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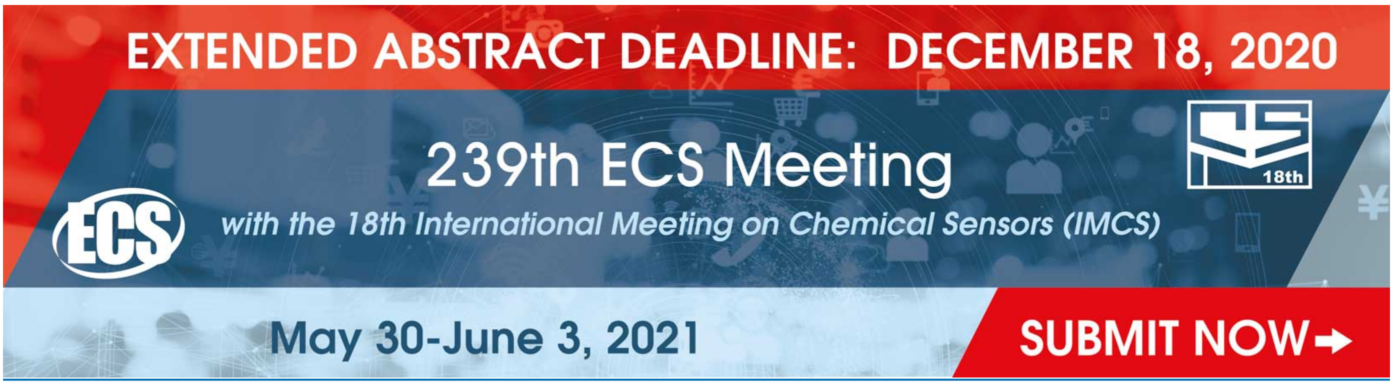

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Key action fields for nearly carbon-neutral districts: stakeholder-specific strategies and practice

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Abstract. In accordance with the UN Sustainable Development Goals, many countries aim at nearly zero carbon emissions of their building sector by 2050. The research college EnEff.Buildings.2050 is a collaboration of five PhD students and their supervisors to support this goal. In this paper, five key action fields for transformation of urban districts are described, and decisive stakeholders are identified and linked to the action fields. As a case study, the urban district Mierendorff-Island in Berlin is introduced.
Three strategies to support transformation are identified: Firstly, new digital planning tools should be applied to assess and improve the energetic performance of new and existing buildings and to illustrate it to decision makers. Secondly, digital processes should be combined throughout the lifecycle of a building by building information modeling (BIM). This can ensure the energetic quality and enable cost-effective construction, servicing and monitoring. Thirdly, start-ups and contractors need support for development of new business models and technical solutions, which can e.g. enable disruptive technologies. Awareness of stakeholders on the transformational state of a district enables them to identify windows of opportunity to spring into action. Framework conditions and support measures determine if they act in favour of the transformation or not.

1. Introduction

1.1. Climate protection goals for buildings in Germany

Today, about 55 % of the global human population lives in cities. This share is increasing and is projected to be 68 % by 2050 [1]. In Germany, the operation of buildings accounts for about 34 % of the national final energy demand [2], corresponding to a share of about 30 % of the direct and indirect national greenhouse gas emissions [3]. This increases further if also building construction, maintenance, refurbishment and deconstruction are taken into account. So climate protection measures have to reduce heat and electricity demands for building operation (e.g. by building refurbishment) and throughout a buildings lifecycle. For the remaining demands, an extensive reduction of the specific carbon emissions has to be achieved, e.g. by enabling the on-site or grid-connected utilization of renewable energy (RE).

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In 2015, within the German *Energy Efficiency Strategy for Buildings*, a reduction target of 80 % of the fossil primary energy consumption of buildings by 2050 compared to the reference year 2008 had been proclaimed [4]. Since 2016, Germany pursues with its *Climate Action Plan 2050* the goal of "extensive greenhouse gas neutrality" by 2050, including a "virtually climate-neutral building stock" to be achieved until then [5]. The intermediate goal for the building sector until 2030 is a decrease in fossile primary energy consumption by 66 to 67 % compared to the reference year 1990 [5]. It is estimated that by 2018 a reduction of 44 % compared to 1990 had already been achieved [3].

The final energy demand reduction potential in residential buildings is significant and only limited by inevitable consumption e.g. for domestic hot water or household electricity. Districts also have industrial and transport demand, where the reduction potentials are smaller. Climate neutrality in densely populated urban districts is challenging because of limited RE sources. Thus, coupling the sectors heating, cooling and transport via the electricity grid is decisive for the successful transformation [6].

1.2. Background and approach of this work

The research college *EnEff.Buildings.2050* is a network of five PhD students and their supervisors from six academic institutions in Germany. Figure 1 shows the five action fields addressed in the research. The action fields and institutions were selected for support based on their anticipated relevance for transformation.

This work summarizes the overarching, qualitative findings of the college. A stakeholder assessment with respect to the action fields is carried out and technical and economic strategies towards carbon neutrality are identified. These strategies are recommended based on an assessment on whether they are a) decisive for transformation, and b) require competences from within the addressed action fields and/or c) allow for synergies between these fields. As a transformation example, the Mierendorf-Island in Berlin is used as a case study.

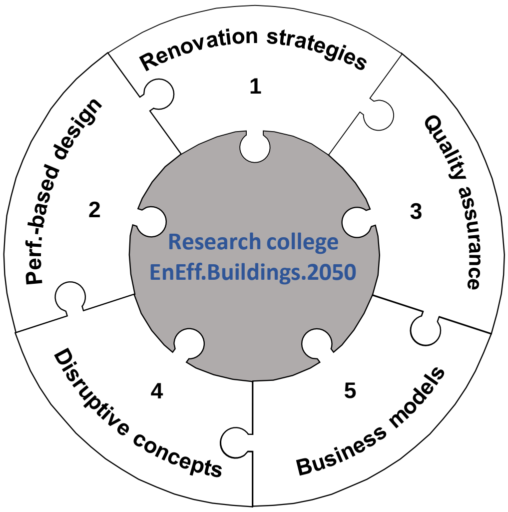

Figure 1. Key action fields of the research college EnEff.Buildings.2050

The college *EnEff.Buildings.2050* aims to support the achievement of the UN Sustainable Development Goals (SDG) [7], namely SDG 11 Sustainable Cities and Communities, SDG 13 Climate Action, and SDG 7 Affordable and Clean Energy. In line with these goals, the discussed strategies aim to reduce the environmental impact of cities. They are intended to assist climate change mitigation and adaption and/or to unlock the high potential of buildings for energy efficiency and as pro- and consumers of RE.

2. Megatrends and key action fields

2.1. Megatrends

The key action fields addressed in the following have to be viewed against the background of the so called megatrends, which highly impact the transition process. A megatrend is defined as a trend that takes place over a longer period of time and leads to significant and long-term changes in several sectors. Megatrends are not limited to a region but take place sooner or later in every region of the world. Megatrends that have an impact on the carbon emissions of buildings are amongst others [8, p. 5-12]:

- climate change, caused by man-made greenhouse gas emissions,
- decarbonisation, caused by growing awareness of society for climate protection,
- scarcity of non-renewable resources, e.g. fossil fuels and minerals,
- urbanization, population growth and demographic change,
- customization and miniaturization, i.e. the desire for individuality and convenience, and the
- digital revolution, i.e. changes triggered by digital technology and fast data transfer.

2.2. Key action fields

1) Consecutive refurbishment strategies for urban districts (Berlin University of the Arts)

Future transformation paths for districts and cities have to be modelled to provide information on realistic, consecutive steps for the achievement of certain future transformation goals. A district perspective ensures that social aspects are taken into account and that building owners and other decision makers have a motivation for and a clear understanding of the successive transformation steps and goals.

For this, it is a pre-condition to assess the current state of buildings, industries and traffic with sufficient accuracy. Object-specific data regarding building type, orientation, dimensions, age, number of occupants, space heating demand, heating technology and energy carrier, potential for RE, etc. can be obtained from local authorities or assessed by using statistical benchmarks or sample measurements. Open data (e.g. GIS data) combined with new digital tools are used to evaluate the current state of a district and to derive energy and cost-efficient strategies for transformation over time.

2) Performance-based design in the early design phase of buildings (University of Wuppertal)

The energy consumption and generation potential of buildings is directly affected by early design decisions, when the principle layout of buildings and districts is defined. Already in this phase, performance parameters like final energy demand, thermal and visual comfort, solar potential and others should be considered [9]. Such feedback enables designers and architects to increase the performance. Adding to that, most clients and other decision makers have difficulties to anticipate the performance of a certain variant. Typically, this requires iteration and deep interaction between designer and owner [10]. So performance-based design can also effectively assist decision making by stakeholders.

In traditional planning, early design decisions regarding sustainability and/or energy performance are often only based on experience. Most architects are not familiar with advanced simulation engines and most of the performance simulation tools do not support the early phases of building design as well. Furthermore, often the file exchange between design software and energy simulation software is not satisfying in terms of complexity of model geometry, material information and central data storage. Amongst the performance evaluation tools to develop, plugins for 3D design software are the most promising, since they provide basic performance analysis within commonly used design tools (cp. example Mierendorff in section 3).

3) New technological approaches to ensure the energetic quality of buildings
(Biberach Univ. of Applied Sciences and Fraunhofer ISE)

Planning and installation errors or failures of technical building equipment like heating or ventilation systems reduce the efficiency of these systems and can highly increase their energy consumption. In hindsight, errors are often not being identified and if they are, their corrections involve major effort. Quality assurance ensures that buildings are implemented and used with minimum errors throughout their life cycle. Plesser et al. [11] developed a methodology for an integral quality assurance within a buildings lifecycle based on DIN V 18599 [12]. By checklists, users verify and document the quality-relevant measures implemented in practice. This includes defined testing and documentation measures. Fundamentals and methods of a well-founded measurement and analysis of the building performance are discussed by Voss, Herkel et al. in [13].

4) Disruptive concepts for the advancement of technical building equipment
(University of Freiburg and Fraunhofer ISE)

The term *Disruptive Technology* was first introduced by Bower and Christensen in 1995 [14]. Disruptive technologies entering a market initially show lower performance than existing technologies and therefore address only a small customer segment. Due to a rapid increase in performance, the technology quickly moves into the focus of customers. After the market invasion, existing technologies cannot adapt quickly enough or do not perform well enough anymore. Additionally, disruptive technologies can also create completely new markets [14]. Research suggests that existing technologies and incremental innovations in business-as-usual scenarios will not suffice to achieve carbon neutrality by 2050 [15, p. 35f]. Hence, technological disruptions may have an important role to play.

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In contrast to incremental innovations, the development of disruptive technical concepts can by nature not be predicted. But historic disruptive technologies like Photovoltaics or LED lighting show common features and preconditions. Analysing these, criteria for potentially disruptive technologies to speed up transition can be defined. They must show a) an innovative technical concept, b) meet key stakeholder's interests, and c) have the potential to significantly increase technological performance and customer value (performance over cost) under current regulatory and market conditions.

5) Business models for energy efficiency and renewable energy in buildings
(Karlsruhe Institute of Technology KIT)

There is a variety of barriers for improving the energy quality of buildings or for switching to RE. These barriers affect private owners in particular. They include a) lack of knowledge about current energy consumption and GHG-emissions, b) lack of knowledge about the type and scope of refurbishment measures and a lack of confidence regarding the predicted saving effects, c) lack of time to prepare and implement the measures, and d) lack of financial resources [16].

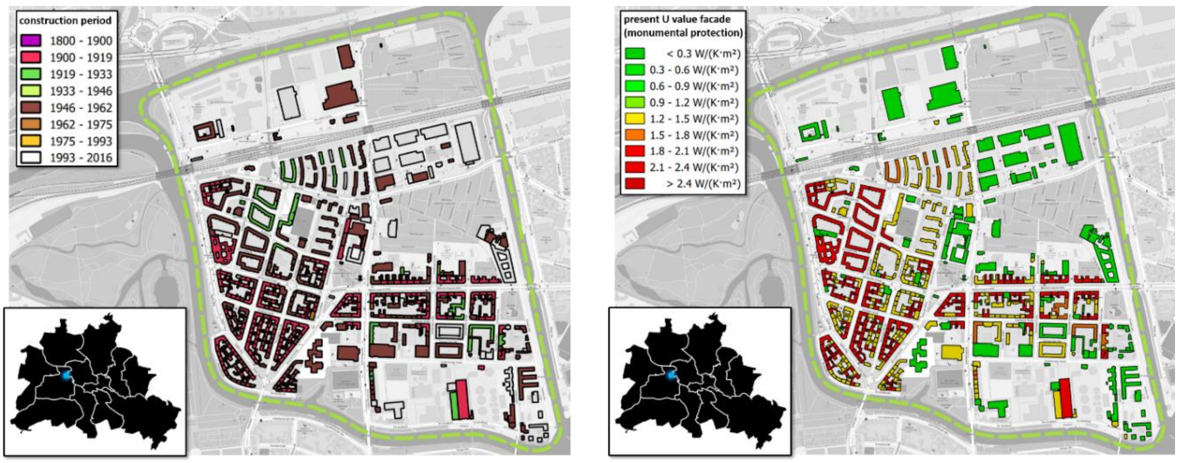
A way to overcome such barriers is services by third parties. They can design business models (BM) that create revenues by energy savings and/or avoidance of greenhouse-gas emissions. The range of such BM extends from financing through guaranteed savings to monitoring of plants in operation. BM for energy efficiency still have a comparatively small market share; and models that guarantee a reduction in emissions per final energy are still unknown. New BM can promote new products, technologies and planning methods. They trigger investments where otherwise no measures would have been carried out.

3. Mierendorff-Island in Berlin

As an example for a typical urban district under transformation, the Mierendorff-Island in Berlin Charlottenburg is described (Figure 2). Implementing many projects regarding future sustainability, the districts administration aims to make Mierendorff-Island a flagship for climate neutral districts.

3.1. Key figures and performance parameters

A population of approx. 15,400 people [17] is living in ca. 8,600 apartments (< 1.8 residents per flat in 2009) within 300 residential buildings. Together with additionally 139 commercial buildings, they are distributed on 1.73 km². Heat supply is covered by two main companies, each supplying about half of the district area, one with natural gas and one with district heating. About 4 % is oil heating. Six different owner categories are present: private owners, private residential communities, three cooperatives, state-owned housing companies, corporate entities, and non-profit organizations (churches).



a) Building construction periods

b) Estimated U-values of the opaque walls, taking monumental protection into account

Figure 2. Information layers of Mierendorff-Island in Berlin, Germany. Own representation based on data from ALKIS [18], FIS-Broker [19], Loga et al. [20], Jochum et al. [21] and Open Streetmap [22].

The geo information system QGIS 2.12.20 gathers open source information like geometry of a building and combines it with statistical data such as average U-values (base plate, walls, windows, etc.) and building age. Using the plug-in Open eQuarter (OeQ) [23] generates a basic dataset for each building (cp. Figure 2). Further figures can be determined: The average construction year of the buildings is 1943 and 21 buildings are under monumental protection. The heat demand of the district is 185 GWh/a (i.e. for residential buildings 147 GWh/a, non-residential 38 GWh/a) or 154 kWh/m²a (with 12.5 kWh/m²a assumed for domestic hot water in residential buildings). With the primary energy carriers used, this is about 46,814 t CO_2/a emitted by the district or 39 kg CO_2/m²a per heated floor space.

3.2. Examples of software used for transformation

Software like OeQ can be used to assess the effects of certain modifications on the districts greenhouse gas emissions. As an example, renovating all buildings according to the German EnEV 2016 standard (i.e. applying the required U-values to the envelopes of all buildings without monumental protection) would result in a reduction of heat demand by approx. 36 % to 99 kWh/m²a, and reduce emissions for heat to 25 kg CO_2/m²a, if current heating technologies are used without changing specific emissions.

Another example is the use of a performance-based design tool for a specific industrial area of Mierendorff (cp. Figure 3 and lower right corner of Figure 2), which is planned to be transformed into a residential and office area. The tool to improve the performance of a fictitious new building design is a newly developed prototype based on the software Ladybug™, Grasshopper™ and Rhinoceros™.

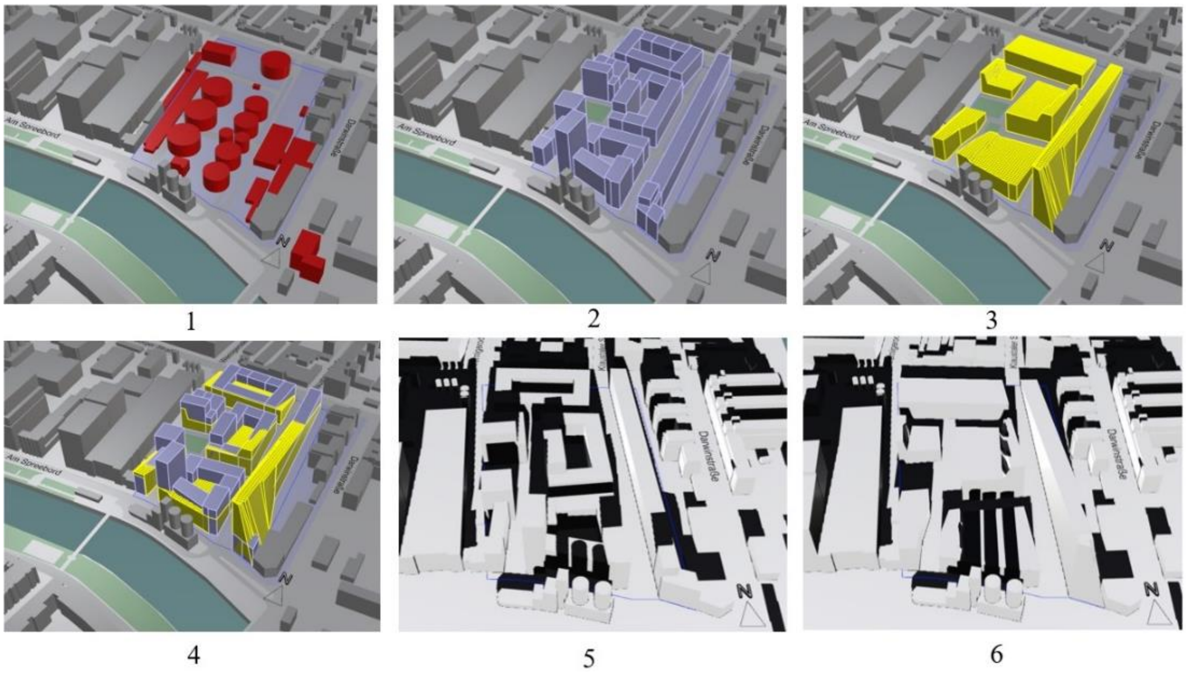


Figure 3. Performance-based solar design for transformation of a city block in Mierendorff. (1) Existing industrial structures (red), (2) Fictitious example for proposed design of new buildings, (3) Solar envelope, (4) Superposition of solar envelopes and proposed design, (5) Shadow analysis for proposed design, (6) Shadow analysis for solar envelope only.

The total area of the considered city block is 2.8 ha and the total construction volume of the new design (cp. Figure 3, (2)) is 313,581 m^3. The method of solar envelope [24] is applied (3) to avoid shading effects on neighbouring buildings and city sections. On 21st December at 12.00 o'clock, all building parts contained within the solar envelope would not violate the sufficient solar access of other buildings. Superposition (4) and shadow analysis of the fictitious new design (5) indicate that this is not the case. Shading could be avoided by designing within the solar envelope (6), which could theoretically be achieved by reducing the total construction volume by only 6.3 %.

4. Stakeholder roles and motivation

In the following Table 1, selected stakeholders within the transformation process are qualitatively characterized. From their perspective, hurdles and opportunities regarding transformation are named.

Table 1. Stakeholder influence on transformation of buildings and districts

Stakeholder	Role and motivation
Building owners (private and public)	Initiate design, construction and refurbishment processes. Decide on efficiency level and use of renewable energy, based on fulfilment of legal and comfort requirements at minimal costs. Knowhow of private owners is often limited. Public owners can act as role models.
Building users (tenants)	Influence performance by user behaviour. Benefit from refurbishment or efficiency measures through cost savings. May suffer from increased rent due to modernisation allocations.
City planners	Decisive for early design phase of buildings. Influence energy performance by determining land use, population density and site layout (local accessibility of renewables).
Architects (and civil engineers)	Consulted by owners to design or refurbish buildings. Compare variants based on performance parameters. Decisive for energy performance due to know-how and influence on owners.
Investors / Contractors	Decide based on profitability and risks. Can highly speed up or hamper transformation.
Suppliers of building equipment	Provide innovative products and systems as well as the know how to use them. Decide on cost/performance ratio of their products depending on market requirements
Craftsmen	Often first contact point for building owners and thus high influence on their decisions. Interested in simple, standardized technical building equipment with reliable performance.
Utility Companies	Will rely on new business models to ensure profitability, otherwise they hamper transformation
Building operators (facility managers)	Monitor energy consumption and user satisfaction. In charge of operation and maintenance of building energy systems. Interest to avoid user complaints by ensuring a high comfort level.
Regulatory authorities	Establish technical and energy efficiency requirements for buildings and systems. Approve planned concepts. Can accelerate or hamper transformation, e.g. by incentives or bureaucracy.
General public	Influences politicians and indirectly regulatory authorities
Start-ups	Offer innovative services and products. Can speed up transformation.
Researchers	Provide objective information to decision makers. Transfer know-how to other stakeholders.

Table 2 qualitatively indicates which stakeholders should specifically be addressed by targeted activities from each of the five key action fields to most effectively support the transformation process.

Table 2. Stakeholder mapping to show the relevance of stakeholders for action fields

Stakeholder / Action field	owners	tenants / users	city planners	architects	investors	civil engineers	techology suppliers	craftsmen	utility companies	building operators	housing companies	contractors	municipalities	regulat. authorities	general public	startups	researchers	**Frequency**
1) refurbishment strategies			x	x	x		x				x		x	x	x		x	9
2) performance-based design	x		x	x	x	x					x	x	x	x			x	10
3) quality assurance	x	x					x	x		x	x	x		x				8
4) disruptive technologies	x	x			x	x	x	x	x	x		x				x		10
5) business models	x				x				x	x	x	x			x	x		8
Frequency	4	2	2	2	4	2	3	2	2	3	4	4	2	3	2	2	2	

The stakeholder mapping shows that the most relevant stakeholders for the key action fields are building owners, investors, housing companies, and contractors. Stakeholder overlap between action fields is highest between 1) and 2), but also significant between 4) and 3) as well as 4) and 5). This indicates where interactions between action fields are promising and required.

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5. Strategies

In the following, the research college EnEff.Gebäude.2050 recommends three stakeholder-specific strategies (across key action fields). They are intended to achieve an increase in the energetic performance of buildings and districts and to speed up their transformation towards climate-neutrality.

5.1. Implementation of new digital planning tools

The Mierendorff example shows that already in the phase of the development of refurbishment strategies for districts and within the early design phase of buildings and districts, digital planning tools can help city planners and architects to determine and significantly improve selected environmental performance parameters. They can also support the communication with and between decision makers like owners, municipalities and the general public. The generated performance information can be a basis for digital building information models, which are linked to buildings throughout their whole lifecycle.

5.2. Combination of digital processes throughout the building lifecycle

Automated data acquisition and exchange between a digital building model and relevant actors throughout the building lifecycle can enable simple and cost-effective construction, quality assurance, monitoring, servicing, refurbishment, and recycling. Automated data inputs into existing BIM models e.g. by craftsmen during construction and by building operators during servicing, simplifies performance assessment and information exchange between owners, service companies, contractors, and users of buildings. Interactions with building equipment and energy consumption can be automatically documented, and measured performance can continuously be compared with expected/planned performance. Digitalization of the building sector can be an enabler for new, disruptive technologies.

5.3. Support of start-ups and contractors in business model development

Effective business model (BM) design and implementation are necessary for technological innovation to be economically successful. The accompanying research initiative *Energiewendebauen* evaluated current building-related research projects in Germany involving BMs. They consider prosumer models (16 projects), leasing (8 projects), but also crowdfunding or sharing economy (9 projects). Full-service programs and contracting (28 projects) were frequently found.

In particular, BM such as Energy Performance Contracting (EPC) and Mini-Contracting can effectively reduce CO2 emissions. They offer the possibility of outsourcing activities such as planning, financing and operating a heating system, and also contractually comply with energy saving targets. In particular private owners of residential buildings should be specifically informed on EPC. Start-ups and contractors need guidelines for the development of promising and marketable BM in order to initiate projects contributing to increased implementation of efficiency and RE in the building sector.

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