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# Energy efficiency measures in buildings for achieving sustainable development goals

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## Abstract

Governments, worldwide, are committed to achieving sustainable development goals (SDGs). In a context where urban agglomerates consume roughly 80% of the global energy, of which buildings account for 40%, energy-efficient buildings can make a significant contribution to meeting SDGs 11 and 13. Currently, the implementation of energy efficiency measures (EEMs) in building is constrained by socioeconomic and technical barriers. Using empirical survey data, the drivers that affect both the supply of and demand for EEMs were identified. These drivers were then categorized within four clusters according to their importance in meeting supply and demand priorities. The following critical drivers were identified: standardization, low transaction costs, energy prices, and stability of the regulatory framework. The findings indicated that an effective energy policy provides consumers with reliable information and project developers with a stable regulatory environment. Investment behavior is rational and responsive to reliable information that prompts a switch toward sustainable building choices.

Keywords: Economics, Energy

## 1. Introduction

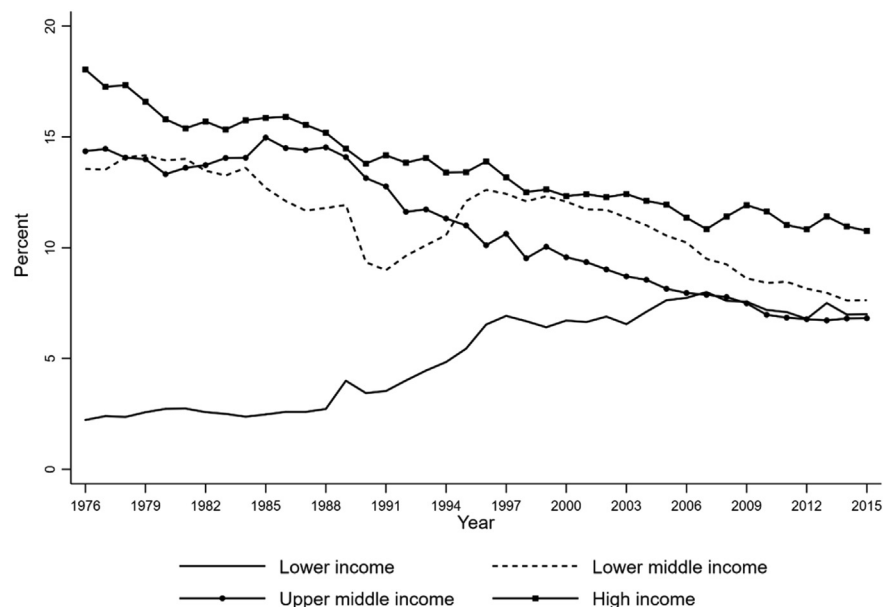
In the light of the current global challenge which calls for the development of sustainable economies through decarbonization, energy efficiency (EE) can potentially

boost socio-economic growth, and promote sustainable development that in today's business environment is a prerequisite to gaining a competitive advantage [1]. The benefits of energy-efficient buildings, which are linked to strategies, currently being discussed, to limit the global temperature rise to "well below 2 °C" considerably outweigh household energy savings for families in importance. If no action is taken to improve EE, global energy demand is projected to rise by 50% by 2050 [2]. This substantial increase in energy demand can be attributed to rapid growth of the construction sector and ancillary services and rising demands for adequate living conditions and new products. Energy efficiency is a policy target and energy efficiency is a mean to reduce carbon dioxide (CO<sub>2</sub>) emissions [3]. Therefore, it is hardly surprising that energy-efficient buildings are central to environmental and energy programs. Thus, a study that links energy-efficient building with sustainable development goals (SDGs) is pertinent, given that such buildings could contribute significantly to sustainability. Energy-efficient building can be linked to SDG 11, aimed at "making cities and human settlements inclusive, safe, resilient and sustainable" and SDG 13 that calls for "urgent action to combat climate change and its impacts." In the context of increasing CO<sub>2</sub> emissions and resource constraints exacerbated by changes in the world economy, the future sustainability of the built environment and the significant potential contribution of energy-efficient buildings to the mitigation of CO<sub>2</sub> emissions have become pressing concerns. Nevertheless, it is important to note that EE improvement does not necessarily support decarbonization unless the energy is generated from fossil fuels. On the contrary, the effect of energy generated from low-carbon sources is weak. As a clear relation is apparent between energy efficiency measures (EEMs) and sustainability it is becoming increasingly urgent to raise public awareness about the importance and convenience of energy-efficient buildings for private as well as social benefits. In this context, it is essential to develop, analyze, and maintain reliable indicators to inform stakeholders in building projects and policymakers in the decision-making process. Because substantial investment will be required to deliver high-performing buildings in the coming decades, the European Commission Directorate-General for Energy and the United Nations Environment Program Finance Initiative (UNEP FI) established the Energy Efficiency Financial Institutions Group (EEFIG) in 2013 to enable stakeholders to work to identify barriers to long-term financing of EEMs. Under current market conditions, investors are not inclined to make such investments unless the possibility of generating multiple benefits in return is given adequate consideration [4]. Moreover, opportunity and value analyses of EEMs should be conducted in a straightforward manner. For this study, empirical data published by EEFIG were analyzed, with the aim of providing information that could facilitate the matching of the priorities of supply (project financiers and developers) and that of demand (typically building owners). First, primary drivers of the implementation of EEMs in buildings were identified. These included stability of

the regulatory framework; standardization; reduced transaction costs; measuring, reporting, and verification systems; regulation and certification of energy performance; and the precise timing of EE actions (risk-return targets). Second, these drivers were categorized into four clusters based on the convergence of demand and supply priorities. It is essential to define drivers that match both supply and demand priorities, as there are two types of behavior that impact on the implementation of EEMs in buildings: investment behavior and habitual behavior. The remainder of the paper is organized as follows. The next section provides the background context, introducing relevant literature, technologies, and a set of regulatory mechanisms. This is followed by a presentation of the research design and a description of the data, population, and the research methodology. Next, the results are presented along with the synthesis and the discussion of the main findings. The final section offers conclusions.

## 2. Background

Successfully limiting the global temperature rise to 2 °C will require coordinated and rapid action, consensus, and unprecedented political agreement at the global scale to achieve sound reduction of emissions from buildings [2]. Regional variations in energy trends relating to the construction sector are significant and are contingent on factors such as climatic conditions, the life spans of buildings, income levels, and the degree of urbanization among many other factors as can be seen from Fig. 1.

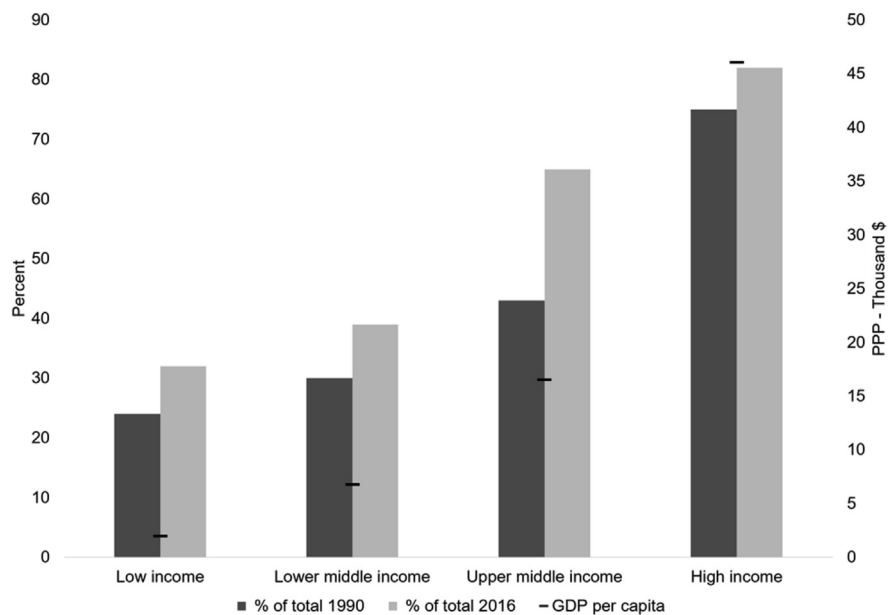


**Fig. 1.** CO<sub>2</sub> emissions from buildings and commercial and public services (% of total fuel combustion). Source: Author's elaboration based on the World Bank's Sustainable Development Index.

Global trends in energy consumption show improvements in EE and reductions in CO<sub>2</sub> in several sectors [5], including buildings.

Evidently, urban agglomerates are critical sites for ongoing and future actions on climate change including EEMs in buildings. Beginning in the latter half of the twentieth century, dramatic urban growth has occurred, worldwide, giving rise to formidable social, environmental, and economic challenges. Currently, urban agglomerates accommodate approximately 55% of the world's population, consuming up to 80% of global energy, with buildings accounting for 40% of this energy consumption [6]. Fig. 2 highlights similar trends in urbanization and purchasing power parity (PPP).

It has been widely acknowledged that EE has direct as well as indirect impacts on economic activity, employment, energy prices, and social equity objectives [7]. Hence, efficient buildings can potentially boost economic growth, improve social development, and promote environmental sustainability. According to the World Bank, the negative impacts of CO<sub>2</sub> emissions on human health are responsible for more than 7 million premature deaths annually, incurring healthcare costs of US\$2–4 billion. The impacts of energy efficiency for social well-being can be similarly measured and monetized using existing methodologies. A recent study demonstrated that improvements in health and well-being were correlated with improvements in the EE of buildings. These benefits can be monetized, for example, through evaluations of the cost of medical care, opportunity costs relating to working



**Fig. 2.** Urbanization trends: percent of people living in urban areas. Source: author's elaboration based on the World Bank's Sustainable Development Index.

time, or child care costs incurred through diseases caused by living in suboptimal conditions. Notably, the return on an investment may be as much as four times higher than the invested capital [7]. Thus, it is important to evaluate the incremental cost of low-energy buildings and of the retrofitting of existing buildings to improve EE as Table 1 shows. In the residential sector, the incremental costs of achieving the Passive House standards range between 6% and 16% of costs compared with standard construction costs. In the commercial sector, incremental costs of low-energy buildings are lower than those for conventional buildings in this sector. Moreover, the heating energy requirement of retrofitted buildings can be potentially reduced by 50–75% in single-family housing and by 50–90% in multi-family housing [8].

Effective regulations and policies can lower the costs of both new energy-efficient buildings and retrofitted buildings. Such policy tools, some of them are outlined in Table 2, can facilitate or stimulate investments through the mitigation of risks and through increasing rewards available for project promoters.

**Table 1.** Cases of extra investment costs by type of energy performance.

Case	Type and Energy performance	Extra investment costs (US\$)	CCE (US\$/kWh)
Passive House: apartment block (EU)	Passive House standard (N)	5% (\$69/m <sup>2</sup> )	—
Very low energy houses (USA)	N	0.070–0.120 (\$/kWh; CCE)	—
Hypothetical 6,000 m <sup>2</sup> office building (USA)	42% energy savings (N)	\$ 2,719	—
10-story, 7,000 m <sup>2</sup> residential building (EU)	14 kWh/m <sup>2</sup> /year (heating) vs. 45 (N)	3.4% (\$115/m <sup>2</sup> )	—
Leslie Shao-Ming Sun Field Station (USA)	NZEB (N)	4–10% based on hard construction costs	—
Hudson Valley Clean Energy Headquarters (USA)	NZEB (N)	\$158/month in energy costs	—
IAMU Office (USA)	NZEB (N)	0.000	—
EcoFlats Building (USA)	NZEB (N)	0.000	—
7,000 m <sup>2</sup> residential building (USA)	NZEB (N)	24% (558 \$/m <sup>2</sup> )	—
Toronto towers (Canada)	194/95% (R)	\$259/m <sup>2</sup>	0.052
1950s MFH (EU)	82–247/30–90% (R)	\$48–416/m <sup>2</sup>	0.023–0.065
1925 SFH (EU)	120 (R)	\$217/m <sup>2</sup>	0.071
1929 MFH (EU)	140–200/58–82% (R)	\$167–340/m <sup>2</sup>	0.060–0.088
19th century apartment (UK)	192–234/48–59% (R)	\$305–762/m <sup>2</sup>	0.068–0.140

Source: author's elaboration based on [8]. N = New building, R = retrofitted building. Reference year for \$ = 2010.

**Table 2.** Policies.

Tool	Policy	Objective
Technical standards	Establish mandatory standards with higher CAPEX allowances	Compensate investors over the long term through OPEX savings
Premiums	Encourage investments via a premium in the WACC	Set premiums at levels that are attractive to project developers
Rules for anticipatory investments	Establish rules relating to anticipatory investments	Help project developers to identify the best investment alternatives
Adjusted depreciation	Define rules on depreciation	Make the investment recovery period more attractive
Exemption from efficiency requirements	Exempt operators from efficiency requirements over a period	Support operators in making investments efficiency failing risks
Sliding scale	Outline targets for specific items such as cost reductions	Incentivize project developers to submit realistic investment forecasts
Advantageous debt/equity ratio	Fix a well-defined debt-equity ratio	Entitle companies to receive attractive rates of return
Stability arrangements	Various tools	Provide project developers with some guarantee of regulatory stability
Early recognition of costs	Allow for specific arrangements for CWIP	Provide favorable and stable information on asset investments that remain to be commissioned

Source: adapted from [9].

From a financial perspective, there are established as well as emerging instruments that comply with requirements relating to the implementation of EEMs in buildings. These instruments encompass dedicated credit lines, Energy Performance Contracts, risk-sharing facilities, direct and equity investments, subordinated loans and leasing, on-bill repayments and on-tax financing, and energy service agreements [10]. Currently, however, a number of social, financial, technical, and administrative barriers continue to undermine the potential for sustainable energy generation in buildings. Paradoxically, even virtuous behavior can become a barrier to project development, typically, for example, when building owners carry out routine maintenance. Consequently, they may avoid investments in sustainable energy because improved efficiency only offers short-term, marginal benefits. Indeed, decision making and investment appraisal occur in a spatial and temporal context that entails the dimensions of uncertainty and irrevocability [11] and in which payback analyses predominate over analyses of the internal rate of return or the standard net present value [12]. A final point of consideration is that EEMs for residential and commercial buildings differ. For residential buildings, typical measures include increasing insulation, draught-proofing, installing double-glazed windows, and switching to appliances that entail advanced technology and metering solutions with demand

response (DR) capabilities [13]. EEMs for commercial buildings include optimization of ventilation and air-conditioning, lighting, and heating systems. Regardless the typology of building the introduced EEM are important factors in making a building energy-efficient. The evolution of concepts, characteristics, and techniques relating to energy-efficient buildings has been well documented [14], and arguably presents one of the most appealing areas of research in the current context of climate change, given their impacts on environmental sustainability [15]. The main greenhouse gases (GHGs) are CO<sub>2</sub>, accounting for 75% of GHGs, which is emitted as a result of human activities along with methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and fluorinated gases, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF<sub>6</sub>). Electricity generation is a primary source of emissions as well as the main source of energy used in buildings via purchased electricity and direct consumption of natural gas and oil for heating and cooling [16]. Demands for thermal energy for residential and commercial buildings can be predicted using Eqs. (1) and (2), respectively, presented below, while the energy demand for appliances can be calculated using Eq. (3) where  $e_r$  denotes the energy demand,  $h$  denotes the number of households,  $p$  denotes the number of people, and  $a$  denotes area, commonly measured in square meters.

$$e_r = h \times \frac{p}{h} \times \frac{a}{p} \times \frac{e}{a} \quad (1)$$

From this information, the following factors can be derived: people per household ( $p/h$ ), use intensity ( $a/p$ ), and energy intensity ( $e/a$ ), commonly measured in KWh<sub>yr</sub>. Similarly, in Eq. (2)  $e_c$  denotes energy demand, GDP represents the gross domestic product,  $a/gdp$  denotes the use intensity, and  $e/a$  stands for the intensity of energy intensity, commonly measured in KWh<sub>year</sub>.

$$e_c = gdp \times \frac{a}{gdp} \times \frac{e}{a} \quad (2)$$

In Eq. (3)  $\Sigma_\mu$  denotes the sum of appliances in use;  $h$  is the number of households;  $n/h$  denotes the number of appliance types,  $\mu$ , per household; and  $e$  embodies the annual KWh consumption per appliance.

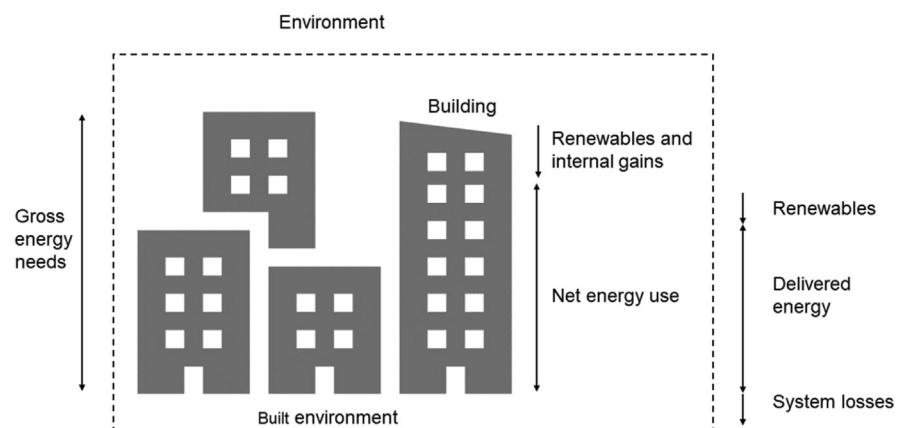
$$e_a = \sum_{\mu} h \times \frac{n}{h} \times \frac{e}{n} \quad (3)$$

There are many approaches for classifying strategies for designing low-energy buildings. For example, there are strategies for reducing the impacts of buildings, such as minimizing energy consumption (especially heating and cooling) through EEMs and adopting renewable energy and advanced power technologies [17] to reduce energy intensity. Energy intensity is decreasing worldwide, and efforts to attain the sustainability and climate change goals established in the SDGs demonstrate an



accelerating trend. EE is connected with energy intensity and denotes the ratio between the energy output and input [18] where the energy output is  $o$ , energy input is  $i$ , and the EE index is calculated as  $\eta = o/i$ . The EE of a building is indicated by the level of its energy consumption per  $m^2$  compared with the reference benchmark for that building under certain conditions. The gross energy consumption of a building represents the building's requirements, with indoor climate requirements, outdoor climatic conditions, and the building's properties constituting the parameters for determining its energy demand. As indicated by Fig. 3, which depicts energy flows within a building, technologies and policies to enhance its performance vary according to local characteristics.

Most of the technological options and policies for promoting the EE of buildings are applicable worldwide, either immediately or in the future. However, given existing resource constraints, prioritization of actions that will have the greatest impact in individual countries is evidently necessary. Implementing EEMs for buildings enables energy consumption to be reduced by maintaining or improving comfort levels of the inhabitants of buildings where they are introduced [20]. The most widely applied measures are aimed at reducing energy demands for heating and cooling, ventilation and lighting, water heating, and the electricity consumption of office appliances. Currently, the most favored financing options for EEMs are in-house funding and energy performance contracts [21]. The literature reveals that there are many factors other than financial ones that influence investment behaviour and its propensity [22]. These factors include, *inter alia*, technological opportunities, standard upgrading, perceived risk levels, a lack of upscaling of investments in small projects into more substantial investments, and a lack of regulations. Much effort has been devoted to formulating construction and urban planning for enhancing EE and reducing GHG emissions. However, accuracy evaluations of energy performance remain limited, affected by the complex interactions



**Fig. 3.** Energy flows within a building. Source: adapted from [19].

between buildings and the urban eco-system [23] and the rebound effect [24], among other factors. The EE market offers numerous technological solutions that if combined with appropriate incentives, may lead to significant outcomes. In recent years, an increasing number of governments have been providing ad hoc incentives, measures, and support for emerging technologies and strategic sectors [25]. The priorities of different stakeholders (e.g., industry, the public, and the government) differ according to the different dimensions of sustainability i.e. environmental, economic and social. Indeed, it is difficult to verify whether individuals and firms have failed to make viable EE investments, leading to a slower diffusion of energy-efficient solutions than would be expected [26]. Lack of upfront capital and technological know-how are usually perceived as hurdles constraining the implementation of EEMs despite their multiple benefits [6]. What is termed an efficiency paradox is the result of a combination of the abovementioned constraints [27]. Last, at a more general level, it is important to highlight the fact that the adoption of various mechanisms, including EEMs for promoting energy-efficient buildings and, more generally, to contribute to SDGs, concerns project promoters and citizens [28]. Accordingly, a number of important drivers of EEM implementation for supporting project developers, buildings owners, and policy makers are identified in this paper.

### 3. Design

The theoretical framework of this study was designed to capture the importance of drivers for supporting EEMs, which is the focal point of the analysis. A multidimensional concept can be derived from the different subcomponents of a composite indicator provided that these subcomponents are statistically independent of each other. In this study, the average value of the scores for three subcomponents (residential, commercial, and public buildings) was derived from the values of the composite indicator. The basis for including drivers in the analysis was their contextual presence both for supply and demand. Composite indicators and sets of indicators are being used increasingly to characterize complex situations, so they fit for analyze drivers and barriers that may hamper investments in EEMs. Indicators are useful because they enable large quantities of data, including unstructured data, from different sources and metrics to be summarized and synthesized into succinct and meaningful information [29].

#### 3.1. Calculation

The research process comprised three phases, progressing from a general picture to precision. The first phase entailed an extensive review of the literature and was grounded in an analysis of the empirical results of a survey carried out by EEFIG. The survey was conducted using an online questionnaire to gather information about

drivers of EEM investments, from a supply-demand perspective, in the three building subsectors according to their use: private residential, commercial, and public buildings [10]. A total of 23 drivers from the supply side and 25 drivers from the demand side were identified. The drivers were listed in order of their prioritization and importance, leading to differences in the measurement scale applied. In the first case, the scale ranged from 1 to 23, whereas in the second case, it ranged from 1 to 25. Because of this disparity, it was not possible to compare supply and demand priorities. Furthermore, Table 3 contains additional data, showing that both public buildings and public rental buildings were categorized under the “Pub” variable, whereas the “Res” variable encompassed both owner-occupied and private rental buildings. In the second phase, the data were normalized using the min-max method, that is, the values of data measured in absolute units were converted into values ranging between 0 and 1 using Eq. (4).

$$z_i = \frac{x_i - \min(x)}{\max(x) - \min(x)}; x = (x_1, \dots, x_n) \quad (4)$$

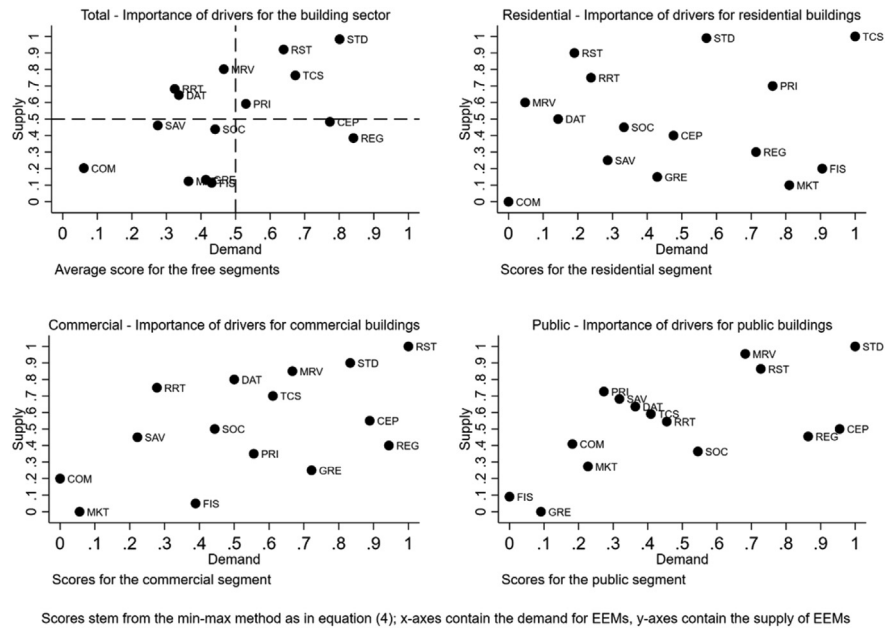
The lowest value (min) was set to 0, and the highest (max) value was set to 1. Thus, values measured using different scales could be compared easily. After the data had been normalized, the drivers were compared, and only those featuring in both the supply and demand sides were maintained, amounting to a total of 15 drivers. Out of these, 13 showed a perfect matching of the supply and demand sides. A focus group discussion (FGD) was held to solicit expert advice on the association of drivers. Typically, focus groups comprise a number of people with similar backgrounds, experiences, and concerns [30]. In this study, focus group members were representatives of two financial institutions, and a consulting company. The FGD facilitated the matching procedure. Ultimately it led to the matching of two drivers based on a review of the drivers’ descriptions. Thus, effective enforcement of regulation was matched with financial regulation and awareness of the appropriate timing for implementing EE measures.

In the third phase, the matched data were clustered to obtain analytical insights. As revealed by the literature, clustering is a viable method of classifying data that share similar patterns [31]. Accordingly, a set of objects with similar features are categorized in the same group [32]. Given that the scores of the subcomponents were equally weighted, average values were used to define clusters based on the association of scores registered for the supply and demand sides. A total of four clusters were identified according to the following parameters. Cluster 1 (shown in the upper right-hand section [total] of Fig. 4) contained drivers for which both demand and supply scores exceeded 0.5. Cluster 2 (shown in the lower right-hand section [total] of Fig. 4) contained drivers with demand scores greater than 0.5 and supply scores less than 0.5. Cluster 3 (shown in the lower left-hand section [total] of Fig. 4) contained drivers with both demand and supply scores

**Table 3.** Raw data on matched and unmatched drivers.

Match	Driver	Supply					Demand				
		Com	Pub	Pub R	Own	Pri R	Com	Pub	Pub R	Own	Pri R
M	DAT	5	9	13	12	10	12	17	19	20	20
M	MKT	21	17	23	20	22	20	20	24	6	7
M	SOC	11	15	19	13	23	13	13	11	16	17
M	CEP	10	12	14	14	13	5	4	3	13	11
M	COM	17	14	21	22	20	21	21	20	23	18
M	SAV	12	8	15	17	18	17	18	16	17	23
M	FIS	20	21	20	18	14	14	25	22	4	1
M	GRE	16	23	22	19	19	8	23	23	14	12
M	MRV	4	2	4	10	8	9	10	15	22	21
M	PRI	14	7	10	8	15	11	19	21	7	24
M	RST	1	4	2	4	3	3	9	10	19	9
M	STD	3	1	1	1	2	6	3	1	11	2
M	TCS	7	10	6	2	1	10	16	12	2	5
M	REG	6	11	9	7	7	4	6	6	8	6
M	RRT	13	13	12	16	16	16	15	13	18	10
D	CBC						1	7	9	9	4
D	AKD						2	2	2	12	13
D	TFP						18	11	7	5	3
D	RTR						7	8	4	15	14
D	FTA						22	5	8	10	15
D	IOP						23	22	18	1	8
D	RUL						25	1	5	25	25
D	MEA						15	14	17	21	19
D	HCA						19	12	14	24	22
D	BEC						24	24	25	3	16
S	IIC	2	5	7	5	4					
S	LRA	8	6	5	6	5					
S	UES	18	3	3	11	9					
S	ACG	19	16	8	9	11					
S	OBM	22	22	18	3	6					
S	FSE	23	18	11	15	12					
S	CME	15	19	16	21	17					
S	SRE	9	20	17	23	21					

Source: author's elaboration based on EEFIG data. Com = commercial buildings, Pub = public buildings, Pub R = public buildings for rent, Own = privately owned building, and Pri R = private rental. Drivers rank 1–23 for supply and 1–25 for demand in terms of their scores for each building segment. M = matched, S = only in supply, and D = only in demand.



**Fig. 4.** Clusters of drivers. Source: author's own elaboration. Each of the subfigures refer to a building segment.

being below 0.5. Last, cluster 4 (shown in the upper left-hand section [total] of Fig. 4) contained drivers with demand scores below 0.5 and supply scores above 0.5. Given their simultaneous representation of the importance of drivers and their matching in terms of supply and demand for project implementation, the clusters provide information that can improve and support investment-related decision making.

### 3.2. Analysis

This study is based on empirical data gathered and released by the EEFIG. Respondents from a total of 51 institutions comprising banks and financial investors (38.5%), research institutions and consultancy services (23%), public administration and EU institutions (13.5%), associations (13.5%), and other institutions (12.5%) completed the questionnaire. The respondents were required to evaluate several previously defined drivers and to weigh the relative importance of each driver of EE investments using a Likert scale of 1–6, where 6 represented a high weighting or importance and 1 represented a low weighting or lack of relevance. Subsequently, each driver was assigned an identifying acronym: availability of key data related to specific EEMs (DAT), consciousness of timing for EE actions and the risk-return target (RRT), awareness, communication, and marketing (MKT), evidence of social benefits and costs e (SOC), regulation and certification of energy performance (CEP), communication between market actors (COM), definition and common understanding of the value of energy cost savings (SAV), effective

enforcement of regulations (REG), fiscal support (FIS), green premium/brown discount (GRE), measurement, reporting, and verification, and quality assurance (MRV), price of energy (PRI), stability of the regulatory framework (RST), standardization (STD), reduction of transaction costs resulting from simplified procedures (TCS), clear business case (CBC), awareness at key decision making level (AKD), availability of tailored financial product (TFP), rules on timing of renovation (RTR), technical assistance (FTA), payment capacity (IOP), rules on public authority accounting (RUL), mandatory energy audits (MEA), human capacity (HCA), personal priorities (BEC), confidence in risk perception (IIC), lender's approach to risk assessment (LRA), use of European funds (UES), aggregation challenge (ACG), on-bill mechanism (OBM), finance supply from Article 7 of the Energy Efficiency Directive (FSE), capital market environment (CME), and sustainable real estate funds (SRE). Table 3 presents information of both matched and unselected (unmatched) drivers.

#### 4. Results

After selecting the drivers for which the demand and supply sides were matched, the data presented in Table 3 were normalized by applying the min-max procedure described in the previous section. Table 4, which lists drivers for commercial,

**Table 4.** Drivers and scores of EEMs.

Code	Demand				Supply			
	Com	Pub	Res	Avg	Com	Pub	Res	Avg
DAT	0.500	0.364	0.143	0.336	0.800	0.636	0.500	0.645
RRT	0.278	0.455	0.238	0.324	0.750	0.545	0.750	0.682
MKT	0.056	0.227	0.810	0.364	0.000	0.273	0.100	0.124
SOC	0.444	0.545	0.333	0.441	0.500	0.364	0.450	0.438
CEP	0.889	0.955	0.476	0.773	0.550	0.500	0.400	0.483
COM	0.000	0.182	0.000	0.061	0.200	0.409	0.000	0.203
SAV	0.222	0.318	0.286	0.275	0.450	0.682	0.250	0.461
REG	0.944	0.864	0.714	0.841	0.400	0.455	0.300	0.385
FIS	0.389	0.000	0.905	0.431	0.050	0.091	0.200	0.114
GRE	0.722	0.091	0.429	0.414	0.250	0.000	0.150	0.133
MRV	0.667	0.682	0.048	0.466	0.850	0.955	0.600	0.802
PRI	0.556	0.273	0.762	0.530	0.350	0.727	0.700	0.592
RST	1.000	0.727	0.190	0.639	1.000	0.864	0.900	0.921
STD	0.833	1.000	0.571	0.801	0.900	1.000	0.990	0.983
TCS	0.611	0.409	1.000	0.673	0.700	0.591	1.000	0.764

Source: own elaboration.

residential, and public buildings, shows the values generated using this procedure. The stability and quality of the regulatory framework are expected to be essential for incentivizing investments in EEMs. The data are thus useful for extracting necessary information for evaluating the costs and benefits of EEMs. Such data are essential for decision making because they enable benchmarking and identification of potential areas of saving.

The information resumed in [Table 4](#) facilitated the identification of patterns of drivers that may concur to incentivize both the supply and demand for projects. Because investments in EEMs may require long time spans, it is essential that the regulatory framework, which plays a significant role in the healthy functioning of market mechanisms, inspires confidence and is “smart” [33]. Standardization is another central factor influencing investments in EEMs because it entails the availability, implementation, and practice of an acknowledged set of standards that is linked to how energy savings are measured, reported, and verified [34]. Data accessibility and the application of standards in investment procedures reduce perceptions of the complexity of investments, thereby streamlining implementation and financing and reducing their transaction costs. It is also possible to identify clusters that can guide investment decisions based on the degree of importance of specific drivers and the match between the demand and supply.

Cluster 1 (shown in the upper right-hand section [total] of [Fig. 4](#)) comprised four indicators: standardization, transaction costs/simplicity, stability of the regulatory framework, and the energy price. The significance of these drivers is evident, indicating a need for regulatory and financial certainty. A regulatory framework that remains stable over time is a prerequisite for the convergence of supply and demand and for the resulting investments. Standardization is also a key driver as availability, adoption, and common usage of standards are key aspects of the EE investment process. Equally important is regulatory stability, given that returns on investments may take a long time to manifest, typically between 5 and 20 years. Therefore, it is crucial that investors are confident that the regulatory framework is robust, stable, and consistent. Clear and transparent investment procedures, data availability, and the implementation of standards facilitate the implementation of investments and counter the perception of their complexity. Cluster 2 (shown in the bottom right-hand section [total] of [Fig. 4](#)) comprises the following items: regulation and certification of energy performance and the effective enforcement of (financial) regulations. Cluster 3 (shown in the bottom left-hand section [total] of [Fig. 4](#)), comprises items with average values below 0.5 for both the demand and supply sides of EEM projects. Last, cluster 4 (shown in the upper left-hand section [total] of [Fig. 4](#)) comprises three essential items on the supply side: availability of key data relating to specific EE investments; the risk-return target; and measurement, reporting and verification (MRV) and quality assurance. [Fig. 4](#) also shows three graphs that respectively plot clusters for each of the three market segments: residential,

commercial, and public buildings. These additional clusters contribute to an understanding of the specific needs of different market segments.

## 5. Discussion

Well-designed EEMs contribute to meeting the focal objectives of current climate and energy policies, especially those aimed at supporting the transition toward a low-carbon economy via more sustainable built environments. An analysis of the data revealed that the overall direction of the results indicated paths that should be seriously considered to enhance the viability of EEMs. Up to now, whether or not EEMs are adopted has been largely up to building owners. Therefore, it is important to raise public awareness regarding the importance and convenience of EEMs. The findings of this study will help to bridge the existing information gap and may enhance stakeholders' understanding of EEMs benefits. They endorse a number of the findings of previous studies, while adding a new finding on the importance of matching drivers of supply and demand as these may diverge [35, 36, 37]. On the supply side, forms of support could comprise appropriate direct or indirect incentive mechanisms. On the demand side, there are many ways of promoting EEMs through direct means, including incentives and tax reductions and indirect means, notably incentives and the reduction of charges to be paid to public administrations. Such incentives target the risk-reward ratio. Therefore, there is a need to improve and stabilize the forms of incentives over time. Accordingly, policies that promote research and the development of high-performance technologies are a prerequisite for reaching this goal. The proposal of the Energy Efficient Buildings Committee to expand the scope of research and innovation in the building sector in the direction of a low-energy consumption built environment is an example of exemplary definition of priorities [38]. Such priorities take into account existing buildings and are aimed at supporting the advancement of the retrofitting market, digitalization to take advantage from big data opportunities interfacing with the built environment, integration with renewable energy and storage, and performance optimization through monitoring and management platforms. They also seek to address integration and cross-cutting issues to ensure stakeholders' engagement, the awareness of users regarding energy efficiency, and the development of new business models and financial instruments. A point to be noted is that the findings of studies that are based on information provided by a limited number of institutions, most of which are financial investors and research and consultancy institutions, should be interpreted with caution. One potential concern about the findings of the present study is the possibility that there are alternative explanations of drivers. For example, the energy price could be treated as an exogenous variable or a determining factor in relation to a beneficiary's decision to undertake an investment rather than as a



driver of the investment. However, given this study's robust framework, externally validated by related studies and internally validated by experts during the FGD, its findings are deemed reliable. The proposed procedure would provide a break-even point for the entire investment chain. A recommendation is to devote more efforts to increasing knowledge and awareness of the economic, social, and environmental values of EEMs among stakeholders to persuade buildings owners, first and foremost, to undertake such investments. Higher levels of knowledge among policy makers would enable them to better assess the impacts of policies [39], provided that they commit to monitoring progress toward the achievement of the SDGs at regular intervals. That said, it is important to highlight that this study also provides insights for policy. To attain the SDGs, policymakers are expected to commit to assuring a substantial increase in policies, measures, and plans directed at enhancing resource efficiency and adaptation to climate change. In the absence of any actions, energy demand is projected to rise by 50% by 2050, thereby constraining the achievement of sustainability objectives. However, there is no single approach for accomplishing significant milestones; what is needed is a mix of delivery strategies and policies, tailored to local circumstances [40] to support investments with positive externalities [41] starting, for example, from the production of materials for buildings [42]. In relation to the built environment, policies aimed at mitigating climate change should support both retrofitting of existing buildings and new, well-designed projects for implementing EEMs. Policy makers should particularly consider the drivers in cluster 1 in relation to design policies for stimulating investments and thus increasing the EE of buildings. Sound technical and risk analysis is essential for supporting the drivers within cluster 1. Specific policies and regulatory measures can be formulated, including those that facilitate investments in R&D and promote incentives, subsidies, voluntary agreements, and tradable permits. Other measures include the introduction of EE certificates linked to energy savings, obligations to produce or purchase renewable energy, and regulatory prescriptions to induce operators to take specific measures. The abovementioned policies should be linked to the following primary objectives. First, minimal energy standards for the renovation of buildings must comply with ambitious objectives in terms of emissions' limits. Second, policy makers should consolidate existing tax deductions in the restructuring sector to make benefits more appealing in relation to costs. What above will be as much useful provided a globally common energy policy that entails an increasing share of low-carbon energy sources in the energy mix along with adequate policies and regulatory mechanisms. Strategies for improving the efficiency of buildings should be deployed in two main directions. First, long-term building renovation strategies that provide a clear vision of the decarbonized housing stock are required. Second, such policies should encourage the use of smart information technologies.

## 6. Conclusion

This study has shown that drivers of EEMs should match the supply and demand sides of projects for their implementation. By highlighting the links between EEMs and the SDGs, the findings of the study contribute to discourses and strategies for promoting global environmental well-being. Accordingly, cooperation, political vision, and leadership need to be harnessed and strengthened through projects that are successful in promoting EEM implementation by matching the requirements of citizens and industry, thereby effecting the transition toward a decarbonized economy. The results of the study, entailing the categorization of drivers within four clusters according to their ranking in relation to both the supply and demand sides can be considered reliable. Cluster 1 contained the following drivers: standardization (i.e., identification and adoption of standard elements often related to data analysis and the calculation of savings), transaction costs arising before as well as after project implementation, the stability of the regulatory framework, and the price of energy. These drivers indicate the need for regulatory and financial certainty in the medium- and long-term. Cluster 2 contained items relating to the regulation and certification of energy performance and effective enforcement of (financial) regulations. Cluster 3 comprised poor drivers, and, cluster 4 included three essential supply-related drivers: availability of key data relating to specific EE investments; the risk-return target; and measurement, reporting, and verification, and quality assurance. This study contributes insights that can facilitate the formulation of effective policies for supporting EE, as it demonstrates the importance of matching the interests of stakeholders. An analysis of the main drivers is necessary to promote and strengthen pro-environmental behaviours and attitudes of citizens, with a particular focus on their relations with EEMs, to define new hypotheses and develop relevant research questions that have not yet been investigated.

## Declarations

### Author contribution statement

Giacomo Di Foggia: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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## Additional information

No additional information is available for this paper.

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