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Lessons learned from international case studies

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ABSTRACT

Renovation at district scale is a key strategy to reduce CO_2 emissions by optimising the implementation of renewable energy sources and taking advantage of economy of scale. This paper focuses on analysing good practice examples on energy renovations at district scale. The paper adapts a qualitative research methodology in four phases, including the multi-perspective analysis of nine exemplary renovation projects in six European countries, including identification of drivers and barriers of different stakeholders.

It is found that the drivers for a district renovation are not restricted to energy savings, but typically also include improving the overall quality of life as well as the image and economic value of a district. Moreover, the need for financial models that can alleviate split-incentive problems between investors and resident organizations is identified.

Barriers for carrying out a district renovation include that there is a need to comply with energy standards, that the renovation scope had to be limited to avoid a noticeable rent increase and that resettling of tenants during the renovation is often not possible.

Lessons learned include that good communication amongst the different stakeholders, especially with residents, plays a key role for the success of the project. Furthermore, a strong leadership is needed to coordinate activities due to the great number of stakeholders.

1. Introduction

Buildings account for approx. 40 % of the world's total energy use and 30 % of CO_2-emissions (European Commission, 2012a). Therefore, the energy efficiency of buildings (reducing energy demand and emissions) and the utilization of renewable energy sources (reducing emissions) are of high priority (European Commission, 2012b, 2018a, 2018b). In recognition of this, most countries have had a strong focus on

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the energy efficiency of new buildings during the last few decades. However, the building stock in e.g. Europe is relatively old and consists of more than 40 % buildings built before 1960 and more than 90 % before 1990 and replacement and expansion rates are extremely low (approx. 1 % per year) (Artola, Rademaekers, Williams, & Yearwood, 2016). Renovation rates are also very low, i.e. the annual reduction in the building stocks primary energy use is approx. 1 % per year (average for years 2012–2016) (Esser, Dunne, Meeusen, Quaschning, & Wegge, 2019), which means that the building sector is right now failing in delivering its share of CO_2-emission reductions.

A lot of research has already been conducted about the energy efficiency of existing buildings and balancing energy efficiency with renewable energy production, but typically, the focus has been set on single buildings, e.g. IEA EBC Annex 56 (Almeida & Ferreira, 2017; Mørck et al., 2016; Thomsen, Rose, Morck, Jensen, & Østergaard, 2015). However, due to the increasing complexity of the energy infrastructure regarding generation, distribution and use, the single building perspective can lead to sub-optimization for the community or society as a whole (Reynolds, Rezgui, & Hippolyte, 2017). Expanding the view to districts will also make it possible to tap into some of the smart grid benefits that will increase the potential of reducing overall energy use beyond what is achievable on the individual building level, by e.g. utilizing the flexibility of the grid and individual buildings (Jensen et al., 2017). Furthermore, focussing on entire neighbourhoods or even entire cities can also be beneficial through e.g. the economy of scale and higher levels of efficiency regarding resource use and waste minimization (Paiho, Abdurafikov, & Hoang, 2015).

Similarly, at European level, there have been several references during the last decade highlighting the necessity of increasing the energy renovation rates in general and the important role of upscaling renovation interventions (European Commission, 2018b). On the one hand, different tools that allow to analyse the potential of rehabilitation at different levels and scales, from an assessment of previous energy consumption and energy modelling, are being explored. In this research line, there are different studies in different European countries (Lidberg, Gustafsson, Myhren, Olofsson, & Ödlund (former Trygg), 2018; Monge-Barrio & Sánchez-Ostiz Gutiérrez, 2018; Romanchenko, Nyholm, Odenberger, & Johnsson, 2020), that show the diagnosis of the real state of the housing stock and energy saving potential based on different energy simulation scenarios. In those, different rehabilitation proposals applied to the entire district heating are assessed, with the aim of reaching a net zero energy consumption neighbourhood. Likewise, studies as the carried out in 1000 residential blocks in Rotterdam (Netherlands) (Nouvel et al., 2015) show that to diagnose and model initial energy consumption at urban scale with accuracy is the crucial starting point for any low carbon energy policy at urban scale. On the other hand, significant energy savings are shown when comparing previous status versus rehabilitated status with real data, as e.g. the study carried out in a neighbourhood at Lublin (Poland). In this study, energy savings after energy renovation of thermal envelope were 20.3 %, and up to 27.2 % with the installation in addition of cost allocators and thermostatic valves (Cholewa & Siuta-Olcha, 2015).

"Renovation Wave Strategy", published in October 2020 by the European Commission, aimed at doubling annual energy renovation rates in the next ten years, mentioning the necessity of developing neighbourhood-based approaches and integrating renewable solutions for creating zero-energy districts (European Commission, 2020).

The development of holistic energy renovation concepts and methodologies is therefore key. However only very limited research has gone into this field until now. Kamari, Corrao, and Kirkegaard (2017) developed a simplified holistic sustainability decision-making support framework based on e.g. a literature review, exploration of existing assessment methods and methodologies along with individual and focus group interviews. Kamari, Jensen, Corrao, and Kirkegaard (2019) developed a holistic multi-methodology for sustainable renovation, providing a framework to involve different stakeholders and making the design process more robust and efficient. Paiho et al. (2014) developed energy renovation concepts for Russian residential districts and Paiho, Abdurafikov, Hoang, and Kuusisto (2015) analysed different possible business models for energy efficient renovation of Russian residential districts. These, however, are very specific and narrow in their scope, and there is a need for methods with a wider perspective and more broadly applicable.

Based on the previously stated, IEA EBC (International Energy Agency, Energy in Buildings and Communities program) has initiated several new projects that focus on districts rather than individual buildings. One of these projects is IEA EBC Annex 75 "Cost-effective building renovation at district level combining energy efficiency & renewables" (2017–2022).

With the purpose of providing a guiding framework on opportunities and challenges for policy makers and investors in such interventions, this article presents an analysis and comparison of nine district renovation case studies. Previous studies have found that not only energy performances and targets are meaningful for driving such interventions, but other factors can be significant in the upscale of interventions targeting energy improvements, such as the reduction on CO_2 emissions (Andrić, Fournier, Lacarrière, Le Corre, & Ferrão, 2018; Rismanchi, 2017), the improvement of comfort conditions for inhabitants (Dall'O', Ferrari, Bruni, & Bramonti, 2020) and the increase in the economic value of buildings (Gustafsson, Gustafsson, Myhren, Bales, & Holmberg, 2016; Paiho, Abdurafikov, Hoang, 2015; Zavadskas, Raslanas, & Kaklauskas, 2008). In that context, the renovation case studies analysed here present different perspectives taken using a district approach which allowed for the reduction of energy consumption and, consequently, related CO_2 emissions. The rest of the paper is organized as following: Section 2 regards the description of the research methodology and phases, Section 3 the detailed description of the investigated district renovation case studies, Section 4 the comparison of the selected case studies based on defined key parameters and results, Section 5 the discussion and Section 6 the main findings and lessons learned.

2. Methodology

The work is based on a methodology described in more detail in Bolliger and Terés-Zubiaga (2020), IEA Annex 75 Webpage and Terés-Zubiaga et al. (2020).

The overarching goal is to develop a methodology for implementing cost-effective building renovation at a district level combining energy efficiency and renewable energy, with a particular focus on finding the optimum balance between them, as anticipated in the introduction, a study was accomplished regarding the assessment of existing case studies of buildings energy renovation at district scale. Following the definition proposed by Paiho, Ketomäki, Kannari, Häkkinen, and Shemeikka (2019), this study considers a "renovation at district scale" as an intervention in different buildings located in the same area. Although it is assumed that there is a relation between the buildings (for example that they could be served by the same district heating or be part of the same neighbourhood), the use of the term "district" is used in this study without juridical or administrative purpose in order to accommodate the different national context analysed in the scope of the project. In order to meet the objectives of the study, a methodology made of 4 phases was adopted (Fig. 1).

The first phase of the methodological approach of this study consists in the definition of the key parameters for the analysis of the case studies. For that purpose, these key parameters were defined through recursive discussions among the expert members of the project, also based on the knowledge acquired in IEA Annex 56 Webpage, which had a similar focus referred to individual buildings: Goal of the interventions, Balance between energy efficiency and renewable energy sources, Drivers (Decisive aspects for the successful implementation), Main barriers and influencing factors, Business models. Hence, based on the defined key parameters, a detailed template for collecting the

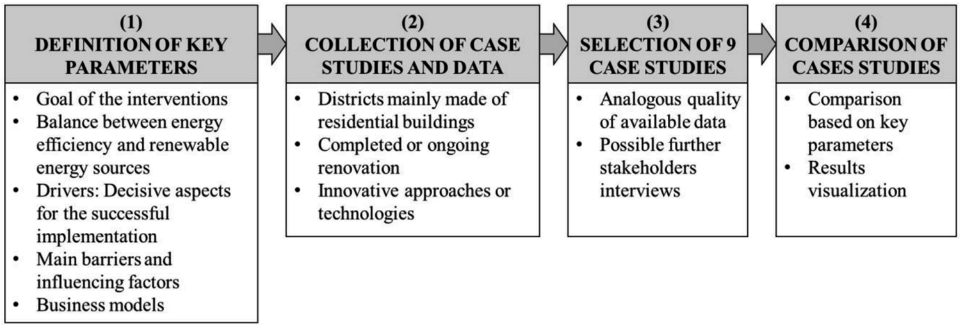


Fig. 1. Diagram of the research methodology.

information on the cross-sectional aspects of each district case study was developed. The detailed data template was made of the following sections:

(i) "Schematic figure or aerial overview",
(ii) "Introduction and description of the situation before the renovation" concerning both the envelope and the installed systems,
(iii) "Description of the renovation goal" either technical or non-technical,
(iv) "Description of the renovation concept" including the technical aspects (i.e. renovation of the envelope, the building or district level distribution system, the supply system for space heating, space cooling and domestic hot water energy demands, the renewable energy-based systems, the energy storages, the electrical systems and the Building Energy Management systems or other advanced control systems) and the non-technical ones (e.g., stakeholder involvement, communication, etc.),
(v) "Project Fact Boxes" summarizing in tables the data on the district characteristics, energy uses before and after the renovation and financial issues,
(vi) "Description of the technical highlight(s) and innovative approach(es)" either technical or not,
(vii) "Decision and design process", aimed at investigating the context and the pre-design steps that led to the retained solution by assessing the general and organizational issues, stakeholders' role and motivation, design approach, technical issues, financing issues, management issues, and policy framework conditions, and
(viii) "Lessons learned and interesting findings" to be transferred.

The second phase of the methodology concerned the collection of the renovation case studies in the different national contexts and of related data based on the technical documentation and interviews of involved stakeholders. Collection of the case studies to be analysed was carried out by the participants considering the following aspects:

- Consistent with the scope of the project, case studies should be districts mainly consisting of residential buildings i.e., single- and multi-family houses, (however, other types of buildings with similar characteristics regarding energy use, e.g., schools, simple office buildings, etc., could have been included in the analysis);
- The renovation intervention should be already implemented (or in the process of being completed).
- The renovation intervention should preferably include innovative approaches or technologies in relation to the common practice in the national contexts.

The initial collection comprised 16 heterogeneous examples of renovation case studies.

The third phase of the methodology consisted in selection of the most appropriate case studies for the further assessment and comparison. For this selection, the quality of available data regarding the criteria collected in Phase 1, as well as the possibility of further interviewing the involved stakeholders were determinant for the final selection constituted by nine case studies.

The forth phase of the methodology consisted in performing qualitative and quantitative comparisons of the selected case studies based on the defined key parameters, in visualizing the related outcomes through charts and, as a final result, drawing conclusions and extracting the lessons learned.

3. Case studies characterization

Table 1 presents a summary of nine case studies of district renovation gathered in the project. More detailed descriptions of each renovation project along with an interactive map showing their respective geographical location can be found in IEA Annex 56 Webpage. These nine projects form the basis for a multi-perspective analysis of similarities and differences between projects, which in the end is used to derive the most important lessons learned.

As can be seen from the table, the majority of the districts are strictly residential and only two are mixed (residential and schools/commercial/cultural). The buildings were constructed between the 1950s – 1980s and renovated during the last 10 years.

Table 2 presents more detailed data on the analysed district renovations. For further information on individual cases please refer to IEA Annex 56 Webpage.

4. Results

A cross-section analysis of the case studies has helped identify similarities, differences and general findings that can feed into the ongoing work. The analysis covered: goals of the interventions, the balance between energy efficiency and renewable energy sources, drivers, e.g. decisive aspects for the successful implementation of interventions, the main barriers and influencing factors, policy instruments, business models examples and the most important lessons learned. Those are the topics described in the data collection template (IEA Annex 56 Webpage), which was based on previous Annexes' experiences (Bolliger & Terés-Zubiaga, 2020), as explained in the methodology section. The topics are considered to cover the different phases and stakeholders of the case studies. As such they contribute to the replicability of the findings in different context of district renovation.

The analysis was carried out by comparing the individual parts of the case study descriptions, e.g. regarding stakeholder involvement or the goal of the intervention and then categorizing and cataloguing each case study for each parameter analysed. This way, case studies that have similarities were grouped and a cross-sectional analysis was carried out to withdraw as much information as possible. The following table summarizes the case-study analysis results, according to the identified topics. More details and elaboration of the results can be found in the respective Sections 4.1–4.5 (Table 3).

Table 1
Summary of the analysed case studies.

Country	Project	Nomenclature	City	Use	Year of	
					construction	renovation
Austria	Strubergasse	AT	Salzburg	Residential	1950–1965	2012–2018
Denmark	Kildeparken	DK	Aalborg	Residential	1970s	2014–2020
Italy	Quartiere Sangallo	IT	Varese	Residential	1960–1970	2015–2017
Portugal	Rainha Dona Leonor	PT1	Porto	Residential	1953	2009–2014
	Vila D'Este Housing	PT2	V. N. Gaia	Residential	1984–1986	2009–2015
	Boavista Neighbourhood	PT3	Lisbon	Mixed	1960	2013
Spain	Coronación district	ES1	Vitoria-Gasteiz	Mixed	1960–1970	2016–2021
	Lourdes Neighbourhood	ES2	Tudela	Residential	1954–1972	2010–2012
Sweden	Linero	SE	Lund	Residential	1969–1972	2014–2021

4.1. Goal of the interventions

The case studies analysed show that the interventions respond mainly to two overarching goals. These are:

- the improvement of the overall quality and sustainability of a degraded neighbourhood, where reduction of energy use plays an important role (AT, DK, IT, PT1, PT2, PT3, ES1, ES2 & SE)

Within the overarching goal of improving the living quality and sustainability of an existing neighbourhood, the following objectives can be highlighted:

- to update buildings to contemporary standards, improving comfort and eliminating building pathologies, where present (AT, PT1, PT2, PT3, DK, ES1, ES2, IT & SE)
- to improve the building stock, ensure the attractiveness of the flats to guarantee that they are rented (AT, DK, SE)
- to maintain affordability without having to raise the monthly rent for the tenants or without having very high investment costs for the owners (ES1, ES2, SE; in DK a reasonable increase in rent is expected)
- to improve accessibility (ES1, ES2, indirectly in SE)
- to improve the public space, the neighbourhood image (AT, PT3, DK, ES2)

Additionally, reduction of energy use and emissions was a goal for all the interventions. Heating and DHW related energy savings in kWh per heated area are presented in Fig. 2, and Fig. 3 shows savings in percent and installed area of local renewable energy. In some interventions, the objective regarding energy efficiency was set according to minimum national requirements (PT1, PT2), but some projects had a clear goal from the planning stage, that goes beyond the minimum national requirements. For example, in DK, the initial goal to achieve the more ambitious "renovation class 1" was lowered to "renovation class 2" (Danish Transport, Construction & Housing Authority, 2018) to achieve a better balance between energy use and system losses. This project also has a goal that the measured building-related energy use in the total housing stock should be reduced by 30 % from the baseline in 2014 until 2030. Some other projects set their objectives in accordance with energy performance certificates (EPC). For example, in ES1, the design target was based on CO_2 emissions reduction in order to reach an EPC class A in each building and in IT, the goal was to achieve a class B of the local energy labelling. In the Swedish case study, SE, different building renovation measures were analysed in terms of life cycle cost (LCC).

Some of the interventions were performed within European Research Framework Programmes: CONCERTO initiative (AT, ES2), European Union's Seventh Programme (SE) and European Union's Horizon 2020 (ES1). Support from these programmes seem to be an important driving force not only in the implementation of interventions, but also in the scope of the measures implemented, probably due to the often strong involvement of research institutions.

4.2. Balance between energy efficiency and renewable energy sources

A focus on balancing energy efficiency and renewable energy is specially set in the Danish case study, DK, where a less ambitious building renovation was chosen. An analysis showed that a more ambitious renovation would have meant that the distribution losses in the district heating network would account for more than 50 % of the total heating needs even if the temperature was lowered to 50 °C (while standard temperature in Danish district heating systems is 70–80 °C). Therefore, more effort was set in improving the distribution system of the district heating. In the Austrian case study, AT, investment costs of three different scenarios including various levels of energy efficiency were compared; however, no balance has been sought between the measures for energy demand reduction and the implementation of renewables. The same is true in the Swedish case study, SE.

Most of the projects include the local production of renewable energy, namely solar thermal (four projects), photovoltaics (two projects) and biomass fuelled boilers (one project). Several projects include solar thermal collectors, AT, PT1, PT2 and PT3, with an installed surface of collectors per heated floor area of 3.2, 6.0, 0.24 and 0.08 m^2 solar collector per dwelling respectively; in the Austrian case study, the installation is located in an adjacent district, with which it shares its energy use. Two case studies, IT and SE, have a photovoltaic installation with a peak power per heated area of 2.1 W_p/m^2 and 3.8 W_p/m^2 respectively. However, in IT the grid-connected photovoltaic system is not working yet because of bureaucracy related problems. In the Spanish case studies, ES1 and ES2, the minimum contribution of energy from renewable sources required by the national normative is supplied by the biomass boiler of the district heating system; no additional systems have been considered. In the Danish case study, DK, a socio-economic analysis showed that "island operation" (self-sufficiency based on renewable energy) everywhere would lead to an over-investment in infrastructure and, therefore, no renewable system was installed; i.e. it is the district heating network that should supply the energy produced by renewables.

There is a predominance of local implementation of solar thermal technology as a renewable source to back up domestic hot water heating in Portugal. This option was also supported by national legislation mandatory minimum requirements.

Therefore, almost all the cases included renewable energy; mostly locally on the form of solar thermal or through district heating based partially or totally on renewable sources.

4.3. Drivers: Decisive aspects for the successful implementation

When analysing the main drivers, it should be noted that they can vary significantly depending on the role of each stakeholder in the process, so differentiating between stakeholders is necessary. In this section, the main drivers are identified considering the point of view of policy actors, investors, district related actors, energy network suppliers and renovation solution suppliers. The information of each case was obtained from the analysis of used business models and verified with project participants. In the following, the drivers for each stakeholder

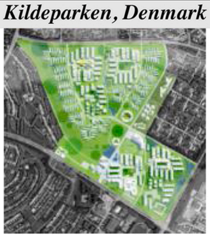
Table 2
Overview of the analyzed district renovations. DHW = domestic hot water; PV = photovoltaics, ST = solar thermal.

Strubergasse, Austria (before/after: 623/636 dwellings) ***AT***

Areas [m^2]	Energy use [kWh/m^{2}y]	before	after
District	Heating	93-150	27-35
45 000	DHW	≈ 30	≈ 20
Heated floor (before/after)	Cooling	0	0
15 500/36 000	Renewable energy (ST m^2)	0	2 048

The renovation of 286 apartments, the demolition of 337 apartments and new construction of another 350 apartments were combined with the connection to an existing district heating network of the Salzburg AG. The intervention included the implementation of a new, high-quality open space and shows a possible way for improving the housing quality for other existing city districts.

Kildeparken, Denmark (before/after: 942/1 228 dwellings) ***DK***



Areas [m^2]	Energy use [kWh/m^{2}y]	before	after
District	Heating	≈ 134	≈ 68
540 000	DHW	≈ 53	≈ 23
Heated floor (before/after)	Cooling	0	0
96 446/119 886	Renewable energy (m^2)	0	0

The buildings in this project have undergone a transformation: building envelopes have been insulated, windows replaced and the district heating network has been refurbished. New buildings have been added and the overall purpose of the refurbishment has been to lift the neighbourhood and make it more attractive to both existing and possible new tenants. The project has succeeded in transforming Kildeparken to a much more interesting community for its inhabitants.

Quartiere Sangallo, Italy (235 dwellings) ***IT***

Areas [m^2]	Energy use [kWh/m^{2}y]	before	after
District	Heating	219	50
7 542	DHW	54	22
Heated floor	Cooling	0	0
23 258	Renewable energy (PV m^2)	0	49

The intervention consists of the renovation of the district heating system, replacing the heat generators, improving control and distribution efficiencies of the heating system as well as the thermal renovation of three of the buildings (enclosed in a square in both figures) having 48 dwellings). In these buildings, a grid-connected photovoltaic system was installed on each building roof along with an air-to-water heat pump per building for producing DHW in the summer period.

(*continued on next page*)

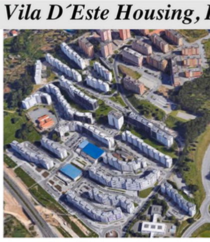
Table 2 (*continued*)

Rainha Dona Leonor, Portugal (before/after: 150/90 dwellings) ***PT1***

Areas [m^2]	Energy use [kWh/m^{2}y]	before	after
District	Heating	119	69
19 700	DHW	37	27
Heated floor	Cooling	6.4	7.8
5 000	Renewable energy (ST m^2)	0.0	540

In this renovation project, heating needs were reduced by 43%. The new cooling system improved indoor living conditions during hot seasons. Renovation measures led to an increase in rent, but it was offset by energy savings. Energy use was reduced by almost 70%, which also enabled users to heat indoor spaces and keep the interior environment within healthy and comfortable temperatures.

Vila D´Este Housing, Portugal (2 085 dwellings) ***PT2***

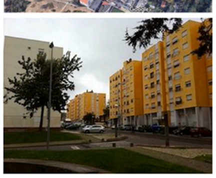


Areas [m^2]	Energy use [kWh/m^{2}y]	before	after
District	Heating	84	57
170 000	DHW	30	30
Heated floor	Cooling	0	0
126 000	Renewable energy (ST m^2)	0	500

This renovation project led to the improvement of the energy performance of the buildings, allowing a potential annual saving of 3 800 ton CO_2-eq. and an estimated annual saving of 837 434 €. The intervention consists of an extensive renovation of all the residential buildings, as well as the implementation of solar energy in the common swimming pools complex.

Boavista neighbourhood, Portugal (1 559 dwellings) ***PT3***

Areas [m^2]	Energy use [kWh/m^{2}y]	before	after
District	Heating	60.5	48.2
55 000	DHW	30	20
Heated floor	Cooling	0	0
80 000	Renewable energy (ST m^2)	0	118



This project is an interesting intervention, because it is the first phase of a project with a significant intervention area of 20 hectares, where approximately 6 000 people live. The intervention was made taking into consideration not only energy efficiency, but also health and thermal comfort concerns. Energy efficiency measures combines with the implementation of renewable energy sources.

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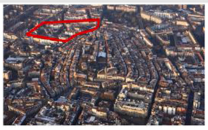
Table 2 (*continued*)

Coronación district, Spain (320 dwellings + 5 tertiary buildings) ***ES1***



Areas [m^2]	Energy use [kWh/m^2y]	before	after
District	Heating	151	70
89 100	DHW	Included in heating	
Heated floor	Cooling	0	0
49 187	Renewable energy (m^2)	0	0

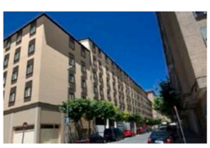
This project is part of SmartEnCity, a project funded under the European Union's Horizon 2020 in which Vitoria-Gasteiz is one of the three lighthouse demonstrator cities. The intervention consisted of the thermal renovation of 320 dwellings and the installation of a new district heating system based on biomass boilers (wood chips). An integrated energy management system will optimise efficiency at dwelling, building and district level. The project was partly financed (up to 54%) by different public institutions; in some cases (households with low incomes), the regional government cover up to 100% of the cost.

Lourdes Neighbourhood, Spain (486 dwellings) ***ES2***

Areas [m^2]	Energy use [kWh/m^2y]	before	after
District	Heating	90	46*/24**
22 500	DHW	Included in heating	
Heated floor	Cooling	0	0
40 448	Renewable energy (m^2)	0	0

* Non-renovated buildings

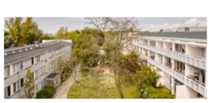
** Renovated buildings



This project responds to the need to promote the integral renovation of this deprived social housing area and the upgrade of the inefficient district heating system (80% renewables with biomass) as well as the improvement of thermal envelopes of only three blocks. The project was framed within a CONCERTO Programme and subsidies and the favourable financing opportunities played an important role in the successful implementation of the intervention. This success is moving other neighbours into action and a second redevelopment project in the district is currently under development, promoting the renovation of thermal envelopes of the rest of the blocks.

Linero, Sweden (379 dwellings) ***SE***

Areas [m^2]	Energy use [kWh/m^2y]	before	after
District	Heating	98-182	66-107
90 300	DHW	12-30	21
Heated floor	Cooling	0	0
40 400	Renewable energy (PV m^2)	0	500



This project was initiated and mainly financed by the municipal housing association LKF and partly funded by EU as one of CITyFiED demo-site district retrofit projects. The intervention included the renovation of the buildings as well as the renovation of the existing district heating network and addition of PV panels, to reach 100 % renewable energy sourcing. The project was initiated to maintain the affordability of the apartments by reducing current and future energy costs. A pilot study carried out on just 4 apartments was performed to ensure the successful implementation of the project.

Table 3
Overview of the case study analysis result. The drivers and barriers are analysed by stakeholders' role in the process: P: Policy actors, I. Investors, D. District-related actors, E. Energy network suppliers, R. Renovation solution suppliers. EE = Energy Efficiency; RES = Renewable Energy Sources; EPC = Energy Performance Certificate; DH = District Heating; GHG = Green House Gas.

Case	Goal of intervention	Balance EE-RES	Drivers	Main barriers and influencing factors	Business models
AT	- Attractive rent - Improve urban space - Better quality, sustainability - Update to contemporary standards	- Evaluated 3 scenarios show similar results for RES or EE oriented renovations - RES solar thermal	P) Improve EE+GHG, Increase density I) Reduce op. costs, Financial assistance D) Better quality of life E) Increase/optimise DH R) Gain prestige	P) Fear to conflicts with residents D) Residents' uncertainty on future and high costs N) Low profit in project R) Difficult work timings if tenants are inside, Residents' lack of acceptance	One-stop-shop
DK	- Attractive rent - Improve urban space - Higher EE - Better quality, sustainability - Update to contemporary standards	- Dual renovation in DH generation and distribution - No additional RES, based on socio-economic study	P) Better quality of life I) Financial sustainability, Improve aesthetics, Update dwellings D) Small rent increases E) Join an existing DH		Market intermediation
IT	- EPC class B - Better quality, sustainability - Update to contemporary standards	- RES solar PV	P) Improve surroundings I) Reduce op. costs E) Increase DH profit	I) Insufficient financial and personal resources, Long decision process N) Management of cash flow over long term R) Difficult work timings if tenants are inside	Energy service company (ESCO)
PT1	- Better quality, sustainability - Update to contemporary standards	- RES solar thermal (local regulation)	I) Financial sustainability, Maintain architecture, Update dwellings	P) Regulations min. EE I) Insufficient financial and personal resources, Insufficient technical personnel D) Need of temporal allocations for tenants	Market intermediation
PT2	- Better quality, sustainability - Update to contemporary standards	- RES solar thermal (local regulation)	P) Improve EE and reduce GHG emissions, Improve surroundings, Better quality of life I) Update dwellings D) Better quality of life	D) Need of temporal allocations for tenants	Market intermediation

(continued on next page)

Table 3 (*continued*)

			R) Gain prestige		
PT3	- Improve urban space - Better quality, sustainability - Update to contemporary standards	- RES solar thermal (local regulation)	P) Improve EE and reduce GHG emissions I) Reduce op. costs, Financial assistance D) Small rent increases R) Gain prestige, Awareness program	I) Poor national economy	Market intermediation
ES1	- Maintain affordability - Accessibility - EPC class A - Better quality, sustainability - Update to contemporary standards	- RES biomass	P) Better quality of life I) Reduce op. costs, Update dwellings, Financial assistance E) Increase DH profit, Promote DH systems R) Profit, quality work	P) Residents' opposition I) Insufficient financial and personal resources, Difficulty to inform residents, owners D) Long decision process N) Low profit in project, Unclear DH regulation R) Long new DH with few joining buildings, Residents lack trust on DH	One-stop-shop
ES2	- Maintain affordability - Accessibility - Better quality, sustainability - Update to contemporary standards	- RES biomass	P) Improve EE and GHG I) Financial sustainability, Reduce op. costs, Update dwellings, Financial assistance D) Small rent increases, Better quality of life	P) Residents' opposition D) Tenants staying during renovation R) Difficult work timings if tenants are inside, Preservation of building appearance R) Need to renovate DH and buildings	One-stop-shop + ESCO
SE	- Attractive rent - Maintain affordability - Accessibility - LCC based renovation - Better quality, sustainability - Update to contemporary standards	- Evaluated scenarios show similar results for RES or EE oriented renovations - RES solar PV	P) Improve surroundings, Better quality of life I) Financial sustainability, Improve aesthetics of buildings and area, Financial assistance D) Small rent increases E) DH increase and optimization, DH customer trust R) Profit, quality work	P) Regulations min EE, accessibility, ventilation P) Regulations min. EE I) Avoid rent increase D) Tenants staying during renovation	One-stop-shop

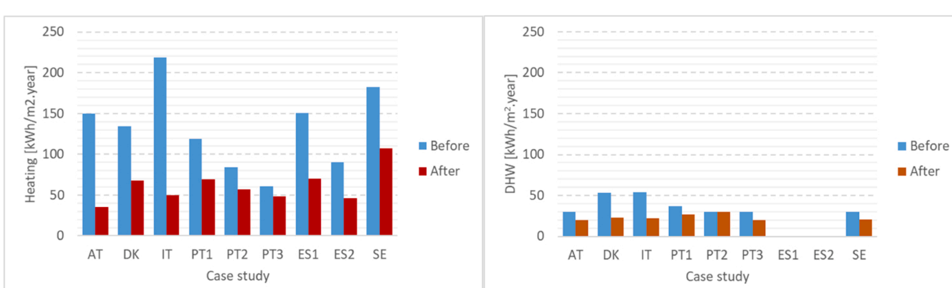


Fig. 2. Total energy use for heating before and after renovation (left) and total energy use for domestic hot water before and after renovation (right).

identified in the evaluated case studies are described.

4.3.1. Policy actors

Main drivers for policy actors include the improvement of the operational management of the building stock and reduction of the energy use. This is expressed in the cases by local authorities aiming to improve the environmental performance of the neighbourhood and its dwellings by reducing the energy use leading to both reduced greenhouse gas emissions and reduced operating costs (AT, ES1, ES2, PT2, PT3). Other common drivers were improving environmental conditions around the buildings in the neighbourhood (IT, PT2, SE) and increasing the quality of life of the residents (ES1, DK, PT2). In one case (DK), the driver was also the integration of the renovated area into the city district.

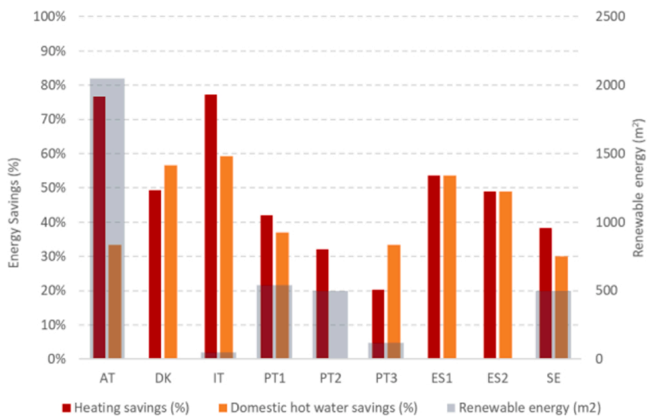


Fig. 3. Total energy savings for heating and domestic hot water [%] and locally produced renewable energy [m^2].

4.3.2. Investors

Typical drivers of investors such as housing companies were maintaining financial sustainability by increasing the value of the residential area as well as making the housing area more attractive by improving its image (DK, ES2, PT1, SE). As for the image improvement, the drivers could differ; in one case (PT1) the aim was to maintain the architectural and urban original characteristics. In other areas and neighbourhoods (DK, SE), the driver was to improve both the outdoor environment in the area as well as the aesthetics of the buildings. Another driver was increasing the residential density (AT).

Another important driver for the investors was to reduce energy demand and consequently operating costs, which will be especially beneficial to medium and low income families in the area (AT, ES1, ES2, IT, PT3, SE). Apart from the need to improve the poor energy-environmental performance of the neighbourhood, these areas were in need of maintenance in general due to the profound state of physical degradation of the buildings. Many investors saw the renovation as an opportunity to improve the standard of the dwellings, e.g. increase the area of the apartments in order to better correspond to today's needs and life patterns of the residents, reduce the running costs through energy savings and increase accessibility (DK, ES1, ES2, PT1, PT2).

In some case studies the financial assistance, e.g. from the European Union, was a decisive driver or facilitator to implement the renovations (or even reaching a higher standard or making more interventions than what was originally planned) (AT, ES1, ES2, SE, PT3).

4.3.3. District-related actors

For district-related actors such as residents' organizations or co-operatives, an important driver was to improve dwellings and surroundings at a small or reasonable increase in rent, creating the least possible disturbance for the residents and ensuring the continuity of families and the social cohesion in the area (DK, ES2, PT3, SE). From the residents' point of view, these areas often have bad interior conditions with high levels of thermal discomfort. One of the drivers for the residents was therefore that the energy renovation would also lead to improving the quality of life of the residents by improvement of living standards – e.g. thermal comfort and accessibility – through installing elevators, improving public space and lower operating and running costs; contributing to health improvement and energy poverty alleviation (AT, ES2, PT2).

4.3.4. Energy network suppliers

Drivers for the energy network suppliers included both modernization, increasing and optimization of the district heating network (AT, SE). Other drivers were maintaining customer trust and satisfaction (SE), increased profit and experience (ES1, IT) as well as promoting district heating networks by gaining of fame or marketing advantages (ES1). Another driver was the possibility to integrate the area in the existing energy supply network (DK).

4.3.5. Renovation solution suppliers

For renovation solution suppliers, drivers included carrying out a profitable and good quality retrofitting work (ES1, SE) as well as implementing a good reference project in order to gain experience and prestige or acknowledgement (AT, PT2, PT3).

In Boavista neighbourhood project (PT3), one of the major success factors of the neighbourhood intervention was its integration in a broader environmental program that aimed at raising energy and environmental awareness in the minds of residents.

4.4. Main barriers and influencing factors

As in the previous section, where the main drivers are identified, main barriers and influencing factors are highly dependent on the considered stakeholder. In the following, the same previously identified stakeholders are taken into account for identifying barriers and influencing factors.

4.4.1. Policy actors

For policy actors, such as local authorities, a significant barrier was the need to comply with the new or current building regulations, especially when it comes to accessibility (SE), but also energy efficiency (PT1, SE), ventilation requirements (SE), etc., which increases the complexity of the renovation. Other barriers include the opposition of part of the residents (ES1 and ES2) or the fear to come in conflict with the residents (AT), as well as the measure or implementation may be politically sensitive.

4.4.2. Investors

For housing companies, a barrier was that the renovation scope had to be limited to avoid monthly rent increase (SE). Other barriers for investors were related to lack of both financial and personal resources including lack of funding for completing the necessary work (ES1, IT, PT1) and lack of competent technical personnel (PT1). Poor national economy was also mentioned (PT3). Another barrier indicated was the difficulty to inform people in order to decide about the intervention (ES1). Barriers related to lengthy decision processes were also reported (IT), as described in detail in Dall'O' et al. (2020).

4.4.3. District-related actors

For district-related actors such as residents' organizations or co-operatives, it was considered a barrier both if tenants remained in the buildings during renovation (ES2, SE) or if they were temporarily transferred to other buildings because of the need to have the buildings vacant to carry out the renovation works (PT1, PT2). Barriers also included the uncertainty and fears among residents for what the future will bring, e.g. increased costs (AT).

Another barrier was the complexity of the task and time necessary to attain a comprehensive agreement regarding the decisions among the neighbours (ES2) was considered as a barrier.

4.4.4. Energy network suppliers

For energy network suppliers the mentioned barriers were that the project does not produce enough profit, thus business as usual was considered easier and more profitable (AT, ES1), and the difficulty of managing the cash flow over the long term while valorising the savings (IT). The legal framework with unclear aspects of the district energy implementation process was also mentioned as a barrier (ES1).

4.4.5. Renovation solution suppliers

For renovation solution suppliers a barrier is that inhabited buildings, when resettling of the tenants is not possible, makes it difficult to plan and execute and difficult to keep the time frame (AT, ES2, IT).

Another barrier mentioned by renovation solution suppliers was that the final appearance of the renovated buildings should not be disruptive or interfere with the surrounding buildings avoiding striking differences (ES2). Furthermore, experience with districts supplied by district heating has shown that it is necessary to rehabilitate both the district heating system and the thermal envelopes of old buildings, otherwise it can result in very different comfort levels between rehabilitated and non-rehabilitated buildings (ES2). In a case of newly installed district energy network (ES1), a relevant barrier is the long network installation costs and the low number of buildings joining the grid in the district renovation process.

For other intermediaries a barrier is the lack of acceptance by the residents (AT). Residents with individual or building scale energy systems are also influenced by a lack of trust in district solutions (ES1).

4.5. Business models examples

A business model describes the rationale of how an organisation creates, delivers, and captures value (Bystedt et al., 2016). In the context of building renovation, the business models range from the traditional 'atomised' and market intermediation model (Brown, 2018) to the emerging and more innovative One-Stop-Shop (Laffont-Eloire et al., 2019) and Energy Service Companies (ESCOs) models (Moschetti & Brattebø, 2016). The case studies were reviewed in order to identify which archetype of renovation business model was applied and how it fitted the scope and the activities of the project. In this context, the atomised market model is not relevant, since the district renovations consists of integrated solutions with multiple measures.

4.5.1. Market intermediation model

In this model, the renovation design and process are managed by an intermediary, instead of the homeowners themselves. The intermediary is typically able to deliver a more comprehensively and thoroughly researched solution. Regarding the case studies analysed, this model was applied to the cases where a bigger consortium was involved in the process, also in the case of research projects. The result was comprehensive renovation solutions, aiming at high energy performance incorporating measures for both envelope and building services upgrades (PT1), renewable energy production on site (PT2, PT3), and connection to district heating (DK).

4.5.2. One-Stop-Shop

The One-Stop-Shop model offers a single point of contact, similar to the market intermediation model, but it often offers a more integrated service, such as audits, arrangement of third-party financing, resident's acceptance and other, next to the technical solution design and implementation. Several case studies are considered to adopt this approach (AT, ES1, ES2, SE).

4.5.3. Energy Service Company

Energy Service Companies (ESCOs) offer a similar service to One-Stop-Shops, but their value proposition is based on ongoing energy performance guarantees. ESCOs primarily use Energy Performance Contracts (EPCs) as a financing mechanism and they keep a long-term relationship with the customer, which includes monitoring, operation and maintenance. A form of an ESCO business model was applied in two of the case studies (IT, ES2)

4.5.4. Additional remarks

In all of the case studies analysed, the main value propositions was the improvement of comfort, the energy use reduction and the reduction of environmental impact. Additional value propositions were related to the improvement of the overall quality of the district. For some of the cases the diversification of apartment sizes was also one of the renovation objectives (DK, PT1).

The customer segment was the building owner and the building user, as tenant and energy consumer. The building owner, depending on the specific context, came in the form of housing associations (public or non-profit), homeowners' associations or public buildings users, such as the municipality. In some cases, owner and building user are the same person.

Regarding financing, in most cases part of the investment came through public money, either as direct financing (AT, DK, ES2, PT1, PT2, SE) or in the form of subsidies to homeowners or other frameworks (ES1, ES2, IT, PT3). In IT, the financing was solved with a combination of one-third public money, while the buildings' owner assigned the remaining two-thirds to an ESCO. In PT1, the municipality initially supported the costs of renovating the existing buildings. At a later stage, the municipality held a public tender to find a private investor who would demolish the three apartment blocks and build "high-end social housing" buildings, as well as a private-owned residential building that would be put on the regular market. Finally, the ES2 project was financed through public grants and private loans to homeowners' associations.

In projects focusing on district heating and its upgrade and expansion (DK, ES2) the decision-maker was a policy actor, mainly the municipality, in collaboration with the energy supplier who would deliver the intervention. The building owners, such as housing associations, were involved in the process, with regards to implementing the connection. Thus, the district heating interventions are generally not part of the renovation business model. Some measures on building level that comply with the district heating, such as low-temperature radiators, are included in the buildings' energy efficiency renovation packages.

5. Discussion

The analysis of the case studies provides some very interesting insights. These findings are drawn inside the limitations of this study, which are namely the limited number of case studies (nine cases chosen from a larger sample of 16 neighbourhood renovations), the relatively large public funding in these projects (in some cases overpassing the 80 % of public support) and the complex methodology to assess qualitative and quantitative aspects from a variety of countries, social-economic backgrounds and objectives. This variability enables the following outcomes to provide insight into other urban environments and contribute to the upscaling of the renovation wave (European Commission, 2020). More detailed research is needed on how developments and decisions on the strategic, tactical and operational levels interact.

First, it is clear that there are typically two overarching goals of interventions; the reduction of energy use and related emissions and the improvement of living conditions for inhabitants of the neighbourhood (improvements of both buildings and surroundings).

As far as intervention energy targets are concerned, only very few projects aim for the minimum national requirements and the major part of the projects go in fact well beyond minimum requirements. It is also clear from the analysis that the energy targets are carefully planned and most often, an in-depth analysis is carried out to establish which level to aim for, taking into account e.g. energy supply and access to renewable energy sources.

Regarding the improvement of the living conditions, these typically cover all aspects related to the so-called co-benefits of energy refurbishment (Jakob, 2006), e.g. all aspects that improve indoor climate, increase general comfort standards and eliminate building pathologies as well as aspects that improve the overall quality of the buildings or even the neighbourhood itself. In fact, the relationship between energy efficient renovation and the improvement of occupant comfort and health has been explored by several researchers (Breysse, Dixon, Jacobs, Lopez, & Weber, 2015; Clinch & Healy, 2003; Thomson, Thomas, Sellstrom, & Petticrew, 2013), but it is an understudied topic that requires further investigations (Ortiz, Itard, & Bluyssen, 2020) to understand and to be able to transmit the potential health improvement and indoor environmental quality (IEQ) benefits that are an important reason to conduct district renovations. IEA Annex 56 participants published an extensive report on this subject (Almeida, Ferreira, & Rodrigues, 2017). For all cases in the analysis, this is also a very important aspect of the interventions, i.e. making the dwellings more attractive and adapting the neighbourhood to contemporary standards.

From the analysis, it is also clear that the balance between energy efficiency and renewable energy sources has not been a strong focus in the projects. Most projects include some locally produced renewable energy (solar thermal, biomass and photovoltaics), but it is clear that the local context, regulations and legislative framework have a significant impact on which types of renewable energy solutions are chosen (i.e. Italy and Portugal have a mandatory minimum requirement for domestic hot water consumption coverage by solar thermal). Therefore, no clear-cut conclusions can be drawn regarding e.g. how this balance is handled in northern European countries as opposed to southern European countries etc., i.e. the legislative framework plays a bigger role than the geographical placement for the case studies. In fact, research has emphasized the complexity in defining general optimal retrofit strategies, due to different contexts and socioeconomic and environmental aspects (Ali et al., 2020; Ma, Cooper, Daly, & Ledo, 2012; Rabani, Madessa, & Nord, 2017).

In a more detailed approach, some success factors for the adoption by stakeholders can be related to innovation theory (Mlecnik, 2013; Rogers, 2003). For example, the more compatible proposed solutions are with the local context of the stakeholders, the more likely they are to be accepted by these stakeholders. Demo initiatives will positively contribute to stakeholders adopting similar future projects and allow suppliers to try out solutions that they perceive as new in the local context (van Hal, 2000) and here, as also highlighted by other studies, municipalities can play a key role (Häkkinen, Rekola, Ala-Juusela, & Ruuska, 2016), as well as in providing suitable urban and energy planning and regulations (Caputo & Pasetti, 2015). The previous description of drivers in the various cases shows that successes can be mainly attributed to stakeholders perceiving a high relative advantage of overarching district values. While policy actors were mainly driven by environmental factors and investors and energy net managers mainly by economic considerations, all actors confirmed the importance of social factors to achieve their goals (Huang, Zheng, Hong, Liu, & Liu, 2020). This underlines the relationship between residential energy and the social characteristics of dwellings as a key element in policymaking in the residential sector (Santamouris et al., 2007). Even concerns about the prolonged liveability of and management problems in a district would lead to initiating district projects that, in turn, could boost investment for environmental upgrade and renovation of buildings to achieve improved comfort, better accessibility and maintenance. Naturally, this could also result in energy saving measures and renewable energies.

Similarly, the description of barriers shows that adoption of district energy renovations can be hindered by stakeholders perceiving a relatively high complexity (Alam et al., 2019; Baek & Park, 2012; Pellegrini, Bianchini, Guzzini, & Saccani, 2019). Policy actors struggle with policies that impose ever increasing energy performance targets (e.g. PT1, SE), while other actors find it too complex to organize financial and social acceptance, for example to avoid increased rent (particularly for vulnerable target groups) and to eliminate burden during renovation works. One decisive aspect of the realisation of the case studies was the alignment of the drivers of multiple types of stakeholders into common values, which highlights the need for a strong lead and collaborative work. In some cases, stakeholder dialogue was also facilitated with financial and organizational support, for example by European projects or local authorities (Laaroussi, Bahrar, Zavrl, El Mankibi, & Stritih, 2020; Monteiro, Causone, Cunha, Pina, & Erba, 2017).

Importantly, the analysis highlights the use of business models that can be considered as adaptations of the ones used for deep renovation of single buildings. The lessons learnt within the nine case studies and the references given above point out the need for more applicable business models to the district scale. This broader approach requires a facilitator, a clearly defined and mandated agent to coordinate and lead in a collaboratively way all the processes with a district perspective (D'Oca et al., 2019; Häkkinen, Ala-Juusela, Mäkeläinen, & Jung, 2019).

6. Conclusions

The case studies analysed have clearly shown that the drivers for a district renovation are not necessarily restricted to energy savings and emissions reduction; these typically also include improving the overall quality, indoor environment, as well as the image and value of a district. Therefore, these aspects need to be integrated into any proposal to ensure the feasibility and acceptance of the intervention.

This work also shows that drivers and barriers for district energy renovation are not prominently of a technological nature. While all technological innovation to achieve district energy renovations are available, policies and strategies should mainly aim for improving the financial and social acceptance of renovations. While policy obligations are considered a barrier, there appears to be a strong need for financial models that can alleviate split-incentive problems between investors and resident organizations. Moreover, local authorities are urged to address the development of appropriate communicative and organizational policy instruments to support district energy renovation. Stakeholder dialogue and continuous management of expectations of various types of stakeholders is the key to successful district-energy renovation projects. To align common values and resources it makes sense to jointly develop a business perspective for achieving the renovations of buildings with multiple stakeholders, while embracing partnerships for the local development of energy grids and district renewal.

Finally, some lessons learned can be extracted from the analysis of the case studies:

- Reducing energy use and emissions
    - o It is possible to perform district scale renovation and achieve cost-efficiency while reducing energy use and CO_2-emissions.
- Communication and demonstration
    - o Good communication amongst the different stakeholders (and especially with residents) often plays a key role for the success of the project.
    - o Citizen engagement is very important as well. Measures for citizen engagement include the creation of citizen service points, professional relocation service if necessary, holding workshops and meetings in the early stages of the project.
    - o The implementation of a pilot project that demonstrates possibilities can help private owners to make the decision of renovating their own buildings.
- Decision making process
    - o The need of a strong leadership to coordinate all the necessary activities since such an intervention accomplishes a complex and great number of different stakeholders.
    - o Public bodies, such as regional bodies, municipalities and their affiliated housing associations, are essential for the decision-making process and the financing of larger projects.
    - o There is a need for comprehensive approaches for district-scale renovation, not only in the implementation of technical solutions but also regarding business and financing models, as well as regarding the process management.
    - o For effectively realizing energy efficiency and renewable energy in district-scale renovations, there is a need to use a comprehensive set of local policy instruments - including organizational and communication instruments - to assist local uptake and co-creation in municipalities, cities and regions.
- Funding
    - o The available funding is the most decisive factor in carrying out an intervention. Business models and innovative financing schemes have to be considered from the beginning of the planning. In some

cases, public funding is indispensable to allow interventions to be carried out.

o EU or other national or regional financing programmes are a good driving force behind the successful implementation of the projects, and having a coordinator that manages the different stakeholders is essential.

These findings will be integrated in a set of guidelines for all relevant stakeholders.

Even though the nine cases studied in this paper clearly demonstrate similar trends, these conclusions and findings are drawn inside the limitations of this study. Limitations are primarily the relatively small number of case studies and the complexity of assessing qualitative and quantitative aspects from a variety of countries, social-economic backgrounds and objectives. To comprehensively validate findings and further support conclusions, future studies should include more specifically directed qualitative interviews of relevant stakeholders, to increase the understanding of the drivers, barriers and influencing factors of district renovations.

Declaration of Competing Interest

The authors report no declarations of interest.

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