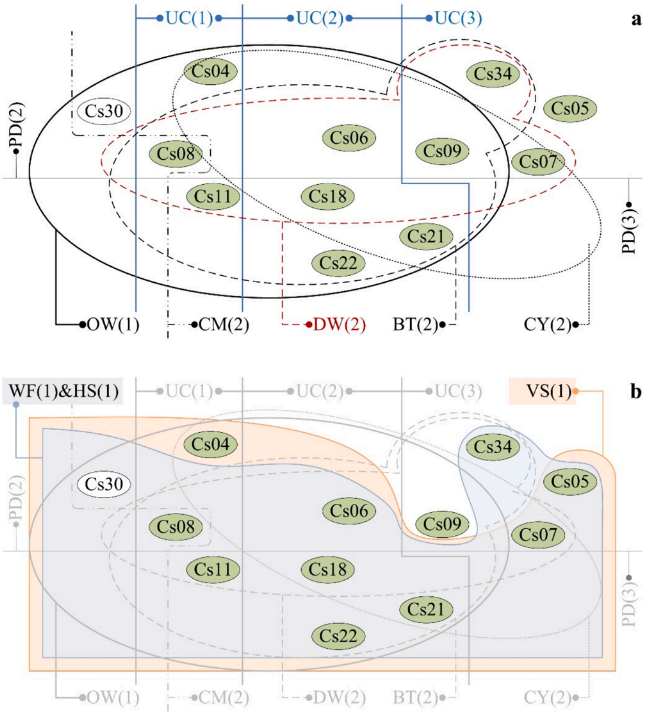

Fig. 12. Rough sets for the One-stop shop business model.

the center-left portion of Fig. 14, UC = 1,2 ∧ PB = 1,2). Nonetheless, more extended payback periods are not an exclusive feature of more expensive projects, even with access to grants and subsidies (see the overlap between the dark blue area and the red circle in the center-left portion of Fig. 14, UC = 1,2 ∧ IM = 1∧ PB = 3).

As far as TKC (Fig. 15) is concerned, a core of attributes related to the specificity of the BM turns out significant: new constructions only, especially small- to mid-sized multi-family buildings completed in a couple of years with just a few exceptions, mostly without broader urban renewal purposes. Some case studies date back to the 2010 s; the others are more recent. Along with construction companies, consulting companies such as architecture studios and engineering firms usually play the role of project developers.

Regarding energy performance, the intervention strategy for the building insulation, windows and frames, and heating system is relatively homogeneous. A mechanical ventilation system is featured in all

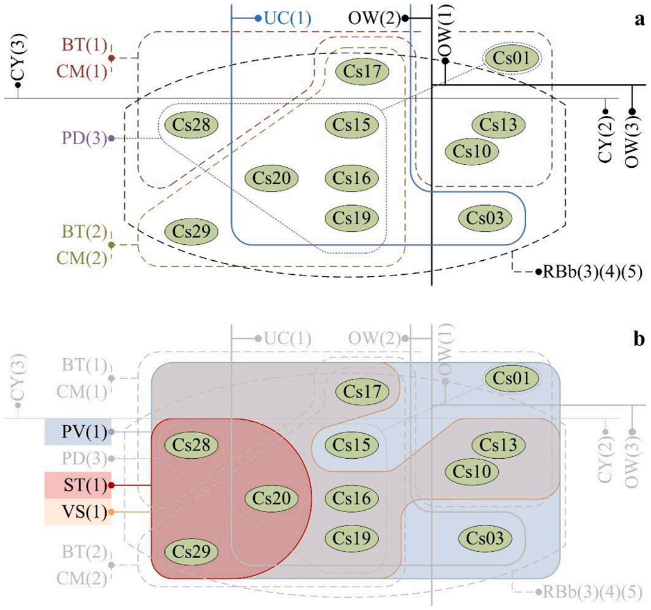

Fig. 13. Rough sets for the Energy performance contracting business model.

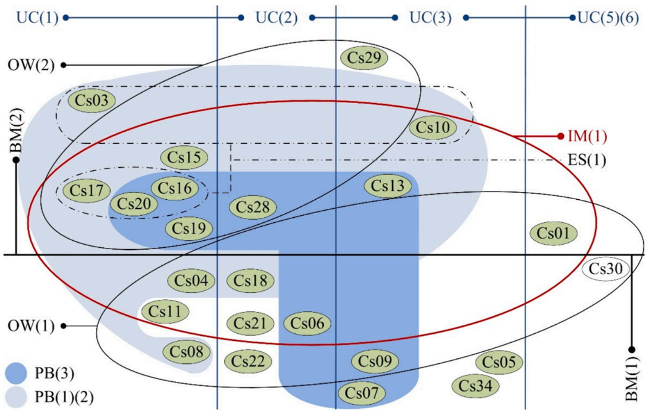

Fig. 14. Rough sets for the OSS and EPC business models as far as incentive measures and payback periods are concerned.

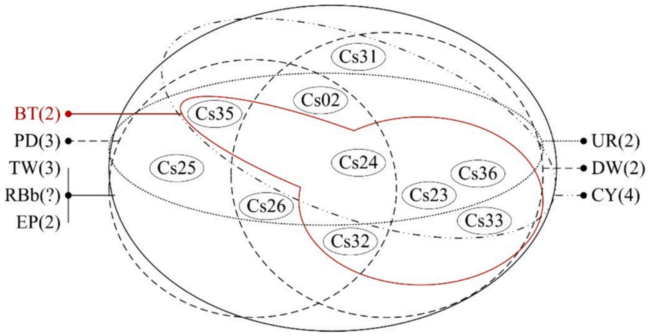

Fig. 15. Rough sets for the Turnkey contract business model.

cases but two, and a cooling system is featured in about half of them. Photovoltaic panels are preferred to solar thermal systems. A rainwater harvesting system is more the exception than the rule.

6. Discussion

At the very least, the empirical evidence presented so far raises three questions. The first concerns the characteristics that distinguish the BMs considered here. The second pertains to the profitability profile of the analyzed BMs. The third points back to the primary research question of this study: which attributes arise as success factors, and which ones of the case studies stand up as best practices?

All TKCs involve new constructions, but not all new construction projects resort to the TKC BM. Nonetheless, that was recalled as one of its distinguishing features compared to the OSS BM. Hence, it seems worth asking: where does the boundary between the BMs lie? The question likely matters not only concerning the thin line separating the OSS and TKC BMs but also the blurred boundary between the OSS and EPC BMs. The significance of the question also lies in the fact that some results may differ from the common knowledge on the topic. As seen earlier, there is an almost perfect overlap between the two BMs and the type of ownership. Nearly all the properties of the OSS BM are owned by public bodies or semi-public organizations, the latter ones including local public and social housing authorities. That is at odds with the typical use of OSSs to support renovating small buildings and single-family homes. In turn, many properties of the EPC BM are owned by private non-profit entities, such as natural persons or housing co-operatives and associations. That is at odds with the ordinary use of EPCs to renovate large apartment blocks, especially under the social housing regime. Accordingly, it seems plausible to assume that the choice of the BM is also subject to drivers other than building typology and the public or private nature of property ownership. It may depend on the relationships between the kind of work to be carried out on the property, the goals of the property owner, the extent of the energy-related services to be provided to the users, and whether this implies a short-term involvement of the contractor – namely, for design and construction only – or a long-term participation of the same – that is, for maintenance and management, too.

The economic viability issue also deserves to be considered regarding the analyzed retrofit case studies. Aside from the cases for which the expected payback period is unknown, the break-even is to be expected in the short run for a few projects only, and much more often, it takes more than two or three decades to (almost) get there. That seems to be primarily independent of the cost incurred to develop the investment – as far as the unit cost is concerned, at least – since the issue also affects cases characterized by moderate to low upfront costs. That seems to be even disconnected from the access to incentive measures – monetary incentives, especially – since the issue also affects cases benefitting from substantial grants and subsidies. There may be two suitable explanations for this empirical evidence. On the one hand, several case studies can be primarily considered demonstration projects, wherein technical feasibility – including energy savings and performance gains – and social acceptability are the primary aspects under scrutiny. The apparent implication is that economic viability is neither the main focus nor the leading concern for the project proponents and developers. On the other hand, many cases do not involve private sector dwellings, thus subject to free market rents; on the contrary, they belong to public or social housing authorities and housing cooperatives or associations, hence being subject to some sort of rent control. The likely implication is that the potential extent of rent increase after retrofit work is also limited, so only part of the energy savings can be translated into higher rents, which – in turn – burdens the projects' economic performance. The considerations above raise a question worth further scrutinizing in future works: whether these kinds of retrofit projects will be able to walk on their feet, in a manner of speaking. To that end, the allocation of energy savings among the involved parties – ownership, contractor, and tenants – seems to be an underrated issue.

As per the last question, attributes such as type of work, nature of the property owner, and time frame of the contractor involvement turn out significant towards the adoption of a specific BM. At the same time, other attributes can be identified as crucial to its success. The extent of the refurbishment work, the adoption of retrofit measures involving as many building elements as possible, and the resulting performance gain are all discerning elements of the analyzed case studies. The topic of cost control and containment is perhaps not among the primary concerns; nevertheless, it cannot be ignored that several case studies show moderate to low unit investment costs. Also, even though grants and subsidies are not determinant towards gaining short payback periods, access to incentive measures still appears essential to support further adoption of innovative BMs.

On the heels of the above reasoning, a few case studies nearly fit the following definition of best practice: a retrofit project wherein the works involve almost all the building elements and most of the systems so as to achieve substantial performance gains, possibly with the use of renewable energy sources, wherein unit costs are nonetheless low, and break-even can be expected in the short run without resorting to public funds. Just one pertinent example (Cs08 for the OSS BM) can be found by comparing the central area of the rough sets for the OSS and EPC BMs (Figs. 12, 13), the upper and lower left corners of the rough sets as far as incentive measures and payback periods are concerned (Fig. 14), and the bottom right panel of the diagram depicting the changes in the energy rating bands before and after the works (Fig. 11). By relaxing the constraints on the attributes, the following, less restrictive definition of best practice fits more case studies: a retrofit project wherein the works involve many building elements and systems so to achieve noticeable performance gains, possibly with the use of renewable energy sources, wherein unit costs are nonetheless low to moderate, and break-even can be expected in short to medium run, even with the use of subsidies and grants. Several pertinent examples (Cs04 and Cs18 for the OSS BM; Cs03, Cs10, and Cs17 – to a lesser extent, also Cs15, Cs16, Cs19, Cs20, and Cs28 – for the EPC BM) can be found by comparing again the central area of the rough sets for the OSS and EPC BMs (Figs. 12, 13), center-left panel of the rough sets as far as incentive measures and payback periods are concerned (Fig. 14), and the right panel of the diagram depicting the changes in the energy rating bands before and after the works (Fig. 11).

7. Conclusions

Western economies are facing an age of multiple transitions. Among them, the green transition is of primary concern, demanding action in several key sectors. The construction industry, its whole supply chain, and the real estate market are required to contribute significantly in the short to medium run. To enable these changes – a paradigm shift from business as usual, if you will – the EU countries have adopted a variety of green stimulus policies and measures, from behavioral incentives to in-kind and monetary incentives. This study assumes that the latter ones, especially the direct cash benefits, have incentivized the rise and growth of innovative entrepreneurial practices, which take the form of emerging business models meant to exploit the pursuit of energy efficiency in the building industry.

This study considers four innovative BMs: OSS, namely, One-stop shop; EPC, which stands for Energy performance contracting; MESA, the acronym for (Managed) energy services agreement; and TKC, short for Turnkey contract. Three of them are applied in 37 case studies across five Central and Western European countries: Belgium, France, Germany, Spain, and The Netherlands. For each case study, the available data belonging to three domains have been gathered: the main features of the adopted BM as far as the first domain is concerned, the characteristics of the properties shape the second domain, and the energy-efficiency measures as far as the third is concerned. The rough set analysis enabled the investigation of the relationships occurring among those attributes.

A few limitations should be borne in mind before generalizing the results. First, the analysis does not encompass some impacts of the relationships between innovative business models and energy efficiency-related works in buildings, such as the social and environmental ones. These aspects may, too, play a significant role in identifying the best practices. In the second place, the empirical findings are dependent on the data coding system. Both qualitative and quantitative variables are translated into categories. Different choices about those categories could result in varying outcomes, with the analysis producing more or fewer sets, meaning there is a trade-off between detail and generalization, better still, between detailed knowledge and information summary. Lastly, data collection is limited to case studies that meet certain conditions as far as the adopted BM is concerned. Therefore, the cases analyzed may not be entirely representative of the efficiency-related measures typically adopted in retrofit and new construction projects, as well as of the building stock in their respective countries and at the EU level.

Concerning the primary results of the study, on the one hand, although the BMs are sometimes characterized by vague boundaries – even fuzzy, so to speak – a few clearly distinguishing features can be identified, particularly concerning the nature of property ownership, building typology, type of work, and extent of the energy-efficiency solutions. On the other hand, incentive measures are extensively adopted, especially direct monetary incentives such as grants and subsidies; still, they are definitely related neither to the unit investment costs incurred while carrying out the projects nor to the payback periods. Nonetheless, there remain open questions as to the financial self-sustainability of the projects.

The latter remark paves the way for some thoughts on policy implications and further developments. Since monetary incentives play a significant role in building energy efficiency, and investment costs are known to increase dramatically when aiming for very high energy performance [34,129], policymakers should address the optimal allocation of grants and subsidies. A crucial question may be posed as follows. Under a given budget constraint, is it more beneficial to concentrate cash incentives on a few investment-intensive, deep retrofit projects, or is it better to subsidize a large number of initiatives that require fewer capital expenditures even though they result in lower energy efficiency gains? By setting the bar very high, EU targets on building energy efficiency seem to favor the first option implicitly. Still, the second option would be prone to speed up the renovation rate of the building stock. In turn, the above issue subtends two research questions and just as many research strands. One approach can be aimed at assessing the two options above from a variety of valuation perspectives: economic viability, considering both property owners' angle and sustainability of public finances; social impacts, including the repercussions on health and comfort in homes and workplaces; and environmental effects. The other approach may aim to evaluate the profitability limits of implementing deep retrofits as, perhaps, not all the building stock deserves a second chance. Possibly, the intended targets of the building energy policy can also be achieved – sometimes, at least – through demolition and reconstruction, provided tearing down outdated buildings and rebuilding them from scratch prove to outweigh the available retrofit options.

CRediT authorship contribution statement

Sergio Copiello: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization, Visualization, Writing – review & editing. **Edda Donati:** Investigation, Formal analysis, Data curation, Writing – review & editing. **Pietro Bonifaci:** Writing – review & editing, Writing – original draft.

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.

Data availability

Data will be made available on request.

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