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Green Building Renovation Through the Benefits of the 110% Superbonus: Process, Technical and Economic-Appraisal Aspects

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Abstract

In recent years, European and national policies on energy efficiency and sustainable construction have promoted a profound rethinking of building practices and strategies for upgrading the existing building stock. With the conversion of Law Decree No. 34 of 19 May 2020 (*Decreto Rilancio*) into Law No. 77 of 17 July 2020, and of Law Decree No. 76 of 16 July 2020 (*Decreto Semplificazioni*) into Law No. 120 of 11 September 2020, the tax deduction rate was increased to 110% for expenses related to specific interventions such as seismic risk reduction, energy retrofit, installation of photovoltaic systems, and charging infrastructures for electric vehicles in buildings—commonly known as the *Superbonus 110%*. Furthermore, the category of “building renovation,” as defined in Presidential Decree No. 380 of 6 June 2001 (art. 3, paragraph 1, letter d), was expanded with specific reference to demolition and reconstruction of existing buildings, allowing—under certain conditions—interventions that do not comply with the original footprint, façades, site layout, volumetric features, or typological characteristics. These measures were designed not only to positively affect household investment levels, thereby significantly contributing to national income growth, but also to support the broader objective of decarbonising the building sector while improving seismic safety. Within this regulatory and policy framework, instruments such as the *Superbonus 110%* have acted as a driving force for the diffusion of renovation projects aimed at enhancing energy performance and reducing greenhouse gas emissions, in line with the objectives of the European Green Deal and the Energy Performance of Buildings Directive (EPBD). This paper is situated within such a context and examines a real-world case of bio-based renovation admitted to fiscal incentives under the *Superbonus 110%*. The focus is placed on the procedural framework as well as on the technical, economic, and evaluative aspects, adopting a multidimensional perspective that combines regulatory, operational, and financial considerations. The case study concerns the demolition and reconstruction of a single-family residential chalet, designed according to near-Zero-Energy Building (nZEB) standards, located in the municipality of San Roberto, in the province of Reggio Calabria. The intervention is set within an environmentally and culturally sensitive area, being situated in the Aspromonte National Park and subject to landscape protection restrictions under Article 142 of Legislative Decree No. 42/2004. The aim of the study is to highlight, through the analysis of this case, both the opportunities and the challenges of applying the *Superbonus 110%* in protected contexts. By doing so, it seeks to contribute to the scientific debate on the interplay between incentive-based regulations, energy sustainability, and landscape–environmental protection requirements, while providing insights for academics, practitioners, and policymakers engaged in the ecological transition of the construction sector.



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1. Introduction

Buildings play a key role in Europe’s energy and climate balance, accounting for approximately 40% of final energy consumption and 36% of direct and indirect Greenhouse Gas emissions (GHG) [1,2]. In addition to causing environmental damage, CO₂ emissions also cause economic damage worldwide; the Carbon Social Cost (CSC) is a social cost of climate change-related damage from CO₂ emissions; economic losses associated with changes in agricultural productivity; risks to human health; property damage caused by a possible increase in flooding; and loss of ecosystem services [3–10]. Much of this demand is driven by heating (70%), cooling (20%) and Domestic Hot Water (10%) [11–13], which together represent nearly 80% of household energy use. Italy reflects this broader European trend; according to the 2024 *Piano Nazionale Integrato Energia e Clima* (PNIEC), the built environment represents over 44% of national final energy demand and about 26% of GHGs [14].

The Italian building stock is markedly old and inefficient; more than 60% was constructed over 45 years ago—before the first national energy efficiency laws, as some academic and professional case studies show [15–18]—and energy cadaster data show that over half of residential buildings fall into the lowest efficiency classes (F and G), with only a negligible fraction in class A [19]. Deep renovation remains limited, with the current rate estimated at just 0.85% per year, far below the levels required to achieve climate neutrality [20–23].

To meet the European Green Deal target of climate neutrality by 2050 and the medium-term “Fit for 55” commitment to reduce emissions by at least 55% by 2030 [24], the regulatory framework for buildings has been significantly strengthened. The recast of the Energy Performance of Buildings Directive (EPBD, 2024)—also referred to as the “Green Homes Directive”—sets binding milestones: from 2030, all new buildings must be zero-emission (public buildings from 2028), and the existing stock must be fully decarbonized by 2050 [25,26]. Member States are required to adopt minimum energy performance standards, with intermediate checkpoints—for instance, ensuring that by 2033 the average primary energy demand of the residential stock reaches at least class D (European Parliament, 2023). In parallel, the “Renovation Wave” strategy aims to at least double the annual building renovation rate by 2030, recognizing the sector’s centrality in the EU’s decarbonization pathway [27].

At the national level, Italy has aligned its energy and climate policies with this European framework through the PNIEC (*Piano Nazionale Integrato per l’Energia e il Clima*) 2024, which strengthens 2030 targets for efficiency and renewable. The plan emphasizes the need for deep retrofits in the civil sector—ranging from extensive thermal insulation to advanced technologies such as heat pumps and building automation systems—alongside an expanded role for renewable energy in both thermal and electrical supply [14]. Yet the gap between ambition and practice remains wide, as with deep renovation at less than 1% annually Italy lags far behind the 2% benchmark deemed necessary by its own plan. To accelerate this process, fiscal incentives have been expanded, most prominently through the *Ecobonus*, *Sismabonus*, and the extraordinary *Superbonus 110%*, together with complementary financial instruments designed to support global efficiency improvements [28]. These measures not only aim at ecological transition and energy retrofitting, but also at seismic safety, improved living comfort, and enhanced architectural quality of the Italian build-

ing stock—an integrated policy package that aligns with the EU Green Deal’s long-term aspiration of a climate-neutral society by 2050.

The *Superbonus 110%* has represented one of the cornerstone measures of Italy’s building renovation incentives. Introduced by the “*Rilancio*” Decree (DL 34/2020), the scheme allowed a 110% tax deduction on expenses incurred, primarily between July 2020 and December 2021, for specific energy efficiency interventions, seismic upgrades, and the installation of renewable energy systems (i.e., photovoltaic panels) or electric vehicle charging infrastructures [29]. The program was conceived as an integrated policy tool aimed at achieving multiple goals simultaneously—ecological transition, improved living comfort, seismic safety, and urban quality—by empowering households and operators with the purchasing capacity to implement comprehensive, high-quality interventions [26]. In essence, the *Superbonus 110%* constitutes the means, while the aforementioned socio-environmental objectives constitute the ends [28].

Eligible interventions under the *Superbonus 110%* are classified as “driving” (*trainanti*) and “driven” (*trainati*) measures. Driving interventions—which are essential to qualify for the benefit—include the installation of external thermal insulation (covering at least 25% of the building envelope), the replacement of heating systems with high-efficiency solutions such as heat pumps or advanced condensing boilers, and seismic upgrading works. Driven interventions, which may also receive the 110% deduction, are allowed only if implemented concurrently with at least one driving measure. Key driven measures include the replacement of doors and windows, installation of photovoltaic systems (with associated storage), and preparation of electric vehicle charging infrastructures. This conditionality ensures that investments target deep renovations rather than incremental improvements.

The technical framework of the *Superbonus 110%* also includes strict expenditure caps per intervention type, designed to focus incentives on the most virtuous and substantial renovations (i.e., €50,000–65,000 per dwelling for insulation, €16,000 for 6 kWp photovoltaic systems, €1000/kWh for batteries). The scheme has had a significant impact on Italy’s building renovation market. By the end of 2022, ENEA data reported approximately 359,440 validated *Superbonus 110%* certifications, corresponding to investments of around €62.5 billion, of which 74.6% had been executed, generating €51.3 billion in accrued tax deductions [29]. The Italian State has committed to covering these deductions, representing a substantial future fiscal commitment.

Overall, the Italian experience demonstrates how strong fiscal incentives, when aligned with European legislative objectives, can catalyze large-scale building modernization. To align Italy’s building stock with the decarbonization trajectories required by 2050, continued and enhanced support for energy efficiency and renewable energy measures is essential, consolidating both financial mechanisms and regulatory frameworks to sustain high-quality interventions [26,28].

On these grounds, the present study is structured to give a clear and thorough analysis of Italy’s *Superbonus 110%* scheme and its impact on the national building stock. The research follows a step-by-step approach. Firstly, it presents a concise review of the legislative framework and key developments in the *Superbonus 110%* regulations, emphasizing the technical, fiscal, and procedural rules introduced over time.

Next, the paper examines the practical rollout of the incentive, analyzing national and regional data on renovation projects carried out between September and October 2023. This stage identifies the opportunities created, such as higher renovation rates and market stimulation, as well as the main challenges, including administrative hurdles and spending caps.

The third methodological step focuses on a detailed case study of a real bio-based building renovation, involving demolition and reconstruction to improve both seismic safety and energy performance. This includes a technical assessment of structural reinforcement, energy efficiency measures, and sustainable building solutions, alongside an economic evaluation covering construction costs, applicable tax incentives, and projected economic and energy savings.

Finally, the paper compares nationwide data with the case study results, highlighting patterns, best practices, and areas where policy could be improved. This stepwise approach provides a balanced assessment of the *Superbonus*'s effectiveness and its role in advancing the decarbonization and modernization of Italy's building stock.

2. The “Superbonus 110%”: Opportunities and Criticalities of Its Implementation

In Italy, the first tax breaks for the energy residential buildings upgrade were introduced in 2007. They took the form of deductions on part of the costs spread over several years, usually ten. Though meant as short-term tools, these breaks have since been renewed again and again, often with changes in the size of the benefit, and in some cases made permanent [24,30].

From the start, the aim was clear:

- to fight undeclared work in the building trade;
- to lift national output by using construction as a lever;
- to meet European energy goals;
- to make homes safer against earthquakes [31].

Currently, three distinct fiscal instruments have been employed to support building retrofits: the “*Ecobonus*”, the “*Sismabonus*”, and the more recent “*Superbonus 110%*”:

1. “*Ecobonus*”, in force until the end of 2024, which provides for an *Irpef* deduction over ten years of expenses for energy redevelopment interventions on real estate units and buildings (including those not intended as a main residence) incurred by the owner or occupant (tenant);
2. The “*Sismabonus*”, introduced in 2017 and subsequently reinforced through later amendments, was specifically conceived as a structural counterpart to the “*Ecobonus*” [32,33];
3. “*Superbonus 110%*”, introduced in 2020, which consists of an enhancement of the *Ecobonus* through an increase in the *Irpef* deduction, to be used in 4 years [34,35].

Unlike older tax breaks, the intent here was also to ease access for households short on cash or with too little income to offset tax (tax incapacity). Yet, the Budget Office (PBO) found that up to 2020 it was still high-income households with property who gained most [36–38].

Later laws—the 2022 Budget Law, Decree-Law No. 4/2022, No. 17/2022, and No. 50/2022—brought major changes and anti-fraud rules. The *Superbonus 110%* soon showed itself costly, with a strong impact on the economy. The idea was simple, but the path hard, marked by hurdles in permits and access to credit [35].

To use the scheme, one must do “driving works”: seismic or energy upgrades, such as cladding of walls, roofs and floors, or replacement of heating, cooling and hot water systems. These may be paired with “towed works”: solar panels, storage, new windows and blinds, smart controls, or charging stations [30,34].

The positive effects on the building and residential sector were many, as shown by Authors previous studies [39–44]. The State gained back (regained) some tax through new work, offsetting lost revenue. Buildings leapt in energy class, cutting fossil use and emissions. Property values rose with the energy grade. Studies show that moving up two

grades from E, F, or G yields an average 4.3% rise in value, higher when moving from mid to top classes [30,35]. Families, thanks to the option of credit transfer and invoice discount (Law Decree No. 34/2020, Art. 121), could start works they could not have paid for. The market also saw more firms, accountants, engineers, and banks dealing in tax credits [45].

On the green side (environmental value), CO₂ fell by 40% on average, with peaks of 70% in big cities, or 1.42 million tons saved [35,46]. But the scheme also warped the field. With costs at 110% of works, the sense of “free” spread, erasing price checks and lifting costs. Even small shares paid by owners could have forced a fairer market [37].

The introduction of too short deadlines has caused real leghold traps, resulting in an excess demand for raw materials, materials, plant components, and labor, whose supply is notoriously rigid, with unfair and distorting consequences. Among the most striking are: increase in inflation, significant slowdowns in the execution times of the works, extraordinary and unjustified increase in the costs of all production factors, and rise in technicians’ fees, established on average between 20 and 30% of the total construction amount, the latter proving in many cases to be far higher than the ordinary cost also due to the use of price lists known to be out of the market [45,47].

Furthermore, the location of the buildings was not taken into account in relation to the market value that they incorporate downstream of the seismic risk prevention/reduction and energy requalification intervention. In many cases, this carelessness has translated into a disinvestment since the total construction costs have far exceeded the market value of the properties in that particular territorial context [35].

The *Superbonus 110%* thus “drugged” the construction sector, triggering speculation. The costs, also due to the non-performing loans as a result of the subsequent measures, were passed on to the companies but above all to the customers. In fact, the impossibility of completing works already started has generated opportunity costs in terms of both the benefits lost due to the freezing of the public financial capital used in the works already carried out, and the postponement of the expected benefits resulting from the completion of the works. Another aspect to be highlighted was the absence of indications and control on the type of materials used in the redevelopments [34].

The ENEA annual report on the *Superbonus 110%* (2023) records 430,661 projects at the national scale: 78,260 blocks of flats (74.7% done, 56.7% of spend); 237,127 single homes (91.5% done, 30.7% of spend); and 115,267 units in blocks (93.7% done, 12.6% of spend). In Calabria alone, 14,021 projects were filed: 2561 blocks (75.2% done, 53.1% of spend); 8244 single homes (88.8% done, 35.1% of spend); and 3216 units (90.5% done, 11.9% of spend). On average, the spend was €582,920 per block, €120,113 per house, and €105,662 per unit. With 12.2 million dwellings in Italy, of which 1.2 million are blocks, this means just over 6% of blocks and under 3.5% of all homes were touched [48–50].

A further critical element relates to the scarce availability of data on the energy efficiency of homes, energy consumption and previous incentive measures, which would instead be necessary both for the development of market solutions and for a correct design of future public interventions [37,51,52].

Yet the *Superbonus 110%* leaves behind more than data on cost and gain. It stands as a stark trial of how bold tax tools can shape both the market and the way households see the worth of energy and safety. Its path shows the power of strong State aid to speed deep retrofits, but also the risk of excess, fraud, and waste when rules run loose or too fast. In this sense, the Italian case gives a warning: future schemes in Europe will need a steadier hand, longer spans of time, and stricter watch on costs and materials, if they are to blend growth, green goals, and fair share. What worked best was the clear link between public push and private action; what failed most was the loss of balance between aid and value.

For policy, the task now is to keep the drive, while cutting the flaws, so that the path to 2050 is firm, fair, and fit for all [35,37,49].

2.1. Main Difference Between “*Ecobonus*” and “*Sismabonus*” with the New “*Superbonus 110%*”

In order to further clarify these differences, Table 1 offers a comparative framework of the three schemes. The “*Ecobonus*” appears as a long-standing fiscal tool, focused on gradual energy efficiency improvements such as thermal insulation, window substitution, high-efficiency heating systems, and building automation, with deduction rates generally between 50% and 65%, and higher percentages (70–75%) when applied to condominium common areas [53,54].

Table 1. Comparative features of *Ecobonus*, *Sismabonus* and *Superbonus 110%* in Italy.

Features	<i>Ecobonus</i>	<i>Sismabonus</i>	<i>Superbonus 110%</i>
Introduction Year	2007	2017	2020
Tax Deduction Rate	- 50–65% for most energy upgrades; - 70–75% for condominiums	- 50–70% for single units; - up to 85% for condominiums; - fixed cap €96,000 per unit/year	- 110% (2020–2022), then 90% (2023), 70% (2024), 65% (2025); - repayment over 4 years
Application Scope	Energy efficiency measures in residential and non-residential buildings, such as: thermal insulation, windows, heating system replacement, building automation	Seismic risk reduction works in seismic hazard zones (classified area 1, 2 and 3): seismic strengthening, demolition and reconstruction permitted	Integrated energy and seismic renovation of residential buildings (extended also to some non-residential uses): combined energy and seismic works, mandatory two-class energy upgrade, integrated driving and driven measures
Beneficiaries Target	- Owners or tenants of residential units; - no primary residence requirement	- Owners of residential and non-residential properties in seismic zones; - both individuals and condominiums	- Wider population due to credit transfer/invoice discount; - households with limited fiscal capacity included
Incentive Mechanism	Deduction spread over 10 years; no credit transfer	Deduction spread over 5 years; capped expenditures	Deduction spread over 4 years; credit transfer and invoice discount enabled (later restricted in 2023)
Policy Objective	Incremental energy efficiency and fossil fuel reduction	Seismic safety enhancement and structural resilience	Deep retrofit with dual aim: decarbonization and seismic resilience, while boosting economic recovery

Source: Authors.

The “*Sismabonus*”, in contrast, was designed to address seismic vulnerability, particularly in zones 1–3, and grants deductions ranging from 50% to 70% for single housing units

(depending on the number of seismic classes improved) and up to 85% for condominium interventions, with a fixed cap of €96,000 per unit per year [32,33].

The “*Superbonus 110%*”, established in 2020 under the “Relaunch Decree,” represented a significant departure from these incremental schemes, offering an unprecedented 110% deduction—subsequently scaled down to 90% in 2023, 70% in 2024, and 65% in 2025—for integrated packages of works that combine “driving” interventions (such as thermal envelope upgrades and heating system replacement) with “driven” ones (including photovoltaic systems with storage, electric vehicle charging stations, and window replacement).

Unlike the “*Ecobonus*”, it required a mandatory two-class improvement in energy performance, while unlike the “*Sismabonus*” it combined structural and energy measures in a single comprehensive framework. Moreover, the introduction of credit transfer and invoice discount mechanisms—later curtailed by Decree Law No. 11/2023—initially widened access to a much broader share of households, including those with limited fiscal capacity.

Thus, Table 1 illustrates how the three incentives, although united by the aim of upgrading Italy’s building stock, differ in their fiscal generosity, technical requirements, and policy reach: the “*Ecobonus*” as a steady mechanism of incremental efficiency gains, the “*Sismabonus*” as a targeted risk-reduction tool, and the “*Superbonus 110%*” as a disruptive and ambitious experiment in deep retrofit policy [38,49,55].

Therefore, compared to the “*Ecobonus*” and “*Sismabonus*”, which remain in force as permanent though less generous schemes, the “*Superbonus 110%*” embodied a more disruptive and ambitious approach, acting as both an economic stimulus and a policy experiment in deep energy and seismic retrofits. This comparative framework underscores the evolving balance in Italy between targeted, incremental incentives and broad, integrated measures designed to align the building stock with European decarbonisation and climate resilience objectives (European Commission, 2021; Tonin, 2025) [30,55].

2.2. “*Superbonus 110%*” Eligibility Criteria and Approval Processes

The eligibility criteria of the “*Superbonus 110%*” are deliberately stringent, reflecting the dual intention of achieving effective energy and seismic improvements while avoiding opportunistic access to the measure. From an energy perspective, one of the fundamental requirements is the obligation to achieve at least a “two-class jump” in the building’s Energy Performance Certificate (*Attestato di Prestazione Energetica, APE*), verified both before and after the intervention through accredited professionals [49]. This implies that only projects capable of producing substantial efficiency gains, rather than marginal improvements, are eligible.

In addition, most residential buildings constructed prior to Law no. 10/1991—covering nearly three-quarters of the Italian housing stock—are considered prime candidates, given their inadequate thermal insulation and outdated systems [54]. On the seismic side, interventions are admissible only if located in high and medium seismic risk zones (categories 1, 2, and 3 as defined by national legislation), and the works must be certified to ensure compliance with current structural safety codes [33].

The approval process is equally complex. Beneficiaries are required to submit a detailed technical dossier, including project design, preliminary energy assessments, and cost estimates, to the relevant municipal authorities and to ENEA for validation. The involvement of multiple professional figures—engineers, architects, energy auditors, and accountants—is mandatory, as each document must be accompanied by *asseverazioni* (formal sworn statements) certifying compliance with statutory requirements and spending limits [56].

The fiscal benefit can only be accessed once the double compliance check is satisfied: both building permits and urban planning conformity must be in place, along with the

technical verification of energy and seismic targets. Furthermore, the financing mechanism of credit assignment (*cessione del credito*) or invoice discount (*sconto in fattura*) requires additional layers of validation by financial institutions, tax authorities, and the Revenue Agency, in order to mitigate the risks of fraud and irregular claims [57].

In this sense, the “*Superbonus 110%*” is not merely a fiscal tool, but a highly structured governance framework that combines architectural, engineering, and financial oversight, aiming to promote deep renovation projects with measurable impacts on national decarbonisation goals [49,56].

In conclusion, the eligibility framework of the *Superbonus 110%* reveals both its ambition and its structural complexity.

By restricting access to buildings constructed before the late 1970s, the policy explicitly targets the segments of the Italian housing stock most responsible for energy waste and seismic vulnerability [58,59]. The requirement of a two-class upgrade in energy performance, coupled with the need for certified seismic compliance in risk-prone zones, further ensures that the measure stimulates only “deep” interventions with tangible environmental and safety outcomes [60].

At the same time, the intricate approval procedures—based on technical certifications, sworn statements, and fiscal audits—act as safeguards against speculative behaviour and fraudulent practices, albeit at the cost of bureaucratic burden and uneven accessibility [61,62].

Thus, the “*Superbonus 110%*” stands as a paradigmatic case of a national policy where ambitious decarbonisation and resilience targets are pursued through a highly selective and tightly regulated incentive scheme [63–65].

3. Ecological Renovation Intervention Under the Superbonus 110%: A Real Case from Southern Italy

The proposed real case study concerns a typical single-family mountain chalet for residential use; it is affected by an ecological renovation through demolition and reconstruction (referred to in Article 10, paragraph 1, letter c, of Presidential Decree 380/2001 and subsequent amendments). It is located in the municipality of San Roberto, Calabria region, Italy, found in Climatic Zone C (with 1190-day degrees), in an area protected by law pursuant to Article No. 142 of Legislative Decree No. 42 of 22 January 2004 within the *Aspromonte* National Park.

Originally built between 60s and 70s, the building exhibited severe structural fragilities, low thermal performance, and inadequate compliance with safety codes. The project, carried out between 2022 and 2023, involved the complete demolition of the existing structure and its reconstruction as a near-Zero-Energy Building (nZEB), combining seismic resilience, high thermal insulation, and renewable energy integration (photovoltaic modules with storage systems).

Following the entry into force of Law No. 34 of 27 April 2022, which converted Law Decree No. 17 of 1 March 2022 (commonly referred to as the “Energy Decree”), demolition and reconstruction interventions may now be qualified as “building renovation” (pursuant to Article 3, paragraph 1, letter d) of Presidential Decree No. 380/2001 (*Presidenza della Repubblica*, 2001). This regulatory innovation is particularly relevant in constrained or protected areas, where such interventions, even when involving variations in shape, height, footprint, volumetric articulation, or typological characteristics, are no longer categorized as new constructions (Legge n. 34/2022).

This reclassification carries significant implications in terms of fiscal treatment: it grants access to national incentive schemes, notably the *Superbonus 110%* introduced by Law Decree No. 34/2020 (the “Relaunch Decree”) (*Governo Italiano*, 2020), without altering

the procedural requirements for obtaining urban planning or landscape authorizations. In essence, while the intervention benefits from a more favorable classification for incentive eligibility, it remains subject to the standard authorization regime applicable to interventions in legally protected zones (e.g., pursuant to Legislative Decree No. 42/2004, known as the Code of Cultural and Landscape Heritage; *Ministero per i Beni e le Attività Culturali e per il Turismo*, 2004). This regulatory evolution reflects a broader national strategy aimed at promoting the environmental, structural, and energetic requalification of the built environment, particularly in fragile or high-value territorial contexts.

The intervention was fully framed within the requirements of the *Superbonus 110%*, as it included at least one “driving” measure—thermal envelope insulation exceeding 25% of the dispersing surface and replacement of obsolete heating systems—along with several “driven” measures such as photovoltaic installation and advanced window replacement. The design process had to comply with multiple layers of regulation, including heritage protection constraints given the building’s location in a legally protected landscape (D.Lgs. 42/2004, art. 142).

Within the procedural framework of the *Superbonus 110%*, building renovation through demolition and reconstruction offers a set of distinct advantages compared to conventional retrofitting. First, it removes the need for preliminary investigations aimed at collecting property-related information that is often fragmented or difficult to retrieve.

Second, it eliminates minor building irregularities which, in the case of renovation without demolition, must otherwise be regularized to gain access to fiscal incentives—thus avoiding additional procedures and time delays.

Third, it allows compliance with the strict technical parameters required by the *Relaunch Decree* and its implementing measures without the necessity of prior feasibility studies or complex preliminary analyses.

Fourth, it makes it possible to achieve the highest levels of seismic safety—resistance, ductility, and resilience—that are not attainable through partial reinforcement interventions [32,65].

Finally, it enables the attainment of superior standards of energy efficiency, including advanced insulation, thermal bridge elimination, thermal inertia, and thermo-hygrometric comfort, which cannot be fully achieved through stand-alone insulation, window replacement, or system upgrades [59,60].

Beyond its technical outcomes, the case illustrates both the opportunities and the challenges embedded in the *Superbonus 110%* framework. On the one hand, it demonstrates how the scheme can enable the regeneration of marginal rural housing stock, yielding integrated benefits in terms of seismic safety, energy savings, and architectural quality [60]. On the other hand, it highlights the procedural complexity associated with multi-level approvals, from energy performance certification to seismic compliance assessments, and the delays often caused by fiscal verification and credit-transfer bottlenecks [62].

Thus, this case study offers a valuable lens through which to evaluate the extent to which *Superbonus 110%* can serve as a driver of sustainable transformation in Italy’s building sector, especially when demolition and reconstruction are required to align with the European decarbonisation trajectory towards 2050.

3.1. State of the Art

The examined building was constructed prior to 1967 and has preserved its original layout, without substantial structural alterations or modifications in use over time. In the cadastral register, it is documented on sheet 10, parcel 60, classified as A/3, class 2.

The property consists of four rooms, with a net internal floor area of 84 m², excluding uncovered external surfaces. In Figure 1 below, the extract from the cadastral map sheet, indicating the location of the parcel, is provided.

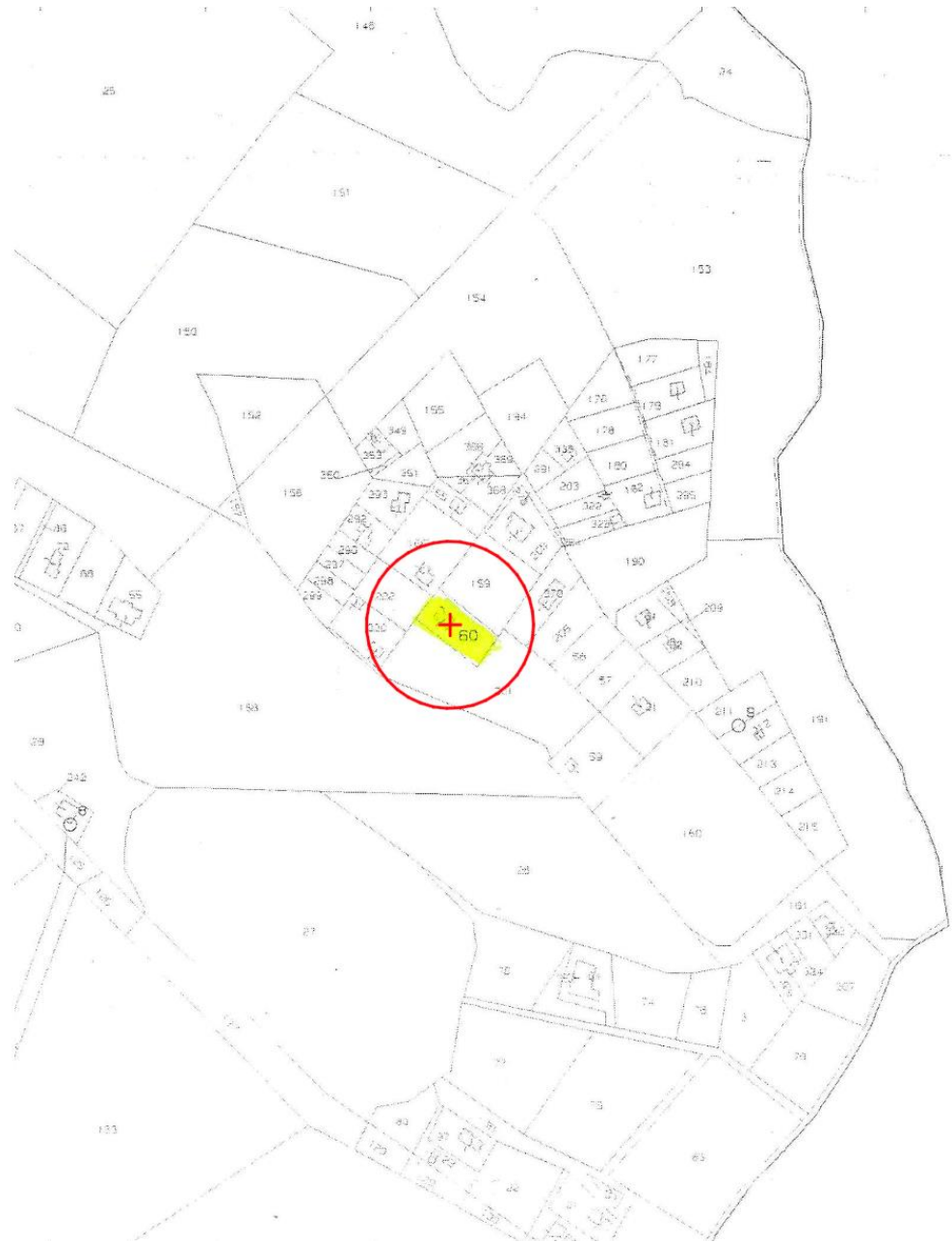


Figure 1. Extract of cadastral map sheet with the red highlighting of the parcel. Source: Authors.

As far as the location is concerned, the extract from the Regional Technical Map (CTR) and the aerial photograph (Figure 1) are shown (Figures 2 and 3).

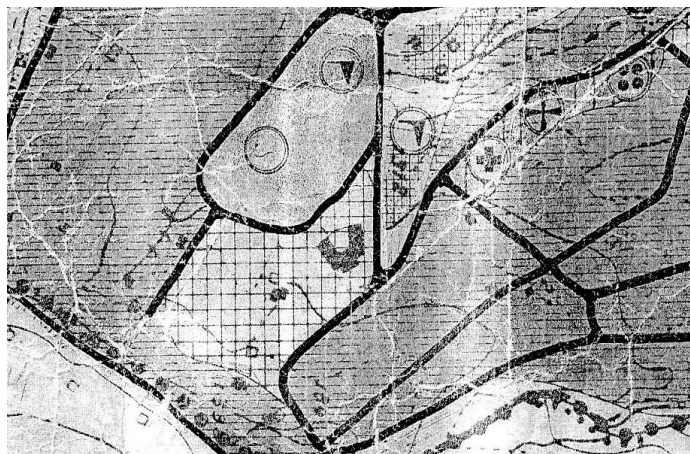


Figure 4. Excerpt from the Pdf of the Municipality of San Roberto with the identification of the affected area. Source: Authors.

The site is located in seismic zone and falls within climate zone C, according to ENEA's Climate Severity Index (Report RdS/2012/107). Knowledge of the seismic classification is essential for eligibility under the *Sismabonus*, which applies only to zones 1, 2, and 3, excluding zone 4 (Art. 119, paragraph 4, Relaunch Decree). Likewise, the climatic zone determines the admissible threshold values for thermal transmittance in building envelopes.

According to the urban destination certificate, the property is subject to Landscape–Environmental, Hydrogeological–Forestry, and Park Authority Constraints, which required additional authorizations prior to obtaining urban planning approval.

The original building (Figures 5–7) was a prefabricated wooden mountain chalet, single-storey, with two entrances: one on the main façade and one on the porch along the side elevation.

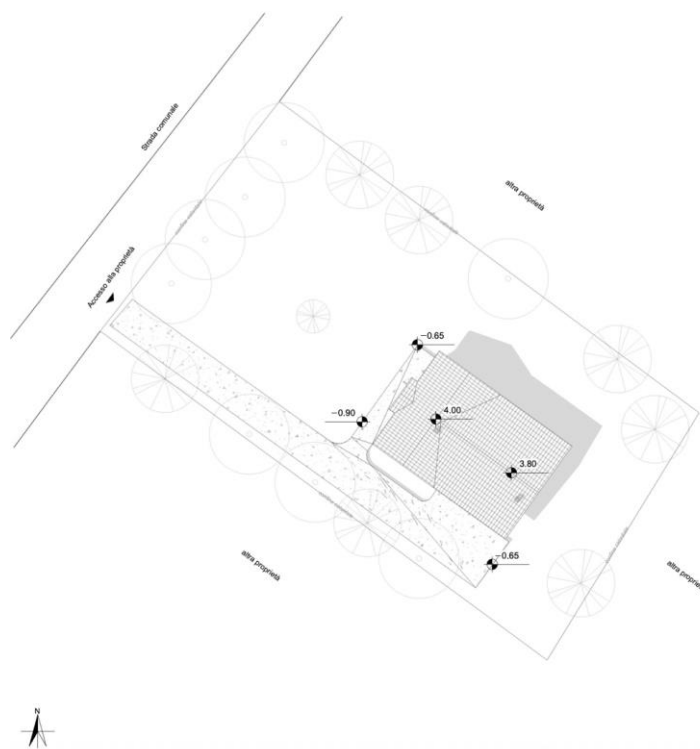


Figure 5. Keyplan *ante operam*. External survey drawing, created in AutoCAD® 3D. [educational version 24.3 (2024)]. Source: Authors.



Figure 6. North elevation. Source: Authors.



Figure 7. North-west elevation. Source: Authors.

The floor plan was rectangular, with gross external dimensions of 7.5 m × 11.2 m (approx. 84 m² of covered area). The structural system consisted of external walls and a spine wall, each 12 cm thick, with an eaves height of 2.60 m. Internal partitions were approximately 6 cm thick.

The building was raised above ground level by means of a stone and concrete base acting as foundation, slightly recessed from the superstructure footprint. Within this base, six reinforced concrete pillars (0.40 × 0.40 m) were integrated to support the wooden floor slab.

The roof consisted of two pitched sections supported by simple timber trusses, with secondary wooden members, originally covered with Marseille tiles and later replaced with Canadian shingles. The ridge height was approx. 4.00 m on the southern side and 3.80 m on the northern side. Roof eaves projected 0.60 m beyond the perimeter walls, yielding a covered footprint of about 110 m² (12.4 m × 8.7 m).

The fenestration system consisted of pine wood frames with double glazing; external panes in the living area and bathroom were leaded with colored glass. Shutters and entrance doors were also made of solid pine wood.

The building was equipped with an electric boiler for domestic hot water, located in the bathroom. Winter heating was provided by a fireplace and a traditional wood-burning stove.

According to the *ante operam* Energy Performance Certificate (EPC/APE), the overall energy performance was rated Class G; the total energy consumption (Heating + Domestic

Hot Water, DHW) was around 350 kWh/m² year; additionally, the consequent generated CO₂ emissions were near zero, around 57 kg CO₂/m² year.

3.2. The Bio Ecological Intervention

The property is a single-family residential building, reconstructed according to green building principles, entirely in wood, with a highly eco-sustainable frame construction system. Construction works started in September 2022 and were completed within approximately 10 months.

The new structure is a near-Zero-Energy Building (nZEB), classified as energy class A and seismic risk class A, thus achieving the highest standards of energy efficiency and seismic safety after intervention. The design and construction aimed to minimize energy demand while balancing consumed and generated energy at near-zero levels.

Since January 2021, Italian regulations require all new constructions to comply with nZEB standards, reflecting their central role in the global sustainability agenda. In this case, the project qualifies as a major level I renovation, as it involved interventions on more than 50% of the gross dispersing surface of the building envelope, together with the installation of a new heating system for winter conditioning.

From a landscape perspective, the reconstruction preserved the visual continuity of the site, while providing a marked architectural improvement compared to the pre-intervention condition. This enhancement is attributable to design choices in typology, technology, and material selection, which improved both the landscape integration and the overall environmental quality of an area previously degraded by neglect.

Furthermore, the building complies with natural and geomorphological constraints. Its construction did not alter soil configuration, vegetation cover, landscape identity, or panoramic views, thereby maintaining perceptual continuity and harmony with the surrounding environment (Figures 8 and 9).



Figure 8. North elevation.



Figure 9. North-west elevation.

3.2.1. Geometric Characteristics

For the reconstruction, the decision was made to preserve the original site footprint, planivolumetric configuration, and typological features. This approach also enabled the use of simplified procedures for obtaining the required authorizations, thereby reducing the time needed to commence construction.

The building has a rectangular plan, with a gross floor area of 94 m² (including entrance and balcony) and a net usable area of 87 m².

The measurements (or geometric characteristics) of the examined building are shown below (Table 2).

Table 2. Geometric characteristics of the reconstructed building.

Total Built Area	Heated Area	Total Average Height	Total Thickness Slabs	Net Average Height	Total Built Volume	Heated Volume
m ²	m ²	m	m	m	m ³	m ³
94.00	87.11	4.00	1.30	2.70	376.00	235.20

In terms of functional layout, as in the pre-existing structure, the design provides a single open space for the living and kitchen area with the roof structure left exposed (Figure 10). The sleeping area is separated by a false ceiling, dimensioned in accordance with energy performance calculations, and includes a sanitary facility.

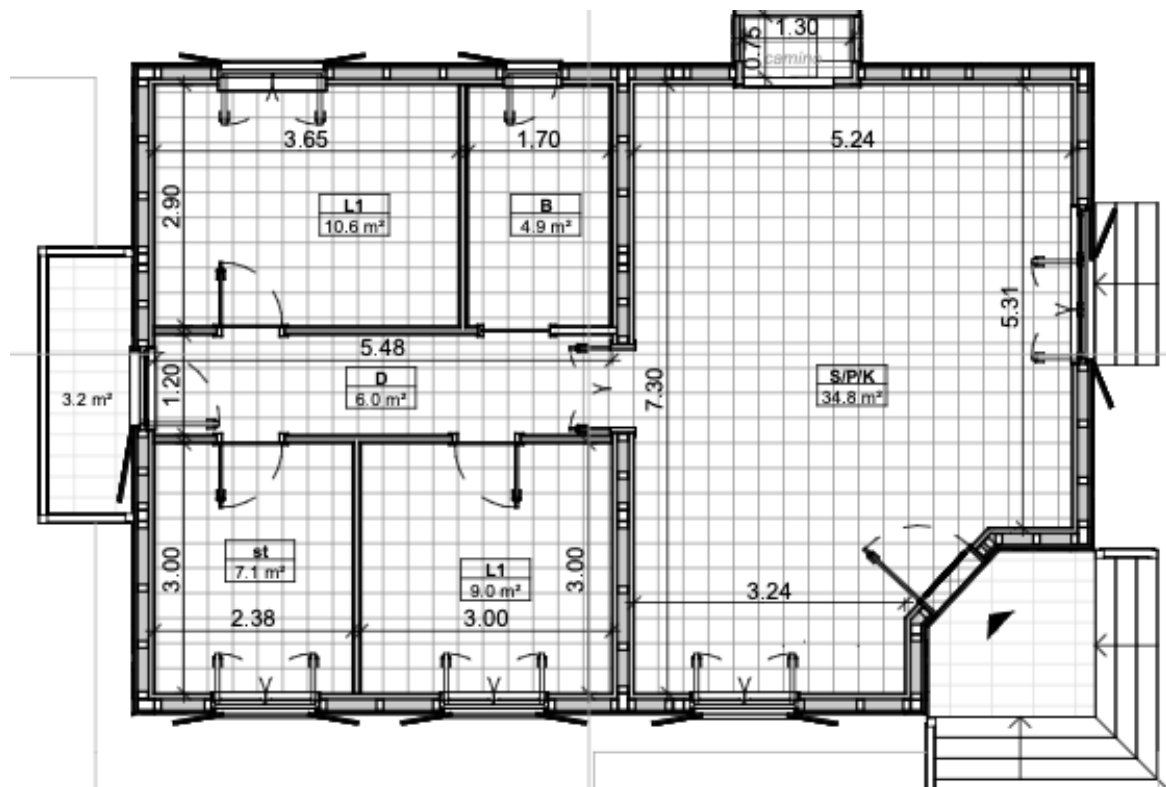


Figure 10. Floor plan *post operam*. External survey drawing, created in AutoCAD® 3D. [educational version 24.3 (2024)]. Source: Authors.

The reconstruction was carried out in full compliance with local urban planning regulations.

As in the previous structure, the building was isolated from the ground by elevating the walking surface. The foundation system was constructed in reinforced concrete and

comprised a base slab, perimeter and transverse walls, a ventilated crawl space with igloo elements, and a floor plate (Figure 11). The base, clad in local stone, presents a variable height that follows the natural slope of the terrain.

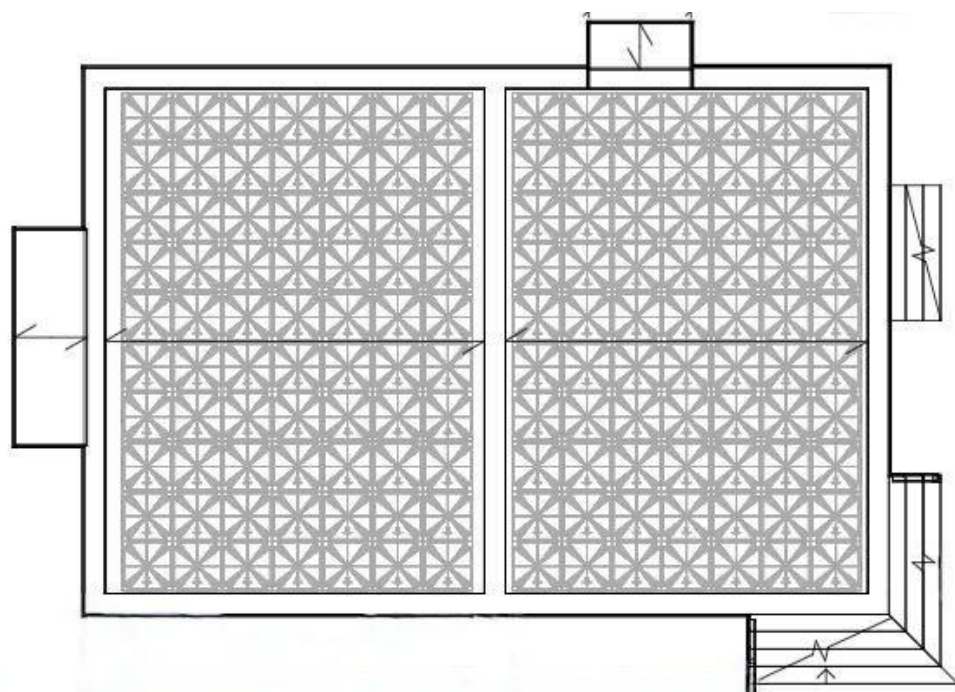


Figure 11. Foundation floor *post operam*. External survey drawing, created in AutoCAD® 3D. [educational version 24.3 (2024)]. Source: Authors.

3.2.2. Thermal Characteristics

The research method is based on use of five scientific methods to detect and to quantify the energy additional efficiency increase in building thanks to ecological reconstruction and on the valuation of related economic impact.

The prefabricated elevation system adopts a timber platform-frame construction, which ensures seismic safety through a favorable weight-to-strength ratio. This configuration allowed the building to reach the highest seismic classification. Structural walls are anchored to the floor plate with steel connectors, providing controlled flexibility. The technology is consistent with Regional Law No. 21 of 11 August 2010 (Extraordinary measures to support building activity aimed at improving the quality of the residential building stock) and subsequent amendments, which encourage the use of timber as a construction material.

Beyond thermal performance, prefabricated timber structures provide additional benefits, including acoustic insulation, fire resistance, and reduced on-site construction times compared to traditional masonry.

As far as the system, for winter heating and DHW (Domestic Hot Water) production, the building employs an underfloor radiant system powered by a high-efficiency biomass boiler (environmental class 5, energy class A+). During the summer period, this system is integrated with a heat pump water heater. The biomass fireplace boiler complies with the requirements set out in Annex G of the Ministerial Decree of 6 August 2020 (*Ecobonus*, letter c). As part of the towed interventions, the property is equipped with a photovoltaic system with a nominal power of 5 kW connected to the electricity grid and a heat pump water heater. The energy not consumed on site is sold to the Energy Services Manager (ESM).

As far as the envelop components are concerned, a ventilated roof system was constructed. This design offers multiple advantages in terms of thermal performance. In winter, up to 70% of indoor heat losses can occur through the roof if not properly insulated. In summer, approximately 65% of indoor heat gains originate from roof overheating, compared with 29% through windows and 6% through external walls.

The load-bearing structure consists of a timber Platform-Frame system clad with cork-based thermal coibentation. The pitched roof is also constructed in timber, while internal partitions adopt the same timber-frame typology. All interior spaces are equipped with windows properly dimensioned to ensure compliance with natural lighting and ventilation requirements.

In accordance with the Regulations on Energy Consumption Reduction and Renewable Energy Sources, the project adopted construction techniques designed to guarantee high energy and environmental performance.

For the building envelope, natural cork panels (6 cm thickness), with low thermal conductivity (λ : 0.043 W/mK), were employed to provide high-performance thermal insulation. The pitched roof, also in timber, was completed with an additional cork coibentation layer (10 cm thickness) and finished with clay tiles. Additionally, an insulating layer of cork panels (6 cm thickness) has been created within the basement floor stratigraphy

According with the requirements of the Aspromonte National Park Authority, and in compliance with the requirements of current legislation regarding the transmittance and shielding factor of the window, wood-effect PVC fixtures, solid wood shutters and an insulated door with 4 cm thick cork panels were installed. The window frames have been made of PVC and double-glazed low emissivity (U_g : 0.67 W/m²K).

The details, the technical parameters and the stratigraphy of the envelop components are shown in the table below (Table 3).

Table 3. Thermal characteristics of the envelop components.

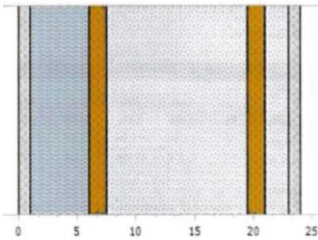
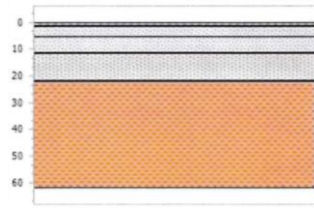
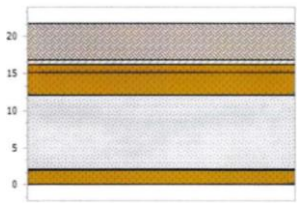
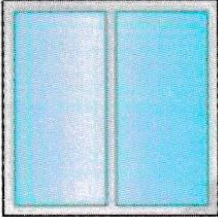
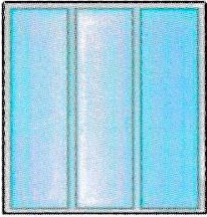


External Walls	Floor	Ventilated Roof
U [W/m ² K]: 0.21	U [W/m ² K]: 0.28	U [W/m ² K]: 0.26
Thickness [m]: 0.28	Thickness [m]: 0.62	Thickness [m]: 0.22
		
Stratigraphy	Stratigraphy	Stratigraphy
(1) External plaster of Natural Hydraulic lime (NHL), 8 mm; (2) Cork panels, 60 mm; (3) Pressed wood chip panels 15 mm; (4) Rock wool panels 120 mm; (5) Pressed wood chip panels 15 mm; (6) Unventilated air 50 mm; (7) Internal plaster, 8 mm.	(1) Floor, 12 mm; (2) Steel sheet 2 mm; (3) Radial Alu G panel 38 mm; (4) Cork panels, 60 mm; (5) Vapour barrier 4 mm; (6) Concrete slab, 100 mm; (7) Waterproofing in PVC 3 mm; (8) Reinforced concrete slab 400 mm.	(1) Fir wood, 20 mm; (2) Vapour barrier in PVC 1 mm; (3) Cork panels 100 mm; (4) Fir wood, 30 mm; (5) Pressed wood chip panels 12 mm; (6) Waterproofing, 5 mm; (7) Canadian roof tile 50 mm.

Table 3. Cont.

Windows (120 × 120)	Windows (220 × 180)	Windows (220 × 90)	Windows (120 × 60)
U_W [W/m ² K]: 1.50	U_W [W/m ² K]: 1.50	U_W [W/m ² K]: 1.50	U_W [W/m ² K]: 1.50
Thickness [m]: 120 × 120	Thickness [m]: 220 × 180	Thickness [m]: 220 × 90	Thickness [m]: 120 × 60
			
Stratigraphy	Stratigraphy	Stratigraphy	Stratigraphy
(1) PVC frame; (2) Double-glazed window with an air gap in between layers	(1) PVC frame; (2) Double-glazed window with an air gap in between layers	(1) PVC frame; (2) Double-glazed window with an air gap in between layers	(1) PVC frame; (2) Double-glazed window with an air gap in between layers

Source: Authors.

The technical solutions that make up the envelope and delimit the heated volumes have been designed in compliance with the thermal insulation requirements, i.e., the maximum transmittance values allowed for access to the deductions reported in Annex E of the Decree of 6 August 2020 of the Ministry of Economic Development's so-called "Ecobonus" for climate zone C (Table 4).

Table 4. Maximum transmittance values provided by Annex E for access to the deduction (climate zone C).

Type of Intervention	Technical Threshold Requirements
Horizontal opaque structures: roof insulation (calculation according to UNI EN ISO 6946 standards)	≤ 0.27 W/m ² K
Horizontal opaque structures: floor insulation (calculation according to UNI EN ISO 6946 standards)	≤ 0.30 W/m ² K
Vertical opaque structures: insulation of perimeter walls (calculation according to UNI EN ISO 6946 standards)	≤ 0.30 W/m ² K
Replacement of windows including frames: (calculation according to UNI EN ISO 10077-1 standards)	≤ 1.75 W/m ² K

Source: Authors.

All the interventions on both the opaque and transparent envelope comply with the thermal transmittance (U-value) thresholds established by the Ministerial Decree of 6 August 2020 (*Requisiti Ecobonus*), as shown in the comparative table below (Table 5).

According to the decree, the maximum allowable U-values are 0.30 W/m²K for external walls, 0.27 W/m²K for roofs, 0.30 W/m²K for floors, and 1.75 W/m²K for windows with frames.

The adopted design solutions achieved U-values of approximately 0.21 W/m²K for the external walls, 0.22 W/m²K for the roof, 0.28 W/m² K for the floor and 1.50 W/m²K for the windows, thus remaining well below the regulatory thresholds.

Table 5. Comparison of U-values: 2020 Decree limits *vs.* achieved values.

	Building Element	U-Value Limit 2020 [W/m ² K]	U-Value Achieved [W/m ² K]
1	External walls	≤0.30	0.21
2	Roof	≤0.27	0.22
3	Floor	≤0.30	0.28
4	Windows	≤1.75	1.50

Source: Authors.

These performances ensure full eligibility for the incentive schemes and confirm the building's compliance with national energy efficiency standards.

As far as the system is concerned, the configuration couples a pellet-fired biomass boiler (environmental class 5, energy class A+) with a heat pump water heater, both connected to a bivalent buffer tank that decouples generation from distribution. DHW is produced by a heat-pump water heater (COP, Coefficient of Performance, 2.60), which operates as the primary source, with the biomass unit providing backup in winter (Table 6). During summer, the heat pump alone covers DHW demand.

Table 6. Thermal generators. Technical specifications.

	Parameter	Biomass Fireplace Boiler (Thermofireplace)	Heat Pump Water Heater (HPWH—Haier)
1	Application	Space heating + DHW	DHW only
2	Fuel/Energy source	Solid biomass (pellet/wood)	Electricity
3	Heat useful thermal output	Water	Water
4	Storage volume	-	200–300 L
5	Nominal useful thermal output	23.4 kW	0.6 kW
6	Electrical input	-	0.2 kW
7	Useful efficiency at 100% load	91.8% (EN 303-5)	-
8	COP	-	2.60 (A15/W55, EN 16147)
9	System role	Primary generator for space heating and DHW	Dedicated DHW production; complementary to biomass unit

Source: Authors.

The buffer supplies a low-temperature radiant floor system, designed to maximize efficiency and comfort. The electricity demand of auxiliary components and the heat pump is partly covered by a 5 kW grid-connected photovoltaic system (Table 7). It consists of moderately ventilated monocrystalline modules with a total capture area of about 12 m². The panels are oriented south, with standard horizontal tilt and an environmental reflectance coefficient of 0.2.

Table 7. PV system technical specifications.

	Parameter	Value
1	Module type	Monocrystalline silicon
2	Ventilation	Moderately ventilated
3	Collector surface	12.00 m ²
4	Nominal peak power (8Wp)	4.8 kW
5	Orientation (Azimuth)	South
6	Tilt (inclination)	Horizontal ($p = 0^\circ$)
7	Environmental reflection (albedo)	0.20
8	Shading	None
9	Annual irradiance on modules	1765.7 kWh/m ²
10	Annual PV output ($E_{el,pv,out}$)	6356.67 kWh
11	Monthly PV output ($E_{el,pv,out}$)	240–754 kWh

Source: Authors.

The system controller schedules DHW production to coincide with PV (photovoltaic) availability, thereby enhancing self-consumption. Surplus electricity is exported to the grid and remunerated through the *Gestore dei Servizi Energetici* (GSE).

The photovoltaic simulation aimed to evaluate the monthly and annual energy production potential based on the solar irradiation incident on the plane of the modules (Table 8) and the resulting electrical output (Table 9). The annual analysis was performed under standard meteorological conditions derived from the PVGIS (Photovoltaic Geographical Information System) dataset, ensuring the representativeness of the results. The solar irradiation data used in this study were obtained from the Photovoltaic Geographical Information System (PVGIS), developed by the Joint Research Centre of the European Commission. PVGIS provides geographically resolved solar radiation datasets and performance estimations for photovoltaic systems under standard meteorological conditions, ensuring reliable input data for energy simulation analyses.

Table 8. Energy irradiated on the module plane (kWh/m²).

	Month	E (kWh/m ²)
1	January	80.43
2	February	103.98
3	March	146.16
4	April	166.73
5	May	203.29
6	June	200.96
7	July	208.67
8	August	209.49
9	September	151.38
10	October	131.71
11	November	96.06
12	December	66.89

Source: Authors.

Table 9. Energia elettrica prodotta ($E_{el,pv,out}$) [kWh].

	Month	$E_{el,pv}$ (kWh)
1	January	289.54
2	February	374.32
3	March	526.16
4	April	600.21
5	May	731.86
6	June	723.45
7	July	751.23
8	August	754.17
9	September	544.97
10	October	474.16
11	November	345.82
12	December	240.80

Source: Authors.

The total annual irradiation on the plane of the modules reached 1765.7 kWh/m², indicating a favorable solar potential for photovoltaic production. The monthly distribution shows expected seasonal variations, with peak values observed between May and August, when solar elevation and daylight duration are highest.

The monthly global irradiation values range from 80.43 kWh/m² in January to 209.49 kWh/m² in August, reflecting a typical pattern for Mediterranean climatic conditions. These data demonstrate consistent solar availability, which supports stable PV system performance throughout the year.

The corresponding electrical energy production ($E_{el,pv,out}$) shows similar trends, with lower values in winter months (e.g., 289.5 kWh in January, 240.8 kWh in December) and maximum production during the summer (754.2 kWh in August). The total annual energy generation amounts to approximately 6456 kWh/year, corresponding to a specific yield of around 1345 kWh/kWp, which aligns well with the expected performance of monocrystalline PV systems under similar climatic conditions.

The performance ratio, derived from the ratio between actual and theoretical energy yield, confirms efficient system operation, supported by adequate ventilation and minimal shading. The moderate ventilation conditions contribute to maintaining acceptable module temperatures, thus reducing thermal losses and improving conversion efficiency during peak irradiation months.

Overall, the photovoltaic simulation indicates that the system can cover a significant portion of the building's electrical demand, contributing both to operational energy reduction and to the broader decarbonization objectives of the building sector.

This configuration reduces primary energy demand for space heating and domestic hot water, leading to lower CO₂ emissions compared to conventional systems. It maximizes the use of photovoltaic production for summer electric loads, maintains low distribution temperatures throughout the year, and ensures compliance with both air-quality and efficiency standards for biomass appliances.

The paragraph below concerns the ecological valuation of the bio ecological development, thus the outcomes of the energy consumption and of the consequent CO₂ emissions generated by the system.

4. Bio Ecological Intervention. Outcomes of the Integrated Valuation

Considering the criteria of the *Superbonus 110%* necessary to take advantage of government tax breaks, the reconstruction of the building has made it possible to obtain the highest level of:

1. seismic safety through the use of seismic-resistant wooden structures;
2. energy efficiency by creating a balance between energy consumed and produced close to zero with a consequent increase in the market value of the property.

To assess both the environmental benefits and the financial viability of the Bio Ecological Intervention, this section presents the results of an integrated analysis applied to the real-world case study described above. The discussion is structured into two parts; the first addresses the ecological dimension, with focus on energy demand and the related CO₂ emissions generated. The second examines the economic dimension, where the evaluation is carried out in relation to the fiscal incentives of the *Ecobonus* and *Superbonus 110%* scheme, underlining how the policy framework supports the intervention's affordability.

4.1. Ecological Valuation

Estimate climate behavior and energy performances of the Bio Ecological Intervention has been carried out through five different energy assessment BEPSPs:

- Energy Plus (Version 8.9) together with Design Builder (Version 6.1.0.006), trial;
- Termolog (Version 13); academy;
- Termus Bim (Version 51.00u); educational;
- Blumatica Bim ArchIt (Version 1.5.0.22); trial;
- DOCET v.3.19.10.51; free.

The geometry was defined according to the actual dimensions and orientations, while the thermo-physical properties of the envelope were assigned following the UNI/TS 11300-1 standard. HVAC systems were modeled according to real configurations and operating schedules. The simulation was carried out on an hourly basis for a typical meteorological year, with boundary conditions reflecting standard residential comfort parameters (20 °C heating, 26 °C cooling). The model was validated through comparison with measured data, achieving deviations within ±5%, thus ensuring the reliability of the results.

Energy simulation software provides the following global (gl) energy (E) performance (P) index (EP_{gl}) for the two different scenarios and the relative difference in absolute value and in percentage; therefore, the behavior performances and saving are expressed in terms of kWh/m² year for the energy consumptions and CO₂ kg/m² year for the CO₂ emissions. As the technical standard UNI TS 11300 indicates [66–70], the performance indicators proposed are:

$$EP_{gl} = EP_H + EP_C + EP_W + EP_V + EP_L + EP_T$$

- EP_H the energy performance index for winter heating (kWh/m² year);
- EP_C the energy performance index for summer cooling (kWh/m² year);
- EP_W the primary energy for domestic hot water (kWh/m² year);
- EP_V the energy performance index for ventilation (kWh/m² year);
- EP_L the energy performance index for artificial lighting (kWh/m² year);
- EP_T the energy performance index for people's transportation (kWh/m² year).

So, the EP_{gl} is determined as the sum of each individual energy performance index provided in the reference building, and it is expressed in kWh/m² year.

The results from the climatic and energy assessment, simulated in the municipality of San Roberto, Calabria region, Italy, Climatic Zone C (with 1.190-degree days) are in the following table (Table 10):

Table 10. Summary table about energy consumption, in kWh/m² y, and CO₂ emissions, in kgCO₂/m² y.

Scenario	EP _{gl} kWh/m ² year	CO ₂ Assessment per Year kg CO ₂ /m ² year
Bio Ecological Intervention	37.30	0.30

Source: Authors.

The Bio Ecological Intervention (based on natural materials) reached the goal of a strong enhancement of thermal building performance, and of significant energy saving because of key interventions listed above. The total energy consumption (Heating + Domestic Hot Water, DHW) is around 37.30 kWh/m² year; additionally, the consequent generated CO₂ emissions is near zero, around 0.30 kg CO₂/m² year.

The operational energy performance of the analyzed building was assessed according to the UNI/TS 11300 standard, by comparing the calculated primary energy indices of the real building with those of the reference building; according to Italian regulation (D.M. 26 June 2015), the reference building is a virtual model having the same geometry, location, orientation, and use of the actual building, but equipped with standard thermal and system characteristics defined by national benchmarks. It serves as a baseline for evaluating the energy performance of the real building and verifying compliance with the minimum efficiency requirements. The comparison between the two models enables the assessment of the energy improvement achieved through retrofit measures and supports the classification of the building's overall performance level.

The evaluation includes the energy requirements for heating, cooling, and domestic hot water production, expressed in terms of annual primary energy demand per square meter (kWh/m²·year).

Table 11 summarizes the main parameters and results obtained from the dynamic simulation and standard energy balance calculations.

- H'_T the mean overall heat transfer coefficient by transmission per unit of envelope area (W/m²K);
- $A_{sol,est}/A_{sup,utile}$ the equivalent summer solar area per unit of useful floor area;
- η_H the average seasonal efficiency of the winter heating system;
- η_W the average seasonal efficiency of the domestic hot water system;
- FER_w the percentage of renewable energy coverage for domestic hot water production;
- FER_{gl} the percentage of renewable energy coverage for total energy needs (heating, cooling, and domestic hot water).

The operational energy consumption was assessed through the calculation of primary energy indices for heating (EP_H), cooling (EP_c), and domestic hot water production (EP_w), in accordance with UNI/TS 11300 standards.

The results clearly indicate that the real building exhibits a substantial improvement in operational energy performance compared with the reference model. They show that the real building achieves a total primary energy demand (EP_{et,tot}) of 37.27 kWh/m²·year, significantly lower than the reference building (75.44 kWh/m²·year).

This improvement reflects both the enhanced thermal performance of the envelope ($U = 0.317$ W/m²K) and the high contribution from renewable sources ($FER_{st} \approx 81\%$), leading to a substantial reduction in operational energy needs.

Subsequently, the economic valuation of the Bio Ecological Intervention is shown in the next section.

Table 11. Summary table about operational energy performance.

	Index	U.M.	Real Case Study	Reference Building
1	H'_T	W/m ² K	0.317	0.550
2	$A_{sol,est}/A_{sup,utile}$	-	0.017	0.030
3	$EP_{H,nd}$	kWh/m ²	15.87	25.58
4	$EP_{C,nd}$	kWh/m ²	28.63	29.02
5	$EP_{W,nd}$	kWh/m ²	15.48	15.48
6	η_H	-	0.894	0.583
7	η_W	-	0.793	0.490
8	$EP_{H,nren}$	kWh/m ²	3.45	8.77
9	$EP_{H,ren}$	kWh/m ²	14.30	35.08
10	$EP_{H,tot}$	kWh/m ²	17.75	43.85
11	$EP_{H,nren}$	kWh/m ²	3.64	6.32
12	$EP_{H,ren}$	kWh/m ²	15.88	25.27
13	$EP_{H,tot}$	kWh/m ²	19.52	31.59
14	$EP_{gl,nren}$	kWh/m ²	7.09	15.09
15	$EP_{gl,ren}$	kWh/m ²	30.18	60.35
16	$EP_{gl,tot}$	kWh/m ²	37.27	75.44
17	FER_w	%	81.35	60.00
18	FER_{gl}	%	80.97	60.00

Source: Authors.

4.2. Economic Valuation: The Metric Appraisal Computation (MAC)

The MCA, Metric Appraisal Computation (bill of quantities and costs), is the document used to quantify the costs of building works—whether new construction, maintenance, restoration, conservative renovation, or full refurbishment. It is a mandatory component of both the technical–economic feasibility project (PFTE) and the executive project in the context of public works, as established by the Procurement Code (Legislative Decree 36/2023) [71]. In practice, the MAC is also widely applied in the private sector, where it serves as a contractual tool regulating the relationship between the client and the contractor.

The MAC is thus a key document in any construction process, and it becomes even more important in procedures related to the *Superbonus 110%*. In these subsidized projects, special care must be taken in defining the costs of each intervention, so that they can be compared against the official cost ceilings defined by law. These ceilings apply to a range of eligible measures, including: structural strengthening and adjustment; thermal insulation of building envelopes; replacement of heating, cooling, and domestic hot water systems; substitution of windows and shading devices; installation of photovoltaic and storage systems; building automation technologies; and charging stations for electric vehicles (Art. 119 of Law 77/2020) [72].

In the present case, the MAC for the green building renovation through demolition and reconstruction was prepared using unit costs taken from the Calabria Region price list (infra-annual Resolution No. 344 of 25 July 2022) and the 2022 DEI Civil Engineering Price List [73]. For items not included in these references, unit costs were determined analytically, in accordance with Annex I of the Ministerial Decree MiSE of 6 August 2020, and aligned with the specific cost ceilings set out in Annex A, as declared by the supplier or installer [74].

The following tables (Tables 12 and 13) have been organized by grouping the main works according to the classification into driving and trailing interventions as provided for by the “Relaunch Decree”, inserting the amounts from MAC without Value-Added Tax (VAT), the amounts including 10% reduced VAT, the total amounts for each area of the classification. The last column was introduced to verify the percentage incidence of each process, without VAT, on the total amount.

Table 12. Amounts from MAC of DRIVING interventions—*SISMABONUS*.

Description	Amount Without VAT €	Amount with VAT €	Incidence %
Demolitions	2671	2938	2.67
Excavation, aggregates, backfilling	4164	4580	4.16
Background works	5344	5878	5.34
Foundation Plate	17,190	18,909	17.18
Foundation Septa	28,107	28,388	28.09
Structural stairs	1788	1967	1.79
Plasterboard partitions	2695	2964	2.69
False ceiling	2031	2234	2.03
Roof	11,498	12,648	11.49
Interior finishes	2418	2660	2.42
External finishes	1237	1361	1.24
Stairs	3152	3467	3.15
External plinth base	1145	1260	1.14
Tinsmith’s works	582	640	0.58
Electrical-data system	7861	8647	7.86
Water and sanitation system	3181	3499	3.18
Construction site safety	5002	5502	5.00
Total SISMA interventions	100,066	107,542	100.00

Source: Authors.

The MAC represents an indispensable benchmark in subsidized construction practices. Its functions include:

- estimating the overall cost of the intervention and the associated fiscal deduction;
- checking compliance with the cost ceilings legally defined for each process;
- verifying the maximum eligible expenditure for each subsidized intervention;
- defining the costs of professional services proportionally to the specific works undertaken;
- certifying the adequacy of expenditures through Work Progress Reports (*Stati di Avanzamento Lavori, SAL*) of at least 30% of the eligible amount;
- validating the expenses incurred for the execution of the subsidized measures.

For this reason, the MAC should be structured in alignment with the categories of *Sismabonus* and *Ecobonus*, distinguishing between “driving” and “trailing” interventions. This approach allows for a clear and efficient interpretation of the cost framework and ensures full compliance with the regulatory requirements.

Table 13. Amounts from MAC of DRIVING and TRAILING interventions—*ECOBONUS*.

Description	Amount Without VAT €	Amount with VAT €	Incidence %
DRIVING			
Infill walls package	28,401	35,727	39.41
Radiant floor package	18,487	20,309	25.66
5-star biomass fuel heat generators	7616	8278	10.57
Sloped Cover Package	16,426	18,070	22.80
Electric water heater in heat pump	1129	1242	1.57
Total ECO Driving interventions	72,059	83,626	100.00
TRAILING			
Replacement windows + shutters	16,434	18,077	57.40
External chimney (in masonry and internal prefabricated elements in stainless steel)	4045	4450	14.13
Supply and installation of photovoltaic system	8153	8968	28.48
Total ECO Trailing interventions	28,632	31,495	100.00
Total ECO interventions (driving and trailing)	104,635	115,121	-

Source: Authors.

The data from the MAC highlight distinct patterns in the allocation of costs. *Sismabonus* interventions are mainly concentrated on structural components, with foundation works alone accounting for nearly half of total expenditure. By contrast, *Ecobonus* measures show the predominance of envelope insulation and radiant floor systems, complemented by renewable technologies such as biomass heating and photovoltaics.

Overall, the energy efficiency interventions (€115,121 VAT included) slightly outweigh the seismic strengthening works (€107,542 VAT included), underscoring the combined relevance of both ecological and structural retrofitting within the *Superbonus 110%* framework.

The 110% Deduction in Application of the Superbonus 110%

The calculation of the 110% tax deduction was carried out on the total eligible expenses for the interventions, including not only VAT but also the professional fees of engineers, architects, and accountants, in accordance with the maximum expenditure thresholds established by the Relaunch Decree (Law 77/2020). Professional services were quantified following the Ministerial Decree of 17 June 2016, which defines fee tables based on the quality and scope of design activities.

Table 14 below reports, for each intervention category, the total amounts including VAT in relation to the legally prescribed expenditure ceilings, and indicates in the final column the excess costs borne by the taxpayer whenever the overall expenditure exceeds the portion covered by the fiscal incentive.

Table 14. Summary of the MAC. Comparison of the amounts with the maximum amount of eligible expenses and surplus expenditure.

Intervention	Description	Amount with VAT €	Maximum Allowable Expenditure €	Surplus Expense €
SISMABONUS	Antiseismic	107,542		
	Professional technical services	32,828		
	Professional services accountant	2928	96,000	47,298
SISMA TOTAL		143,298		
ECOBONUS				
DRIVING	Infill walls package	35,727		
	Radiant floor package	20,309		
	5-star biomass fuel heat generators	8278	50,000	
	Sloped Roof Package	18,070		
	Electric water heater in heat pump	1242		
TRAILING	Replacement windows + shutters	18,077		35,349
	External masonry flue and internal prefabricated stainless-steel elements	4450		
	Supply and installation of photovoltaic system	8968	60,394	
	Professional technical services	28,060		
	Professional services accountant	2562		
TOTAL ECO interventions		145,743		
		289,041	206,394	82,647

Source: Authors.

In summary, the green building renovation of the property, despite the critical issues discussed in Section 2, generated a total eligible deduction of €227,024 but required an outlay of €82,647 by the owner, corresponding to 28.6% of the overall cost of €289,041, or approximately €3000/m². This construction cost is significantly above market levels, particularly when considered in relation to the local territorial context. The ex-post analysis of the process indicates that the surplus borne by the client was primarily due to the unit prices listed in official cost catalogues, the unjustified increase in the price of production factors during the construction process, and the professional fees of technicians and accountants (as reported in Table 11). It should also be noted that, in the case of single-family buildings, particularly for demolition and reconstruction projects, the likelihood of fully covering the intervention through fiscal incentives is considerably lower than for multi-family buildings, where the expenditure ceilings are calculated in proportion to the number of housing units.

5. Discussion

The integrated assessment highlights both the environmental and economic effectiveness dimensions of the ecological retrofitting strategy supported by the *Superbonus 110%*. On the environmental side, the bio-based renovation significantly enhanced the

building's thermal performance, lowering the combined demand for heating and DHW to 37.3 kWh/m²·year and reducing CO₂ emissions to 0.3 kg/m²·year, effectively approaching near-zero operational impact. These results are consistent with previous national studies on deep retrofits supported by fiscal incentives [75,76], which emphasize the effectiveness of natural materials, advanced insulation systems, and renewable integration in achieving high energy savings.

International literature confirms this trend: German and Austrian case studies on bio-based retrofits have reported reductions of 70–80% in operational energy [77,78], while French and Spanish applications of combined envelope and renewable upgrades also point to substantial emission cuts and indoor comfort gains [57].

From an economic perspective, however, the results show persistent challenges. Despite the substantial deduction of €227,024, the owner had to sustain an outlay of €82,647, equal to 28.6% of the total investment (€289,041, or ~€3000/m²). The MAC analysis revealed that *Sismabonus* measures were dominated by structural reinforcement—with foundation works alone exceeding 45% of total seismic expenditures—while *Ecobonus* measures were driven by infill wall insulation (39%) and radiant floor systems (26%), complemented by biomass heating and photovoltaics. This confirms findings in the Italian literature [30,79] that seismic and ecological upgrades can be effectively integrated, but also that unit prices, rising production factor costs, and professional fees often generate surplus expenses beyond the incentive coverage. International comparisons further underscore this point: while the German KfW programme and the French MaPrimeRénov' offer substantial cost coverage, recent studies [80,81] stress that even generous subsidies rarely eliminate owner contributions, particularly in single-family demolitions and reconstructions where expenditure ceilings are less favorable than in multi-unit retrofits.

Overall, the study demonstrates that the *Superbonus 110%* functions as a decisive lever for feasibility, enabling ambitious ecological and seismic retrofits that would otherwise remain unaffordable. Yet, it also shows that the economic accessibility of single-family projects remains limited compared to multi-family contexts, where ceilings are scaled to the number of units. The Italian case thus aligns with the broader European debate on how to design fiscal incentives that not only maximise environmental benefits but also ensure long-term affordability and equity across building types.

For Italy, the experience of the *Superbonus 110%* underscores the importance of aligning expenditure ceilings with market conditions, ensuring equitable access across building types, and consolidating incentives within a long-term strategy consistent with the EU Green Deal and the 2050 decarbonization target.

6. Conclusions

The critical economic and social framework generated by the COVID-19 pandemic in 2020 led the Italian Government to adopt extraordinary measures to counter the sharp slowdown in the national economy. Among these, the *Superbonus 110%* played a central role by offering unprecedented tax deductions for interventions on existing real estate, aimed at reducing seismic risk—including through structural monitoring systems—and improving energy efficiency.

This study demonstrates how the Italian *Superbonus 110%* has acted as a powerful lever to accelerate ecological and seismic retrofitting in the residential sector, in alignment with European climate and energy objectives.

The application of the *Superbonus 110%* to the real-world case study presented in this paper confirms both the technical and economic attractiveness of bio-based renovation through demolition and reconstruction. The *Superbonus 110%* enabled the creation of an nZEB building, simultaneously reaching the highest levels of seismic safety and energy

efficiency, which would have been unattainable through ordinary tax-relief interventions on existing structures. The 110% deduction rate, combined with the possibility of invoice discounts or credit transfers, represented a unique policy on the international stage. It proved to be a powerful driver of private investment with significant macroeconomic spillovers [24,36,82].

Looking forward, incentive mechanisms for seismic risk reduction and energy efficiency must evolve to more effectively support the ecological transition and the full decarbonization of the building stock. Future schemes should:

- prescribe the use of only nature-based ecological products;
- require a degree of financial participation by beneficiaries (20%), in order to trigger virtuous cycles among stakeholders;
- be more calibrated to expected total costs and be proportionated to the socio-economic conditions of households;
- be designed as ordinary, predictable, and long-term measures, without unrealistic deadlines in consistent with building processes;
- pursue goals of geographic equity and redistribution, taking into account the significant regional and social disparities across Italy.

In particular, ensuring that incentives attract greater investment to disadvantaged areas will be crucial to prevent further territorial inequalities.

The new framework must move beyond fragmented bonus schemes to promote the ecological transition in line with the European Directive (Energy Performance of Building Directive), support the renovation demand of more than 10 million households with heterogeneous income and tax profiles, and enable the seismic and energy upgrading of the national building stock. In line with the European Green Deal and the recast Energy Performance of Buildings Directive (EPBD), the next generation of incentives should move beyond fragmented bonus schemes, aiming instead at a stable, fair, and fiscally sustainable framework. Such an approach would ensure not only environmental effectiveness, but also social inclusion and long-term economic viability, thereby consolidating Italy's contribution to the EU trajectory towards climate neutrality by 2050.

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