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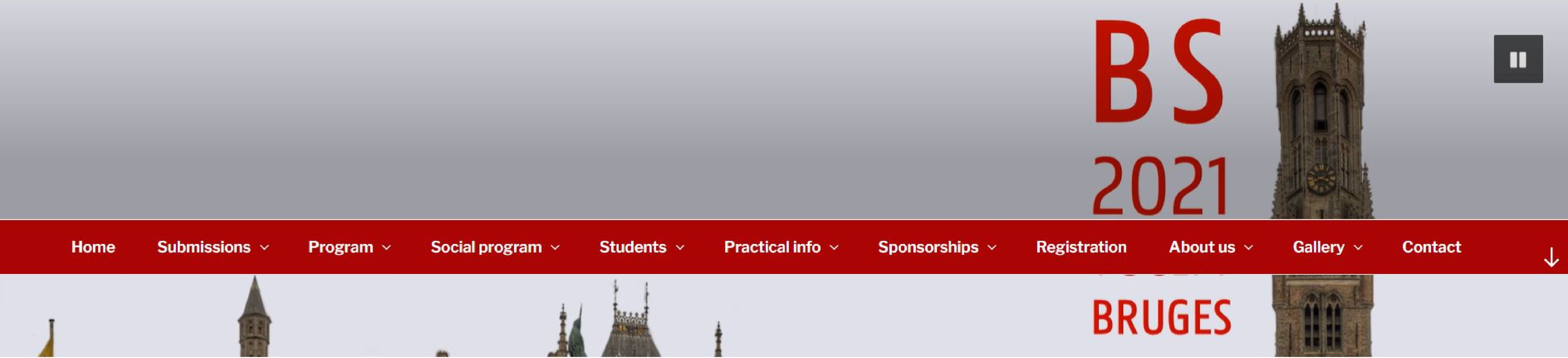

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Analysis of step-by-step individual buildings roadmaps – what can we learn about the practice?

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Abstract

The EPBD 2018/844/EU introduced new instruments: the national long-term strategies and the building renovation passports. One aspect of the building renovation passports is the step-by-step renovation roadmap, a long-term plan that mainly indicates the building's stepwise energy performance decrease. Other non-energy related indicators as investment costs and co-benefits (thermal comfort and indoor air quality) are also included. This paper aims to analyze the individual building roadmaps developed during the EU-funded iBRoad project. Furthermore, to verify their compliance with the national long-term renovation strategies (LTRS). Because many countries still do not have submitted their LTRS yet, the present paper proposes seven indicators to assess the roadmaps. However, none of the buildings fulfilled all indicators. 4 buildings in Portugal and 1 in Bulgaria complained more than 80% of the requirements. The results show that there is still a need for financing schemes and policy design that considers the step-by-step approach's singularities.

Key Innovations

- Energy demand calculation and the step-by-step renovation approach
- Step-by-step individual buildings roadmaps tools
- The link between building retrofitting activities and building stock decarbonization

Practical Implications

This paper aims to contribute to the acceleration of renovation activities in the European building stock. This goal can be achieved by improving policy and financing design schemes closer to real-life renovation practices.

Introduction

The recast of the Energy Performance of Buildings Directive (EPBD) 2018/844/EU introduced new instruments to help accelerate building stock's decarbonization targets. In Article 2a, the EPBD calls all EU countries to establish their national long-term renovation strategy (LTRS) for the building stock. The EU Member States should have submitted their first strategies by 1 January 2020. In Article 19a, the building renovation passport (European Parliament, 2018) is introduced as an instrument to provide a long-term and step-by-step deep renovation roadmap for individual buildings.

In Europe, there are already some demonstration projects, which focus on the key concept of building passports and step-by-step renovations as the EU-funded H2020 iBRoad project (Fabbri et al., 2018) and (Monteiro and Fragoso, 2018).

During this project, a software tool was implemented to help energy auditors develop individual step-by-step renovation roadmaps of owner-occupied single-family houses. Besides using the iBRoad tool to develop the roadmap, the energy auditors also used national energy performance calculation software (the same as used to issue energy performance certificates, EPCs). This energy demand calculation assesses the potential stepwise energy savings by the implementation of each renovation step.

This paper aims to analyze the developed roadmaps and verify their compliance with the national long-term renovation strategies, and consequently, with the EU's building stock decarbonization strategy. This analysis should also provide insights into how the step-by-step concept is understood and interpreted in the energy auditor's practices. The following questions will be analyzed:

1. Which trends and co-relations could be observed in the developed roadmaps?
2. According to the national long-term renovation strategies submitted to the EU-Commission, which are relevant indicators to assess individual building renovation roadmaps?
3. Are the building roadmaps in line with the long-term national renovation strategies?

This paper adds to the existing literature by verifying the alignment between energy auditing practice and EU instruments. Therefore, contributing to bridging the gap between real-life building renovation practices and the EU's target for building stock decarbonization.

Long-term renovation strategy

The revised Energy Performance Building Directive EPBD (2018/844/EU) calls all EU countries in Paragraph 2a to establish their national long-term renovation strategy (LTRS) and submit their first LTRS to the European Commission until 10 March 2020. However, not all Member States have done it so far or have presented incomplete documents. The LTRS should enable building stock's energy transition and decarbonization by 2050, and they will be part of EU countries' integrated national energy and climate plans (NECPs) (European Commission, 2019).

Article 2a of the EPBD suggests a structure for the LTRS and presents all requirements that the Member States should specify. These are (European Parliament, 2018):

1a - Overview of the national building stock and expected share of renovated buildings in 2020;

1b – Cost-effective approaches to renovation considering potential relevant trigger points;

1c – Policies and actions to stimulate cost-effective deep renovation, including, for example, introducing an optional scheme for building renovation passports;

1d – Overview of policies and actions to target worst performing segments of the building stock, split-incentive dilemmas and market failures and an outline of actions that contribute to the alleviation of energy poverty;

1e – Policies and actions to target all public buildings

1f – Overview of national initiatives to promote smart technologies and well-connected buildings and communities, as well as skills and education in the construction and energy efficiency sectors;

1g – Evidence-based estimation of expected energy savings and wider benefits, such as those related to health, safety, and air quality;

2 – Roadmap with measures and progress indicators, with a view to the long-term 2050 goal of reducing EU GHG emissions by 80-95% compared to 1990. The roadmap shall include indicative milestones for 2030, 2040, and 2050;

3 – To support mobilization of investments, facilitate access to appropriate mechanisms for:

a. Aggregation of projects and packaged solutions

b. Reduction of perceived risk for investors and private sector

c. Use of public funding to leverage additional private-sector investment or address specific market failures

d. Guiding investments into an energy-efficient public building stock

e. Accessible and transparent advisory tools

4 - Include summary results of the public consultation into the LTRS and establish modalities for consultation in an inclusive way during its implementation

5 – Include implementation details of the latest LTRS

Historical indications about renovation approaches

When considering the time dimension, there are mainly two different approaches to perform retrofitting: 1) the whole package of measures is performed at once (one-step), and 2) various measures are performed at different times. The second one can also be called "partial renovation", referring to the fact that part of the building is renovated in each step. Some building energy experts criticize the partial renovation because satisfactory energy savings are often not achieved.

Different studies have evidenced that in real life, many (if not most) retrofit activities are not performed at once rather partially. Fehlhaber showed the share of capital volume (in Bn. Euro) invested in repair and refurbishment activities in the German building stock (residential, commercial, and public buildings). The study strongly evidenced that most activities were done partially, about 75%. Especially in the residential sector, this rate was 85% (Fehlhaber, 2017).

A detailed analysis with almost 7510 households was carried out with mostly residential buildings to analyze the renovation activities in the German building stock; and its consequences on the renovation rates (Diefenbach et al., 2010). This study statistically evidenced that in real life, many renovations are performed partially. The results from this study showed a diversified picture of residential building stock's energy performance standards. The study indicated many partial renovations and different energy efficiency standards of the performed measures across one building through the variety of insulation thickness of the building's element. Among other results, the authors showed the percentage of insulation per building element (walls, roof or upper floor ceiling, cellar ceilings, or floor) for different construction periods and the distribution of various insulation thickness installed in the buildings.

Regarding the heating systems, the study showed the distribution of different heating technologies. A relevant finding of this study is that in many cases, the renovation measures were performed at a different time – serving as statistical evidence that partial renovation is commonly performed in real-buildings. It was also shown that many renovation cases did not comply with the energy efficiency standards in force by the time. This study alerted to the emerging danger of not achieving building stock decarbonization targets in Germany due to the low rates of deep renovation.

Some years later (2016), Diefenbach et al. repeated a similar approach to the previous one. This second study explicitly proved that most renovation activities were done partially until that date (stead of the whole building) and showed the different renovation rates for each building element – between 2010 and 2016: 1,8%/a windows and glazing replacement; 1,5%/a roof or upper floor ceiling; 0,8%/a facade, and 0,4%/a floor and cellar ceiling. Regarding the heating system's replacement, the identified rates were 3%/a (Cischinsky and Diefenbach, 2018).

Partial renovation can be divided into further sub-categories: room-by-room, measure-by-measure, and step-by-step (Fawcett, 2014) (Topouzi et al., 2019). In the step-by-step approach, each step consists of a measure or a combination (package) of measures.

Although the described studies and real-life evidence have strongly indicated that partial renovations are widely performed, most policy instruments have until very recently only considered the one-step renovation approach. Mainly, as soon as the one-step renovation is performed, energy savings can be faster achieved than in the step-by-step approach. Also, because in the step-by-step approach, there is a high risk that the process of renovation is stopped by the building owner for different reasons, for example, lack of incentives and lack of technical instructions. In these cases, the whole building is not completely renovated (as also shown by the literature review).

With the recast of the Energy Performance of Buildings Directive (EPBD) 2018/844/EU and introduction in the Article 19a of the building renovation passport (European Parliament, 2018), new instruments and tools to support real-life renovation practices may be triggered to be further explored and supported by appropriated policy schemes. These allow diversifying the range of solutions that aim to achieve the main goal of accelerating deep renovation activities and decarbonizing EU's building stock.

Individual building step-by-step renovation tool

The EU-funded H2020 iBRoad project aims to explore principles and describe the Concept of Building Renovation Passports (BRP), including the step-by-step renovation approach.

During the iBRoad project, two IT solutions were implemented and demonstrated – Logbook and Roadmap Assistant (Monteiro and Fragoso, 2018). The "Roadmap Assistant" has the main function to serve as a supportive tool for energy auditors in the development of the "iBRoad-Plan", which is a document that includes the long-term individual renovation roadmap for the specific building. The "Roadmap assistant" is a complementary tool to the national energy demand calculation software, used to calculate the energy performance of each planed step. Together with the energy performance indicators, the individual building roadmap provides more detailed information for each step: renovation measures (or the package of measures), primary energy, useful energy, total investment, carbon emission, and energy carrier.

Figure 1 shows an example of a summarised roadmap.

STEP	MEASURE	PRIMARY ENERGY DEMAND [kWh/m²]	USEFUL ENERGY DEMAND [kWh/m²]	CARBON EMISSION [kg/m²a]	INVESTMENT COST [Euro]	MAIN ENERGY SOURCE
0	status quo	600	327	100		electricity
1	Thermal insulation on exterior walls - application on the inside with light coating; thermal insulation with sloped roof - application on the slopes on the resistant structure of the sloped roof; Replacement of existing frames with energy class A windows	249	99	36	14500	electricity
2	Add a biomass boiler	51	112	7	3000	wood
3	Installation of individual inclined solar thermal system	27	87	4	2000	wood

Figure 1: Exemplary summarised individual building renovation roadmap information[1]

Method

During the iBRoad project testing phase, energy auditors in three different EU countries Bulgaria, Portugal, and Poland, developed 55 real-building roadmaps while testing[2] the iBRoad-tool. This activity included the calculation (for each building and each step) of building energy performance (current state and for each renovation step) and CO_2 emission (showed in Figure 1). The calculation was carried out with a national energy performance software, the same tool used for issuing EPCs (Energy Performance Certificates) in the mentioned countries, which follow the national standards of energy performance calculation Table 1 describes each tool.

Table 1: Description of the national energy performance calculation software

	Bulgaria	*Poland*	*Portugal*
Software for energy performance calculation	EAB Software (ENSI, 2019)	Audytor OZC (Sankom, 2019) or ArCADia Thermo BuildDesk Energy Certificate (Arcadia Soft, 2019)	National Excel spreadsheets (Itecons, 2019)
Available version in English	Yes	Yes	No
Main calculation method	mainly ISO 13790:2008, adapted to Bulgaria	PN-EN 12831, PN-EN ISO 13370, PN-EN ISO 13790	Decree-Law No. 118/2013 of 20 August (republished on 23 June 2016)
Price to afford a license	Up 140 Euro (1299 NOK)	Up 550 Euro	Up 165 Euro

The present methodology consists of mainly two parts. In the first part, the renovation related information developed during the iBRoad roadmaps will be statistically described in terms of the calculated primary energy (for the current state), the number of buildings per country, building construction period, total investment costs, and the number of steps specified in the roadmap. Moreover, in the second part, the roadmaps will be assessed according to defined LTRS indicators.

This first analysis's main objective is to determine if any trend can be observed that correlates the building characteristics (building constructions year and primary energy[3] demand) or the total investment costs with the number of steps chosen by the energy auditor. Because the number of steps reflects how fast the planed energy and carbon savings are achieved: the higher the number of steps, the longer it would take to finish performing the whole renovation plan.

The following co-relations will be analyzed:

[1] The energy performance indicators were calculated by each energy auditor, using their national calculation software.

[2] More information about the project's activity related to the conduction and test procedures can be found in the project's report (Mellwig et al., 2019).

[3]Another energy indicator could be energy needs. In the context of the project, energy needs are available in iBroad-Log (or logbook). However, it was not available in the roadmaps, therefore it was not part of the present analysis.

1. **Construction year versus the number of steps:** it is expected that the roadmap of older buildings would be divided into more steps. This assumption presumes that no deep renovation activity had been undertaken before;
2. **Primary energy versus the number of steps:** similar to the indicator, it is expected that the roadmap of older buildings would be divided into more steps. (indication for that are the high primary energy, assuming that no deep renovation activity has been done before);
3. **Total investment costs versus the number of steps:** it is expected that roadmaps with higher investments are divided into more steps.

The second part of this analysis consists of a literature review of the existing national long-term renovation strategies. Secondly, based on this literature, indicators will be defined, and the roadmaps are assessed according to them. Recently, a study assessing the until now delivered LTRS across the EU Member States stated that many LTRS' are still uncompleted or do not fill all the requirements (Staniaszek et al., 2020). Spain and Flanders Region (Belgium) were cited as best-practice examples. Ideally, the iBRoad roadmaps and their accordance with LTRS should be assessed according to the country-specific LTRS, Bulgaria, Poland, and Portugal. However, Bulgaria and Poland have not submitted their LTRS yet, and the Portuguese LTRS was considered incomplete for the present study. Because of that, the documents provided from Spain (Ministerio de Fomento, 2017) and Flemish Region (Belgium) (Flemish Region, 2017) served as a guideline to define and propose seven indicators to assess the LTRS. Finally, the consistency will the LTRS indicators are also expressed in a final scoring – equally-weighted average.

According to the National Long-term renovation strategy of the Flemish Region, energy performance regulations from 2015 have established that "major energy renovation of homes, apartments, offices, and schools were required to comply with a global energy performance requirement (E90[4])". Furthermore, major energy renovation has been defined according to the following criteria:

- At least 75% of the building elements adjacent to the outside air have to be insulated;
- Installation of a ventilation system;
- Replacement of the heating system
- 45% primary energy savings (achievement of level E90[5])

Under the requirements, for cost-effective approaches (see also the chapter above *Long-term renovation strategy*), the document suggests the economic indicator (TCC) evaluate the renovation measures economically over 30 years. This indicator expresses the building's life-cycle costs and includes initial investment costs, energy consumption costs, annual maintenance costs, replacement costs, the residual value of investments, subsidies, and CO2 emissions costs.

While the Flemish LTRS focus on the technical characteristics of deep renovation activities, the Spanish LTRS has a stronger focus on policy and financing

deep renovation practices. Between other singularities, the Spanish document specifies the indicator of carbon dioxide emission ($kgCO_2/m^2$ year) to be used to rate the building's renovation targets.

Based on the previous literature, the following seven numeric indicators and criteria will be used to assess the roadmaps:

1. Primary energy savings

The indicator "primary energy savings" expresses the savings that should be achieved after all steps have been performed based on the initial building status quo:

$$PEsav = \frac{PEinitial - PEstepX}{PEinitial} \quad (1)$$

PEsav = primary energy savings [%]

PEinitial = primary energy initial (without renovation) [kWh]

Step X = last renovation step, according to the roadmap

PEstepX = primary energy in the last renovation step [kWh]

2. Carbon dioxide emission savings

The indicator "carbon dioxide emissions savings" expresses the savings that should be achieved from the initial building status quo and after all steps have been performed.

$$CO2sav = \frac{CO2initial - CO2stepX}{CO2initial} \quad (2)$$

CO2sav = carbon emission savings [%]

CO2initial = carbon emission initial (without renovation) [kgCO2]

Step X = last renovation step, according to the roadmap

CO2stepX = carbon emission in the last renovation step [kgCO2]

3. Heating system replacement

The measure heating system replacement has to be foreseen in the roadmap, to guarantee that a more efficient heating system is installed.

4. Renewable energy source for heating

Beyond the heating system's energy efficiency, its energy source (if renewable or not) is relevant to be in line with decarbonization targets (see more in the chapter Long-term renovation strategy). Therefore, preferably renewable energy sources should be installed.

5. Available incentives

As affordability is one of the main barriers to perform deep renovation, the EU member states should design attractive financing schemes (see more in the chapter Long-term renovation strategy).

[4] The E-level is a national whole building indicator developed in the Flemish region, a weighted average based on the floor area

6. Payback time

The total period to return the initial investments called payback time. Although no legislation regulates that the payback time should be used as an indicator, this is considered by building owners (or not buildings experts) to be an easily understandable indicator. The minimum payback time assumption should be reasonable and acceptable value, especially from the building owner's perspective.

$$PBT = \frac{IC-L}{(EC+OMC)savings} \quad (3)$$

PBT = payback time [a]

IC = initial investment for renovation activity [Euro]

L = available incentive [Euro]

EC savings = energy costs savings due to the heating system replacement [Euro]

OMC savings = operation and maintenance costs due to the heating system replacement [Euro]

7. Investment net present value

The investment net present value allows an economic evaluation of renovation-related investment and building-related expenditures (energy and maintenance costs) and available incentives. It calculates the net present value of the investment for 30 years.

$$IPV = \frac{IC-EC-OMC-L}{(1+r)^t} + \frac{R}{(1+r)^T} \quad (4)$$

IPV = investment net present value [Euro]

IC = initial investment for renovation activity [Euro]

EC = energy costs [Euro]

OMC = operation and maintenance costs [Euro]

L = available incentive [Euro]

r = return rate, 3% [%]

t = year [a]

T = assessment period, 30 years [a]

Results

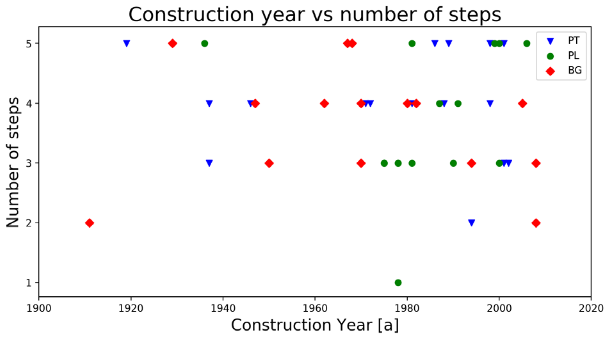
The results of the analysis are divided into two parts. Firstly, a general description of the roadmaps and interpretation of the step-by-step approach. Secondly, verification of compliance with the suggested long-term renovation indicators.

General description of the roadmaps

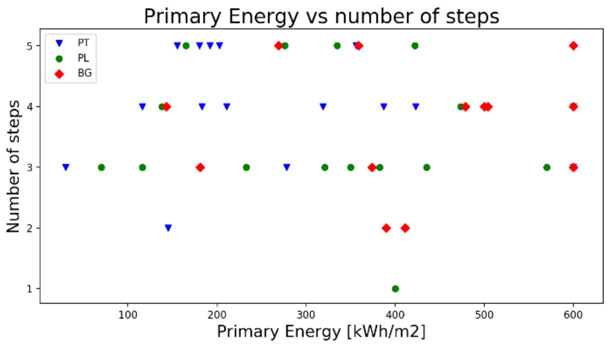
Although 55 buildings were tested in the project, 50 roadmaps obtained the present analysis's necessary information.

These 50 buildings were divided as followed: 18 in Portugal (PT), 17 in Poland (PL), and 15 in Bulgaria (BG). Most buildings have a construction year between 1900 and 2010, except for two buildings in Portugal with construction year respectively 1500 and 1575.

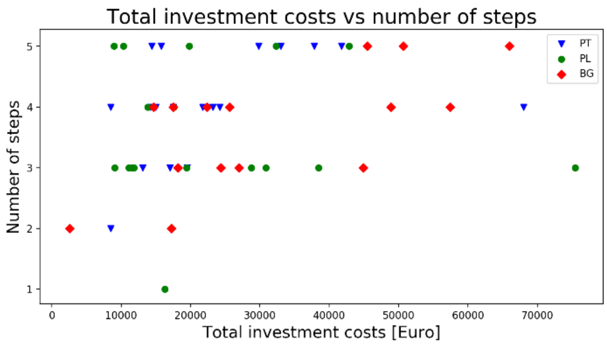
Graphs 1 to 3 below show the correlation between the parameters construction year, primary energy demand, and total investment costs versus the number of steps chosen by the energy auditor.



Graph 1: Construction year [a] and number of steps per analyzed building



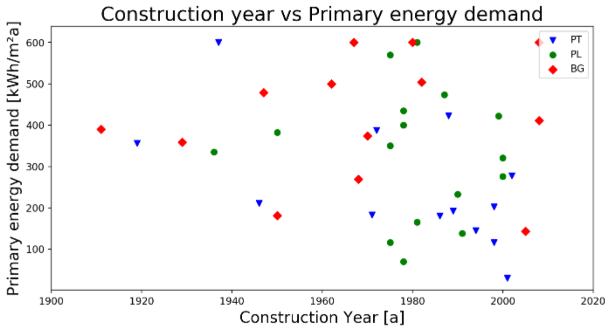
Graph 2: Primary energy demand [kWh/m²] and the number of steps per analyzed building



Graph 3: Total investment costs [Euro] and the number of steps per analyzed building

The graphs show no direct correlation between the parameters and the number of steps in any countries. It was expected that the number of steps increases according to the primary energy demand or total investment costs. However, this can also indicate that individual preferences from building owners were taken into account during the definition of the roadmaps. It can also indicate the necessity of training energy auditors on specifies regarding the step-by-step approach.

When assessing the building's primary energy demand with the construction year below, Graph 4 shows a heterogenic sample. Inclusive buildings with the same construction year, but different primary energy demands, such as buildings constructed in 1980 in Poland, vary between 550 and 50 kWh/m²a. There are the following reasons: renovations activity might have occurred, or different energy sources are installed or even.



Graph 4: Primary energy demand [kWh/m2] and construction year[a]

In general, it can be concluded that a complex and wide range of buildings exists when assessing real-life buildings. No trends and correlations could be identified, answering the first research question. The step-by-step approach is probably less explored, and energy auditors developed the roadmap without specific technical guidance. For example, on the definition and choice about the number of steps according to the building characteristics. Also, to correlate the construction year with primary energy demand, more information about renovation activity and building elements is required.

Compliance with LTRS indicators

In the chapter *Method,* seven indicators are suggested to assess step-by-step roadmaps. Below, threshold values and criteria for each one are specified –answering the second research question:

1. Primary energy (PE) savings[6] >45%
2. Carbon dioxide emission[4] (CO_2) savings >70%
3. Heating system (HS)[4] replacement = yes
4. Installation of renewable energy source[4] (RES) = yes
5. Available incentives = yes
6. Payback time (PBT) < 7 years
7. Investment net present value (IPV) > 0

The next tables show the results for each indicator and a final score.

Table 2: Number of compliant buildings per country. Indicators primary energy demand savings and carbon dioxide emission savings

	Number of compliant buildings	
Country	PE sav > 45%	CO_2 sav > 70%
PT	16	14
PL	11	3
BG	13	7

The primary energy savings requirements were achieved (65% in Poland and 89% in Portugal). However, the number of complaint buildings with the carbon dioxide requirements were low, especially in Poland (18%) and Bulgaria (47%). The main difference relies on the heating system's energy source: while in Portugal biomass is widely used, in Poland, hard coal and natural gas are still very common. Although many main energy sources were wood or electricity (heat pumps) in Bulgaria, the percentage of non-renewable second energy source supply (natural gas and hard coal) is still high.

Table 3: Number of compliant buildings per country. Indicators heating system replacement and renewable energy source

	Number of compliant buildings	
Country	HS replacement	RES replacement
PT	16	16
PL	13	5
BG	14	13

In all countries, the heating system replacement requirements were achieved. However, the replacement for renewable energy sources was not achieved in Poland (only 29%). In Portugal, most roadmaps advise heating system replacement to a biomass boiler, while in Bulgaria to a heat pump and Poland to a condensing gas boiler.

Table 4: Number of compliant buildings per country. Indicator available incentive and investment net present value

	Number of compliant buildings	
Country	Available incentive	IPV > 0
PT	6	0
PL	7	0
BG	4	0

Ideally, the net present value should be positive; otherwise, it is not economically feasible. Especially in deep renovations, energy use costs savings, and sufficient incentives benefit the net present value and turn it into a positive value. However, in all countries, the availability of incentives is quite low. Moreover, no roadmap obtained a positive investment net present value.

Table 5: Number of compliant buildings per country. Indicator payback time

	Number of compliant buildings
Country	PBT < 7a
PT	8
PL	1
BG	3

In all countries, less than half of roadmaps presented payback time lower than seven years. The very low

[6] Building's main energy source

numbers in Poland reflect that the calculated energy costs savings were also very low.

In terms of final scoring, no roadmap full filled all seven indicators. 4 buildings in Portugal and 1 in Bulgaria full-filled more than 80% of the requirements, answering the third research question.

Conclusion

This paper aims to contribute to the overarching question if building renovation advice activities are compatible with the building stock decarbonization targets set by the EU for 2050. It analyses and assesses 50 individual building renovation roadmaps developed in three different countries, Portugal, Poland, and Bulgaria, during the EU-funded H2020 iBRoad project. To develop the step-by-step roadmaps, energy auditors calculated the buildings' energy performance using national EPC software.

However, the consistency and correctness of the roadmaps themselves were not part of the present scope. One possible further study could be the deep analysis of the calculated energy savings and plausibility verification.

In the step-by-step renovation approach, the number of steps is an important parameter as it allows a qualitative indication of the time to complete the whole building renovation. If divided into many steps, there is a higher risk that the building owner interrupts the renovation process before finishing the whole project. Thus, the Salzburg Land (in Austria) has, for example limiting the number of steps to a maximum of 3. The roadmaps analyzed in this paper presented between 1 and 5 steps. There could not be any correlation between the number of steps and other parameters as construction year, primary energy demand, or total investment step, answering the first research question. Suggesting that, in real life, energy auditors should be trained on how to develop LTRS or climate compliant roadmaps. Also, national building passports should provide a more detailed indication of that.

In the iBRoad project context, additional building-related information was stored in the logbook (or iBRoad-Log). However, when treated as a single document, the roadmap should include further building-related information: building energy needs, building-related information (U-values), historic building envelope activities (partial renovation), and exact specification of the proposed measure (for example, the thickness and the heat conductivity of the insulation material).

In the second part of the analysis, the recently submitted LTRS were reviewed and answered the second research question. Until now, not all EU-member states have submitted their LTRS or have submitted uncompleted documents. From the iBRoad pilot countries, Bulgaria and Poland have not submitted their LTRS yet, and the Portuguese LTRS was considered incomplete for the present study. EU member states will have to resubmit their complete LTRS in the next months. A recent study (Staniaszek et al., 2020) cited Spain and Flanders Region (Belgium) as LTRS best-practice examples; both of these documents were deeply analyzed and guided the definition of seven indicators and their criteria suggested in the present paper.

The results showed that in terms of final scoring, no roadmap full filled all seven indicators. The analysis also shows different tendencies in terms of heating systems and respective energy sources. In Portugal, the biomass boiler was the most recommended heating system. In Poland, the building stock decarbonization targets still represent a big challenge as fossil fuel sources have been frequently recommended in the roadmaps. Furthermore, in Bulgaria, although many roadmaps suggested the replacement by heat pumps, the structure of gross electricity generation in this country consists mainly of 39,2% (hard coal), 37,4% (nuclear energy), 15,8% renewable (IAEA, 2020). These results answer the third research question.

The percentage of compliance with the economic indicators (availability of incentives, investment net present value, and payback time) were very low in all countries – evidencing the economic barriers faced by building owners in real life. There is still a need to increase the available incentives for deep renovations, with incentive sums and financing schemes that turn economically feasible the investments on a deep renovation. Also, mechanisms as CO_2 taxes are important to accelerate the replacement by renewable energy sources. Overcoming the economic barriers will enable the national building stock decarbonization of EU-member states. In Spain, according to Spanish LTRS, many regulative efforts will be made in this direction. Complementary to that, new financing schemes that take the singularities of the step-by-step approach into account should be designed.

Finally, although the EPBD (2018/844/EU) introduces the step-by-step approach, it does not introduce specific metrics to evaluate the energy and carbon emission savings of step-by-step roadmaps. Nevertheless, there is a need to use metrics that consider the time aspect of the roadmaps; otherwise, deep renovation might not happen as fast as necessary to achieve the EU's building stocks decarbonization targets. Exemplary metrics could be cumulated energy savings, minimum energy savings per step and estimated cost per saved primary energy (or energy needs). In this case, the time to perform each step gain importance. However, the roadmaps did not provide any specific indication on that. Other tools could be developed to support energy auditors in specifying this optimum time, such as the step-by-step optimization model developed by the authors, which calculates each step's optimum timing (Maia and Kranzl, 2019).

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