Sustainable Real Estate in France: Impact of One-Stop Shop and Turnkey Contract Models on Energy Efficiency

Edda Donati[1(✉)] and Dorothée Charlier[2]

[1] Department of Architecture and Arts, University IUAV of Venice, Santa Croce 191, 30135 Venice, Italy
edonati@iuav.it

[2] IREGE, Université Savoie Mont-Blanc, 4 chemin de Bellevue, 74940 Annecy-le-Vieux, France

Abstract. This study examines the relationship between business models for energy efficiency projects and the measures implemented in renovation and new construction in France.

A Hierarchical Cluster Analysis (HCA) is applied to 20 case studies using the One-Stop Shop and Turnkey Contract models. To further explore correlations, Cramér's V-test assesses the relationships between climate zones, business models, and photovoltaic system installations.

Two clusters emerge: Cluster 1, in continental climate zones, includes renovated buildings under the One-Stop Shop model with public incentives. Cluster 2, in oceanic climates, consists of new constructions under the Turnkey Contract model, without government support. Significant differences are observed in costs, surface area, and technologies used.

Cramér's V-test confirms the link between climate zone, business model, and technology adoption, showing that solar radiation influences photovoltaic system installation. The oceanic climate's favorable conditions explain the higher use of such technologies in new constructions.

These findings highlight the need to adapt business models to the local climate and building conditions. The study proposes targeted measures for policymakers to optimize energy efficiency through differentiated approaches.

Keywords: Innovative Business Model · Energy efficiency · Climate influence

1 Introduction and Background Literature

The real estate sector is a major contributor to environmental emissions, largely due to the poor energy efficiency of existing buildings. In Europe, outdated real estate assets account for approximately 48% of total emissions, exacerbating climate change [1–4].

To address this, the EU has implemented directives since the early 2000s, promoting energy-efficient renovations and nearly zero-energy buildings [5–8] National policies

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2026
O. Gervasi et al. (Eds.): ICCSA 2025 Workshops, LNCS 15889, pp. 410–428, 2026.
https://doi.org/10.1007/978-3-031-97603-2_26

and incentives have further driven sustainable business models focused on improving building efficiency [9–13].

The One-Stop Shop business model, and the Turnkey Contract business model fall under these innovative business models.

The first model, the One-Stop Shop was developed in accordance with Directive 2018/844/EU and is exclusively used for the renovation of existing buildings. It is a place, either physical or virtual, where owners can obtain all the information and services they need to realize their renovation project. The One-Stop Shop offers a wide range of services to help customers at every stage of the project. It can therefore be described as a communication channel for owners and service providers [14–19]. There are different types of One-Stop Shop linked to the project and to the needs and resources of the client who wants to carry out efficient work. The model considered in this research is like the all-inclusive model or Energy Service Company (ESCo) model, where the ESCo ensures full continuity for the owners during the project phase by taking over the execution of the efficiency work from planning to implementation. It also ensures that the work is completed within the agreed timeframe and covers the project budget upfront, with the client repaying the costs after the work is completed [20, 24, 25] (Fig. 1).



Fig. 1. One-Stop Shop (All-inclusive) business model process

The second business model, the Turnkey Contract, originated in the United States and is limited to the construction of new buildings. It requires the involvement of a large construction company that manages the design and the construction of the property on behalf of the client [20–22]. The Turnkey Contract model, which is used exclusively for newly constructed real estate, differs from the One-Stop Shop mainly in the relationship between the contractor and the client and in the commissioning of the project. With Turnkey Contract, the customer only defines the desired result, while the contractor develops the project, sets a fixed price and deadline. Finally, the project is awarded through a tendering process to select the most suitable contractor [20, 23] (Fig. 2).

Although 5 of the 20 case studies from the dataset have already been used to analyze the best practices that characterize the adopted business models and the associated economic figures, no study has yet focused on whether there is a direct link between the business model and the efficiency work performed [11, 19, 24].

This study aims to verify the existence or not of a significant relationship between the business model adopted and efficiency works promoted by analyzing 20 case studies on efficiency measures on the existing buildings and on the construction of new ones in

France, as it is one of the few European countries that has supported and promoted a policy aimed at making existing facilities more efficient [25–28].



Fig. 2. Turnkey Contract business model process

The aim is to verify, using Hierarchical Cluster Analysis (HCA) and Cramer's V-test, whether the choice of business model can be considered as a characteristic element in the selection and promotion of the efficiency measures to be implemented.

The results obtained show that the two clusters identified differ not only in terms of the business model applied and the efficiency works promoted, but the subsequent Cramér's V-test between the variable of the business model and the works carried out underlines how much the installation of photovoltaic panels or not depends on the business model adopted in the project.

The article is organized as follows: Sect. 2 the methods adopted, Sect. 3 the data, Sect. 4 the results of the analyses performed, Sect. 5 contains their discussion and finally, Sect. 6 presents the conclusions.

2 Method

2.1 Hierarchical Clustering Analysis (HCA)

Hierarchical Cluster Analysis (HCA) is a widely used unsupervised learning technique for grouping similar objects into clusters.

It is particularly suitable for this study as it does not require specifying the number of clusters in advance and provides a hierarchical representation through a dendrogram, which helps interpret relationships within the data.

Given the dataset's characteristics, comprising only 20 observations with both continuous and categorical variables, HCA proves more effective than methods like K-Means, which is better suited for numerical data and larger datasets. Additionally, HCA allows for a flexible cluster structure without rigid assumptions about their shape. The quality of clustering can be evaluated using the Silhouette Score, which measures how well each observation fits within its assigned cluster compared to others, ensuring the robustness of the chosen methodology.

HCA builds a hierarchy of clusters using two main approaches: bottom-up (agglomerative) and top-down (divisive). This study adopts the divisive approach, where all observations start in a single cluster and are iteratively split into sub-clusters until a predefined number of clusters is reached or each object forms its own cluster. This approach

is particularly useful for detecting natural separations within a dataset and provides a clear structure for interpreting clustering results [29–32].

Two fundamental concepts underlying the analysis method are the linkage criterion and the calculation of the distance between objects.

The linkage criterion defines how the distance between two clusters is calculated during the merging process in hierarchical clustering. There are different linkage criteria (e.g. simple linkage, complete linkage, etc.), but in this case, the focus will be on Single Linkage. [33].

Objects' distance, on the other hand, is a measure of dissimilarity that indicates how different two datasets (e.g. feature groups or objects) are. This concept is often used in clustering, especially when dealing with categorical or binary data.

Given two clusters C_1, C_2 and D as the distance between two objects x and y belonging to $C_1 and C_2$, the distance between the two clusters is expressed as:

$$D(C_1 C_2) = \frac{1}{|C_1| * |C_2|} \sum_{\mathrm{x} \in C_1,\, \mathrm{y} \in C_2} d(x, y) \tag{1}$$

where

- $|C_1| e |C_2|$ are the sizes (number of objects) of the clusters C_1 e C_2;
- $d(x, y)$ is the distance between two objects x and y that belong to the clusters respectively C_1 e C_2.

The sum is done on all possible pairs of objects, one for each cluster.

There are different types of distance measures, but this study will focus on the use of Jaccard distance which is a dissimilarity metric that quantifies the difference between two datasets [34, 35].

Given two sets A and B, the Jaccard similarity is defined as:

$$J(A, B) = \frac{|A \cap B|}{|A \cup B|} \tag{2}$$

where

- $|A \cap B|$ corresponds to the number of common elements between the two sets (the intersection);
- $|A \cup B|$ it is equal to the total number of elements joined between the two sets (union).

The Jaccard distance is the complement of the Jaccard similarity, and is therefore equal to:

$$D(A, B) = 1 - J(A, B) = 1 - \frac{|A \cap B|}{|A \cup B|} \tag{3}$$

2.2 Cramér's V-test

Cramér's V-test is a statistical measure to assess the strength of the relationship between two categorical variables. It is a normalized form of chi-square (X^2), that considers the sample size and the number of categories of the variables involved [36, 37].

The Cramér's V value varies between 0 and 1, where 0 means no association and 1 stands for a perfect association [38–42].

It is particularly useful when comparing contingency tables of different types. The following formula gives the value of Cramér's V:

$$V = \sqrt{\frac{X^2/n}{min(k-1, r-1)}} \tag{4}$$

where:

- X^2 is the chi-squared test value calculated from the contingency table;
- n is the total number of observations;
- k is the number of columns in the contingency table;
- r is the number of rows in the contingency table;
- $\min(k-1, r-1)$ is the smaller number between $k-1$ e $r-1$.

In this study, both analyses (HCA and Cramér's V-test) are conducted using the high-level programming language Python 3.0.

3 Data

The data analysis covers 20 case studies of projects involving the renovation of existing buildings or the construction of new ones, promoted through the One-Stop Shop or Turnkey Contract business model in France.

The collaborative web-based platform Construction21, which is aimed at all professionals in the construction sector and sustainable cities, is used to collect data. It presents numerous projects for the renovation and construction of new real estate that have taken place in Europe and beyond. Access to the platform is completely free and the content provided by users is moderated by recognized experts to ensure quality.

Although the web-based platform features numerous projects on the renovation of existing buildings and the construction of new ones in France, 20 case studies are selected as they focus on efficiency measures or new constructions promoted through business models classified under the One-Stop Shop and Turnkey Contract approaches. The first action performed is the naming and localization of the different cases. For each case, the identification code (ID), name (Name), business model adopted (BM) (One-Stop Shop or Turnkey Contract), Type of Intervention (IT), Construction Year (CY) and Investment Cost (IC) are recorded (Table 1). Once the naming is completed, it proceeds with the localization of the cases.

As can be seen in Fig. 3, the cases are divided according to the type of business model adopted: orange for the cases that use the One-Stop Shop business model and yellow for the cases that utilize the Turnkey Contract model.

Once this phase has been completed, the variables required for the HCA and the subsequent Cramér's V-test are determined (Table 2). They concern both the contractual aspect of the project (BM, IT, IC, INCEN) and the physical aspect of the building, which has been made more efficient or built from scratch (NFA, CY, ECb, ECa) and finally the climate in which the property has been improved or built from scratch (CZ).

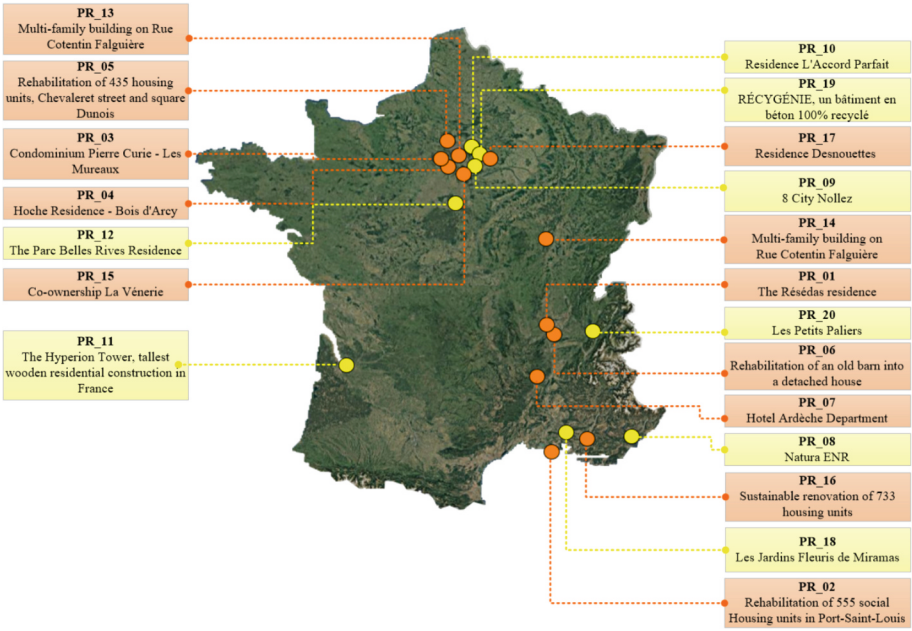


Fig. 3. Identification and localization of case studies

Great importance is given to the efficiency measures promoted, the type of heating, cooling and ventilation system installed (Heat, Vent, Cool) in addition to the installation or non-installation of photovoltaic systems (PVP). The installation or non-installation of insulation inside the building has not been considered, as in all cases have it included in the project.

The dataset consists of 20 case studies, 12 of which represent the One-Stop Shop business model and 8 Turnkey Contract model. The properties are evenly distributed between the Continental (8 out of 20), Oceanic (7 out of 20) and Mediterranean (5 out of 20) areas. The dataset shows an average investment cost (IC) of €6,574,236 and an average net floor area (NFA) of 9,884 m^2. In addition, most of the properties can be attributed to the condominium architectural typology (11 out of 20), most of which were built between 2019–2024 (6 out of 11) and between 1950–1976 (5 out of 11).

The Turnkey Contract business model is strongly linked to the installation of photovoltaic systems and the achievement of high levels of energy efficiency, as evidenced by the frequency of A and B class energy certificates in these buildings.

In contrast, the One-Stop Shop model is more common in buildings equipped with gas heating and alternative heating systems. This indicates a greater diversification of technological choices and management, which may be less focused on the implementation of sustainable technologies, such as photovoltaic systems.

The differences between the two business models are also reflected in the management strategies and energy efficiency outcomes.

The One-Stop Shop model shows greater variability in energy certification outcomes, including a significant percentage of buildings being categorized into energy

Table 1. Identification and coding of case studies

ID	Name	BM	IT	CY	IC
PR_01	The Résédas residence	One-Stop Shop	Renovation	1975	€1,800,000
PR_02	Rehabilitation of 555 social Housing units in Port-Saint-Louis (France)	One-Stop Shop	Renovation	1972	€16,400,000
PR_03	Condominium Pierre Curie - Les Mureaux	One-Stop Shop	Renovation	1974	€4,360,000
PR_04	Hoche Residence - Bois d'Arcy	One-Stop Shop	Renovation	1966	€1,700,000
PR_05	Rehabilitation of 435 housing units, Chevaleret street and square Dunois	One-Stop Shop	Renovation	1974	€18,295,000
PR_06	Rehabilitation of an old barn into a detached house	One-Stop Shop	Renovation	1940	€230,000
PR_07	Hotel Ardèche Department	One-Stop Shop	Renovation	1985	€3,400,000
PR_08	Natura ENR	Turnkey Contract	New Construction	2013	€4,200,000
PR_09	8 City Nollez	Turnkey Contract	New Construction	2022	€200,000
PR_10	Residence L'Accord Parfait	Turnkey Contract	New Construction	2022	€11,500,000
PR_11	The Hyperion Tower, tallest wooden residential construction in France	Turnkey Contract	New Construction	2019	€18,066,921
PR_12	The Parc Belles Rives Residence	Turnkey Contract	New Construction	2022	€4,174,695
PR_13	Multi-family building on Rue Cotentin Falguière	One-Stop Shop	Renovation	1950	€4,000,000
PR_14	20 dwellings Nuits-Saint-Georges	One-Stop Shop	Renovation	1972	€626,263
PR_15	Co-ownership La Vénerie	One-Stop Shop	Renovation	1976	€3,071,611

(*continued*)

Table 1. (*continued*)

ID	Name	BM	IT	CY	IC
PR_16	Sustainable renovation of 733 housing units	One-Stop Shop	Renovation	1975	€19,130,000
PR_17	Residence Desnouettes	One-Stop Shop	Renovation	1970	€2,950,000
PR_18	Les Jardins Fleuris de Miramas	Turnkey Contract	New Construction	2024	€9,800,000
PR_19	RÉCYGÉNIE, un bâtiment en béton 100% recyclé	Turnkey Contract	New Construction	2024	€9,869,070
PR_20	Les Petits Paliers	Turnkey Contract	New Construction	2022	€755,000

Table 2. List, description and values of variables

Variable	Description	Type	Code	Values
Business model adopted	Type of business model applied in the project	Categorical (Nominal)	BM	1: Turnkey Contract; 2: One-Stop Shop
Intervention typology	The intervention included renovation of the property or new construction	Categorical (Nominal)	IT	1: New construction 2: Renovation
Investment Cost	Total cost of the project	Categorical (Ordinal)	IC	1: €230,000 - €990,000; 2: €1,212,000 - €1,880,000; 3: €2,134,905 - €2,997,329; 4: €3,071,611 - €3.400,000; 5: €4,174,695 - €4,500,000; 6: €5,426,000 - €6,105,160; 7: €9,195,278 - €11,500,000; 8: €16,400,000 - €18,066,921

(*continued*)

Table 2. (*continued*)

Variable	Description	Type	Code	Values
Net Floor Area (m^2)	Total area of the property	Categorical (Ordinal)	NFA	1: 162 – 516; 2: 1,119 – 2,948; 3: 3,420 – 5,760; 4: 6,372 – 9,138; 5: 12,343 – 56,000
Construction Year	Year of construction of the property	Categorical (Ordinal)	CY	1: 1890 – 1940; 2: 1950 – 1968; 3: 1970 – 1985; 4: 2003 – 2010; 5: 2011 – 2024
Building Typology	Architectural typology of the property studied	Categorical (Nominal)	BT	1: Office; 2: Condominium; 3: Single - detached house
Energy Certificate before	Energy performance certificate of the building before the efficiency measures	Categorical (Ordinal)	ECb	1: C; 2: D; 3: E; 4: F; 5: N/A
Energy Certificate after	Energy performance certificate of the building after the efficiency measures or new construction	Categorical (Ordinal)	ECa	1: A; 2: B; 3: C; 4: D
Heating system	The project includes efficiency measures on the building's heating system	Categorical (Nominal)	Heat	1: Central heating; 2: Heat pump; 3: Gas heating; 4: Other; 5: Electric heating
Ventilation system	The project includes efficiency measures related to the building's ventilation system	Categorical (Nominal)	Vent	1: Mechanical ventilation; 2: Natural ventilation; 3: No ventilation
Cooling system	The project includes efficiency measures related to the building's cooling system	Categorical (Nominal)	Cool	1: Active cooling; 2: Passive cooling; 3: No cooling

(*continued*)

Table 2. (*continued*)

Variable	Description	Type	Code	Values
Installation of photovoltaic panels	The project includes the installation of photovoltaic systems to generate electricity	Categorical (Nominal)	PVP	(Binary) 1: Yes
Incentives	Use of incentives for the realization of the project	Categorical (Nominal)	INCEN	(Binary) 1: Yes
Climate Zone	Climate zone in which the property is located	Categorical (Nominal)	CZ	1: Oceanic; 2: Continental; 3: Mediterranean

classes C and D. Post-intervention energy certification makes these differences even more pronounced.

Buildings managed under Turnkey Contract achieve better results in terms of energy efficiency, with the majority achieving an A or B class certification.

In contrast, the One-Stop Shop model, although successful in improving energy efficiency, does not achieve the highest scores as frequently, as shown by the presence of buildings certified in the lower energy classes.

4 Results

4.1 Hierarchical Clustering Analysis (HCA)

The analysis is performed using HCA to identify homogeneous groups within a dataset of categorical variables, and an initial dendrogram of the dataset was created (Fig. 4). To ensure an accurate representation of the relationships between observations, Jaccard distance and the average linkage method are applied, and the optimal number of clusters is set to two based on the characteristics of the dataset. The quality of clustering is assessed using the Silhouette score, which reached an average of 0.440 value. As can be seen in Appendix 1– 2, the Silhouette score for two clusters proves to be the best, thus confirming the choice of the two clusters for the analysis, as the scores obtained for three or four clusters are worse and lower than the score of the two clusters.

A detailed description of the two identified clusters (Cluster 1 and Cluster 2) is then given. Since both clusters are represented by categorical variables, the description is made by calculating the mode of each variable to highlight the particular characteristics of each group (Table 3).

Cluster 1 comprises buildings in a continental climate zone that have been renovated on the basis of the One-Stop Shop business model and have benefited from government incentives. The average investment costs for these projects are between €16,400,000 and €18,066,921. The buildings in this cluster have a net floor area between 12,343 m^2 and 56,000 m^2, were built between 1970 and 1985 and are condominiums with an original

energy rating of D and a final one equal to B. The efficiency measures in the renovation plan include the installation of a gas boiler and the introduction of a mechanical ventilation system, but cooling systems or photovoltaic panels are not included (Table 3).

Cluster 2 includes buildings in an oceanic climate zone that are built from scratch using the Turnkey Contract business model, with no government incentives for implementing the project. The average cost of these projects ranges between €9,195,278 and €11,500,000, with a net floor area that varies between 6,372 m^2 and 9,138 m^2. The buildings in this cluster were built between 2003 and 2010, belong to the condominium typology and have a final energy class of B. The planned efficiency measures include the installation of a mechanical ventilation system, a heat pump and photovoltaic systems, while a cooling system is not considered (Table 3).

This initial analysis shows that the only variables common to both clusters are the building typology of the condominium (BT = 2), a final energy class equal to B (ECa = 2), the installation of a mechanical ventilation system (Vent = 1) and the not installation of a cooling system (Cooling = 3).

Table 3. Clusters description

Variable	Cluster 1	Cluster 2
BM	2	1
IT	2	1
IC	8	7
NFA	5	4
CY	3	4
BT	2	2
ECb	2	5
ECa	2	2
Heat	3	2
Vent	1	1
Cooling	3	3
PVP	2	1
INCEN	1	2
CZ	2	1

4.2 Cramér's V-test

Although this initial analysis provides a clear distinction and description of the two characteristic clusters of the dataset, it does not yet answer the research question, i.e. whether the business model and the implementation of certain energy efficiency measures are correlated.

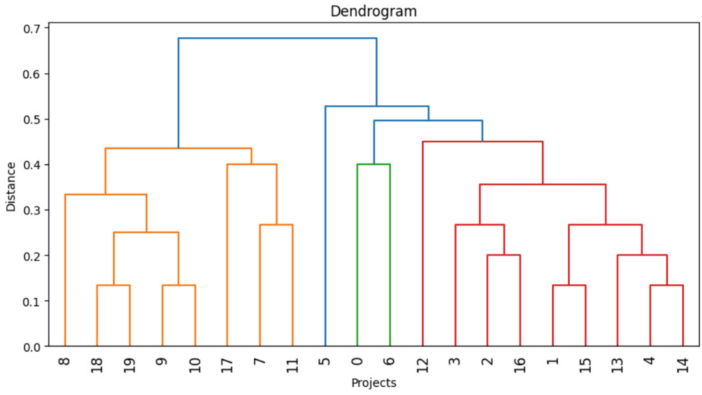


Fig. 4. Dendrogram representing the result of the hierarchical clustering analysis

To answer this question, Cramér's V-test is performed between the variables of the chosen business model (BM), the respective energy efficiency measures promoted in the projects (Heat, Vent, Cooling, PV) and also the variables related to the climate zone (CZ) and the use or non-use of government incentives (INCEN), as these also have a direct influence on the chosen energy efficiency measures or the type of business model.

The analysis of the correlations between the categorical variables using Cramér's V-test reveals significant results regarding the interactions between the chosen business model (BM) and some key variables of the energy efficiency measures. Table 4 shows the main results of the analysis.

The business model (BM) shows a moderate correlation with the installation of photovoltaic panels (PVP), with a Cramér's V of 0.578 and a p-value of 0.0098. The data suggests that the Turnkey Contract model is more frequently associated with the presence of PVP than the One-Stop Shop model. This correlation could be due to the nature of the Turnkey Contract model itself, which is more suited to new projects and major building interventions, while the One-Stop Shop model, which tends to focus on the renovation of existing buildings, demonstrates a tendency to exclude this technology from major interventions. Another significant correlation is found between the business model and access to public incentives (INCEN), with a Cramér's V of 0.636 and a p-value of 0.0045.

The results suggest that the One-Stop Shop model benefits more from the incentives, probably due to the greater compatibility of the renovation interventions with public financing programs for energy efficiency (as remarked in the existing literature).

This result is consistent with the role of incentives as a key element in stimulating investment in the sustainable renovation sector. A particularly strong and statistically significant correlation is found between the business model and the climate zone (CZ), with a Cramér's V value of 0.913 and a p-value of 0.0002.

This result shows how the choice of business models is influenced by the climatic context. In particular, the One-Stop Shop model is predominant in continental zones, where the harsher climate often requires interventions on existing buildings to improve their energy efficiency. In contrast, the Turnkey Contract model is more common in

Table 4. Cramér's V-test results

Variable 1	Variable 2	Cramer's_V	P-Value
BM	CZ	0.913	0.000
BM	Cooling	0.000	1.000
BM	Heat	0.441	0.421
BM	Vent	0.000	1.000
BM	PVP	0.578	0.010
BM	INCEN	0.636	0.004
CZ	Cooling	0.598	0.028
CZ	Heat	0.420	0.531
CZ	Vent	0.194	0.686
CZ	PVP	0.650	0.015
CZ	INCEN	0.674	0.011
Cooling	Heat	0.593	0.134
Cooling	Vent	0.000	1.000
Cooling	PVP	0.288	0.197
Cooling	INCEN	0.000	1.000
Heat	Vent	0.264	0.846
Heat	PVP	0.620	0.104
Heat	INCEN	0.351	0.652
Vent	PVP	0.000	1.000
Vent	INCEN	0.000	1.000
PVP	INCEN	0.348	0.120

oceanic zones, where more favorable climatic conditions facilitate the construction of new energy-efficient buildings. The relationship between CZ and the installation of PVP is also significant (Cramér's $V = 0.650$; p-value $= 0.0147$) and indicates that PVP are more frequently installed in oceanic zones, which are characterized by greater solar radiation and climatic conditions that favor the adoption of this technology.

5 Discussion

The HCA allows the identification of two different clusters reflecting significant differences between the buildings in terms of the chosen business model, energy efficiency measures and climatic context.

Cluster 1, characterized by buildings in continental climates renovated according to the One-Stop Shop model, shows a tendency to use public incentives for measures focused on thermal insulation and energy efficiency improvement.

In contrast, Cluster 2 includes buildings in oceanic climate zones that have been built from scratch using the Turnkey Contract model and are more inclined to use advanced technologies such as photovoltaic panels, despite the lack of government incentives.

Cramér's V-test assessed the significance of the relationships between the key variables and deepened the differences that emerged across the clusters. To aid interpretation, it is worth recalling that Cramér's V is a measure of association between categorical variables, with values ranging from 0 (no association) to 1 (perfect association). In this context, higher values indicate stronger links between variables such as the business model, climate zone, and adoption of technologies. The associated p-values show the statistical significance of these associations, with values below 0.05 indicating that the relationships are unlikely to be due to chance.

The strong correlation between business model and climate zone (Cramér's $V = 0.913$, p-value $= 0.0002$) indicates that climatic conditions directly influence the choice of operating model. Similarly, the significant relationship between the climatic zone and the installation of photovoltaic systems (Cramér's $V = 0.650$, p-value $= 0.0147$), which in turn are strongly correlated with the business model (Cramér's $V = 0.578$, p-value $= 0.010$) shows that local factors, such as greater solar radiation, are decisive for the adoption of certain technologies.

In France, the continental climate is characterized by cold winter temperatures, which prioritize measures to improve the energy efficiency of existing buildings. This context favors the adoption of the One-Stop Shop model, which focuses on energy-efficient renovations and is often supported by public incentives.

In contrast, the oceanic climate has milder temperatures and conditions that facilitate new construction projects. This suits the Turnkey Contract model, which is particularly suitable for the construction of energy-efficient buildings from the planning phase onwards. In addition, the greater solar radiation in some oceanic regions explains the significant correlation between the business model and the installation of photovoltaic systems (Cramér's $V = 0.578$, p-value $= 0.0098$).

The Turnkey Contract, associated with new projects, is suitable for more complex and technologically advanced measures, such as the introduction of photovoltaic systems and heat pumps.

The One-Stop Shop model, on the other hand, is geared towards measures that aim to significantly increase the energy class of existing buildings, such as the replacement of heating or ventilation systems.

This distinction is also in line with the characteristics of the French building stock: in the continental regions, the greater presence of buildings built between 1970 and 1985 requires renovation measures to bring them up to modern energy standards. In the oceanic regions, on the other hand, the availability of land and the absence of constraints linked to historical heritage favor the construction of new residential complexes.

The combination of HCA and Cramér's V-test offers valuable insights into the relationships between business models, technologies, and climatic factors. However, the results are influenced by the selected variables and the specific national context, which may limit broader applicability. Despite these limitations, the approach is effective for identifying patterns and informing targeted policy decisions.

6 Conclusions

This study investigates the correlation between business models and energy efficiency measures in 20 case studies of building renovations and new constructions across France. The case studies were selected based on geographic distribution (continental, oceanic or mediterranean climate), type of intervention (renovation vs. new construction), and the adopted business model (One-Stop Shop vs. Turnkey Contract).

The HCA clearly identifies two distinct clusters based on the business model, energy efficiency measures, and climatic contexts. The findings underscore the significant role of local climatic conditions in shaping the choice of business model and the technological measures implemented.

Cluster 1, representing buildings in continental climates, follows the One-Stop Shop model and relies on public incentives. The average investment costs for these projects range from €16,400,000 to €18,066,921, with a net floor area between 12,343 m^2 and 56,000 m^2. These buildings, primarily built between 1970 and 1985, undergo renovations that focus on improving energy efficiency but do not include advanced technologies like photovoltaic panels. Cluster 2, located in oceanic climates, includes new constructions under the Turnkey Contract model, with a focus on advanced energy solutions like heat pumps and photovoltaic panels. The costs for these projects range from €9,195,278 to €11,500,000, and they were built between 2003 and 2010.

The Cramér's V-test further strengthens the relationships between climate zone, business model, and technological adoption, revealing how solar radiation influences the decision to install photovoltaic systems. The oceanic climate's more favorable solar conditions explain the higher prevalence of such advanced technologies in new construction projects. While these results are insightful, several methodological considerations arise that could guide future research in this area.

First, local climate conditions appear to be a decisive factor in the selection of business models and technologies. Future research could replicate this study in different geographical areas or countries with varying climates to assess whether similar patterns emerge. This would help validate the findings and increase their applicability across different regions.

Second, a more qualitative approach could complement the findings. Interviews or surveys with industry professionals, such as building owners or developers, could provide deeper insights into the decision-making process behind the selection of business models and energy efficiency measures. Incorporating qualitative data would allow for a more nuanced understanding of the motivations, challenges, and constraints that influence these choices.

Based on the study's findings, policy makers are recommended to tailor energy efficiency programs to local climate conditions and building typologies. In continental climates, efforts should prioritize retrofitting and upgrading existing buildings, supported by business models such as the One-Stop Shop. In contrast, oceanic regions would benefit from promoting new energy-efficient constructions through models like the Turnkey Contract. Aligning energy efficiency initiatives with regional needs and characteristics would foster more effective implementation and adoption of sustainable measures.

Future research should expand the sample size and include a broader range of case studies to enable a more detailed examination of the relationship between climate, business model and technology adoption. In particular, research should explore adaptive business models tailored to regional climate variability to help policy makers, developers and investors make more informed decisions. This could accelerate the deployment of advanced technologies, such as photovoltaic panels and heat pumps, in regions where they are most effective.

Moreover, future studies should integrate quantitative variables—such as investment costs, renovation timelines, and energy performance indicators—together with qualitative insights gathered through interviews or focus groups with building owners and stakeholders. This mixed-method approach would significantly enrich the interpretation of the findings and provide a more comprehensive understanding of the motivations, constraints, and decision-making processes behind the adoption of energy efficiency strategies. It would also support clearer segmentation and comparison of case studies, contributing to more transparent and replicable methodologies. The methodology employed in this study is highly replicable in other regions or countries with similar climatic and regulatory contexts. The business model clustering technique can be applied to a wide range of energy efficiency initiatives across Europe and beyond, particularly where climate and technological factors influence real estate decisions. Applying this approach in diverse geographical areas would enhance the robustness of the results and increase their generalizability.

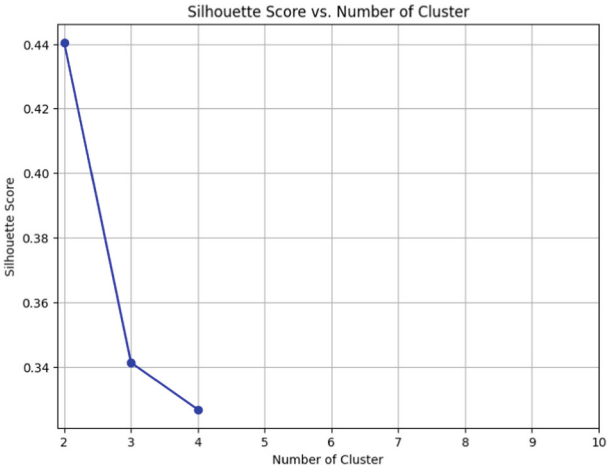
Disclosure of Interests. The authors have no competing interests.

Appendix

Appendix 1: Number of clusters and their different silhouette score

Number of clusters	Silhouette score
2	0.440
3	0.341
4	0.327

Appendix 2: Table number of cluster and their different silhouette score



References

1. Maduta, C., Melica, G., D'Agostino, D., Bertoldi, P.: Towards a decarbonised building stock by 2050: the meaning and the role of zero emission buildings (ZEBs) in Europe. Energ. Strat. Rev. **44**, 101009 (2022). https://doi.org/10.1016/J.ESR.2022.101009
2. Miezis, M., Zvaigznitis, K., Stancioff, N., Soeftestad, L.: Climate change and buildings energy efficiency – the key role of residents. Environ. Climate Technol. **17**(1), 30–43 (2016). https://doi.org/10.1515/rtuect-2016-0004
3. Baglivo, C., Albanese, P.M., Congedo, P.M.: Relationship between shape and energy performance of buildings under long-term climate change. J. Build. Eng. **84** (2024). https://doi.org/10.1016/j.jobe.2024.108544
4. Xu, S., Fang, L., Govindan, K.: Energy performance contracting in a supply chain with financially asymmetric manufacturers under carbon tax regulation for climate change mitigation. Omega (Westport) **106**, 102535 (2022). https://doi.org/10.1016/J.OMEGA.2021.102535
5. I (Legislative acts) DIRECTIVES DIRECTIVE (EU) 2023/1791 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast) (Text with EEA relevance)
6. DIRECTIVE (EU) 2018/844 OF the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (Text with EEA relevance)
7. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings
8. DIRECTIVE 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.
9. Munaro, M.R., do Freitas, C.D., Tavares, S.F., Bragança, L.: Circular business models: current state and framework to achieve sustainable buildings. J. Constr. Eng. Manag. **147**(12), 04021164 (2021). https://doi.org/10.1061/(ASCE)CO.1943-7862.0002184
10. Zhao, X., Pan, W., Lu, W.: Business model innovation for delivering zero carbon buildings. Sustain. Cities Soc. **27**, 253–262 (2016). https://doi.org/10.1016/j.scs.2016.03.013

11. Copiello, S., Donati, E., Bonifaci, P.: Energy efficiency practices: a case study analysis of innovative business models in buildings. Energy Build. **313**, 114223 (2024). https://doi.org/10.1016/J.ENBUILD.2024.114223
12. Sinkovics, N., Gunaratne, D., Sinkovics, R.R., Molina-Castillo, F.J.: Sustainable business model innovation: an umbrella review, MDPI AG (2021). https://doi.org/10.3390/su13137266
13. Ensign, P.C.: business models and sustainable development goals MDPI (2022).https://doi.org/10.3390/su14052558
14. McGinley, O., Moran, P., Goggins, J.: Key considerations in the design of a one-stop-shop retrofit mode. Civil Engineering Research in Ireland, pp. 354–359 (2020)
15. Bagaini, A., Croci, E., Molteni, T.: Boosting energy home renovation through innovative business models: ONE-STOP-SHOP solutions assessment. J. Clean. Prod. **331**, 129990 (2022). https://doi.org/10.1016/J.JCLEPRO.2021.129990
16. Pardalis, G., Talmar, M., Keskin, D.: To be or not to be: the organizational conditions for launching one-stop-shops for energy related renovations. Energy Policy **159** (2021). https://doi.org/10.1016/j.enpol.2021.112629
17. Bjørneboe, M.G., Svendsen, S., Heller, A.: Using a one-stop-shop concept to guide decisions when single-family houses are renovated. J. Archit. Eng. **23**(2), 05017001 (2017). https://doi.org/10.1061/(ASCE)AE.1943-5568.0000238
18. Commission, E., Centre, J.R., Boza-Kiss, B., Bertoldi, P., Della Valle, N., Economidou, M.: One-stop shops for residential building energy renovation in the EU – analysis & policy recommendations. Publications Office (2021).https://doi.org/10.2760/245015
19. Donati, E., Copiello, S.: The one-stop shop business model for improving building energy efficiency: analysis and applications. In: Gervasi, O., et al. (eds.) Computational Science and Its Applications – ICCSA 2023 Workshops. ICCSA 2023. LNCS, vol. 14106. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-37111-0_30
20. Doe, J., Nitek, D., Minamikata, N., Smith Freehills, H.: Construction Arbitration and Turnkey Projects, Construction Arbitration and Turnkey Projects (2021). https://globalarbitrationreview.com/guide/the-guide-construction-arbitration/fourth-edition/article/construction-arbitration-and-turnkey-projects
21. Schneider, M.E.: Turnkey contracts - Concepts, liabilities, claims. In: 4, vol. 3. London: LLYOD'S OF LONDON PRESS LTD (1986). https://www.lalive.law/wp-content/uploads/2019/10/mes_turnkey_contracts.pdf
22. Mimoso, M.J.: The Turnkey Contract and the Globalization Era
23. Merna, A., Smith, N.: Project managers and the use of turnkey contracts. Int. J. Project Manage. **8**(3), 183–189 (1990). https://doi.org/10.1016/0263-7863(90)90021-3
24. Donati, E., Copiello, S., Bonifaci, P.: Applications and economic profiles of the turnkey contract business model. In: Gervasi, O., Murgante, B., Garau, C., Taniar, D., Rocha, A.M.A.C., Faginas Lago, M.N. (eds.) Computational Science and Its Applications – ICCSA 2024 Workshops, pp. 143–161. Springer Nature Switzerland, Cham (2024)
25. Lévy, J.P., Belaïd, F.: The determinants of domestic energy consumption in France: energy modes, habitat, households and life cycles. Renew. Sustain. Energy Rev. **81**, 2104–2114 (2018). https://doi.org/10.1016/J.RSER.2017.06.022
26. Ravigné, E., Ghersi, F., Nadaud, F.: Is a fair energy transition possible? Evidence from the French low-carbon strategy. Ecol. Econ. **196**, 107397 (2022). https://doi.org/10.1016/J.ECOLECON.2022.107397
27. Sebi, C., Vernay, A.L.: Community renewable energy in France: the state of development and the way forward. Energy Policy **147**, 111874 (2020). https://doi.org/10.1016/J.ENPOL.2020.111874

28. Giraudet, L.G., Bourgeois, C., Quirion, P.: Policies for low-carbon and affordable home heating: a French outlook. Energy Policy **151**, 112140 (2021). https://doi.org/10.1016/J.ENPOL.2021.112140
29. Baker, F.B., Hubert, L.J.: Measuring the power of hierarchical cluster analysis. J. Am. Stat. Assoc. **70**(349), 31–38 (1975)
30. Schonlau, M.: Visualizing non-hierarchical and hierarchical cluster analyses with clustergrams. Comput. Stat. **19**, 95–111 (2004)
31. Köhn, H., Hubert, L.J.: Hierarchical cluster analysis. Wiley StatsRef: statistics reference online, pp. 1–13 (2014)
32. Contreras, P., Murtagh, F.: Hierarchical clustering. Handbook of cluster analysis, pp. 103–123 (2015)
33. Yim, O., Ramdeen, K.T.: Hierarchical cluster analysis: comparison of three linkage measures and application to psychological data. Quant. Method Psychol. **11**(1), 8–21 (2015)
34. Dolev, S., Ghanayim, M., Binun, A., Frenkel, S., Sun, Y.S.: Relationship of Jaccard and edit distance in malware clustering and online identification (Extended abstract). In: 2017 IEEE 16th International Symposium on Network Computing and Applications (NCA), pp. 1–5 (2017). https://doi.org/10.1109/NCA.2017.8171380
35. Mammone, N., Ieracitano, C., Adeli, H., Bramanti, A., Morabito, F.C.: Permutation jaccard distance-based hierarchical clustering to estimate EEG network density modifications in MCI subjects. IEEE Trans. Neural Netw. Learn. Syst. **29**(10), 5122–5135 (2018). https://doi.org/10.1109/TNNLS.2018.2791644
36. Gregory, G.G.: Key words: CRAMER-VON MISES TYPE TESTS FOR SYMMETRY (1977)
37. Rodriguez, J.C., Viollaz, A.J.: A cramer - von mises type goodness of fit test with asymmetric weight function. Commun. Stat. Theory Methods **24**(4), 1095–1120 (1995). https://doi.org/10.1080/03610929508831542
38. Taylor, H.M.W.A.T.C., Gusnanto, A.: Properties and approximate p-value calculation of the Cramer test. J. Stat. Comput. Simul. **90**(11), 1965–1981 (2020). https://doi.org/10.1080/00949655.2020.1754820
39. Laio, F.: Cramer-von Mises and Anderson-Darling goodness of fit tests for extreme value distributions with unknown parameters. Water Resour. Res. **40**(9) (2004). https://doi.org/10.1029/2004WR003204
40. Tamura, R.N., Faries, D.E., Feng, J.: Comparing time to onset of response in antidepressant clinical trials using the cure model and the Cramer-von mises test (2000). https://doi.org/10.1002/1097-0258(20000830)19:16<2169::AID-SIM513>3.0.CO;2-O
41. Tomizawa, S., Miyamoto, N., Houya, H.: Generalization of Cramer's coefficient of association for contingency tables: theory and methods. S. Afr. Stat. J. **38**(1), 1–24 (2004). https://doi.org/10.10520/EJC99072
42. Baker, R.D.: A new perspective on the cramér-von mises test. J. Nonparametr. Stat. **7**(3), 255–277 (1997). https://doi.org/10.1080/10485259708832703