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A Transition Pathways Approach for Energy Renovation in EU Building Market Ecosystems

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Abstract: The European Union aims to achieve climate neutrality by 2050, prioritizing energy efficiency particularly in the building sector. Despite significant policies, such as the EU Green Deal and Renovation Wave initiative, the rate of deep energy renovations remains insufficient, with only 0.2% annually versus the 3% required. Multiple barriers hinder the progress of deep energy renovations (DERs), including fragmentation among stakeholders, the limited coordination of RDI (Research, Development, and Innovation) efforts, and a lack of systemic approaches. The objective of this paper is to illustrate a holistic methodological approach for enhancing the DER market uptake based on transition pathways theory (TPT) and is designed to drive structural evolution in DER markets aimed at overcoming their main current constraints. To this end, five key transition pathways are outlined—namely institutionalization, clusterization, capitalization, digitalization, and exploitation—and are conceived for fostering coordination, integration, promotion, and efficient scaling of innovations along the whole DER value chain. This approach was tested in seven EU building market ecosystems under the H2020 re-MODULEES project, aimed at developing a market activation platform conceived as a digital enabler for next-generation One-Stop Shops (OSSs). This project yielded practical evidence on the potentiality of the TPT frame to strengthen and empower local ecosystems through stakeholders' engagement and cooperation. The findings suggest that the TPT-based approach tested in re-MODULEES can effectively address structural challenges in diverse DER renovation markets, and for this reason, it may be also tested and extended in other ecosystems across Europe in order to be validated as a strategic approach at the EU level for facilitating the transition to low-carbon buildings.

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1. Introduction

An EU priority is to become climate neutral by 2050. To this end, the EU has set strategic initiatives and adopted a framework of policies aimed at reducing greenhouse gas emissions in several sectors, including the building sector. The EU Clean Energy Package [1], EU Green Deal [2], Renovation Wave initiative [3], EU directives (e.g., EPBD etc.) [4,5], and REPowerEU initiatives [6] pursued a significant improvement of the energy efficiency (EE) of buildings, targeting a doubling of the annual energy renovation rate by 2030. According to Eurostat energy balances [7] and the EEA Greenhouse Gas Inventory for 2023 [8], almost 85% of EU buildings were built before 2000 and, amongst those, 75% have a poor energy performance [5]. Enhancing the EE of existing buildings is thus an unavoidable step towards EU's climatic ambitions; in this respect, it is estimated that the yearly deep energy renovation rate of the built stocks should increase up to 3% [9], while the rate in 2021 was a poor 0.2% [10]. In particular, in 2022, the residential sector alone accounted for 25.8% of the total EU final energy consumption, of which only 22.6% was provided by RES. Although EU member states have already defined national plans to accelerate building retrofitting actions, it is essential that they give priority to innovative policies, models, solutions, and processes able to concretely address the real challenges faced by deep energy renovation (DER) markets. Despite the evident benefits of energy renovation, the sector grapples with numerous limits and barriers that hinder its progress. Such barriers have already been targeted by thea substantial literature, which traced them back to an intertwined background of technical, financial [10], regulatory, social, and cultural [11] issues [12,13]. Based on this, it is possible to summarize a set of challenges that impact not just single aspects of the DER markets, but their very structural characters, in the way they are organized and perform as systems:

- poor awareness and understanding among the various actors of the renovation value and supply chain (RVSC) of the real market dynamics, as well as of their constraints of different natures;
- poor cooperation among the various RVSC actors due to the inherent complexity and the excessive fragmentation of the overall retrofitting process;
- low impact of RDI (Research, Development, and Innovation) projects, due to undersizing issues, poor coordination among initiatives, weak exploitation strategies, as well as to a lack of systematic capitalization measures at the EU level.

As a consequence, few market actors, including the institutional players, may gain a complete overview of the barriers and constraints limiting the market uptake of deep renovation, and this may lead to (largely) sub-optimal decisions. On the other hand, fostering collaboration among diverse stakeholders in the renovation process is essential for driving systemic change [14]. By facilitating knowledge sharing, capacity building, and partnership creation, stakeholders can leverage collective expertise and resources to overcome barriers and accelerate progress towards sustainable building renovation. Positive experiences in this direction are reported, e.g., in the activation of multidisciplinary teams in support of building owners [15], in the implementation of "co-creation processes" of building retrofitting [16], or in the spontaneous creation of "project clusters" among RDI projects aimed at fostering cross-learning and joint action in response to shared issues [12]. In addition, harnessing technological innovation can enhance the efficiency and effectiveness

of renovation processes, making them more attractive and accessible to market players. Tools such as building information modeling (BIM), energy modeling software, ICT platforms [17], decision support systems, and remote sensing technologies enable dialogue among stakeholders aimed at co-deciding and co-optimizing process management, design, construction, and performance monitoring throughout the renovation lifecycle. These premises provide evidence that an effective response to the challenges listed above may not be found within sectoral, stand-alone solutions: it should rather pursue an evolution of the very DER markets, by leveraging collaborative, holistic, and integrated approaches able to harness the collective efforts of stakeholders from the different market sides and their interaction along the whole course of the RSVC. With respect to this evidence, the literature shows a wealth of innovation proposals focused on the improvement and optimization of single aspects, segments, or operations of the DER process, compared to a substantial scarcity of contributions related to holistic approaches, probably due to the intrinsic complexity of the multi-faceted, multi-actor, and multi-level nature of DER. Examples in this direction are especially concentrated on the development of the One-Stop Shop (OSS) concept [18–21], while other contributions regard aspects such as holistic protocols [22], policy roadmaps [23], motivational aspects [24], or the standardization of market data at the EU level [25]. An effective interpretive key for strengthening this direction relies on the transition thinking of the market's evolution, where "transition" is intended as a reconfiguration across levels in nested systems composed of complex bundles of phenomena [26]. According to the literature [27], transitions are not predetermined and linear, but rather involve context-dependent evolutionary processes with emergent properties. Steering transitions require a particular kind of sense-making, i.e., the ability to "zoom in and out" between levels of analysis and to "zip back and forth in time" [27]. A particular focus is set on the "transition pathways" (TP) concept, which can be defined [28] as patterns of changes in socio-technical systems, unfolding over time and leading to new ways of achieving specific societal functions and policy targets. TPs can be seen as an analytical construction varying across approaches and involving varying degrees of reconfiguration across technologies, supporting infrastructures, business models, production systems, as well as the preferences and behavior of consumers. Thus, they can position responses to climate change solicitations in relation to, and not separate from, social, cultural, political, economic, and institutional contexts [29].

Starting from this viewpoint, this paper presents a holistic methodological approach based on the transition pathways theory (TPT) and aims at tackling the innovation challenges of the DER market summarized above by stimulating a multi-level and cross-domain evolution of their socio-technical configurations. This approach foresees the activation of a set of integrated TPs, which will allow funneling and streamlining innovation along well-defined directions, favoring the coordination, concentration, and management of the efforts, as well as the punctual monitoring of the effectiveness of single measures implemented along each pathway with respect to the changes induced by the overall process across the whole system. In order to maximize the efficacy of this approach, the following principles for the TPs definition were adopted:

- robustness: sound conceptual and disciplinary framework for each TP;
- autonomy: clear differentiation in terms of nature, goals, and characters of each TP;
- synergy: evidence of wide interconnections and added values between each TP;
- extension: comprehensive coverage of the challenges by the joint bundle of TPs;
- economy: minimization of the TP number to be selected.

The application of these principles to the DER market challenges listed above (Table 1) led to the selection of the TP set summarized in the following table, intended as building

blocks of the methodological approach presented, which will be duly described in the next paragraph.

Table 1. Transition pathways for energy renovation of buildings.

TP N.	TP Label	Objective
1	Institutionalization	New practices of sharing and cooperation among stakeholders of local DER ecosystems
2	Clusterization	Standardized knowledge at EU level related to local DER market features, needs, and constraints
3	Capitalization	Valorization of RDI solutions through their coordination along the DER process and their matching with market needs
4	Digitalization	ICT platforms, homogeneous frames, and process automation for the integrated management of DER process
5	Exploitation	Cross-fertilization and impact making by means of the coordinated management of the TPs

Considering the synergy of the individual transition pathways for the holistic shift from a fossil-fuel and energy-wasting building renovation market to a market based on renewable resources and energy savings, a broad stakeholder involvement and international cooperation are necessary. Therefore, in the framework of the EU H2020 CSA re-MODULEES project, this TPT-based methodology was applied to seven pilots on the energy efficiency of buildings (EEBs) markets, with special reference for the residential sector, emphasizing a people-centered approach, cross-digitalization, and process exploitation, through the capitalization of tools aimed at facilitating an effective market renovation uptake across Europe.

Starting from these premises, the main objective of this paper is introducing the TPT-based approach, which is articulated along the five TPs listed above (Section 2). The underpinning assumption for such an approach is that the cooperation among well-planned and integrated TPs would allow for boosting the mobilization and deployment of resources and innovation both at local and at higher levels, thus increasing the capacity of EU EEB markets to holistically tackle the main challenges individuated (Section 1). To this end, the practical case study provided by the re-MODULEES project is duly presented (Section 3), and the results obtained are discussed (Section 4). Through this exposition, this paper tries to give an answer to a broader research question, devoted to scouting the potential effectiveness of a strategic and enduring capitalization process at the EU level of the innovations produced or achieved in the EEB field, for fostering the transition of EEB markets into collaborative and reflexive ecosystems, where the cooperation among actors and policies can lead to better overall market performances.

2. Presentation of the TPT-Based Methodological Approach

2.1. Institutionalization (TP1)

This pathway is related to the implementation of a structured and oriented stakeholder engagement, aimed at promoting the establishment of evolved socio-technical configurations devoted to providing systemic responses to the solicitations posed by the decarbonization goals of the built stock. This pathway relies on the application of the following multi-level perspective [30] on the EEB sector:

- the macro level (the "landscape") is operated by the pull of global trends (e.g., energy and material costs) as well as by national or EU policies (e.g., Clean Energy Package regulation, 2019 [1]; New Green Deal, 2019 [2]; Renovation Wave, 2020 [3], etc.);

- the micro level (the "innovation niches") is populated by technical or non-technical innovation pushes (e.g., delivered by RIA/CSA projects);
- the meso level (the "socio-technical regimes") is organized according to market logics constrained by a wide set of local non-economic conditions.

The meso level can be understood via a multi-level perspective as an inertial domain forming the "deep structure" of EEB market, evolving due to the interaction of push and pull dynamics, and thus it can be recognized as the ideal space for bridging EEB policy goals and innovation potentials of the EU ecosystems within a market-oriented framework. The first TP here considers thus the evolution of local EEB markets and of their deep structure actions as its primary domain of activity. This outcome is hampered by lock-in effects related to the very nature of the socio-technical regimes; in order to overcome this risk, the structuration theory of Giddens [31] is assumed as a key methodological reference, according to which "the structural properties of social systems are both medium and outcome of the practices they recursively organize" [31]. Enduring and recursive innovative practices may trigger the progressive reconfiguration of social structures, laying the ground for the establishment of new institutional actors or routines embedding the informally established new courses of action. The concept of "structuration" is operationalized in TP1 through that of "institutionalization" [32], which is based on four main implementation steps: i. encoding, ii. enacting, iii. revising, and iv. objectification and externalization. As for the first step (encoding), TP1 pursues, on the one hand, an adequate engagement of the local stakeholders community in order to fully represent the EEB deep market structures and dynamics; on the other hand, it pursues the testing of new interaction practices among actors based on mutual learning and co-thinking, and is aimed at raising awareness and knowledge on shared issues and solutions, stimulating joint commitment, coordinating innovation agendas, and situating these agendas within systemic action frameworks. TP1 thus deals with strengthening the structural features that turn a fragmented building market into an integrated ecosystem characterized by specific social–geographical–economic–policy conditions. To this end, a strategic design approach can be opportunely adopted, based on two process-related strategic tools [33]: i. *"infrastructuring"*, that is, the design of open-ended innovation processes where the construction of relationships among actors is essential for creating concrete conditions of future co-design opportunities; ii *"seeding"*, that is, the spread of ideas coming from innovation niches of one context to another, aimed at stimulating their joint implementation in the frame of design network-based processes. Table 2 represents a synthesis of this framework, where the implementation steps of TP1 (row 1) are matched with the strategic design tools mentioned above (row 2); at step 4, seeds begin to sprout as "joint design opportunities" to be harvested later in time. From this match, the following four engagement and design principles can be derived (row 3), aimed at providing a practical guidance for the implementation steps: i. well structured, ii. goal-oriented, iii. interactive, and iv. rewarding.

Table 2. Conceptual framework for TP1—institutionalization.

Implementation Steps	i. Encoding	ii. Enacting	iii. Revising	iv. Objectivization Externalization
Strategic Tools	seeding infrastructuring	seeding	infrastructuring	(joint design opportunities)
Engagement Principles	well structured goal-oriented	interactive rewarding	interactive	goal-oriented

This framework has been concretely exploited in the application context presented in the following Section 3.1.

2.2. Clusterization (TP2)

This pathway is related to the construction of a homogeneous, organized, and integrated knowledge of the variegated landscape of local EU EEB markets, starting from the collection of data and information, up to their thematic and geographic analysis. TP2 addresses the inherent complexity of EEB markets, expressed by the numerous quantitative and qualitative variables affecting them (e.g., regulatory framework, renovation awareness, socio-cultural backgrounds, market structure, access to finance, political commitment and government support, etc.). TP2 aims at developing a comprehensive analysis framework where the different dynamics, limits, and potentials of local EEB markets can be effectively grasped and compared in order to highlight similarities and differences among them, and where insights on local behaviors and specificities can be further understood in the light of cross-regional trends and correlations. Thanks to this process, different market profiles can be finally devised, generating a "market topology" based on which a new relational geography of the EEB EU markets could be drafted. To this end, a "divide and conquer" (divide et impera) approach [34,35] can be adopted in order to identify frequent item sets from a partially unstructured collection tailored to specific topics within each local market. Starting from this, "data clustering" [36] is defined as the task of partitioning a set of objects into groups based on their similarity, while maintaining dissimilarity between groups.

To this end, TP2 adopts an agglomerative hierarchical clustering method to define various levels of clustering [37]. This method can be subdivided in three main steps:

1. Data collection: performed using qualitative–quantitative approaches;
2. Pre-processing: the vast amount of data collected are homogenized and summarized through a process of data cleaning and transformation, including merging, standardizing, de-duplicating, verifying, and exporting the initial data;
3. Hierarchical clustering: this is based on a bottom-up approach, where single objects are merged into larger clusters until specific conditions are satisfied and then the new clusters can be merged into higher clusters, and so on.

The relevance of step 1 is evident for properly framing clusterization within a transitional approach. To this end, a relational model can be adopted for the investigation of EEB markets, representing the system as a network of actors, actions, and mutual connections [38]. Further contributions for the implementation of this market's profiling activity can be drawn from the Theory of Constraints (ToC, [39]), which suggests selectively detecting and tackling the constraints acting on a system in order to unlock its embedded potentialities. Additionally, in terms of a flux through a network, and from relational economics [40], this model interprets the transactions occurring among the actors of a system not only in the traditional form of exchange, but also in terms social dynamics framed into polycontextual and polylingual environments, and where the organization of a system strongly affects the capacity of its actors to deploy the potentiality of relational networks.

Therefore, TP2 should rely on a combination of human and data-driven approaches, where the former recognizes the core role of persons in any activities of the renovation path, whether in business, technology, or society at large. TP2 is built on the principles of applied ethnography, sometimes also referred to as People-Centered Development (PCD) [41], and aims to deeply understand the people driving market activities and influencing building renovation and/or retrofitting processes in various modes. This people-centered approach is more than simply beneficial: as with any product or service design initiative, tools and processes for market innovation can only be effective and impactful if they are valuable and meaningful to the people they serve, directly or indirectly [42]. Moreover, this

approach is appropriate from the standpoint of Responsible Research and Innovation (RRI) [43,44], which is far beyond compliance with minimal ethical standards, and which makes the transition process more transparent, inclusive, sensible, and ultimately credible. In practice, PCD is a relatively broad term that accommodates essentially any tailored qualitative research framework that requires researchers to engage with their 'end-users' (the people) from the beginning to the end of an R&D process, ideally for a prolonged period and within their everyday-life environments. Tailored PCD approaches can also be foreseen, which may enable ethnographic research models to fit within tighter frames typical of RIA/CSA projects [45–47]. Most significantly perhaps, PCD approaches can create space to practice interdisciplinarity, enabling researchers, stakeholders, and other relevant actors of EEB markets from different knowledge and expert backgrounds to work towards the shared aim together as opposed to working in parallel, or in 'silos' ([48]). This feature allows us to stress the close connection between TP1 and TP2, where the investigation and clusterization processes are turned into new relational practices able to nurture institutionalization processes.

2.3. Capitalization (TP3)

This pathway deals with the valorization of best practices and innovation resources (methods, tools, services, solutions, concepts, approaches, etc.) drawn from a multiplicity of roots (EU, national, or local RDI initiatives), and with their optimal positioning in a variety of market knowledge frameworks ("market profiles"). As it was highlighted in Section 1, the production of innovation in the EEB field often occurs in a fragmented way, made of parallel and disjointed development pipelines, leading to underperforming exploitation results. TP3 aims at interconnecting innovation resources in order to generate value accumulation by unleashing untapped possibilities of coordination among them. TP3 does not deal only with TRL-scale issues, such as the "valley of death" [49]: it regards above all the resources already at hand, which are not yet systematized in a way to fully exploit their implicit potential. The main reference for this pathway can be traced to the work of Mariana Mazzucato, and the expressed need for a mission-oriented approach [50,51], where the outcomes of research or innovation activities are not singled out as autonomous and competing market products, but are required to cooperate in view of achieving wider impact and effectiveness in the real world. According to this view, TP3 pursues the establishment of a standardized process with two main aims:

- performing a continuous, ever-evolving scouting and analysis of innovation resources, where complementarities, differences, connections, and synergies among them can be highlighted, so as to let their combined potential for the improvement of the retrofitting process emerge;
- bridging this combined potential within concrete market opportunities by developing a "reasoned map" where innovation resources are matched with specific innovation needs and market constraints to be addressed.

TP3 regards capitalization as an inherently multi-layer, multi-sector, and multi-actor strategic activity, which requires, on the one hand, taking into consideration the ecosystemic dynamics of EEB markets as a whole, and on the other, focusing attention and knowledge generation on each single segment along the retrofitting process, as well as on the input–output relations connecting the actors and their activities involved in each segment. For all these reasons, TP3 exposes strong connections with TP4, especially due to the possibility to foster the automation of the capitalization process and thus to enhance its standardization. With TP2, this can be seen in relation to the need to gain a deeper comprehension of EEB markets dynamics and logics; and with TP1, this is about the creation of privileged

connections among key actors, which is necessary for stimulating a mission-oriented, systemic capitalization of the innovation resources available.

2.4. Digitalization (TP4)

This pathway is related to the integration and automation of the best fitted resources to each market, in order to maximize the ability by end users to access, use, or share them. Thanks to this, TP4 aims to turn individual disconnected resources into a node of facilitation that can be exploited in the long term thanks to a careful analysis of the context; a design aimed at solving the real needs of its users; and a robust development (and at the same time flexible and scalable) that allows for adequate maintenance and future adaptability and growth. In particular, automation is intended as a wide range of technologies aimed at reducing human intervention in processes, mainly by predetermining decision criteria, subprocess relationships, and related actions, and can embody those predeterminations in machines [52]. The literature has paid increasing attention to digitalization as a core engine of the fourth industrial revolution, and specifically, to its transformative capacity of the supply chains in such a way that value creation is concentrated in boundaries and inter-relationships [53]. Digitalization applied to the EB field should thus aim at joining and combining the knowledge, approaches, and tools already available, in order to optimize their uptake on local markets, by addressing and integrating the following main themes:

- users' needs: it should consider people (tenants, property owners, professionals, and entrepreneurs, or the public sector) by offering solutions according to their specific needs and expertise (user profile);
- resources scopes: it should deal with the available resources, intended as every innovative input that may cope with and ease end users' needs, by considering a multi-targeted approach, in terms of their adaptation to regional climatic, building, socio-economic, and market conditions;
- renovation process: it should be associated with a "breakdown" of the overall retrofitting process into individual segments corresponding to homogeneous sets of activities.

A strong methodological reference for this goal is the GEO Knowledge Hub (GKH) (https://gkhub.earthobservations.org/; accessed on 31 January 2025) solution, a digital repository providing access to knowledge required to build applications of Earth observations with the purpose of revealing all components available and needed for a given application on that topic [54]. Accordingly, TP4 could be implemented by developing a GIS-based ICT platform, which could act as a unique entry point to the different resources or resource combinations addressing specific market challenges, and which could improve the capacity of stakeholders to use innovative resources for supporting their decision-making, lowering the barriers for new users to find the enormous amount of data, tools, applications, and methodologies openly available. In this context, a digital platform could be a turning point for the market uptake of the energy retrofitting of existing residential buildings, connecting the possibility of capitalizing on validated resources in support of the retrofitting process developed by different organizations, in different environments, with different objectives, but presenting evident relevant intersections. While the emergence of open digital platforms has had a deep impact on designing and positioning products, modularity emerged as a key aspect to facilitate openness and successfully scale-up results, as well as to meet with the rapid pace of change and uncertainty typical of high technology markets [55]. To this end, it will be essential to provide a reference framework which would allow the connection and integration of these resources with the end users addressed, by synthesizing local market structures into a comprehensive, modular architecture that could be applied across all the EU. This feature highlights the close connection of TP4

with TP2 and TP3, for the necessity of maintaining a close correlation of the integration frameworks adopted for the clusterization of knowledge, the capitalization of resources, and their digitalization.

2.5. Exploitation (TP5)

This pathway is related to enhancing the capacity of innovation processes to rapidly achieve social, economic, and scientific impact, thus transforming public or private investments into a concrete value for society. Such transformation is neither obvious nor spontaneous: it needs to be facilitated through proper exploitation activities, aimed at spreading the use and enhancing the benefits of innovation. To this end, a challenge-driven approach should be adopted [56,57], according to which the expected results of RDI projects need to be oriented towards unsolved economic, societal, or scientific challenges, in order to achieve tangible outcomes and mobilize impact. On this basis, TP5 assumes as a main reference the methodological approach developed by the DG RTD (Directorate-Generale for Research and Innovation) of the European Commission (EC) by means of the Horizon Results Booster (HRB, [58]), where exploitation is intended as a value creation process pursuing different objectives at different scale levels:

- setting and improving processes, quality of life, products, services, etc.
- increasing the organization/community's distinctive skills;
- gap filling, e.g., if a result is adopted by a public body to better serve citizens;
- generating revenues, if there are customers available to pay for using a result.

The HRB focuses in particular on the Key Exploitable Result (KER) of a RDI project/action, that is, one or more results responding to specific needs/demand of a well-defined group of "customers". KERs are selected and prioritized on the basis of their exploitation potential, which can be synthesized as a Unique Value Proposition (UVP), which differentiates a specific KER with respect to alternative market solutions. The HRB provides a whole set of integrated services, methods, and tools conceived for supporting the value creation process associated with KER development right from the start, articulated into two main categories:

- Dissemination Services: identification and creation of a portfolio of RDI results (KERs), and the development and execution of the Portfolio Dissemination Plan;
- Exploitation Services: development or improvement of exploitation strategies, business plan development, and go-to-market support.

A correct approach to exploitation should therefore consider the following phases:

- identifying the needs to be addressed through projects/actions;
- preparing an exploitation plan describing how each KER will be developed and used, the outcomes to be pursued, and the impact to be mobilized in the short and long terms;
- preparing an Action Plan describing the activities to be concretely carried out, their operative steps, roles and responsibilities, and the resources needed.

TP5 provides a conceptual and operational framework for enhancing value generation and exchange across the TPs previously described. This goal is synthesized in Figure 1, where the outcomes expected from the four TPs described above are regarded as the main results of an overall innovation process to be targeted by exploitation activities; in particular, the scheme highlights the interconnections among the different TPs, which substantiate the integrated nature of the holistic methodology presented in this paper.

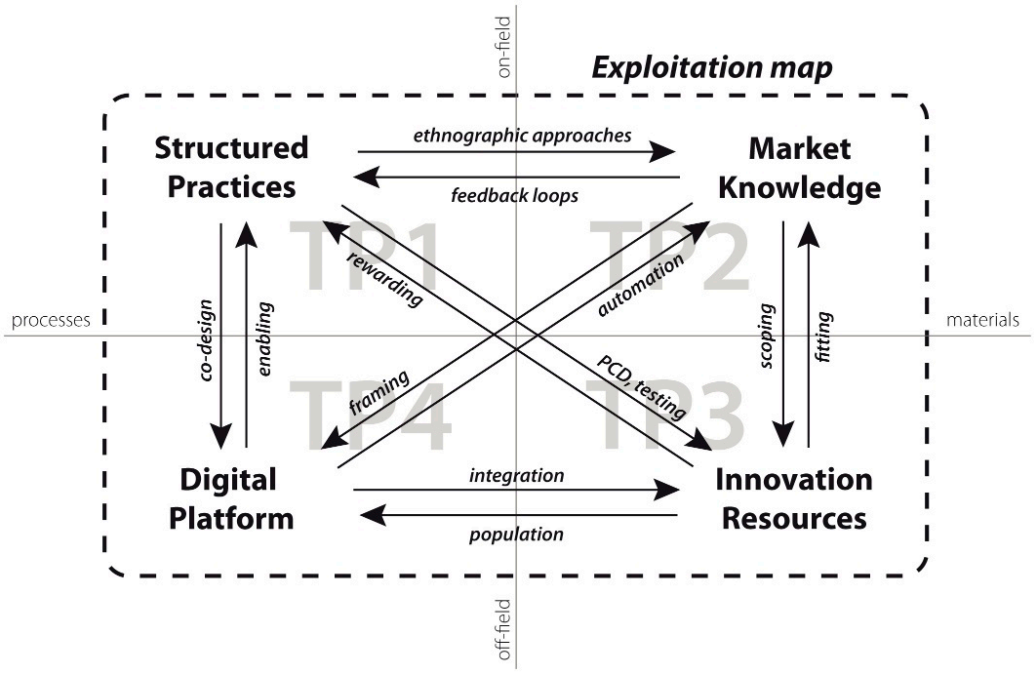


Figure 1. TPT-based methodological approach scheme.

3. Application Case Study and Results

The transition pathways theory (TPT) was concretely applied in the H2020 European project re-MODULEES [59]. Through a multi-level, multi-sector, and multi-target approach, this project aimed at accelerating retrofitting markets for the creation of an EU-wide retrofit market activation framework in the residential building sector, supported by digital and physical Renovation Hubs and by the capitalization of results from an array of innovation projects. The TPT application was carried out in four main WPs: i. capitalization of modularity, aimed at carrying out a deep profiling of the pilot markets, at surveying innovative tools, services, and applications (TSAs), and at matching them with the innovation demand emerging from the markets; ii. integration and digitalization, aimed at capitalizing the previous results by developing a digital platform for the automation and adaptation of multi-target solutions to regional, climatic, building, socio-economic, and market conditions; iii. demonstration, aimed at supporting financially viable and attractive renovation actions at the local level by activating and managing re-LABs in the selected ecosystems; and iv. business modelling, aimed at boosting the project impact via the development of business models and market uptake actions for the main project KERs. The re-MODULEES project stemmed from an informal project cluster promoted by several H2020 CSA-funded projects in the EEB field, which sought to enhance the exploitation of their KERs through mutual learning and joint dissemination. The basic idea of re-MODULEES was generating a strategic capitalization framework for the RDI results in the EEB field, which is able to combine the granularity of good practices at the local level, which are often under-scaled and thus unexploited, with the necessity of achieving a wider scale, with an EU-level impact. To this end, re-MODULEES was tuned not to act at the pilot building or district scale, which in the viewpoint of a transition may correspond to an innovation niche, but to address directly the mesoscale level, which was identified as the very "renovation pilot market", i.e., as a geographical area with an adequate scale for a structured and autonomous EEB supply and value chain (SVC) to develop in relation to other value chains. This choice made it possible to concentrate all key players of an EEB market within a single geographical area to test a TPT-based methodology. Testing was performed on three scale levels (NUT 1, 2, and 3), with the aim of stimulating a deeper understanding of scale-related implications. The

project pilots selected are representative of different social–geographical–economical–policy ecosystems in EU (e.g., north–south–east–west), as well as of the most relevant EU climate zones, including arid (steppe), temperate (dry/no dry), and cold (no dry) zones according to the Köppen–Geiger climate classification [60]. Furthermore, in each pilot market, the following four main market sides were addressed, with the aim of engaging all the key local actors of the deep energy renovation process: 1. demand; ii. offer; iii. financial; and iv. institutional sides. Table 3 summarizes the pilot markets activated.

Table 3. Pilot markets activated within re-MODULEES [59].

NUT	Country	Pilot Market	Consortium Partners
1	Slovenia	Slovenia	IRI-UL
2	France	Departments FR-06 Alpes Maritimes, FR-69D Rhone, FR-69M Lyon Metropole	R2M, DOWEL
2	Italy	Emilia–Romagna Region (frontrunner) Puglia Region (follower) Bolzano Province (follower)	CERTIMAC CNR—ITC EURAC RESEARCH
2	Netherlands	Noord Brabant, Rotterdam community	HIA, ISSO, BOUWHULP
2	Spain	Valencian Community	IVE
3	Bulgaria	Gabrovo Municipality	ENEFFECT
3	Greece	Municipality of Vyronas	CRES

The main objective of re-MODULEES was the creation of an EU-wide digital retrofitting market activation platform (MAP) for EE in existing residential buildings, aimed at joining efforts and evidence among key actors of the EEB-SVC, at shaping cross-regional policies, and at generating wider, homogeneous, integrated, and facilitated retrofitting market areas. While the first MAP nucleus is focused on the pilot markets listed above, its methodological base and ICT frame are purposed for a wider extension across the EU. For this reason, re-MODULEES leveraged the vast background of the H2020 cluster projects as well as other EU programs, in order to combine and systematize the TSAs already available within a clear and modular framework, conceived in order to optimize their uptake on local markets with different profiles. On this basis, the approach exposed in Section 2 was implemented in the re-MODULEES project, as shown in Table 4.

Table 4. Declination of the TPT-based methodological approach in the re-MODULEES project framework.

Transition Pathways (TPs)	TPs in re-MODULEES Project
Institutionalization	Activation of renovation Local Advisory Boards (re-LABs) to become re-HUBs on the basis of a Standard Action Plan (SAP) and Local Deployment Plans (LDPs)
Clusterization	Gathering needs, constraints, and drivers for each type of targeted stakeholders in each local context by combining data-based and human-based approaches
Capitalization	Crossing demand and offer of innovation delivered by the activities from the previous pathways for identifying resources and functionalities to be co-designed and implemented in the market activation platform (MAP)
Digitalization	Developing the market activation platform architecture basing on the insights gathered from the previous steps
Exploitation	Defining exploitation strategy aimed at describing how the KERs will be implemented in the long run, which outcomes will be achieved, and which impact will be mobilized

3.1. Institutionalization

The re-MODULEES project put forward a multi-actor perspective aimed at triggering a stakeholders' community-building process spanning across the whole market SVC, and turning the classic approach based on users, platforms, and contents into a new paradigm focused on community, usefulness, and results. To this end, the re-MODULEES project activated a renovation Local Advisory Board (re-LAB) in each pilot market, composed by stakeholders' representatives of all the four market sides addressed, acting as "umbrella" actors for a wider engagement process. re-LABs were at the core of the transition pathways: as a testbed, they could effectively steer a capitalization process by testing, co-creating, and validating innovative solutions, and by extending their outreach across the market; as knowledge insiders, they could provide valuable knowledge about the specificities and uniqueness of local markets; as strategic acceleration points, they could co-develop activities aimed at maximizing the impact of the project outputs at the local level. Finally, as network catalyzers, they could play a key role in building up support networks at local and national levels. A total of 125 stakeholders were involved in the re-LABs during the project activities (33 for the demand, 43 for the supply, 19 for the financial, and 30 for the institutional sides, respectively), representing a wide range of actor typologies, such as associations of professionals or building owners, companies, federations, institutional clusters, NGOs, etc. In this way, each actor onboarded in the re-LAB had the potential to serve as an aggregator (or "umbrella member") for a larger number of smaller actors in their markets. While these stakeholders had previously experienced fragmentation and segmentation within their market dynamics, the fruitful interaction enabled by the re-LABs allowed turning such a pattern of "disaggregated data and experiences" into a new pattern of "aggregation platform and communities". In turn, community creation proved to be seminal for the successive establishment of a new type of market actor, namely the "renovation HUBs" (re-HUBs), intended to ensure continuity with the transition process after the end of the project, by taking over the task of operating the market activation platform (MAP) within their markets. Re-HUBs are multi-actor and multi-level strategic networks, conceived on the one side as aggregators of local SVCs, and on the other side as local branches of a wider, trans-national cooperation framework. In this sense, re-LABs also acted as incubators for the establishment of re-HUBs, thanks to the signature of formal agreements among partners and stakeholders. Figure 2 shows the interactions between the different entities established in the project.

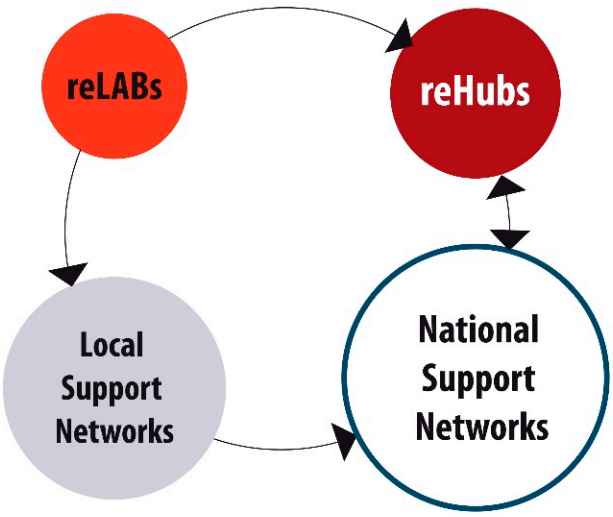


Figure 2. Network creation from re-LABs to re-HUBs.

Two tools were developed in order to structure and guide the engagement process: a Standard Action Plan (SAP), and Local Development Plans (LDPs). The SAP provided the project partners with a shared methodological framework conceived as a roadmap, where steps and actions for the stakeholders' community building are scheduled and duly described, with the aim of fostering the transition from an initial results, testing, and validating environment (re-LABs) to self-sustaining entities (re-HUBs) in each pilot market. The SAP is not intended as a rigid framework, but as a general coordination tool, which each pilot leader needs to customize and specialize into a Local Deployment Plan (LDP) fitting the specificities of each pilot market, the background of experiences and approaches of each re-LAB, as well as the personal expectations and goals of local stakeholders. LDPs constitute an ex-post narration of the adjustments put in place at each step of the engagement process for maximizing the viability of the SAP as a guidance tool, with the aim of exploiting all the opportunities and potentialities arising from the interaction within and around the re-LABs. In this way, the re-MODULEES approach is fully consistent with the engagement principles listed in Section 2: i. goal oriented: towards the establishment of re-HUBS; ii. structured: availability of a Standard Action Plan; iii. rewarding: representation of grass-root issues and requirements through co-design activities on the market activation platform (MAP); iv. practical: knowledge transfer of innovative tools and solutions available for energy renovation of buildings; v. interactive: customization of the SAP into LDPs based on feedback loops. The SAP coded for re-MODULEES (Figure 3) is organized according to several overlapping lines of action; at the beginning of the project, a full profiling of the pilot market was carried out, based on which a "Customer Journey" (CJ) for the renovation process was drafted. At the same time, a survey of innovative tools, services, and applications (TSAs) viable for addressing needs and constraints that emerged from the market profiles was launched. This allowed us to match the TSAs with the CJ frame, and to start the scouting for testing opportunities for TSAs across the stakeholder engaged via the re-LABs. These activities were preliminary for the MAP co-design path, which was carried out through a close interaction with the re-LABs. At the core of this project phase, Demo Days (DDs) were organized in all the pilot markets based on the alpha version of the platform, where its potentialities were presented and feedback was collected on the TSAs to be prioritized, leading to the development of the MAP beta version, and to its final validation. DDs were also the chance for pursuing the enlargement of the initial stakeholders' network towards the construction of support networks at a local and national scale. At this point, the focus of re-LABs was progressively shifted from innovation system co-design to the re-HUBs incubation and start-up, which was finally concluded by the definition of business plans for the re-HUBs, and by the signing of agreements.

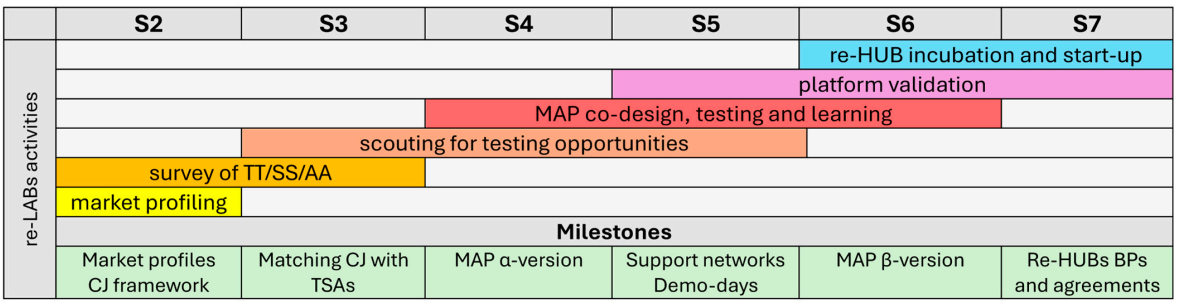


Figure 3. Scheme of the Standard Action Plan (SAP) describing the lines of action and the correspondent milestones (S = semester of project implementation, CJ = Customer Journey, TSAs = tools, services, and applications, MAP = market activation platform).

3.2. Clusterization

The clusterization process was based on a "data collection phase"; on the one hand, this relied on data-based information such as the local, national, and international literature, reports, and other sources, and on the other hand, this relied on human-based information. Data were collected through the following main approaches:

- Semi-structured face-to-face interviews with re-LAB members, through which the main challenges in their pilot markets were discussed, by exploring their real-life experiences, roles, shared field insights, obstacles, success stories, and regional market constraints.
- Records of the collective discussions held during re-LAB meetings focused on market challenges, which were supported by virtual whiteboards in order to map both market potentialities and criticalities.
- Survey sheets addressing each pilot market and filled-in by re-MODULEES partners in collaboration with re-LAB members. These sheets were informed by insights derived from the two previously mentioned activities; desk research conducted by partners; and partners' direct experience and expertise gained through hands-on market activities or participation in EU projects.

The data collection in each pilot market led to an in-depth analysis of local market structures, constraints, and trends, leading to the construction of a large knowledge base, which formed the basis for the successive clusterization phase. In particular, the following main results were achieved [11]:

- Renovation Process Structure (RPS): this represents the succession of phases and the connections of actors involved in each phase, of the deep renovation process (Figure 4). The renovation process is made up of the connections and the networks established among these actors. Both the actors and the RP phases list, as derived from the clusterization process, should be considered shared across the pilot markets, thereby forming a reference framework for their comparison. The RPS is organized according to the phases of the renovation process, where different actors play a role. The actors are mentioned in each RP phase with different colors according to the category corresponding to a market side: supply, demand, public, and financial (see the legend in the figure).
- Constraints: they represent the main barriers affecting the market actors, their activities, connections, and networks within each market side. After gathering the most relevant information regarding the key constraints affecting deep energy retrofits in each pilot market thanks to re-LAB members' involvement, a hierarchical clustering was carried out by summarizing the collected data through a process of cleaning and transformation (Figure 5).

Although there are some differences among ecosystems depending on geographic, social, and political characteristics, it is evident from the graphs in Figure 5 that constraints in renovation markets are in greater numbers on the demand side. This side is the one that basically starts the innovation process involving the other market sides Consequently, the numerous constraints affecting this side slow down renovation market evolution. The supply side also faces many constraints, with differences for ecosystems based on the maturity of technical knowledge and organizational capacity with often low-skilled workers. The institutional and financial sides, however, are affected by constraints hindering their ability to trigger renovation.

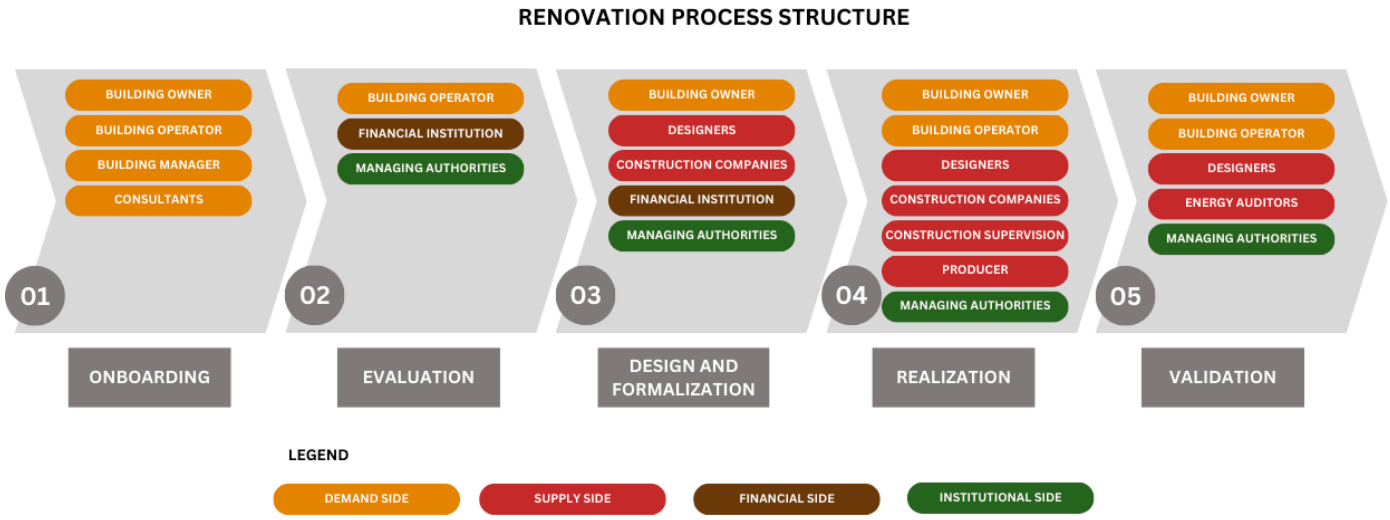


Figure 4. RPS scheme. The actors are mentioned with different colors according to the corresponding market side: demand, supply, financial, and institutional.

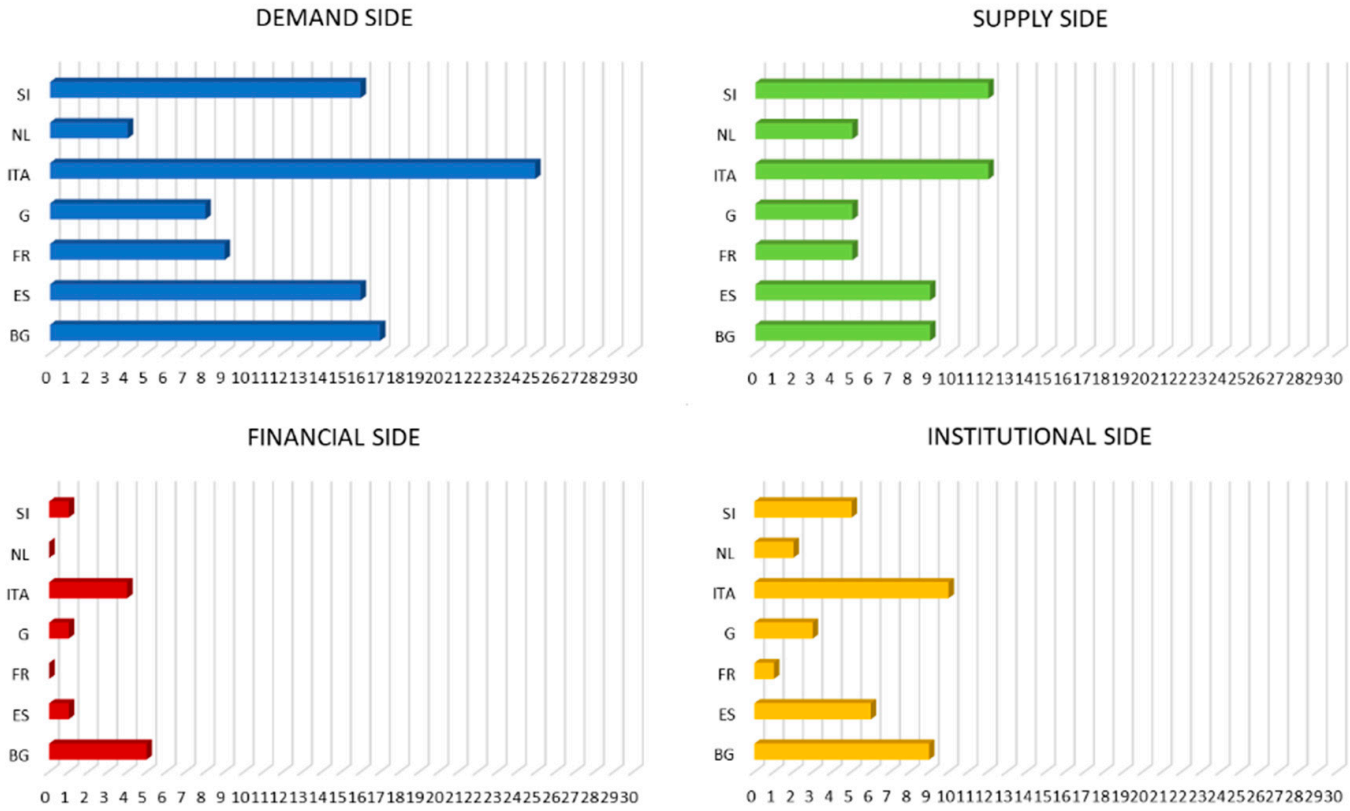


Figure 5. Number of clustered constraints for each pilot market—demand, supply, financial, and institutional.

This first clusterization phase still produced a vast amount of data to be analyzed. For this reason, a further investigation was needed by means of a deeper global check list made up of all constraints collected after the clusterization process. The goal was to attribute quantitative values to the constraints in order to achieve a more rigorous comparison capacity in terms of their perceived relevance. For any further details on the analysis of market constraints, see [11].

The findings about constraints were used to populate an opportunity matrix, highlighting untapped market potential as well as market limitations and barriers in relation to

the capitalized innovative tools, services, and applications (TSAs). This matrix (Figure 6) is the outcome of the capitalization pathway described in the following Section 3.3.

- Innovation trends: during the data collection phase, pilot markets were asked to summarize key innovation trends on the supply side, covering aspects like organizational issues, financial mechanisms, renovation design, and technical features (e.g., building materials, renovation solutions, and techniques). Innovation trends were grouped into four main categories: organizational, design, financial, and technical.

Each pilot market could report on current or emerging trends with the potential to significantly impact future market developments. Partners relied on their own expertise to identify these trends, which was supplemented by the existing literature for detailed descriptions. The collected trends were then clustered and analyzed for their presence or absence across pilot markets (Appendix A—Table A1). The process identified n. 11 organizational, n. 8 design, n. 9 financial, and n. 28 technical trends. The top organizational trend was "Energy communities" (seven out of nine ecosystems), while "One-stop-shop renovation services" and "Renovation-focused tools and apps" were shared by three of nine ecosystems. Regarding design, BIM usage stood out (four of nine ecosystems), enabling Digital Twin creation for predictive maintenance. Two ecosystems highlighted "Digital platforms for renovations" and "Quality certifications." Key financial trends included "Eco-loans" and "Public incentives for energy efficiency" (three of nine ecosystems). Finally, in the technical category, "Renewable Energy Sources" was the most shared trend (four of nine ecosystems), with "Pre-fabrication", "IoT construction products", and "Sustainable materials" each shared by three ecosystems.

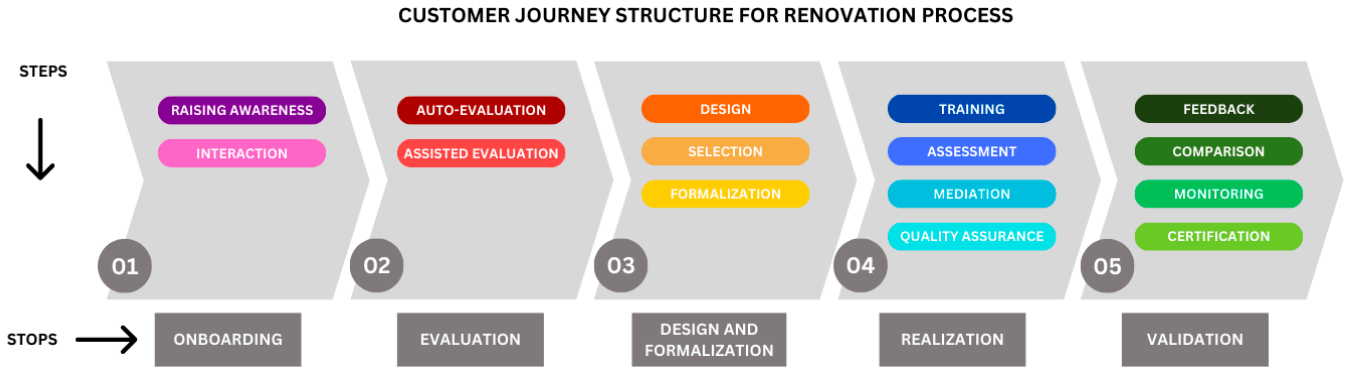


Figure 6. Customer Journey structure for renovation process.

3.3. Capitalization of Innovative Tools, Services, and Applications

The re-MODULEES project identified and analyzed a large number of innovation resources from European initiatives at different scales, highlighting potential interconnections among them. This required first developing a Customer Journey (CJ), which further refined the RPS in Figure 4 by adding 15 steps so as to describe the renewal process in greater detail (Figure 6) and facilitate comparisons among the selected tools.

Each step was then associated with several needs and functionalities required by the re-LABs members for the development of the platform, addressing each side of the market.

Based on this coordination frame, a large set of European projects and other relevant initiatives at national and local levels were analyzed and filtered in order to evaluate the uptake potential of innovative tools, services, and applications (TSAs) in the retrofit processes of each pilot market. This "sourcing scenario" was analyzed in order to understand possible synergies and overlaps between the selected TSAs, and to fill eventual gaps that may prevent their full market exploitation.

The scouting of TSAs included three survey steps:

1. Preliminary understanding: collection of all the most relevant elements for a quick understanding of the proposed TSAs, and for starting the capitalization in the pilot markets through the re-LABs involvement.
2. Deeper information: collection of necessary data to better understand the capitalization and integration conditions of the TSAs through the re-MODULEES platform.
3. Matching constraints: focused on matching each selected TSA with the clustered constraints for each market side (demand, supply, financial, and institutional).

A total of 45 TSAs (listed in Table A2—Appendix B) were finally selected and analyzed through the CJ, associating each to the most pertinent steps.

TSAs were divided into three scope groups in relation to how many CJ steps -are addressed, as represented in Figure 7:

- Wide Scope (WS): TSAs which have ≥ 9 addressed steps distributed among the stops from the beginning to the end of the CJ;
- Multiple Scope (MS): TSAs which have a medium number of addressed steps;
- Specific Scope (SS): TSAs which have a low number of steps (≤ 3), but which could be particularly useful in a specific step of the CJ.

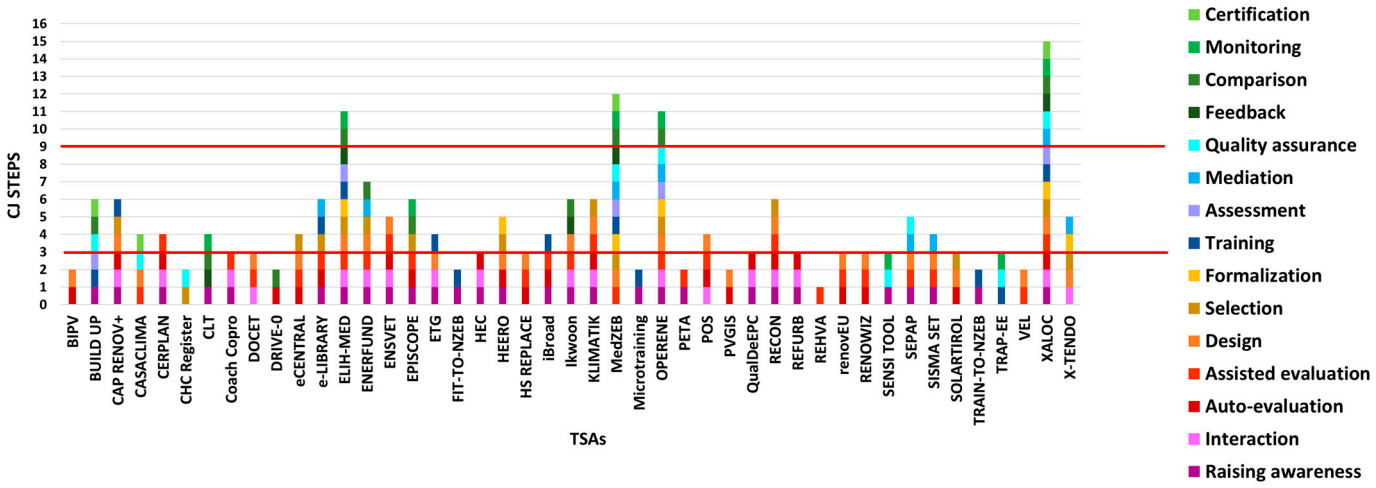


Figure 7. Addressed Customer Journey steps by each TSA.

Data relating the matching between the selected TSAs and constraints for each side were collected thanks to surveys fulfilled by all re-LAB members of the seven pilot markets. TSAs play a crucial role in enhancing the demand side: with respect to the 45 TSAs analyzed, most of them solve constraints like "Lack of information", "Lack of knowledge and understanding", or "Lack of awareness". "Lack of information" is addressed by 33/45 TSAs.

As explained in Section 3.2, the tools available in more European countries were analyzed in order to give a European scenario in which not only the seven pilot markets could draw useful information, but in which also other member state markets could find interesting guidelines concerning available TSAs, real constraints of the renovation market, and how these elements interact with each other.

An opportunity matrix (Figure 8) was populated combining data related to the steps and the needs/functionalities of the Customer Journey addressed by each TSA, and the number of constraints addressed by each TSA. In the opportunity matrix, the number of CJ steps are shown on the abscissa and represent the "Versatility", the number of constraints on the ordinate represents the "Utility", while the size of the bubbles is proportional to the number of CJ needs/functionalities addressed by each tool considered. Therefore, this matrix helps with the selection of the most suitable TSAs for each local renovation

market based on filters related to Customer Journey steps, needs, functionalities, and market-clustered constraints. It is possible to highlight the TSA that can address the greatest number of constraints (e.g., n. 27 Operane) or CJ steps (e.g., n. 44 XALOC) or CJ needs/functionalities (e.g., n. 25 MedZEB), but in any case, any TSA can be chosen based on the main objectives that the specific platform user needs to achieve in their local market.

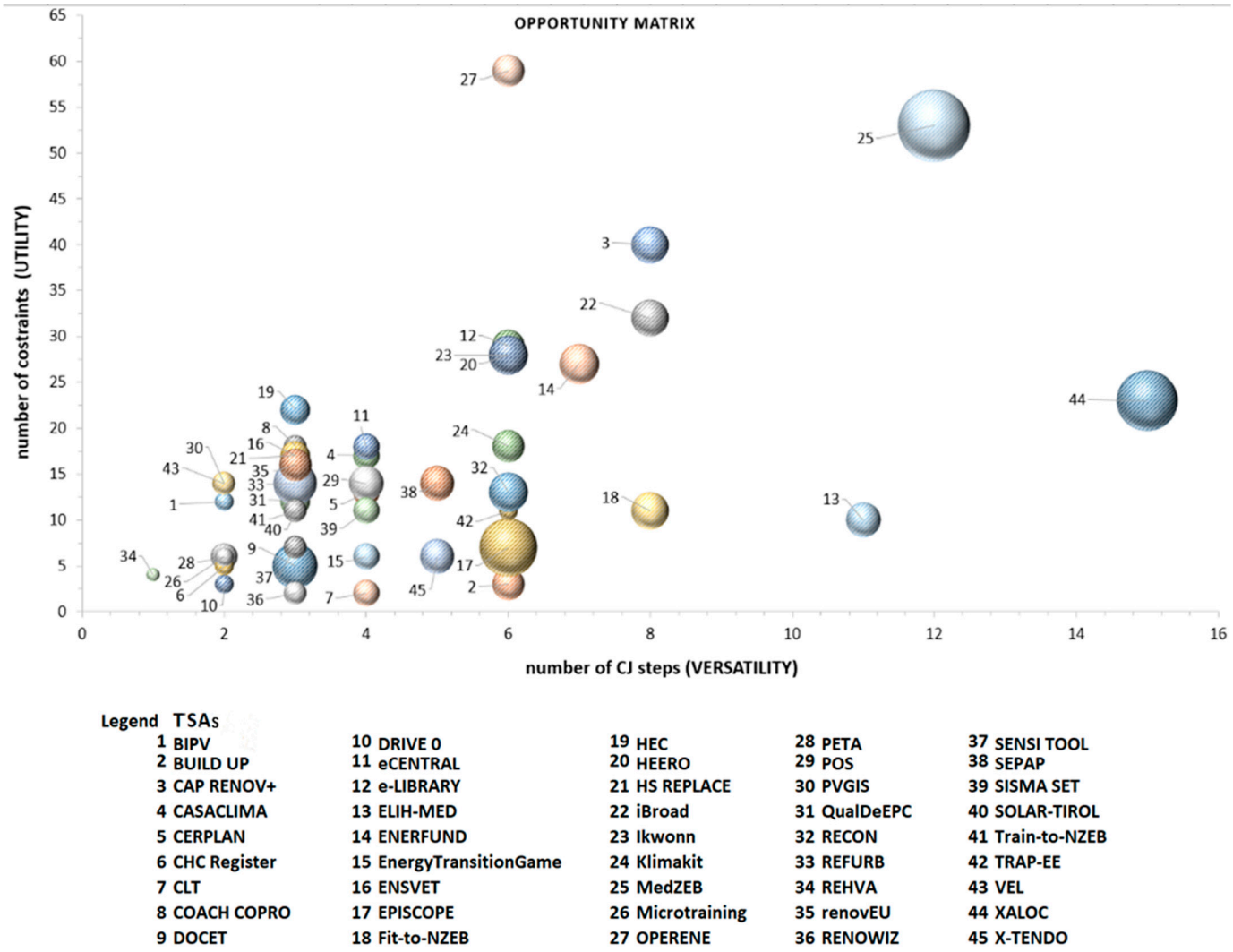


Figure 8. Opportunity matrix: TSAs versus the steps and the needs/functionalities of the Customer Journey, and the number of constraints addressed.

3.4. Digitalization: re-MODULEES Platform

The digitization transition pathway in the re-MODULEES project supports community structures and processes, focusing on people. The re-MODULEES platform aids the EEB renovation market, by offering automated modules for innovative tools, solutions, and approaches tailored to local conditions. It serves various clients, including tenants, property owners, professionals, entrepreneurs, and the public sector according to each profile's concrete needs and expertise.

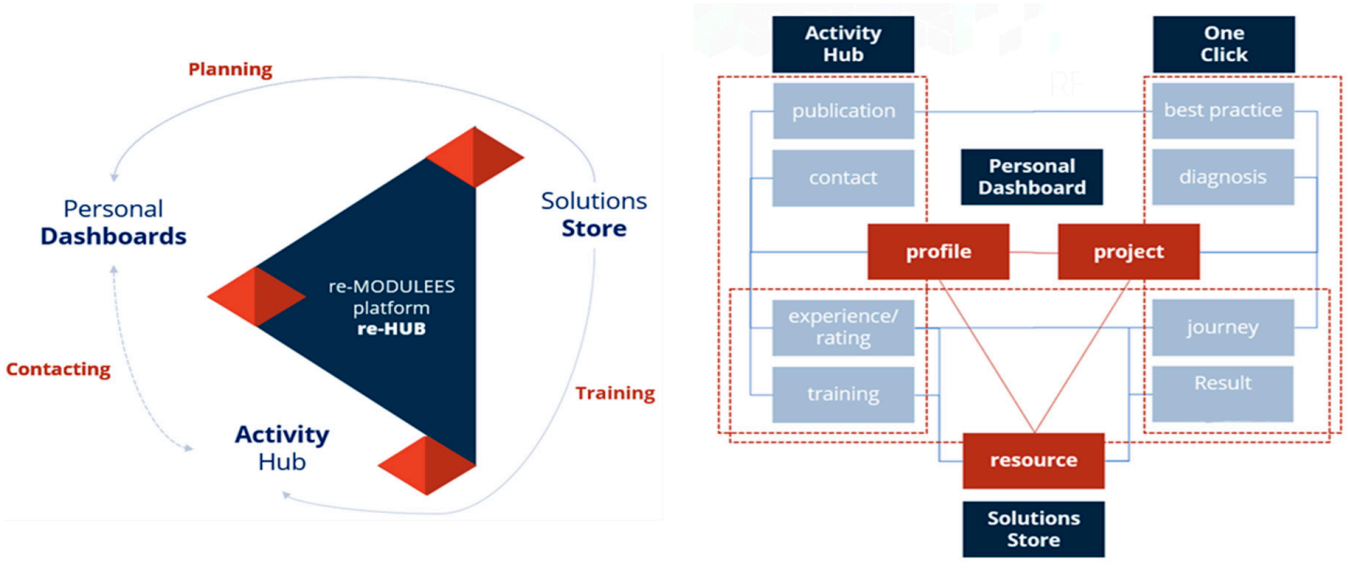
The project breaks down the retrofit process into standardized, modular segments, integrating existing knowledge, methods, and tools into local markets. A GIS-based ICT platform customizes access to modules by building location and user profile, available in multiple languages.

The platform is built on a modular architecture; thus, it is scalable and can be implemented in different territorial contexts. Furthermore, it was designed according to

a user-friendly approach. For its development AGILE and Scrum methodologies were used for iterative progress and continuous team involvement. The design considered data and human aspects, creating a "Solution Store" that integrates personal management and marketplace elements.

The platform workspaces are configured (Figure 9a,b) as follows:

- Landing: access to all workspaces, highlighted functionalities, and language control
- Solutions Store: it allows access to TSAs as well as to relevant documents, regulations, and methodologies supporting the renovation process on the basis of a specific location and profile, and through training and review resources. A core tool of the Solutions Store is the One Click, where users can explore maps with relevant information about pilot markets, energy diagnosis, renovation options, success stories, or best practices, capitalizing on the TSAs gathered. In particular, an increasable number of 20 success stories was mapped and duly described across the different pilot markets, thanks to the re-LABs involvement (Figure 10).
- Activity Hub: publications, news, and professional membership to configure the market stakeholders' space.
- Personal Dashboard: managing work, experience, and network.
- Admin Panel: managing the content of a platform version related to a geographic area.



(**a**) (**b**)

Figure 9. (**a**) Visual re-MODULEES platform concept; (**b**) visual framework of platform content.

Moreover, the renovation solutions considered within re-MODULEES are grouped considering interventions on Systems, Envelope, Renewable Energy Source (RES), Behavior, Financing, or Innovation. These solutions not only address the technical and structural aspects but also account for user behavior and financial practices, offering a holistic approach to building retrofit projects.

Thanks to the TSA survey, the capitalized resources have been associated to one or multiple modules, creating a versatile tool for navigating the array of available options for each TSA through the following filters:

- the addressed constraints for each market side (demand, supply, financial, and institutional) and categories (cultural, technical, social, processual, and financial)
- the main interested country and the other countries;
- the type of solution considered (Systems, Envelope, Renewable Energy Source (RES), Behavior, Financing, or Innovation);

- the CJ stops (no. 5) and steps (no. 15) of the renovation process to be faced;
- the building typology of the renovation interventions (Apartment Block; Multi Family Home; Single Family Home; Terraced House).

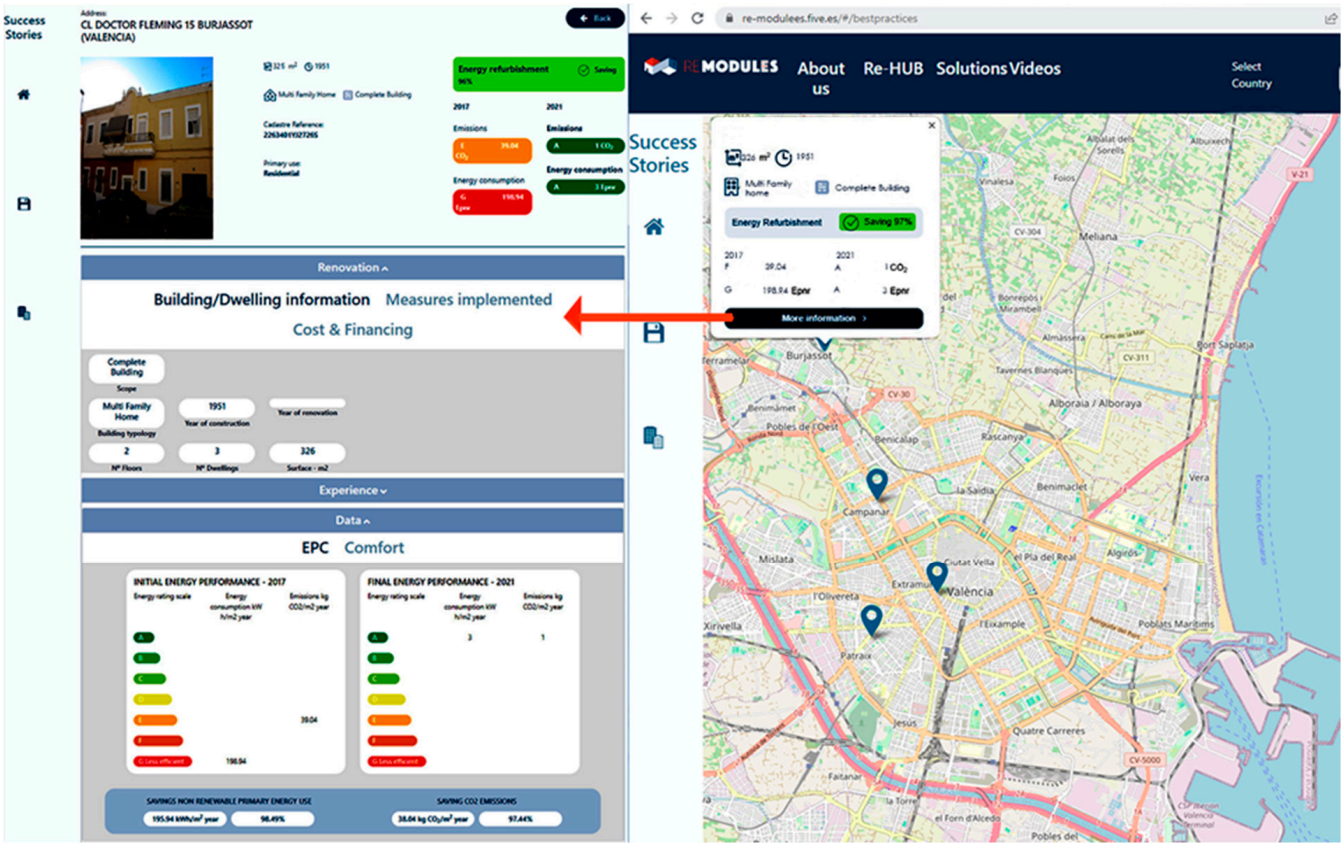


Figure 10. Success stories on GIS-based map of re-MODULEES platform.

In this way, it is possible to select filters and obtain the most suitable tools according to the user's needs.

For instance, an owner wishing to use the platform should first select "Solution" from the menu bar at the top, which grants access to the "Solutions Store." Within the Store, there are two levels of filters available. At the first level, the owner may select the "Demand" side option and then choose a constraint category. This action opens a dropdown list with relevant constraints, allowing the owner to select the appropriate ones and so, to identify the most suitable TSAs (Figure 11a). Following this, by clicking the "Filter" button on the right, additional filters are presented for more refined searches. The owners may then specify their country (e.g., Italy, as shown in Figure 11b), the desired interventions, CJ stops, steps of interest, and, finally, the building typology. The corresponding TSAs are then displayed (Figure 11b).

The platform's development (https://re-modulees.five.es/#/home; accessed on 24 October 2024) leveraged a combination of robust software tools, integrating a previous design that supports various functionalities, including data management, processing, web hosting, and map integration.

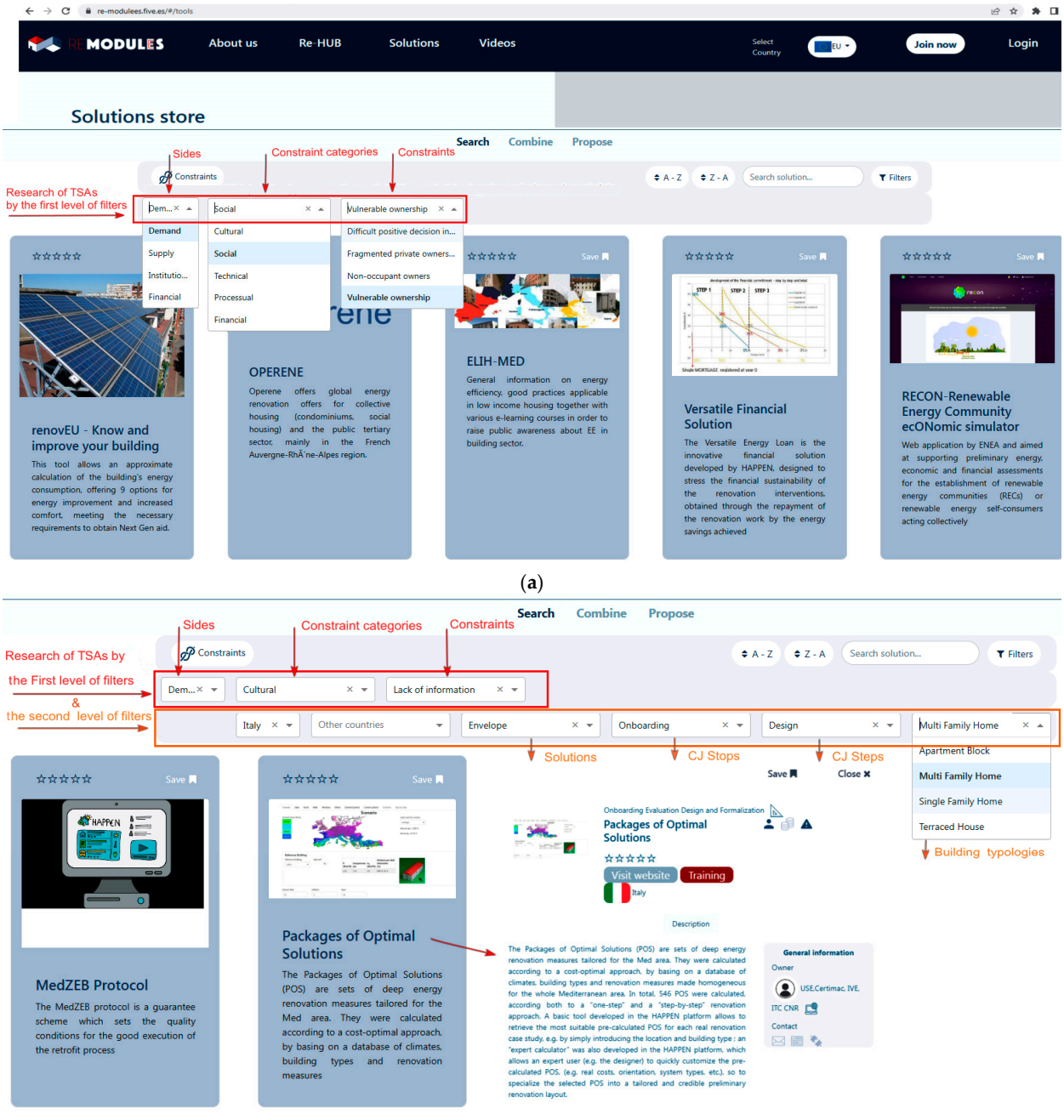


Figure 11. TSA research with the filters of re-MODULEES platform according to the first level of filters based on market side, constraint category, and specific addressed constraint (**a**) and according to the second level of filters based on countries (the Italian ecosystem is chosen), kind of solutions, CJ stops and steps, and building typologies (**b**).

3.5. Exploitation

One of the main objectives of re-MODULEES was to incubate re-HUBs from re-LABs to rationalize their mission and functioning, to guarantee their long-term sustainability, and to enhance their market uptake capacity of innovative tools and services. To this end, an exploitation approach was adopted based on the following main activities:

- accurately identifying and characterizing project KERs;
- co-developing tailor-made business plans (BPs) and exploitation plans (EPs);
- performing a targeted KERs promotion across stakeholders' communities.

The project KERs detected and addressed for exploitation were the market activation platform (MAP) and the re-HUBs. Exploitation activities proved to be crucial in mobilizing commitment and stimulating outcomes, and contributed to enhancing the overall credibility of the innovation process carried out by re-MODULEES. The following operational choices provided a concrete added value to the exploitation process:

- capturing real end-user needs and market actor experiences by co-generating user and success stories;
- collaborating with EU umbrella associations;
- developing policy recommendations for better alignment among market sides.

In this frame, a set of powerful tools were used for achieving the specific objectives of the project SAP, namely: the characterization table (CT), the lean canvas (LC), the exploitation roadmap (ER), and the pitch template (PT). Table 5 shows the features of each tool, while Figure 12 shows their positioning in the SAP scheme, highlighting the exploitation milestones (ML) in which each tool was used. In particular, the KERs workshop was dedicated to defining the main project KERs, namely the re-HUBs and the MAP; the exploitation workshop was used for an in-depth characterization of the KERs in view of their exploitation; the lean canvas workshop was used to identify the business models for each KER exploitation; the re-HUBs workshops were used to define the exploitation roadmaps for each KER; and the pitch workshops were used to prepare the 3 min pitches used in the final events, where the re-LABs presented the experiences gained and the lessons learned during the project for promoting the re-HUBs in front of the stakeholder communities. Table 6 summarizes the main contents that emerged from these pitches.

Table 5. Features of each tool.

Tool	Key Information
Characterization Table (CT)	- Novel solution: Problem solved, USP, description of the result - Market: Size, trends, customers, competitors - External factors: Legal requirements, standards - Exploitation strategy, IPR status
Exploitation Roadmap (ER)	- Partner contributions - Funding sources after project end - Implementation costs and timeline - Estimated product/service price and adequacy of staff/external partners
Lean Canvas (LC)	- Who is the customer? - What is their problem? - How do they solve it now? - Is our solution more efficient?
Pitch Template (PT)	- Clear, concise presentation - Ideal for short, well-prepared pitches - Useful for securing funding or additional resources

These experiences were capitalized upon in each re-HUB by drafting policy recommendations at EU, national, and local levels, which aimed at increasing the capacity of the actual policy and regulatory frameworks to enhance the socio-economic sustainability of the ambitious EU de-carbonization targets of the built stock. Collected recommendations regard six main trends: i. Legislative Framework and Implementation; ii. Investment in Research, Innovation, and Education; iii. Deployment of Circular Value Chains; iv. Promotion and Support of One-Stop Shops (OSSs); v. Local Empowerment and Tailored Interventions; and vi. Promoting Awareness and Outreach. While the EU level is mostly concerned with

issues such as legislative harmonization, EU-wide certification, and support to innovation and research, national and local levels are mostly involved in implementation issues related to the financial support for DERs, as well as to upskilling and capacity building. The local level is also concerned with the deployment and durability of One-Stop Shops (OSSs) in the territory.

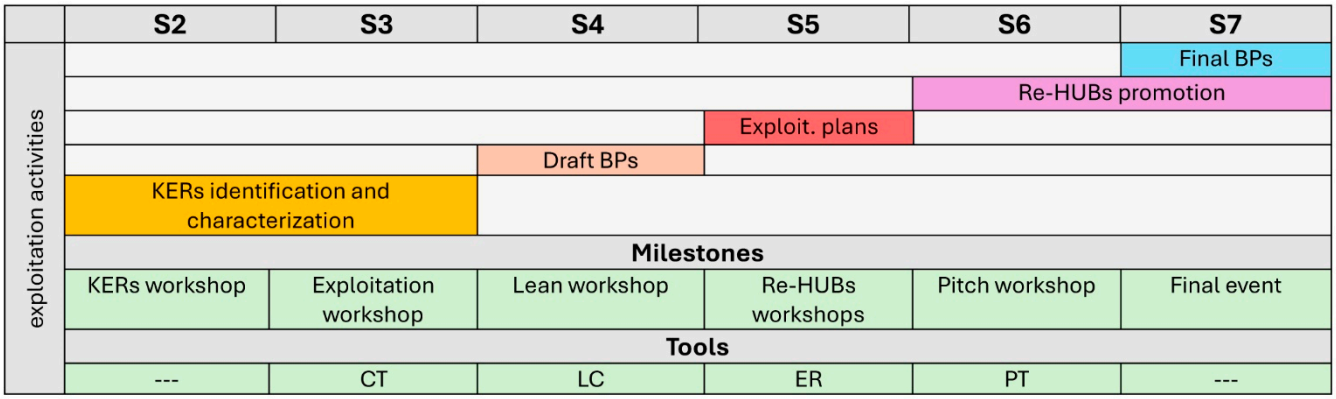


Figure 12. Exploitation activities involved in the SAP implementation.

Table 6. Focus and contents of re-LAB pitches.

Slide focus	Content
Main Challenges	Low stakeholder engagement and fragmented market. Lack of financial incentives. Complex technical and regulatory alignment.
Approaching the challenges	Stakeholder workshops for engagement. Financial models to reduce investment risk. Cross-sector collaboration.
Re-Hubs services	Digital platform for collaboration. Advisory services for financing. Training programs for professionals.
Lessons Learned & Future	Partnerships are key to long-term success. Simplified processes drove adoption.

Finally, the following table shows a synthesis of the business models (BMs) developed for each project KER, exposing the variety of solutions proposed by each re-LABs for their re-HUBs. The first KER regards the MAP, which is a horizontal digital asset transversal to all the re-HUBs forming the following KERs group. The table highlights the type of re-HUB activated in each pilot country, which can be operated either digitally based on the remote MAP usage, or physically by means of in-presence support. The possible MAP exploitation options regard a direct (commercial) use based on a "provision of service" principle, or an indirect use based on a licensing principle. Most re-HUBs conceived a business model based on a direct approach, while the French case envisaged a "business transfer" strategy. Services other than the MAP usage may vary from "free-to-use" up to "premium support". Their clustered list includes the following:

- integrated design service (IDS);
- technical, financial, and administrative support (TAFS);
- training, education, and capacity building (TECB);
- digital resources and tools (DRTs);
- enhancement of existing services (EESs);

- advice on adding new services (AANSs);
- signing innovation agreements (SIAs);
- business and networking opportunities (BNOs);
- incentive management (IM).

Three governance schemes were devised for operating the re-HUBs, which referred to different ownership settings: public, where public entities play a central role in driving renovation efforts and fostering trust among homeowners; private, where private actors are key players in the renovation market, focusing on efficient project delivery and service provision; mixed, where public and private stakeholders collaborate to accelerate deep renovation rates and address complex market dynamics. Finally, for each re-HUB, specific sets of early adopters were detected to be targeted in the start-up phase (Table 7).

Table 7. Business plans for the project KERs.

KER	Use	Gov.	Business Models in Brief	Focus on Early Adopters
MAP	Digital	---	Direct use: provision of services Indirect use: licensing of the code, knowledge transfer.	Focus on re-HUBs
Re-HUB: BG	Digital Physical	Public	Provision of services: IDS; TAFS; TECB; DRT.	Focus on demand side (owners, SMEs)
Re-HUB: F	Digital	Private	Indirect use: knowledge transfer to an organization embedded in the French renovation ecosystem	Focus on transfer partners: institutional, supply or financial
Re-HUB: GR	Digital	Public	Provision of services: EES; TAFS; TECB.	Focus on institutional (association of municipalities, technical chamber) and supply sides (associations of professionals, manufacturers and suppliers).
Re-HUB: IT	Digital	Mixed	Provision of services: TAFS; IM; TECB; BNO.	Broadband focus (multiple actors at Regional and National levels from demand, supply, financial and institutional sides)
Re-HUB: SI	Digital Physical	Public	Provision of services: TAFS; IDS; TECB; EES.	Focus on demand (housing managers) and supply sides (network of energy advisors)
Re-HUB: ES	Digital Physical	Public	Provision of services: EES; TECB; DRT; SIA.	Focus on institutional (Regional and other level PAs, public housing associations) and supply sides (professionals)
Re-HUB: NL	Digital	Mixed	Provision of services: EES; AANS; TECB.	Focus on energy-related service providers (energy desks, fixers, banks, cooperatives, OSS)

4. Discussion

Even if the same approach to transition was applied to seven local ecosystems with different features, the results highlight both several commonalities—regardless of the NUTS and context-related aspects, which are discussed below for each transition pathway.

TP1 guides the establishment of re-LABs and re-HUBs as key mechanisms for driving sustainable change. re-LABs are experimental and exploratory entities and have served as

incubators for new ideas, technologies, and methodologies, generating valuable insights and knowledge.

The analysis of the interaction outcomes with the stakeholders involved in the re-LABs intersects with TP2 and reveals several key commonalities and differences across the pilot countries. A consistent theme was the vital importance of stakeholder engagement. Active participation and collaboration among all actors, including homeowners, contractors, suppliers, local authorities, and financial institutions, were crucial for driving deep renovation initiatives. Furthermore, building trust emerged as paramount for success. This includes trust in the renovation process itself, the information provided, the digital tools employed, and the competence of contractors involved. Underpinning these factors is the need for clear communication. Accessible, transparent, and comprehensive information on renovation benefits, processes, costs, and available support mechanisms is essential for homeowner buy-in and project success.

Further results highlighted that, while digital tools like the re-MODULEES platform (TP4) can facilitate renovation by providing information, connecting stakeholders, and streamlining processes, their effectiveness hinges on user-friendliness and active promotion. However, despite these commonalities, distinct differences about constraints and needs also emerged across the ecosystems. For instance, the application of the approach showed that the Netherlands faces a particularly fragmented renovation market, requiring focused efforts to enhance visibility and foster collaboration among market players. In addition to process fragmentation, Italy reveals a significant fear among homeowners regarding the complexity, costs, and potential disruptions associated with deep renovation, highlighting the need for trust-building measures and showcasing successful projects.

Interestingly, Bulgaria has reported a relatively high level of business readiness for energy efficiency, suggesting opportunities to leverage existing knowledge and motivation within the private sector. While most countries prioritize information and platform-based solutions, Bulgaria has emphasized the need for Energy Centers to provide concrete services and products to actively engage consumers and businesses. The Netherlands has stressed the importance of securing public recognition and support for deep renovation, particularly concerning labor and financial incentives, to drive wider adoption. Slovenia, on the other hand, has reported significant regional differences in renovation regulations and processes, underscoring the need for location-specific guidance and support.

More generally, the results achieved highlight several key takeaways. Firstly, transition strategies in the EEB sector, even though a common framework is taken into account, must be tailored to the specific context of each country, considering unique challenges and opportunities. Secondly, trust serves as the foundation for successful deep renovation initiatives. Transparency, clear communication, and active stakeholder engagement are essential for building trust and driving homeowner buy-in. Moreover, the establishment of re-HUBs was possible thanks to exploitation activities that envisioned re-HUBS as permanent, self-sustaining entities underpinned by specific business models developed through ongoing feedback and learning from re-LABs (TP5). To this end, the toolkit composed by Standard Action Plan and Local Deployment Plans allowed for flexibly coordinating the re-LABs activity in the shape of an "open process", which, while keeping hands on its method and goals, could effectively enable and drive local ecosystems to experiment using a variety of innovation trajectories. As a result, re-HUBs are digital in all the pilot countries and have a physical presence in Bulgaria, Slovenia, and Spain. The analysis of the experiences and outcomes across different ecosystems revealed that while re-HUBs indeed share common goals, their specific contributions vary based on the local context and their value propositions. Common themes that emerged include streamlined access to information and services.

By leveraging the comprehensive suite of outcomes from the re-MODULEES project (TP2, TP3 and TP4), including the sophisticated digital platform and its diverse functionalities, the re-HUBs are equipped to drive impactful change on multiple fronts. re-HUBs simplify the complex renovation process by providing a central point of access to information, technical expertise, financial guidance, and a network of qualified professionals. They also enhance trust and transparency by acting as neutral and independent facilitators, providing reliable information, promoting transparent communication, and ensuring quality control throughout the renovation process. Moreover, re-HUBs foster collaboration and networking by serving as platforms for connecting diverse stakeholders, including homeowners, contractors, suppliers, financial institutions, and local authorities. This facilitates knowledge exchange, partnerships, and innovation within the renovation ecosystems; thus, it enhances and extends the ecosystem's capacity for carrying out joint actions, from the understanding of the specific needs and challenges of each region (social, cultural, technical, financial, regulatory, etc.), up to the development of multi-actor and multi-sector policy ideas. By promoting deep renovation, policy innovation, and the adoption of energy-efficient technologies, re-HUBs may indeed exert an impactful contribution to market transition, and stimulate economic growth in the green building sector. Despite these shared goals, differences in re-HUB implementation and focus were evident. The re-MODULEES project aimed to establish re-HUBs as digital, physical, or phygital One-Stop Shops (OSSs) across different European ecosystems, buttheir implementation and focus varied significantly due to the diverse levels of OSS maturity in each region. This highlights that the re-HUBs' role is intrinsically linked to the existing OSS landscape and its specific needs. Acknowledging the challenges faced across the EU in establishing and sustaining OSSs for building energy renovation, the Energy Performance of Buildings Directive (EPBD, 2024/1275) Article 22 (4) specifically calls for OSSs to offer technical, administrative, and financial advice, highlighting their crucial role in achieving EU energy-efficiency goals through the support of public authorities and /or appropriate private entities. The EPBD also allows for flexibility in how OSSs are implemented, leading to diverse approaches across Europe. This is already reflected in the three distinct OSS models identified with reference to the phygital re-HUBs established within the ecosystems (public, private, mixed ownerships). These varied approaches demonstrate the adaptability of the re-HUB concept and its ability to cater to diverse ecosystems, leading to a scenario in which OSSs of different types can be intended as the very "operating arms" of local ecosystems with different features.

Further discussions are needed on digitization, which can be the core of OSSs to improve and disseminate services and innovative tools.

While the built environment, including buildings and infrastructure, faces challenges in adopting digital technologies, the implementation of TP4 highlighted that the renovation sector exhibits varying levels of digital readiness across different ecosystems with reference to the renovation process. This disparity was particularly evident in the accessibility and availability of building data, a critical factor for efficient and effective renovation processes.

Within this context, the work of TP4, which was focused on the development of the re-MODULEES platform, proved essential in driving the digitalization of renovation processes across these diverse ecosystems. Overall, the development of the platform was a complex endeavor that necessitated a multi-faceted approach to address the challenges inherent in such a large-scale project. One of the primary hurdles encountered was the establishment of effective communication channels among the diverse stakeholders involved, including IT developers, end users, and project partners. The platform was designed to be more than just a collection of tools; it was envisioned as a comprehensive service capable of

addressing the specific needs and expectations of its users and driving positive change in the building renovation sector.

The development of TP4 in the ecosystems was a complex and iterative process that required a significant investment of time, resources, and expertise. By prioritizing effective communication, collaborative partnerships, and a user-centric approach focusing on context, interaction, and follow-up workspaces, it was possible to overcome challenges and deliver a powerful tool as a holistic solution that would empower users to make informed decisions and implement sustainable building renovation practices.

5. Conclusions

This research investigated the application of transition pathways theory (TPT) as a comprehensive frame to address the complex challenges inherent in the building renovation market. The TPT-based methodological approach presented in this paper and tested within the ecosystems examined is characterized by several key elements, each contributing to a holistic transition of the renovation landscape:

- Market Activation: This ongoing effort seeks to stimulate demand for renovation services and products by raising awareness among key stakeholders. Targeted campaigns will disseminate comprehensive information on the benefits of building renovation, while also facilitating access to existing financial incentives, technical assistance programs, and regulatory guidance. This continuous engagement aims to catalyze both immediate action and long-term behavioral shifts towards energy efficiency.
- Impactful Renovation Processes: Recognizing the need for efficiency and accessibility, this element focuses on streamlining and optimizing renovation processes. By leveraging and capitalizing on existing resources, such as digital platforms, standardized procedures, and best practice guidelines, the TP approach ensures that renovation solutions are both efficient and tailored to individual building needs. This includes promoting the use of building information modeling (BIM) and other digital tools to enhance the design, planning, and execution of renovation projects.
- Innovative Vision: This element encourages a shift away from conventional thinking, promoting the adoption of forward-thinking and innovative solutions that address the complex challenges of building renovation. This includes exploring new technologies, materials, and construction methods, as well as fostering cross-sectoral collaboration to develop integrated solutions that consider energy efficiency, occupant comfort, and environmental impact. It also involves the individuation and deployment of innovative policy approaches at different levels, intended as enablers and stimulators of more advanced market behaviors.
- Community Building: Recognizing the importance of stakeholder engagement, this element facilitates the creation of vibrant, interconnected communities. By bringing together building owners, occupants, industry professionals, policymakers, and researchers, the TPT-based approach fosters collaboration, knowledge exchange, and shared learning. These communities serve as platforms for identifying challenges, developing solutions, and disseminating best practices, ultimately accelerating the transition towards a sustainable built environment.
- Focus on Usefulness and Results: This element prioritizes the development and delivery of practical, user-centric solutions that yield tangible benefits for all stakeholders. By focusing on the needs and priorities of building owners, occupants, and the broader community, the TPT-based approach ensures that renovation efforts translate into real-world improvements in energy efficiency, comfort, affordability, and environmental performance. This includes the clear communication of renovation benefits, simplified access to financing options, and ongoing support throughout the renovation process.

The application of the TPT frame within the re-MODULEES project demonstrated its effectiveness in holistically addressing the complexities of the renovation market. By integrating these key elements, the project facilitated the development of a robust framework for activating One-Stop Shops (OSSs) with both public and private support. These OSSs serve as central hubs for information, guidance, and assistance, streamlining the renovation process and empowering building owners to undertake energy-efficiency upgrades. This achievement aligns with the objectives of the Energy Performance of Buildings Directive (EPBD) (2024/1275), which emphasizes the role of OSSs in driving deep renovation and the decarbonization of the building stock.

These results were achieved thanks to a multi-level, multi-sectoral, and multidisciplinary approach integrating expertise from research institutions, commercial enterprises, financial institutions, and public authorities at both local and national levels. This collaborative effort ensured that the developed framework for OSS activation is comprehensive, sustainable, and responsive to the needs of all stakeholders.

The research carried out provides compelling evidence for the efficacy of the TPT-based methodological approach applied in the studied contexts. The variety of input and output resources characterizing the pilot processes implemented suggests the capacity of the tested approach to cope with a wide range of differences between local ecosystems—geographical, social, economic, climatic, institutional, etc.—and produces an opportunity in favor of its replication potential across EU countries and territories. However, further investigations are necessary to validate its applicability in other territorial settings within or outside Europe. These future studies should consider variations in digital TPT adoption, stakeholder engagement maturity, and policy awareness. For instance, regions with limited digital infrastructure may require alternative approaches to information dissemination and service delivery. Similarly, contexts with lower levels of stakeholder engagement may necessitate more intensive capacity-building efforts to foster collaboration and knowledge sharing.

Ultimately, this research contributes valuable insights into the potential of TPs to drive sustainable building renovation, promoting a more energy-efficient, environmentally responsible, and sustainable built environment. By embracing a holistic, user-centric, and collaborative approach, the TPT-based methodological approach presented offers a promising perspective for achieving the EU's deep renovation targets. In particular, the article confirmed the soundness of the research question underlaying the present study, which aimed at investigating the importance of supporting the EU's EEB markets by means of a strategic and enduring capitalization process of the innovations produced at the EU level. Far from being exhaustive with respect to the variety of EEB market ecosystems in the EU, the experimentations carried out in the re-MODULEES project concretely showed how this process can be seminal for stimulating the transition of actual renovation markets into collaborative and reflexive ecosystems, as well as for framing the further implementation of such a transition within and across EU countries.

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Appendix A

Table A1. Innovation trends after clustering process.

Organizational Innovation Trends
Relationship with local universities
Construction fairs for promotion and innovation camp
Green public procurement promotion
Coordination of training for local suppliers
Different administrative levels coordination
One-Stop-Shop renovation services
Energy communities
Projects, tools, cluster, and app around renovation or regeneration issues
Presence of public service that provide guidance (free of charge) in energy renovation activity
Institutions to support building market innovations
Financial incentives to improve quality of buildings and urban regeneration
Design Innovation Trends
Growing use of BIM
Co-design, user-centered solutions, friendly visualization (3D, virtual reality) design
Digital buildings platforms and tools for renovation projects
Growth of quality ratings/labels/certifications awarded by third-party and independent entities to reinforce and build trust of the quality work
Construction products reuse: renovation of buildings coupled with circularity economy
Building electronic ID mandatory
Blower door test mandatory
Energy community as a broker between the government and home-owners

Table A1. *Cont.*

Financial Innovation Trends
Green mortgages
Public grants—private funding combination
Financing through contractor
Third-party investment, associated to emerging one-stop shop renovation services
Uptake of eco-loans or green loans from banks
Public incentives for energy saving measures anti-seismic interventions and the use of renewable energy sources
Uptake of ESG investments in renovation
Crowdfunding bottom-up financing for the implementation of projects in the energy sector
Loans made available by the (local) hub
Technical Innovation Trends
Use of better insulation materials and airthightness components
Implementation of RES
Mechanical ventilation with heat recovery
Use of triple glazed windows
Electrification (no fosil fuels), provision of electrical infrastructure to enable at later stage, the installation of recharging points for electric vehicles
Pre-fabrication
BIM (building information modelling)
Augmented workers and equipment (AI help human decision making, augmented reality, connected workers)
Augmented construction products (IOT, connected objects, green products)
Big data
Services platform and artificial intelligence
Uptake of energy efficient heat pumps due to high cop
Uptake of natural gas boilers
Provisions for building systems automations and controls in new buildings and where feasible in renovations (introduction of buildings 'smart readiness indicator')
District heating
Integration of RES in existing building in historic center
Hybrid HVAC systems with two heat generators powered by a fossil fuel and a renewable source
HVAC systems with innovative storage systems
Sustainable and efficient materials (including biomaterials) for building envelope
HVAC systems to guarantee indoor air quality limiting virus circulation
Sensor-based materials which allow predictions of the degradation of walls
ICT tools to measure, monitor, and analyze existing buildings
Innovative technologies for the seismic improvement of buildings, avoiding interruption of their use
ICT tools to support on-site work execution
New system for addressing both energy and seismic retrofitting. it is based on the partial use of waste materials, such as fly ash and expanded glass (acting as a matrix) and a fiber open grid reinforcement
"Biomattone" (biobrick) is a solution which offers high energy savings, combined with the sustainability of materials and products, while remaining, in terms of shape and size, very close to the culture and construction system
Biocompound (mixture) of hemp, lime, and minerals (not cement) to build and insulate walls, roofs, floors, or attics.
Plug in PV to cover belt electricity use in multifamily buildings and individual houses

Appendix B

Description of TSA synthesis of each TSA is reported in Table A2.

Table A2. Description of each TSA.

1	BIPV	Building Integrated Photovoltaic
Synthetic description	Software for the early design phase of BIPV systems.	
Availability	Energy Matching Platform (https://platform.energymatching.eu/, accessed on 31 January 2025)	
Geographical Scope	Europe.	
2	BUILD UP	BUILD UP Skills advisor app
Synthetic description	An app that enables craftsmen and professionals to explore upskilling opportunities with regards to sustaining the built environment. It also has functionality to train on quality assurance with visual checks.	
Availability	Apple and Google app-stores.	
Geographical Scope	The app is available in German, Hungarian, Slovak, English, and Spanish languages. It is implemented in Ireland, EU (as region), and the Netherlands. Implementations for Spain, Austria, North Macedonia, France, and Hungary are in progress.	
3	CAP RENOV+	CAP RENOV+ (additional modules CAP RENOV AIDES)
Synthetic description	CAP RENOV+ is an app simulating an energy renovation, while CAP RENOV AIDES is an additional module simulating available financial support for a given energy renovation.	
Availability	https://www.cap-renov.fr/fonctionnalites-logiciel-aides-financieres.html (accessed on 31 January 2025) https://www.cap-renov.fr/ (accessed on 31 January 2025))	
Geographical Scope	France.	
4	CASACLIMA	PROCasaClima2022
Synthetic description	Energy performance calculation tool developed by the CasaClima Energy Agency of Province of Bozen.	
Availability	https://www.agenziacasaclima.it/it/e-online-procasaclima-2022--9-2419.html (accessed on 31 January 2025)	
Geographical Scope	Autonomous Province of Bozen and Italy.	
5	CERPLAN	CERPLAN
Synthetic description	The software developed by Eurac Research will make it possible to organize a correct planning of interventions and, above all, to identify where and when to intervene with a rapid economic return.	
Availability	https://cerplan.eurac.edu/login/ (accessed on 31 January 2025)	
Geographical Scope	Italian context. Tool available in English and Italian.	
6	CHC Register	BUSLeague—CHC Register
Synthetic description	BUSLeague aims to stimulate the demand for energy-skilled workers and increase the number of skilled workers by recognizing energy skills and using effective training methods. It also provides a scheme to offer transparent information about buildings, companies, professionals, and products.	
Availability	https://registrochc.five.es/ (accessed on 31 January 2025)	
Geographical Scope	EU, specifically Austria, Bulgaria, Spain, France, Netherlands, and Slovenia.	
7	CLT	Triple A-reno Combined Labeling Tool
Synthetic description	A method to conclude monitored data gathered with different tools in different countries and ensure that the results can be compared with each other, even though different tools were used.	
Availability	https://triplea-reno.eu/results/ (accessed on 31 January 2025)	
Geographical Scope	Netherlands, Spain, Slovenia, Italy, Greece, and Hungary.	
8	COACH COPRO	Coach Copro
Synthetic description	Coachcopro is a free and independent service made available to condominiums to initiate their renovation procedures and undertake their future projects.	
Availability	https://www.coachcopro.com/ (accessed on 31 January 2025)	
Geographical Scope	France.	

Table A2. *Cont.*

1	BIPV	Building Integrated Photovoltaic
9	DOCET	DOCET V3.7
Synthetic description	DOCET is a monthly steady-state simulation tool for energy performance certificates (Attestato di Prestazione Energetica—APE) of existing residential buildings.	
Availability	https://www.efficienzaenergetica.enea.it/servizi-per/cittadini/docet.html (accessed on 31 January 2025)	
Geographical Scope	DOCET is an Italian software that can be use in each Italian region that has not emanated specific and different procedure. The software is in the Italian language.	
10	DRIVE-0	DRIVE-0 Circular Homes
Synthetic description	DRIVE 0 aims to enhance the deep renovation process to be more attractive, eco-friendly, quicker, and cost-effective by integrating circularity, product, and process innovation. It offers consumers and investors clear information on lifecycle performance and provides questionnaires for potential renovation solutions.	
Availability	https://www.circularhomes.eu/es/herramienta-circularidad-vivienda/ (accessed on 31 January 2025)	
Geographical Scope	EU, specifically Belgium, Estonia, Spain, Italy, Ireland, Netherlands, and Slovenia.	
11	eCENTRAL	The Living EPC Tool
Synthetic description	The Living EPC tool analyzes data from collected energy performance certificates and provides combinations of cost-optimal measures for reaching nZEB requirements in public buildings.	
Availability	https://nzeb.thorium.software/ (accessed on 31 January 2025)	
Geographical Scope	This tool was designed as an open-source application and therefore can be used by any interested party.	
12	e-LIBRARY	e-LIBRARY
Synthetic description	e-LIBRARY is a free online repository of publications where users may find useful information about energy saving, RES, and rational use of energy issues.	
Availability	http://www.cres.gr/cres/pages/xrisima/xrisima.html (accessed on 31 January 2025) http://www.cres.gr/cres/pages/xrisima/xrisima_uk.html (accessed on 31 January 2025)	
Geographical Scope	Greece (in Greek and English).	
13	ELIH-MED	ELIH-MED experience
Synthetic description	ELIH-MED develops energy efficiency policies through large scale pilot actions on 6 Mediterranean countries. It aims to identify cost-effective technical solutions, smart metering and energy awareness campaigns, and innovative financing mechanisms for energy efficiency measures.	
Availability	The official website of the project (www.elih-med.eu) is no longer available but there are a large number of resources available, particularly as regards the Greek and the Spanish pilot projects. Indicative project outcomes can be found here: https://we.tl/t-aItUwOILtt (accessed on 31 January 2025)	
Geographical Scope	Project partners were from 7 Mediterranean countries (Italy, France, Spain, Greece, Malta, Cyprus, and Slovenia). A total of 9 large-scale pilot projects were implemented in Italy, France, Spain, Greece, Malta, and Cyprus.	
14	ENERFUND	ENERFUND tool
Synthetic description	ENERFUND is a tool that evaluates and rates deep renovation opportunities. It helps energy companies identify customer segments, allows environmental heads to prioritize renovations and allocate funds, and enables financial institutions to offer targeted loans for building retrofits.	
Availability	https://app.enerfund.eu/ (accessed on 31 January 2025)	
Geographical Scope	Austria, Bulgaria, Cyprus, Denmark, France, Greece, Ireland, Romania, Slovakia, Slovenia, Spain, and UK.	

Table A2. *Cont.*

1	BIPV	Building Integrated Photovoltaic
15	EnergyTransitionGame	Tripe A-reno Energy Transition boardgame
Synthetic description	Tool to co-create retrofitting concepts to sustain buildings. With the use of gamified support tools, TripleA-reno helps the stakeholders understand the renovation process, guiding them into making economically wise and sustainable decisions in home renovations.	
Availability	https://buildupskillsnederland.nl/ (accessed on 31 January 2025)	
Geographical Scope	Available in Dutch, Hungarian, Slovenian, Spanish, and English.	
16	ENSVET	Informative resources on the renovation
Synthetic description	Informative resources on the renovation market: 1. Marketing materials from national subsidy provider 2. How to obtain a subsidy 3. Network of energy advisors (EnSvet).	
Availability	http://www.kocevje.ensvet.net/ (accessed on 31 January 2025)	
Geographical Scope	Slovenia.	
17	EPISCOPE	EPISCOPE
Synthetic description	The overall strategic objective of the EPISCOPE project was to make the energy refurbishment processes in the European housing sector transparent and effective.	
Availability	https://episcope.eu/building-typology/webtool/ (accessed on 31 January 2025)	
Geographical Scope	Case studies were conducted in 16 countries to track the implementation of energy saving measures and their effect on the consumption in practice.	
18	FIT-TO-NZEB	FIT-TO-NZEB trainings
Synthetic description	FIT-TO-NZEB aims to increase the competence and skills of building professionals through unique educational programs and pilot training courses which contribute to both the quality and the scale of the deep energy building renovations.	
Availability	http://www.fit-to-nzeb.com/bulgaria.html (accessed on 31 January 2025)	
Geographical Scope	Ireland, Czech republic, Italy, Croatia, Bulgaria, Greece, Romania, Austria, Ukraine, and Turkey.	
19	HEC	Home Energy Check
Synthetic description	Home Energy Check is a free online tool which allows homeowners to learn the energy consumption of their dwellings as well as to find different ways to save energy.	
Availability	https://www.energyhubforall.eu/ (accessed on 31 January 2025)	
Geographical Scope	Austria, Belgium, Greece, Italy, Poland, Portugal, Slovakia, Netherlands, and UK.	
20	HEERO	HEERO
Synthetic description	The HEERO platform is an intelligent online registry keeping track of the maintenance and management of the house.	
Availability	www.heero.fr (accessed on 31 January 2025)	
Geographical Scope	France.	
21	HS REPLACE	Heating system calculator replacement
Synthetic description	The aim of this tool is to objectively compare heating systems for your existing building over the entire operating life and draw conclusions about actual costs and environmental performance.	
Availability	https://www.energieinstitut.at/tools/Replace/ (accessed on 31 January 2025) https://ceu.ijs.si/projekti/zamenjaj-star-kotel.html (accessed on 31 January 2025)	
Geographical Scope	Austria, Germany, Bosnia and Herzegovina, Bulgaria, Croatia, North Macedonia, Slovenia, and Spain.	

Table A2. *Cont.*

1	BIPV	Building Integrated Photovoltaic
22	iBroad	Roadmap Assistant and Logbook
Synthetic description	The Individual Building Renovation Roadmap offers a customized long-term renovation plan by allowing users to input building information and define renovation steps. The iBRoad Roadmap serves as a diagnostic tool and step-by-step renovation guide, while the iBRoad Logbook acts as a digital repository for all building-related data and efficiency representation.	
Availability	Roadmap: https://ibroad.blue-planet.be/ (accessed on 31 January 2025) Logbook: https://ibroad-logbook.blue-planet.be/ (accessed on 31 January 2025)	
Geographical Scope	Developed and tested in 3 EU countries (Bulgaria, Poland, Portugal) with more than 20 real buildings per country.	
23	Ikwoon	Ikwoon
Synthetic description	The Ikwoon web application helps homeowners to show interesting sustainability options for their home. With the app they can, after filling in a number of questions, see exactly the smartest, fastest, and cheapest solutions to make their home more sustainable.	
Availability	http://www.ikwoon.io/ (accessed on 31 January 2025)	
Geographical Scope	The tool was developed for the Dutch market. Replication to other markets is possible; however, the structure of the specific housing market should be added.	
24	KLIMAKIT	KLIMAKIT
Synthetic description	KlimaKit project aims to support the construction and energy sector in South Tyrol by promoting public housing institutions and public administrations to test innovative solutions and models for the energy renovation of residential buildings.	
Availability	https://www.eurac.edu/en/institutes-centers/institute-for-renewable-energy/projects/eu-fesr-klimakit (accessed on 31 January 2025)	
Geographical Scope	Retrofit of the residential buildings located in the Province of Bozen.	
25	MedZEB	MedZEB Protocol
Synthetic description	The MedZEB Protocol is a flexible tool for renovation processes that involve all stakeholders and it can be customized on the basis of energy saving targets according to the needs and financial resources of investors.	
Availability	https://medzeb-happen.eu/ (accessed on 31 January 2025)	
Geographical Scope	Mediterranean Area. Partner Countries: Croatia, Cyprus, France, Greece, Italy, Slovenia, and Spain.	
26	Microtraining	BUS League—Microtraining
Synthetic description	BUSLeague aims to stimulate the demand for energy skilled workforce (demand side), along with hands-on capacity building to increase the number of skilled workforce across the building design, operation, and maintenance value chain (supply side).	
Availability	https://www.youtube.com/channel/UCwyZir-H6jMQIZcDlqFB1RQ (accessed on 31 January 2025)	
Geographical Scope	EU, specifically Austria, Bulgaria, Spain, France, Netherlands, and Slovenia.	
27	OPERENE	OPERENE
Synthetic description	Operene offers comprehensive energy-renovation packages and intervenes at every stage of the project, from the financial study to the coordination of a group of local businesses.	
Availability	http://operene.fr/ (accessed on 31 January 2025)	
Geographical Scope	Region Auvergne Rhone Alpes (part of our re-LAB).	
28	PETA	Pan-European Thermal Atlas
Synthetic description	The Pan-European Thermal Atlas (Peta) was developed within the Heat Roadmap Europe (https://heatroadmap.eu/; accessed on 31 January 2025) project series to map the heat sector and the potential for district heating in European countries.	
Availability	https://www.seenergies.eu/peta5/ (accessed on 31 January 2025)	
Geographical Scope	Europe.	

Table A2. *Cont.*

1	BIPV	Building Integrated Photovoltaic
29	POS	Packages of Optimal technical Solutions
Synthetic description	The Packages of Optimal Solutions (POS) are sets of deep energy renovation measures tailored for the Med area. They were calculated according to a cost-optimal approach based on a database of climates, building types, and renovation measures made homogeneous for the whole Mediterranean area.	
Availability	https://medzeb-happen.eu/ (accessed on 31 January 2025)	
Geographical Scope	EU Mediterranean area (validated in Spain, France, Italy, Slovenia, Croatia, Greece, and Cyprus). Existing residential building stock.	
30	PVGIS	PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM
Synthetic description	PVGIS provides information about solar radiation and photovoltaic (PV) system performance for any location in Europe and Africa, as well as a large part of Asia and America.	
Availability	https://re.jrc.ec.europa.eu/pvg_tools/en/ (accessed on 31 January 2025) Available in English, French, Italian, Spanish, and German.	
Geographical Scope	Whole of Europe, Africa, Asia, and America.	
31	QualDeEPC	Home/Building Energy Renovation Tool
Synthetic description	The Home/Building Energy Renovation Tool aims to inform people about the energy demand, energy rating, and CO_2 emissions in their home/residential building (accessed on 31 January 2025)	
Availability	Not available yet.	
Geographical Scope	Greece, German, Bulgaria, Latvia, Hungary, Belgium, Spain, and Sweden.	
32	RECON	Renewable Energy Community ecONomic simulator
Synthetic description	RECON is a web application created by ENEA aimed at supporting preliminary energy, economic, and financial evaluations for the establishment of Renewable Energy Communities (RECs) or self-consumers of renewable energy acting collectively according to the Italian regulation.	
Availability	https://recon.smartenergycommunity.enea.it/whatis (accessed on 31 January 2025)	
Geographical Scope	Italy (in Italian and English).	
33	REFURB	REFURB
Synthetic description	The REFURB project focused on bridging the gap between the supply side (building construction sector) and demand side (homeowners) by developing dedicated renovation packages for different market segments within the residential sector.	
Availability	https://www.refurb-project.eu/cases/ (accessed on 31 January 2025)	
Geographical Scope	REFURB is a consortium of 13 partners from the following countries: Belgium, The Netherlands, Denmark, Slovenia, Estonia, and Germany.	
34	REHVA	REHVA calculator to estimate the effect of ventilation on COVID-19 airborne transmission.
Synthetic description	REHVA created COVID-19 Task Force to respond to pandemic-related implications in HVAC of buildings. Excel-based calculator for risk assessment based on room geometry and ventilation properties.	
Availability	For single room https://www.rehva.eu/covid19-ventilation-calculator (accessed on 31 January 2025) Multi room https://www.rehva.eu/activities/covid-19-guidance/covid-19-multi-room-calculator (accessed on 31 January 2025)	
Geographical Scope	Available in English, guides are translated to several languages.	
35	renovEU	Save the Homes
Synthetic description	Save the Homes will create innovative “integrated home renovation services” within already established frameworks for OSS networks in Valencia (ES) and Rotterdam (NL).	
Availability	http://renoveu.five.es/#/Welcome (accessed on 31 January 2025)	
Geographical Scope	EU, specifically Spain, Netherlands, and Slovenia.	

Table A2. *Cont.*

1	BIPV	Building Integrated Photovoltaic
36	RENOWIZ	Triple-A-Reno"pro design" renovation wizard
	TripleA-reno solves the main market barriers for deep renovation by developing an open-end user-centered gamified platform for validation and community building.	
Availability	https://bramo.eu/tar-lrvl-8/public/wizard-pro (accessed on 31 January 2025)	
Geographical Scope	Available in English, countries with data are EU27 and Norway.	
37	SENSI TOOL	Triple A-Reno SensiSensor Tool
Synthetic description	Tool to measure the indoor climate of your home. The SensiSensor Tool measures temperature, CO_2, humidity, light, and movement. No installation needed and accessible from an online dashboard.	
Availability	https://www.huygen.net/innovaties/binnenklimaat-expert-nodig (accessed on 31 January 2025).	
Geographical Scope	This tool was used specifically in the Netherlands during TripleA-Reno and now they are testing it in Spain (Valencia) if all works out.	
38	SEPAP	Smart Energy Performance Assessment Platform
Synthetic description	SEPAP is a cloud platform integrating three modular approaches and making use of the most advanced techniques in dynamic and automated simulation modeling, big data analysis, machine learning, inverse modeling, or the estimation of potential energy savings and economic viability check.	
Availability	Not developed yet.	
Geographical Scope	Austria, Belgium, Finland, Germany, Greece, and Spain.	
39	SISMA SET	SISMA SET TOOL
Synthetic description	SISMA's main goal is to develop innovative financing schemes that combine public resources with private investments and create conditions for deep investments for energy efficiency of public buildings considered bankable by the market.	
Availability	https://sisma.interreg-med.eu/sisma-set-tool/ (accessed on 31 January 2025).	
Geographical Scope	Italy, Greece, Slovenia, France, Spain, Bosnia, and Herzegovina.	
40	SOLARTIROL	SOLARTIROL
Synthetic description	The tool aims to support the local objective of the Land Tyrol and the Autonomous Province of Bolzano to enforce the utilization of renewable energy, in particular solar energy.	
Availability	/ https://www.eurac.edu/en/institutes-centers/institute-for-renewable-energy/tools-services/gis-energy-maps (accessed on 31 January 2025).	
Geographical Scope	Tyrol and Province of Bozen.	
41	Train-to-NZEB	The Building Knowledge Hubs of Europe
Synthetic description	Methodology for creating a full-fledged learning center for which we have a specification on how to make a learning center, specification on demonstration packages and learning materials (teaching aids, demonstration materials). It is used as a concept for the Re-HUB in Gabrovo.	
Availability	https://train-to-nzeb.com/ (accessed on 31 January 2025).	
Geographical Scope	Bulgarian, Romania, Czech republic, Ukraine, and Turkey.	
42	TRAP-EE	Training for maintenance staff
Synthetic description	The main goal of the TRAP-EE is to develop a training program for caretakers towards achieving operational energy efficiency of the public buildings.	
Availability	https://iri.uni-lj.si/arhiv/trap-ee/ (accessed on 31 January 2025).	
Geographical Scope	Slovenia, Austria, and Croatia.	

Table A2. *Cont.*

1	BIPV	Building Integrated Photovoltaic
43	VEL	Versatile Energy Loan financial solution
Synthetic description	The Versatile Energy Loan, developed by HAPPEN, is a solution designed to ensure the financial sustainability of the retrofitting interventions, obtained through the repayment of the renovation works by the energy savings achieved (also by taking into account eventual incentives).	
Availability	https://medzeb-happen.eu/ (accessed on 31 January 2025).	
Geographical Scope	EU Mediterranean area (validated in Spain, France, Italy, Slovenia, Croatia, Greece, and Cyprus) Existing residential building stock.	
44	XALOC	Save the Homes—XALOC network
Synthetic description	Save the Homes aims to create innovative "integrated home renovation services" within already established frameworks for OSS networks in Valencia (ES) and Rotterdam (NL). It promotes an integrated home renovation service: One-Stop Shops as Citizens' Hubs to support home retrofitting.	
Availability	XALOC network (for Valencia Region)—https://xarxaloc.es/ (accessed on 31 January 2025).	
Geographical Scope	EU, specifically Spain, Netherlands, and Slovenia.	
45	X-TENDO	X-tendo toolbox
Synthetic description	X-tendo toolbox introduces ten features of the next generation of energy performance certificates, to provide public authorities with improved compliance, reliability, usability and convergence of next-generation energy performance assessment and certification.	
Availability	https://x-tendo.eu/toolbox/ (accessed on 31 January 2025).	
Geographical Scope	Austria, Belgium, Denmark, Estonia, Greece, Italy, Poland, Portugal, Romania, and UK.	

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