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Barriers and challenges of the assessment framework of the Commission Recommendation (EU) 2019/786 on building renovation by European RTD projects

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ABSTRACT

The refurbishment of buildings is one of the main keys to pursue the targets of the European Green Deal, and to accomplish the European Union has applied two mechanisms among others: the European policy and the European Research and Technological Development (RTD) projects. On the one hand, the EU has published the Commission Recommendation (EU) 2019/786 with an assessment framework composed by Measurable Progress Indicators (MPI) that can be considered the main legal instrument to measure the progress of the decarbonisation together with health & wellness, social and economic related targets of the Directive 2018/844, the Energy Performance of Buildings Directive (EPBD). On the other hand, the RTD projects also pursue the targets of the EU but following their own assessment methodology composed by Key Performance Indicators (KPIs). Considering the parallelism of these two mechanisms, the objective of this study is to analyse the applicability of the EU's assessment framework by the RTD projects, establishing a critical point of view of the viability of the MPIs and identifying the barriers and challenges of the evaluation system proposed by the EU. Regarding the methodology, the applicability of MPIs by RTD projects has been analysed in five stages: (1) Identification and listing of the MPIs of EU Recommendation; (2) selection of European RTD projects; (3) identification of the KPIs applied by the projects; (4) study of the concordance of the MPIs of the Commission Recommendation's assessment framework and the KPIs of the RTD projects; (5) evaluation of the barriers and challenges of the applicability of the EU's MPIs based on the level of agreement with the projects' KPIs. This investigation shows that although some evaluation scopes of the Commission Recommendation (EU) 2019/786 do agree with high degree with RTD projects, many MPIs present barriers related to the low reliability, the absence of standardised calculation methods, and the lack of data. Besides, the assessment framework of the Commission Recommendation (EU) 2019/786 also presents challenges to improve the evaluation of the building renovation like calibration techniques, standardised input data and the shortlisting of the MPIs to improve the effectiveness of the method. The main conclusion is that the readjustment of the assessment framework proposed in the Recommendation (EU) 2019/786 is needed. This readjustment is proposed to be done by shortlisting the MPIs and defining standardised measurement methods in order to build a common roadmap that could be followed and assessed homogenously towards the decarbonisation of the European building stock.

1. Introduction

Buildings are responsible of about the 40 % of the energy consumption and the 36 % of the greenhouse gas emissions of the European Union (EU), taking into account all the stages of the buildings' life; they are, in fact, one of biggest responsible of the greenhouse effect [1]. According to the European Commission, nowadays around the 75 % of the EU building stock is inefficient, and only the 0.4 %-1.2 % of it is renovated per year [1]. Higher renovation rates could make a big reduction of energy consumption and greenhouse gas emissions, ergo, in order to achieve the climate and energy objectives these rates should be at least doubled [1]. As a response to this, improving the energy efficiency is an important field in order to achieve the European Green Deal by 2050, which is the goal of carbon-neutrality [1]. The study investigates two

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mechanisms applied by the EU among others to pursue the mentioned targets: (i) The assessment framework of the Commission Recommendation (EU) 2019/786 and (ii) European Research and Technological Development (RTD) projects.

1.1. European energy Policy: Energy performance of buildings Directive and Commission Recommendation (EU) 2019/786

The main instrument of European energy policy on building renovation is the Energy Performance of Buildings Directive (EPBD), introduced for the first time in 2002, (Directive 2002/91/EC) [2] and updated in 2010 (Directive 2010/31/EU). Its objective is to improve the energy performance of buildings within the European Union, taking into account outdoor climate and local conditions, as well as indoor climate requirements and cost-effectiveness [3]. The last update was accepted in 2018 as part of as part of the "Clean energy for all Europeans" strategy [4] by the Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018, amending directive 2010/31/EU on the energy performance of buildings and directive 2012/27/EU on energy efficiency [5]. The legal framework promotes policies that will help to achieve a highly energy efficient and decarbonized building stock by 2050 in order to reach to the EU's energy and environmental targets, promoting the decarbonizing, the improvement of the energy efficiency and also the quality of citizens' life, together with additional benefits to the economy and the society [5].

The main measures added in the EPBD by the Directive 2018/844 were republished as Commission Recommendation (EU) 2019/786 of 8 May 2019 on building renovation, providing a wider explanation in order to transpose the EU new regulations [6]. This document "focuses on the provisions relating to the renovation of buildings and concerns Articles 2a, 10, 20 and Annex I to the EPBD, which include provisions on long-term renovation strategies, financing mechanisms, incentives, information and the calculation of energy performance of buildings" [6]. The added Article 2a (2), sets out a framework for the Long Term Renovations Strategies (LTRS) to support the renovation on national building stock into highly efficient and decarbonised buildings including: a) measurable progress indicators (MPIs), and b) indicative milestones [6]. It also includes an assessment framework composed by the MPIs with the purpose to guide the evaluation of the decarbonising processes of the building stock in Europe, in accordance with the Article 2a (2) of the EPBD [6].

The MPIs are developed by the breakdown of the referring text of the first and third paragraphs of the Article 2a (2) of the EPBD [5]: the first paragraph defines a framework with certain assessment scopes with the aim of reduce the Greenhouse Gas (GHG) emissions, decarbonise the building stock and facilitate the cost-effective transformation; the third paragraph defines the assessment about the access of mechanisms that can support the "mobilisation of investments into the renovation needed to achieve the goals" [6].

1.2. European research and technological development (RTD) projects

As the second main mechanism to pursue the energy renovation on buildings, several RTD projects have been carried out funded by European Commission's research and technological development funding programs: Seventh Framework, Horizon 2020 Interreg among others. These programs have funded several RTD projects focused in the improvement of the performance of the building stock in Europe aligned with the EU policy objectives. Many studies have been done analysing the barriers and opportunities of these projects as D'Oca et al. [7], which analyses the renovation solutions and techniques applied identifying technical, financial, and social barriers and challenges in deep building renovation. Furthermore, as the precedent of the present paper, a previous study investigated the assessment methodologies applied by RTD projects, declaring the lack of a common assessment roadmap in projects with similar nature [8], analysing 18 European research projects on energy retrofit of buildings.

Measurable parameters for the assessment of the project's development in order to achieve its milestones and objectives are denominated as "Key Performance Indicators" (KPI). As defined, "KPIs reflect the project's goals and provide means for the measurement and management of the progress towards those goals for further learning and improvement" [9], matching up with the definition of MPIs by the Commission Recommendation (EU) 2019/786 "quantitative or qualitative variables to measure progress towards the long-term 2050 goal" [6]. Many studies reclaim that KPIs is one of the most popular and valuable tools to measure the process and sustainability [910]. As an overview of the use of KPIs on building retrofit processes, Kylili et al. [9] carry out an extended review of the KPIs used in the measurement of sustainability of building retrofit processes, classifying them into eight groups: economic; environmental; social; technological; time; quality; disputes; project administration. Furthermore, another study made by Ho et al. [10] collected 19 indicators for the evaluation of commercial building retrofits via survey classified into four categories: environmental; economic; health and safety; users' perspective.

These two mechanisms are important tools of the EU to answer the need of renovation of the building stock and to follow the EU's targets, assessing their process by indicators: RTD projects use KPIs and the European policy proposes the MPI (see the Fig. 1). Following this, in order to test the applicability of the assessment framework composed by MPI defined by Commission Recommendation (EU) 2019/786, European RTD projects are the main tool, evaluating them by theoretical studies or by real case studies. Moreover, these projects can also be used to identify exemplary good practices, as it is shown right in the Commission Recommendation (EU) 2019/786 [6].

2. Objectives

The objective of the study is to analyse the applicability of the different MPIs of the assessment framework defined by the Commission Recommendation (EU) 2019/786 related to the renovation of buildings to pursue the targets of the European Green Deal by European RTD projects. This makes possible, on the one hand, to identify the barriers in the application of the assessment framework; and on the other hand, to identify the challenges that presents the evaluation framework, making possible a wider assessment for further projects on building renovation.

3. Methodology

In order to follow the objective, the present study is developed by a 5-stage methodology, graphically explained in the Fig. 2.

In the first stage MPIs defined by the Commission Recommendation (EU) 2019/786 are studied, as well as the interpretation of the Article 2a of the EPBD (Directive (EU) 2018/844 [5]). These indicators are directly defined in the EU's document, and in this stage, these indicators are listed, numbered and organised in the 12 scopes divided into 2 groups already defined in the Commission Recommendation (EU) 2019/786. The numbering is done in order of appearance in the Commission Recommendation for a simplified identification of each MPI.

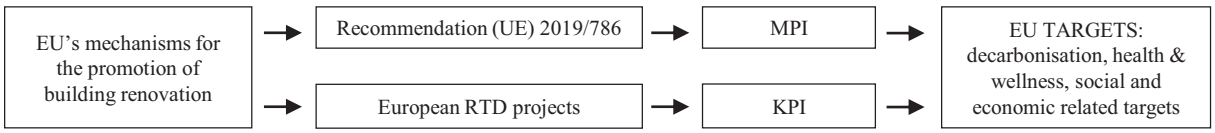

Fig. 1. EU mechanisms to pursue energy renovation of buildings.

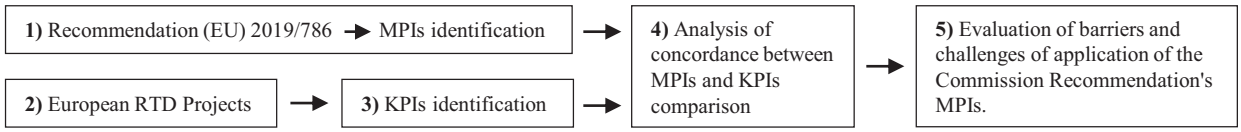

Fig. 2. The five stages of the working methodology.

For the second stage, European RTD projects based on energy renovation of buildings to be analysed were selected following the next criteria and conditions:

1) Direct connection with the objectives of the European Union relatives to the renovation of buildings, ergo, the Energy Performance of Buildings Directive, the Directive (EU) 2018/844 and Directive 2010/31/EU.
2) Funding by the main RTD Programs from the EU (Seventh Framework, Horizon 2020, Interreg) ensuring the acceptation of the European Commission and a large scale impact.
3) Requirements for the dissemination level: Open reports about the development and results of the project and open access scientific publications or indexed documents (by Scopus or Google Scholar) explaining the objective, methodologies and results of the project.

The next stage analyses the RTD projects chosen, studying the assessment framework followed by each project, focusing in the KPIs used to assess the progress and results. The KPIs used by each project are identified, listed and numbered. As source of information of RTD projects, published information has been used expressly: deliverables and reports of the projects as well as scientific publications linked to the projects. The data search has been carried out firstly using the search engines of indexed documents "Google Scholar" and "Scopus", and secondly the European RTD programmes' webpages (CORDIS and Interreg projects) and the projects' webpages. For the identification of KPIs of the projects the next assumption has been done: An indicator has been considered a parameter (quantitative or qualitative) that is used to define criteria for the assessment of a project; and the following key words have been used for the identification: indicator; key indicator; key performance indicator (KPI); parameter; assessment criteria. Only published open data have been used, in the possible case of projects with KPIs that are not published, are not taking into consideration.

In the forth and main stage of the investigation, the KPIs of the European RTD projects identified in the second stage and the MPIs of the Commission Recommendation (EU) 2019/786 listed in the third stage are compared, analysing their concordances. For this, it is checked the application of the MPIs of the Commission Recommendation as the KPIs of each RTD projects, making the connection between them. It has been considered that if two indicators (MPIs and KPIs) are evaluating the same concept, characteristic or impact they do have a concordance, even if the measurement method or the unit is not exactly the same. The analysis is made with the MPIs, which have been one by one categorized by the scopes defined in the Commission Recommendation, and the level of connections is 0 or 1, there is a concordance or there is not.

To finish, in the last stage, opportunities and barriers of the applicability of the MPIs of the Commission Recommendation (EU) 2019/786 [6] are evaluated according to the results of the concordance with the RTD projects' KPIs. The identification of the barriers and opportunities is made by evaluating the level of concordance of the indicators and by making the interpretation according to the existing literature. On the one hand, the barriers will be defined by the circumstances than can make not possible the usable application of certain evaluation scope or indicator. On the other hand, new challenges will be determined, as well as the possibilities to extend the evaluation framework of further projects, by the use of new scopes to assess that have not been applied in the latest experience. Lastly, new lines of research to perform in the assessment of projects on building renovation will be defined as the challenges to pursue.

4

Based on the structure of the methodolody presented in the Fig. 2, the study on each of the 5 stages is shown below.

4.1. Measurable progress indicators (MPI) of the Commission Recommendation

The MPIs have been listed following the scheme presented in the text of the "Commission Recommendation (EU) 2019/786 of 8 May 2019 on building renovation". Forty-four MPIs have been identified and classified into twelve scopes divided into two sections, using original text for both the definition of the scopes and the indicators. The twelve scopes divided in two sections are listed below, and the list of individual MPIs is indicated in the Chapter 4.4 (see Table 3).

Section 1: (7 scopes and 39 MPIs): Areas to be covered by long-term strategies to support the renovation of the national building stock (residential and non-residential, public and private) "highly energy efficient and decarbonised building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero-energy buildings" [5]:

"Overview of the national building stock, based, as appropriate, on statistical sampling and expected share of renovated buildings in 2020". (9 MPIs)
"Identification of cost-effective approaches to renovation relevant to the building type and climatic zone, considering potential relevant trigger points, where applicable, in the life-cycle of the building". (2 MPIs)
"Policies and actions to stimulate cost-effective deep renovation of buildings, including staged deep renovation, and to support targeted cost-effective measures and renovation, for

example by introducing an optional scheme for building renovation passports". (4 MPIs)
"Overview of policies and actions to target the worst-performing segments of the national building stock, split-incentive dilemmas and market failures, and an outline of relevant national actions that contribute to the alleviation of energy poverty". (4 MPIs)
"Policies and actions to target all public buildings". (1 MPI)
"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". (7 MPIs)
"Evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety and air quality". (12 MPIs)

Section 2: (5 scopes and 5 MPIs): "To support the mobilisation of investments into the renovation needed to achieve the goals referred to in paragraph 1, Member States shall facilitate access to appropriate mechanisms" [5] in the following areas:

"The aggregation of projects, including by investment platforms or groups, and by consortia of small and medium-sized enterprises, to enable investor access as well as packaged solutions for potential clients". (1 MPI)
"Reduction of the perceived risk of energy efficiency operations for investors and the private sector". (1 MPI)
"Use of public funding to leverage additional private-sector investment or address specific market failures". (1 MPI)
"Guiding investments into an energy efficient public building stock, in line with Eurostat guidance". (1 MPI)
"Accessible and transparent advisory tools, such as one-stop shops for consumers and energy advisory services, on relevant energy efficiency renovations and financing instruments". (1 MPI)

4.2. Selection of European research and technological development (RTD) projects

There are several RTD projects based on the renovation of buildings, with different working scopes, scales and with different funding entities, with their own methodologies for the assessment of their process and results. In the present study, 38 European RTD projects have been selected according to the criteria defined. The selection has been carried out to reflect the current trends of the nowadays research and development initiatives based on the actual main European level RTD funding programmes, "FP7", "Horizon 2020" (H2020), and "Interreg" programmes. Horizon 2020 is the eighth RTD funding programme of the European Commission, the "eighth framework programme" (FP8), from 2014 to 2020. In the research, twenty-eight H2020 projects were included, as the main research and technological development current in the EU; moreover other two projects belonging to the last two years previous programme, FP7, were added because of its significance in the path followed by the European Commission's RTD funding programmes. This path has been continued with the ninth framework program (FP9) named "Horizon Europe" (2021–2027), but no projects of this programme were included because their status in early stages is not enough for the analysis. Regarding more specific and local conditions, "Interreg" is a set of territorial cooperation programmes, funded by the European Regional Development Fund (ERDF). For the study-eight projects from different "Interreg" programmes have been included, all of them from "Interreg V5", the fifth edition the funding framework, from 2014 to 2020. Apart from this, although national and minor scale research programmes also follow the same targets only projects belonging to the EU have been selected, as direct key instruments of the EU. In the Table 1 the selected projects to be studied are listed indicating the funding research program, period and coordination entity, together with the references of the published documentation of the projects; the projects are ordered by the RTD programme (FP7, H2020 and Interreg) and period.

Twenty-one of the RTD projects have been elected due to their mention in the Commission Recommendation (EU) 2019/786 document, as the "Good practice for complying with Article 2a of the EPBD" [6]. The projects are mentioned as exemplary cases of the application of the assessment scopes of the MPI of the Commission Recommendation. In the 1-B scope, referring "Cost-effective approaches to renovation", the project E2ReBuild is mentioned as demonstration of cost-effective and energy efficient advanced renovation solutions of residential buildings creating added value by the industrialised retrofitting. In accordance with the scope 1-C, "Policies and action on deep renovation", two projects perform strategies as roadmaps; the projects iBRoad and ALDREN make use of renovation strategies and propose a building renovation passport (BRP) as a voluntary certification. The scope 1-D, about "Policies and actions on worst-performing buildings and energy poverty" count with four projects as exemplary cases: the ENER-FUND project is based is the assessment of deep renovation by a decision making tool, focusing in the worst performing segments of the building stock; the ASSIST project is focused in the alleviation of energy poverty by the service network of vulnerable consumer energy advisors; and, EnerSHIFT and Transition Zero projects study deep renovation solutions by the refurbishment of social housing. Furthermore, the project EmBuild works out renovation strategies for local authorities in relation with the scope 1-E, "Policies and action on public buildings". In terms of "Incentives for smart technologies and skills", in the scope 1-F, three linked projects have been identified, aiming the development of smart technologies to assess energy renovation of buildings; Smart-up used smart-meters and trained stakeholders in smart-technologies to encourage the active use of these technologies for energy renovation of vulnerable households; PEAKapp is based on the efficient use of the energy and also aims to shift the consumption loads to the peak production hours of renewable; and the third one, MOBISTYLE promotes the awareness in order to achieve improvements in indoor environment and heath with a better understanding of the use of energy by the use of information and communication technology (ICT) based services. In the scope 1-G, "Estimate of energy savings and wider benefits", the COMBI project aims the creation of policymaking by decision making support frameworks that calculates the non-energy benefits and energy efficiency. For the second section of MPI of the Commission Recommendation, about "Mechanisms to support the mobilisation of investments", also certain projects have been identified performing investment strategies to promote the aims followed by the assessment of the first stage. For the 2-A scope, the "Aggregation of projects", the PadovaFIT project follows the generation of economic advantages and guarantees the quality of renovation works by grouping multi-family buildings to retrofit and with energy performance contracting; with a similar aim, the CITYN-VEST project studied innovative financial models for building renovation focusing in public buildings by "one-stop shop" model. In the case of exemplary cases of the scope 2-B, "Reducing the perceived risk of energy efficiency operations", the SEAF project performed an evaluation framework to assess holistic sustainable energy efficiency projects, improving the connection between the project developers and investors; besides, the EUROPACE project is focused on tax financing mechanisms for local authorities. In relation with the scope 2-C, based on "Public funding to leverage private-sector investment or address market failures", on the one

Table 1
European RTD projects analysed.

PROJECT	REF.	PROGRAM	PERIOD	Cordination entity
E2ReBuild	[11–14]	Seventh Framework	2011–2014	NCC AB
EASEE	[15–17]	Seventh Framework	2012–2016	Rina Consulting SPA
Smart-up	[18,19]	Horizon 2020	2015–2018	Alpheeis SAS
COMBI	[20–22]	Horizon 2020	2015–2018	Wuppertal Institut fur Klima, Umwelt, Energie Ggmbh
CITYNVEST	[23–25]	Horizon 2020	2015–2018	Climate Alliance
TRUST-EPC-South	[26–30]	Horizon 2020	2015–2018	Creara Consultores SL
REFURB	[31–34]	Horizon 2020	2015–2018	Vlaamse Instelling Voor Technologisch Onderzoek
REScoop MECISE	[35–37]	Horizon 2020	2015–2019	Ecopower
REVALUE	[38–40]	Horizon 2020	2015–2019	Bax Innovation Consulting SL
OptEEmal	[41–44]	Horizon 2020	2015–2019	Fundacion CARTIF
RemoUrban	[45–47]	Horizon 2020	2015–2020	Fundacion CARTIF
TRANSITION ZERO	[48–50]	Horizon 2020	2016–2018	The National Energy Foundation
EmBuild	[51–53]	Horizon 2020	2016–2018	Deutsche Gesellschaft fur Internationale Zusammenarbeit
SEAF	[54–56]	Horizon 2020	2016–2018	Joule Assets Europe Ab Oy
ENERFUND	[57–59]	Horizon 2020	2016–2019	Technologiko Panepistimio Kyprou
PEAKapp	[60–62]	Horizon 2020	2016–2019	Energieinstitut an der Johannes Kepler Universitat Linz
REScoop PLUS	[63–65]	Horizon 2020	2016–2019	Levelcardinal Unipessaoal LDA
EnerSHIFT	[66–68]	Horizon 2020	2016–2020	Regione Liguria
MOBISTYLE	[69–71]	Horizon 2020	2016–2020	Huygen Installatie Adviseurs
REPLICATE	[72–75]	Horizon 2020	2016–2021	Ayuntamiento de Donostia San Sebastián
iBRoad	[76–78]	Horizon 2020	2017–2020	Sympraxis Team P.C.
ALDREN	[79–82]	Horizon 2020	2017–2020	Centre Scientifique et Technique Du Batiment
ASSIST	[83–85]	Horizon 2020	2017–2020	Aisfor SRL
QualitEE	[86–88]	Horizon 2020	2017–2020	E7 Energie Markt Analyse GMBH
Innovate	[89–91]	Horizon 2020	2017–2020	Energy Cities / Energie-Cites Association
RenoZEB	[92,93]	Horizon 2020	2017–2021	Solintel M&P SL
EuroPACE	[94,95]	Horizon 2020	2019–2021	Centrum Analiz Spoleczno Ekonomicznych
BUILD UPON [2]	[96–98]	Horizon 2020	2019–2021	Green Building Council-España
EEnvest	[99–101]	Horizon 2020	2019–2022	Academia Europea di Bolzano
PadovaFIT	[97,102]	Horizon 2020	2019–2022	Comune di Padova
SHERPA	[103,104]	Interreg Mediterranea	2016–2019	Generalitat de Catalunya
REbus	[105,106]	Interreg Europe	2016–2021	Agenzia Regionale Recupero Risorse
ENERPAT	[107–109]	Interreg Sudoe	2016–2019	Communauté d'Agglomération du Grand Cahors
PrioritEE	[110,111]	Interreg Mediterranea	2017–2019	National reserach council of Italy
ATLAS	[112–114]	Interreg Alpine Space	2017–2021	Eurac Reserach
Area 21	[115,116]	Interreg Baltic Sea	2017–2020	HafenCity University Hamburg
INDU-ZERO	[117,118]	Interreg North Sea	2018–2022	Province of Overijssel (NL)
BIPV meets history	[119,120]	Interreg Switz.-Italy	2019–2022	Eurac Reserach

hand, the projects REScoop-PLUS and REScoop-MECISE studied the cooperation financing to boost the investments in building energy retrofit by energetic cooperatives, local authorities and citizens; on the other hand, the QualitEE project developed model contracts with standardized quality criteria, institutionalization of the process and active promotions schemes in order to ensure the quality and financeability of investment programs. In the 2-D scope, "Guiding investments into an energy efficient public building stock", the TRUST-EPC-South project performed a normalized framework to assess the risks and compare investments in energy efficiency on a real stated platform. To finish, in concordance with last assessment scope 2-E, "Accessible and transparent advisory tools", the project Innovate studied the investment pilot models and services offered to the houseowners.

Furthermore, additional projects were elected from the previous study [8] that analysed the assessment methodologies of energy retrofit European RTD projects; seven projects were added following the criteria established in the working methodology, belonging to the FP7 and H2020 funding programmes. These projects have different type of nature working out in several fields. As a project with a social base, the REFURB project proposes different renovation packages based not only in energy, also in the features and needs of the dwelling and dweller creating a methodology. Furthermore, BIM (Building Information Modelling) based methodologies are also developed, like RenoZEB project, researching in new renovation constructive solutions using prefabricated elements. Investment and property value has been also studied, example is the REVALUE project, which performed norms and standards to recognise the energy efficiency of public and private residential buildings to promote the retrofitting. Regarding the development of an Energetic Action Plan for cities, let's mention the projects REPICATE and RemoUrban, which follow a similar schedule with three main working areas being one of them the improvement of energy efficiency of existing buildings. As a tool development OptEEmAL is based on different energy conservation measures in to perform the energy use at building and district scale. The project EASEE investigated different innovative envelope solutions with short payback periods. Moreover, another project was added, BuildUpon[2], due to its assessment methodology for local strategies for building retrofit built based on KPIs, studied in deep together with numerous local authorities.

In addition, other eight RTD projects from Interreg programmes were included in order to consider actions with more specific needs of certain regions of Europe. These projects take more in consideration the heritage value of vernacular architecture like "BIPV meets history" project was based on the integration of photovoltaic panels in historic buildings or the ATLAS project that investigates the refurbishment solutions for alpine traditional buildings. Together with the heritage value Interreg projects also focus their efforts in the enforcement of the local economy and the cooperation, like the ENERPAT project, based on the "eco-renovation solutions" of the housing of historic centres, experimenting on networks of cooperation in the local economy and Area 21 project that also worked in the cooperation for energy plans at district level.

All these projects are focused in the improvement of the energetic behaviour of buildings, together with other benefits, and lead to the implementation of strategies through their lessons learned.

As the base of the research projects about policy, the COMBI project claimed the strong need for the integration of respective research and evaluation schemes into policy. In this line, REScoop PLUS concluded that policy about self-energy generation and sharing needs to be re-established. To boost investors, CITYNVEST projects shows that the cooperation between public authorities and private investors needs to be reinforced. In addition, REVALUE project expresses that the only recognised effective market driver on energy renovation is stricter policy but alerts that the increasing the energy efficiency standards can lead decrease value of unrefurbished buildings. Also the market needs to be mobilized according to the REScoop MECISE project, and SEAF project found out the need to bridge the finance gap for small energy efficiency projects. Another issue is the awareness of users, and E2ReBuild project concluded that benefits are not enough to initiate the renovations; an external trigger is needed, taking into account social, economic aspects. Also REFURB project saw that energy savings is not enough to encourage users to refurbish their buildings and solution need to specified for a particular business model and the cooperation of energetic consultants. Furthermore, education can also increase this awareness by teaching about the energy use, indoor environment and healthy behaviour according to the lessons learned by MOBISTYLE project. For these purposes and for the better decision making of different stakeholders many projects developed tools like OptEEmal that had a very positive feedback. However, for the use of these type of tools data collection is crucial and projects like RemoUrban and Enerfund demanded open and geo-referred data because difficulties were found in the data collection for the development and assessment during the projects. Finally, the correct technical solutions are crucial so RenoZEB and EASEE projects studied new solutions such as prefabricated modular façade systems identifying critical points and found out the special need of optimization for the economic feasibility of this type of solutions.

4.3. Key performance indicators (KPI) of RTD projects

There are several fields to assess in RTD projects on building renovation, using KPIs to evaluate the sustainability of different fields. Many studies have been carried out about KPIs and its classification in different assessment fields. This study have identified four main KPI categories according to the existing literature and assessment methods of the analysed European RTD projects: Environmental & Energetic KPIs; Economic KPIs, Social KPIs and Wellbeing & Health related KPIs. The most assessed fields are the environmental & energetic and the economic according to the existing literature [9,10,121,122] and also the most evaluated scopes by European RTD projects according to the previous study of Arbulu et. al [8]. Moreover, most of the analysed projects of this study, 28 of 38, make use of environmental & energetic and economic KPIs. The other two categories play a minor role in the evaluation of the social and health & wellbeing aspects of the RTD projects, assessing 18 of 38 projects; this minor role of the social and health & well-being scopes was also demonstrated in the previous work already mentioned, about the analysis energy retrofit assessment methodologies in buildings by European research projects [8]. The main KPIs identified in the RTD projects are indicated in the Table 2, organized by KPI categories and the Fig. 3 reflects the use of the KPIs by the RTD projects.

The most significant category related to the targets of the European policy is the environmental & energetic KPIs category, which evaluates the environmental impact and the energetic behaviour (directly linked with the environmental impact) of the building and its renovation processes. Although the fields of energy and environment can be distinguished, most of the investigations about the use of KPIs in projects on energy retrofit of buildings treat them as a single scope, both energetic and environmental evaluation. In the investigation of H. Alwaer & D.J. Clements-Croome [121] about the assessment of sustainable intelligent buildings, all the KPIs related to environment and energy were grouped in the "environmental indicator group" assessing fields such as energy, use of natural resources, use of water, use of land and GHG emissions. Moreover, the analysis about KPIs on building renovation made by A. Kylili et al. [9] identified many indicators from a number of studies, categorizing them as "Environmental KPIs" the indicators assessing several fields: atmosphere, land use, water resources, ecology, noise, visual impact, indoor quality, energy, reuse / recycle and waste management. In terms of research projects, the present work shows the use of environmental KPIs in almost all the RTD projects analysed. According to the existing literature and the analysis of the projects, seven main "environmental & energetic KPIs" have been defined in the Table 2 indicating the projects containing each KPI or similar. On the one hand, the most used KPIs are the ones related with the use of energy of the building using several formats, as energy savings, energy consumption, primary energy and energy demand, being used by 26 projects; the KPIs related specifically with the renewable energy sources (RES) are used in 11 projects,. On the other hand, as the environmental indicators, the KPIs about greenhouse gas (GHG) emission or similar (CO_2 eq. emissions, CO_2 emissions) have also a relevant use as the main indicator of environmental impact in terms of global warming potential. The study of De Wilde and Tian [123] quantified the impact in the climate change of a theoretical office building assessing the process by tree indicators, choosing the "Annual carbon emissions" as the environmental indicator; Dijkstra [124] also included the "GHG emissions" as an environmental KPI because of the political decision-making in climate change. In addition, more environmental indicators are used, in a minor way, related to the use of water, the use of natural resources, the embodied energy and the impact measured as the ecological footprint.

Together with the previous category, the economical KPIs are the most significant and they are the ones that assess the economical sustainability of a process, in this case, the economic feasibility of the energetic improvement of the building. According to the study made by A. Kylili et al. [9] the economical KPIs are "associated with the costs of the project, as well as the economic performance of the building according to the perception of the involved stakeholders". The economic feasibility is affected by all the costs and savings that are involved the process to assess, taking into account direct and indirect costs as well as savings attributable to the process, from the beginning and during all the lifespan of the building. The study demonstrates that the economic feasibility of building renovation is fundamental in building refurbishment projects as the economical field is one of the most assessed fields in European RTD projects, being economical KPIs identified in almost all the projects. The most used KPIs are the ones based on the economic cost of the process of the energetic improvement of the building (applied in 17 projects) and the running costs related to energy and maintenance (applied in 15 projects), as it is indicated in the. More into deep, several projects used indicators that can directly evaluate the economic performance like the "payback period" (10 projects), the "life cycle cost (LCC)" (5 projects) and the "net present value (NPV)" (3 projects). The "payback period" method is one of the most popular method to calculate the economic feasibility, predicting the amount of time needed to recover the investment with the savings attributed to the renovation [125]. The LCC method can be considered one of the most complete economical methods, with the standard EN16627:2016 [126] for the assessment of economic performance of buildings. As another indicator, the net present value (NPV) "marks the dissimilarity between the current value of cash inflows and the value of cash outflows considered over some time" [127]. Moreover, other eco-

Table 2
KPIs of the RTD projects.

KPI CATEGORY		EUROPEAN RTD PROJECTS
Environmental & Energetic KPIs		
1- Use of energy (demand, consumption, savings, primary)	26	E2ReBuild, iBroad, ALDREN, ENERFUND, ASSIST, EnerSHIFT, Transition Zero, EmBuild, PEAKapp, MOBISTYLE, CITYNVEST, EuroPACE, REScoop Plus, REScoop Mecise, QualitEE, Trust-EPC, Innovate, Enerpat, Refurb, Revalue, Replicate, RemoUrban, OptEEmal, EASEE, Build-Upon^2, Atlas
2- GHG emissions / CO_2 emissions	15	ENERFUND, EnerSHIFT, PEAKapp, MOBISTYLE, COMBI, REScoop Mecise, QualitEE, Trust-EPC, Enerpat, Replicate, RemoUrban, OptEEmal, EASEE, Build-Upon^2, Atlas
3- RES (generation, use)	11	E2ReBuild, iBroad, ALDREN, Transition Zero, REScoop Mecise, Revalue, Replicate, RemoUrban, OptEEmal, Atlas
4- Water use	6	MOBISTYLE, QualitEE, Trust-EPC, Replicate, RemoUrban, Atlas
5- Embodied energy	4	Enerpat, Replicate, OptEEmal, Atlas
6- Ecological footprint	1	COMBI
7- Natural resources	2	COMBI, Atlas, BIPV m. h.
8- Ecological footprint	1	COMBI
Economical KPIs		
9- Investment cost, Renovation cost	17	E2ReBuild, ENERFUND, EnerSHIFT, EmBuild, CITYNVEST, SEAF, REScoop Plus, REScoop Mecise, Trust-EPC, Innovate, Enerpat, Revalue, Replicate, RemoUrban, OptEEmal, EASEE, BIPVm.h.
10- Running Costs / Energy costs	15	E2ReBuild, ENERFUND, EnerSHIFT, Transition Zero, EmBuild, Smart-Up, COMBI, EuroPACE, Innovate, Revalue, Replicate, OptEEmal, EASEE, Build-Upon^2, BIPVm.h.
11- Payback period	10	ENERFUND, EmBuild, CITYNVEST, Trust-EPC, Innovate, Enerpat, Replicate, OptEEmal, EASEE, BIPVm.h.
12- Economical savings	9	ASSIST, EmBuild, PEAKapp, QualitEE, Trust-EPC, EASEE, Reavlue, Build-Upon^2, BIPVm.h.
13- Subsides / Incentives	7	ENERFUND, Transition Zero, EmBuild, EuroPACE, QualitEE, Innovate, Replicate
14- Markel value	6	ALDREN, ENERFUND, Innovate, Refurb, Revalue, RemoUrban
15- Life Cycle Cost (LCC)	5	ALDREN, ENERFUND, Revalue, OptEEmal, Atlas
16- Net Present Value (NPV)	3	EnerSHIFT, CITYNVEST, EASEE
Social KPIs		
17- Energy poverty	9	ASSIST, Trabsition Zero, Smart-Up, EuroPACE, Enerpat, Replicate, RemoUrban, OptEEmal, Build-Upon^2
18- Communication and information	9	E2ReBuild, SEAF, REScoop Plus, QualitEE, Innovate, Refurb, Replicate, RemoUrban
19- Economic income	7	Smart-Up, EuroPACE, REScoop Plus, Refurb, Revalue, Replicate, RemoUrban
20- Public perception / acceptance	7	E2ReBuild, Transition Zero, EuroPACE, REScoop PLUS, QualitEE, Enerpat, BIPVm.h.
21- Time	3	Transition Zero, REScoop Plus, Trust-EPC,
22– Citizen participation	2	E2ReBuild, Replicate
Health & Wellbeing KPIs		
23– Thermal conditions	11	E2ReBuild, ALDREN, Transition Zero, Smart-Up, MOBISTYLE, Enerpat, Revalue, RemoUrban, OptEEmal, Build-Upon^2, Atlas
24- IAQ (Indoor Air Quality)	10	E2ReBuild, ALDREN, Transition Zero, MOBISTYLE, Enerpat, Revalue, RemoUrban, OptEEmal, Build-Upon^2, Atlas
25- Light conditions	6	E2ReBuild, ALDREN, Transition Zero, MOBISTYLE, Enerpat, OptEEmal
26- Acoustic conditions	5	E2ReBuild, ALDREN, Transition Zero, Enerpat, Revalue
27- Comfort level	6	iBroad, ASSIST, Trust-EPC, EASEE, BIPV m. h.
28- Moisture / Humidity conditions	4	E2ReBuild, MOBISTYLE, Revalue, RemoUrban
29- Work productivity	4	COMBI, QualitEE, RemoUrban, EASEE
30- Health parameters	2	MOBISTYLE, COMBI

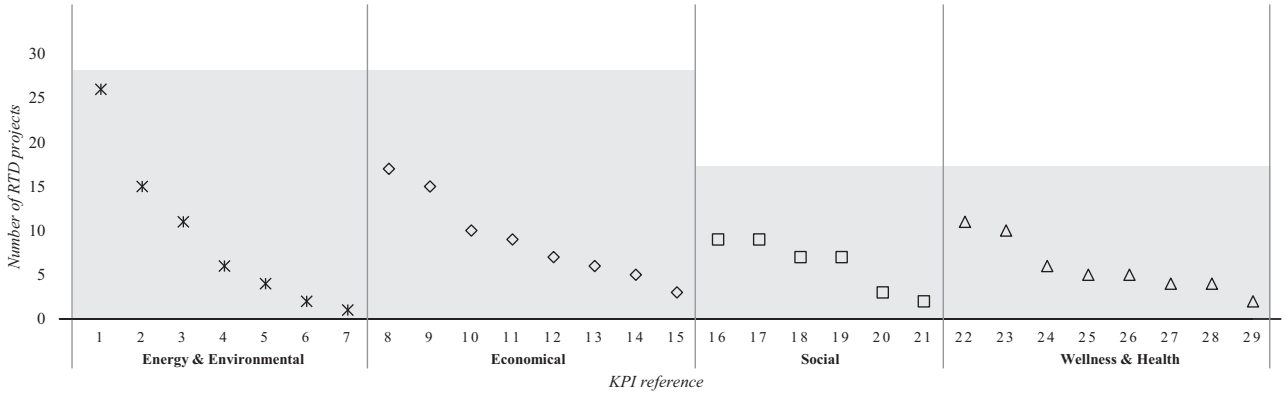

Fig. 3. Number of RTD projects in concordance with each KPI by categories.

nomical KPIs are applied, such as subsides or incentives for a renovation and the fluctuation of the market value of the property according its energetic behaviour and conditions as economic benefits.

The social KPIs are directly linked to many objectives of the European policy [1] but they are not as significant as the environmental & energetic or economical categories. The social KPIs assess the direct impact of the project in the stakeholders and their perception analysing the socioeconomic situation and influence on public following the main indicators identified, shown in the Table 2. The most assessed indicator is the "energy poverty" or "fuel poverty" defined as the situation where "its energy consump-

Table 3
Concordance of the MPIs of the Commission Recommendation (EU) 2019/786 and European RTD projects' KPIs.

Scope	Measurable Progress Indicator (MPI)	E2ReBuild	EASEE	CITYNVEST	COMBI	REFURB	Smart-up	TRUST-EPC-South	Opteemal	REScoop MECISE	REVALUE	RemoUrban	EmBuild	SEAF	TRANSITION ZERO	PEAKapp	REScoop PLUS	ENERFUND	EnerSHIFT	MOBISTYLE	Replicate	ALDREN	ASSIST	iBRoad	Innovate	QualitEE	BUILD UPON 2	EuroPACE	EEnvest	ENERPAT	ATLAS	BIPV meets history
1-A) Overview of the national building stock,based,as appropriate,on statistical sampling and expected share of renovated buildings in 2020.	**1-** Number of Buildings (type, age, size, climatic zone)	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	x	–	–	–	–
	2- Number of Dwellings (type, age, size, climatic zone)	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–
	3- Surface [m2] (Building type, age, size, climatic zone)	x	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–
	4- Annual energy consumption (by Building type, End Use)	x	x	–	–	x	–	x	x	–	x	x	x	–	x	–	–	x	–	x	x	x	–	x	–	–	x	x	–	x	x	x
	5- Annual % renovated (by Building type, Building sector)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–
	6- Renovated m2 (by Building type, size, age)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	x	–	x	–	–	–	–	–	–	–	–	–	–	–
	7- Number of EPCs (by Building type, Energy class)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	8- Number of NZEB (by Building sector)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	9- m2 of NZEB (by Building sector)	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1-B) Identification of cost-effective	**10-** Cost-effectiveness of main renovation measures	x	x	x	–	–	–	x	x	–	x	–	x	x	–	–	x	x	x	–	x	x	x	–	x	–	–	x	x	x	x	x
	11- Total energy saving potential	–	–	x	–	–	–	x	–	x	x	–	–	–	–	x	–	x	x	–	–	–	x	–	–	–	x	x	x	x	–	–
1-C) Policies and actions to stimulate cost-effective deep renovation of buildings.	**12-** % of buildings undergoing deep and NZEB renovation	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	13- Public incentives for deep renovation	–	–	–	–	–	–	–	–	–	–	–	x	–	x	–	–	x	–	–	–	–	–	x	–	–	–	x	–	–	–	–
	14- Public and private investments in deep renovations	–	–	–	–	–	–	–	–	x	–	x	–	–	x	–	–	x	x	–	–	–	–	–	x	–	x	–	–	–	–	–
	15- Energy savings from deep renovations	–	–	–	–	–	–	x	x	–	–	–	x	–	–	x	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
1-D) Overview of policies and actions to target the worst-performing segments of the national building stock.	**16-** Public investments in policy addressing social issues	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	17- % of rented houses with EPCs below a certain performance level	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	18- Energy poverty indicator	–	–	–	–	–	x	–	x	–	–	x	–	–	x	–	–	–	–	–	x	–	x	–	–	–	x	x	–	x	–	–
	19- of buildings in lowest energy classes	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1-E) Policies and actions in public buildings	**20-** Renovated public buildings in m2 (Building type, age, size, climatic zone)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1-F) Overview of national initiatives to promote smart technologies and well-connected buildings and communities.	**21-** No. of b. with building energy management systems (BEMSs) or similar smart systems	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	22- Public and private investments in smart technologies (including smart grids)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	23- Citizens participating in energy communities	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	24- No of graduated students related to energy efficiency	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	25- No of installers skilled in new technologies and working practices	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	x	–	–	–	–	–

Concordance of the MPIs of the Commission Recommendation (EU) 2019/786 and European RTD projects' KPIs.

Scope	Measurable Progress Indicator (MPI)	E2ReBuild	EASEE	CITYNVEST	COMBI	REFURB	Smart-up	TRUST-EPC-South	Opteemal	REScoop MECISE	REVALUE	RemoUrban	EmBuild	SEAF	TRANSITION ZERO	PEAKapp	REScoop PLUS	ENERFUND	EnerSHIFT	MOBISTYLE	Replicate	ALDREN	ASSIST	iBRoad	Innovate	QualitEE	BUILD UPON 2	EuroPACE	EEnvest	ENERPAT	ATLAS	BIPV meets history
1-F) Overview of national initiatives to promote smart technologies and well-connected buildings and communities.	**26-** Budget of national research programmes in the field of building energy efficiency	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	27- Participation of national universities in international scientific research projects (e.g. H2020) on energy efficiency in buildings- related topics	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1-G) Evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety and air quality	**28-** Reduction in energy costs per household (average)/decrease in energy poverty	x	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	x	–	–	–	x	–	–	–	x	x	–	–	–	–
	29- Actual energy savings achieved	x	x	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–
	30- Average/aggregate indoor air quality indices (IAQ) and thermal comfort index (TCI)	x	x	–	–	–	x	x	x	–	x	x	–	–	x	–	–	–	–	x	–	x	x	x	–	x	x	–	–	x	x	x
	31- Cost of avoided illnesses/reduction in health costs attributable to energy efficiency measures	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	32- Reduction of whole life carbon	–	–	–	x	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–
	33- Disability Adjusted Life Year (DALY)/Quality Adjusted Life Year (QALY) improvements attributable to the improvement of building stock and living conditions	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	34- Labour productivity gains from better working environment and improved living conditions	–	x	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–
	35- Reduction of emissions	–	x	–	x	–	–	x	x	x	–	x	–	–	–	x	–	x	x	x	x	–	–	–	–	–	x	–	–	x	x	–
	36- Employment in the building sector (No of jobs created per EUR million invested in the sector)	–	x	–	x	–	–	–	–	x	–	x	–	–	–	–	–	–	–	–	x	–	–	–	–	–	x	–	–	x	–	–
	37- GDP increase in the building sector	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–
	38- % energy imports for the Member State (energy security measures)	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	39- Removal/prevention of accessibility barriers for persons with disabilities	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2-A) Aggregation of projects.	**40-** No of integrated/aggregated projects	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2-B) Reduction of the perceived risk.	**41-** Perceived risk of energy efficiency operation (survey-based)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2-C) Public-private initiatives.	**42-** Public investments as percentage of total investments in energy saving Public-private partnership initiatives	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2-D) Investments in public building stock.	**43-** Investment in energy efficiency renovation on the public building stock	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
E) Accessible and transparent advissory tools,	**44-** Perceived risk of energy efficiency operation (survey-based)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–

tion does not meet basic energy needs" [128] applied by 9 projects. Related with the socioeconomic situation of the tenants or householders, the economic income is also taken into account in 7 projects. Moreover, the interaction levels with the users can also originate indicators evaluating communication and information given to the stakeholders, performed in 9 projects. The public perception and the acceptance is also taken into account in 7 projects adding the value of the bidirectional communication; and in addition, the evaluation of the citizen participation has been included in 2 projects, a decisive factor to assess according to C.C. Menassa & B. Baer [129] that demonstrated that "the capital planning process must incorporate and integrate stakeholders that represent all aspects of operations and use throughout a building's lifecycle to increase transparency, efficiency, and cost effectiveness".

In response to the targets of the European policy, the health and well-being in indoor spaces evaluation are also a key factor in building renovation [1], which are applied in 18 projects, as shown in the Table 2. These KPIs are related to the indoor environmental conditions that affect in the perception of the users, measuring the comfort and health conditions of the building. In certain studies, this evaluation is included in the "Environmental KPIs" as it measures the environmental conditions [9,122], or it could be also categorized as "Social KPIs" as it assess the user's perceptions that affects in the social life [121], but, the present study has reserved a specific category for such scope due to the structure of the assessment categories of the RTD projects and the specific evaluations performed published in the existing literature [130–132]. In a previous investigation about the assessment of projects, the scope of "health & well-being" evaluation had also the same organization according to the analysis of assessment methodologies followed by European RTD projects [8]. The KPI about the thermal conditions is the most evaluated parameter, applied in 11 projects, together with the in 10 projects, the two main factors defined in the standard EN 16798:2020 among with lighting and acoustic conditions. These last two factors are also taken into account, although in less projects, assessing the lighting conditions in 6 projects and acoustic conditions in 5 projects. Following the criteria of the standard EN 16798:2020 based in the mentioned four main factors (indoor air quality, thermal environment, lighting and acoustic), the project ALDREN developed the "TAIL" method for rating the indoor environmental quality following the same four: T – thermal environment, A – acoustic environment, I – indoor air quality, and L – luminous environment [133]. Furthermore, other four projects also evaluate the comfort level but as a single indicator. The humidity conditions, which are an important factor in order to consider a healthy indoor environment, were also applied in the study about the indoor environmental quality in social housing in Spain, by A. Serrano-Jiménez et al. [134]. As the measurement of the consequences of the health and well-being, conditions the work productivity attributed to the comfort level and other health parameters are analysed.

It is important to mention the limitations of the investigation work of this section in terms of data availability; although all the chosen projects have the required dissemination level, seven of them, the projects PadovaFIT, RenoZEB, SHERPA, REBUS, PrioritEE. Area 21, INDU ZERO have not published any evaluation framework with defined indicators limiting the number of projects with KPIs to 31. Moreover, during the investigation all the data search was carried out methodologically, analysing more projects further than the 38 mentioned, but many of them did not have the minimum dissemination level, with many projects without any peer reviewed scientific of indexed publications and very limited open reports.

4.4. Analysis of concordance between the MPIs of the Commission Recommendation and the KPIs of the European RTD projects

The MPIs of the EU Recommendation 2018/844 and the KPIs applied by the studied RTD projects have been compared indicating the concordance of the assessment methods and their trends. As the analysed projects work out different specific areas of the building renovation, the research did not expect the concordance of certain MPIs with KPIs of most of the projects. Nevertheless, the election of the projects covers a wide working area so the aspects treated by each scope of the proposed European assessment framework are performed by the RTD projects; the fact of the election of projects contains the ones mentioned in the EU's Recommendation 2018/844 document as the "Good practice for complying with Article 2a of the EPBD" [6] demonstrates the direct connection of the MPIs of the EU's Recommendation 2018/844 and the RTD projects. Assuming this fact it should exist a concordance between the EU Recommendation's and the RTD projects' KPIs. The results are reflected in the indicating the number of RTD projects with KPIs in concordance with each MPI of the EU Recommendation, classifying them in the categories adopted in the analysis of KPIs (Environmental & Energetic, Economic, Social, Well-being & Health or other). Certain scopes matches with more than half of the projects, the scopes 1-A, 1-B and 1-G, while the MPIs of the scope 1-E do not coincide with the KPIs of any of the projects, and the MPIs of the Section 2 have a very low coincidence, if not null. The concordance of all the MPI with the RTD projects are shown in the Table 3, indicating the existence of any coincidence

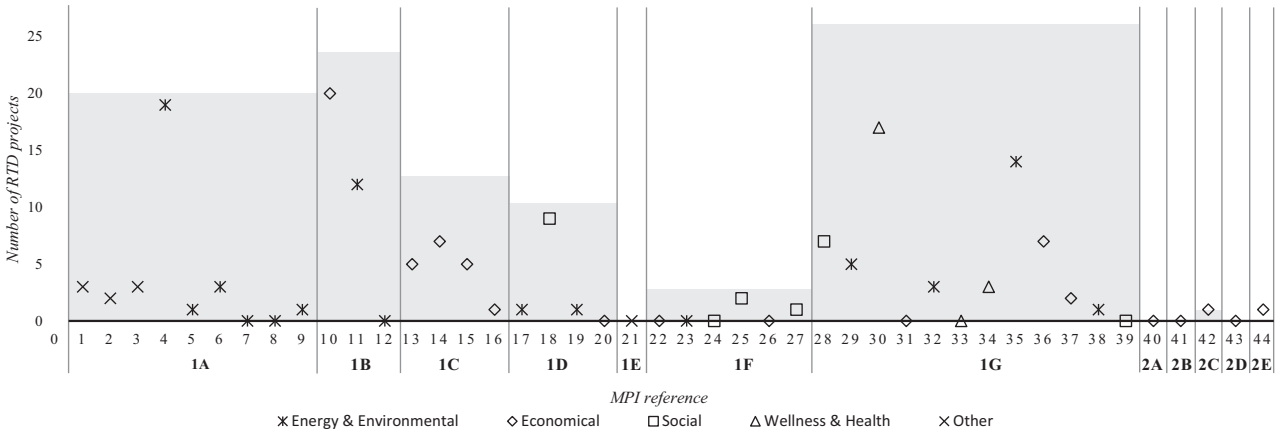

Fig. 4. Number of RTD projects in concordance with each MPI of the EU Recommendation 2019/736 by KPI categories.

between the MPI and the KPIs of the project (including only the projects with defined evaluation framework with indicators); and these concordances are graphically expressed in the Fig. 4, indicating the number of RTD projects with KPIs linked for each MPI, grouped in scopes and indicating the KPI category. The MPIs are directed to the evaluation of national LTRS, so many indicators do not match due to the differences of action area and scale.

The first assessment scope of the EU Recommendation, the "Overview of the national building stock, based, as appropriate, on statistical sampling and expected share of renovated buildings in 2020", composed by MPIs that evaluate the current situation by general quantities and measurements in terms of energy efficiency, is one of the most assessed scopes, making connection with 20 of 38 projects (see Table 3). The most assessed MPI is the "4- Annual energy consumption", applied in 19 projects as the KPI of the general quantification of the overall use of energy, together with all the KPIs of the scope. Moreover, other indicators are applied in more than one project in order to evaluate the quantification of the buildings to assess as the main picture of the buildings and the renovated fraction. Nevertheless, the quantification of the nearly zero energy buildings (nZEB) and energy performance certificates (EPC) are not considered by the projects as a key parameter for the assessment.

The scope 1-B, about the "Identification of cost-effective approaches to renovation relevant to the building type and climatic zone, considering potential relevant trigger points, where applicable, in the life-cycle of the building renovation", is the second most assessed field by RTD projects, by 24 of 38 (see Table 3), with a big connection with most of the economical KPIs. Mostly, the MPI "10- Cost-effectiveness of main renovation measures" coincides with economical KPIs of 20 projects, such as the economical KPIs of "Payback period" (10 projects), LCC (4 projects) and NPV (3 projects); moreover, the MPI "11- Total energy saving potential" is related with the KPI of savings attributed to the reduction of energy consumption in 12 projects. The project E2ReBuild, mentioned in the EU Recommendation 2019/786 [6] as exemplary case, counts with a deep investigation about holistic strategies for the retrofit to achieve energy-efficient residential buildings. It develops four KPIs to assess the cost-effectiveness of the renovation measures [14] taking into account the initial investment, the costs break down according to maintenance, energy improvements and modernization, the costs break down of building elements, envelope elements and services and the Estimated Remaining Service Life (ERLS).

The next scope, 1-C, evaluates the "Policies and actions to stimulate cost-effective deep renovation of buildings, including staged deep renovation, and to support targeted cost-effective measures and renovation, for example by introducing an optional scheme for building renovation passports", coinciding with both economical and energetic KPIs of 13 projects (see Table 3). Three of the four MPIs are used by 5 to 7 projects, quantifying the investments into deep renovations, the availability of public incentives and the energy saving from deep renovation. The exemplary cases of this scope present, the projects iBRoad and ALDREN, implementing the BRP to stimulate energy renovations, do not apply any of the MPI of the EU assessment framework in their evaluation.

The main social evaluation and in the same way the social KPIs of the projects are directly linked with the scope 1-D, assessing the "Overview of policies and actions to target the worst-performing segments of the national building stock, split-incentive dilemmas and market failures, and an outline of relevant national actions that contribute to the alleviation of energy poverty" (see Table 3). The MPIs of this scope are applied in 9 projects, and in all of them, the main social KPI is the one based on the MPI "18- Energy poverty indicator", as it is identified as the most used social KPI in the previous section. The rest of the MPIs do not have a relevant role in the studied RTD projects. The exemplary projects of this scope according to the EU Recommendation document [6] are the projects ASSIST and Transition Zero, both applied KPIs to evaluate the energy poverty and in the case of Transition Zero. Also the MPI "16- Public investments in policy addressing social issues" was assessed. The other two projects defined as exemplary cases of this social scope, the projects ENERFUND and EnerSHIFT, do not apply any of the MPIs of the scope 1-D but they do have the bases of the project focused in the refurbishment of the housing stock of the worst performing segments housing stock.

In the case of the scope 1-E about the "Policies and actions to target all public buildings" assessing the "Renovated public buildings in m2", no concordance with the KPIs of the evaluation of the studied RTD projects was found (see Table 3). The EU Recommendation 2019/786 [6] defined the project EmBuild as the exemplary application of purchase the policies and actions to target all public buildings but the projects does not make use of the MPI "20- Renovated public buildings in m2 (Building type, age, size, climatic zone)".

The scope 1-F evaluates the "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", applied in 3 of 38 projects, showing a reduced concordance level between the EU assessment framework and the evaluation of the RTD projects (see Table 3). The two MPIs applied are "25- No of installers skilled in new technologies and working practices" and "27 - Participation of national universities in international scientific research projects", both assessing the socioeconomic activity related with knowledge on energy renovation, but according to the RTD projects are not relevant. The projects linked with the purposes of the 1-F scope according to the EU Recommendation 2019/786 are Smart-up, PEAKapp and MOBISTYLE, where none of the projects have KPIs that coincide with the proposed MPI of the EU Recommendation 2019/786.

In the case of the scope 1-G about the "Evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety and air quality" is related with Environmental & Energetic (MPIs 29, 32, 35, 38), Economical (36, 37), Social (28, 29), and Health & Wellbeing (30, 31, 33, 34) KPIs of 26 analysed projects, being the most assessed scope (see Table 3). The most assessed MPI is the "30- Average /aggregate IAQ and TCI", applied in 17 projects, and aligned with the most used KPIs of the category of Health & Wellbeing. The most evaluated MPI in concordance with the Environmental & Energetic KPIs is the MPI "35- Reduction of emissions" which coincides with the KPI "GHG emissions / CO2 emissions" included in 14 projects. Furthermore, social aspects are also taken into account with the MPI "28- Reduction in energy costs per household /decrease in energy poverty" (7 projects) and economic aspects play a minor role (7 projects). The EU Recommendation 2019/786 [6] includes the project COMBI as the exemplary case of this scope; the analysis found 5 MPIs in concordance with Environmental & Energetic, Economic and Health & Wellbeing KPIs of the project.

For the second section of the MPIs of the EU Recommendation 2018/844 [6] that evaluates "Mechanisms to support the mobilisation of investments" almost no concordances were found (see Table 3), even in the nine studied projects referred by the EU Recommendation document as exemplary cases. Even so, the projects do follow the aims of the MPIs of the section 2, and the analysis shows the difficulty to measure this certain MPIs.

This analysis shows the low homogeneity on the concordance level of the evaluation scopes of the Commission Recommendation 2019/786 and the evaluation frameworks of the European RTD projects, where three levels of concordance can be distinguished for the evaluation scopes: High for the scopes with at least 20 RTD

projects assessing them, Medium with between 5 and 20 RTD projects and Low/Null the ones with less than 5. The scopes with a high level of concordance, the ones related with the general statistical data (1-A), the economic effectiveness (1-B) and the one about the energy savings together with holistic benefits related to the well-being of users (1-G) are directly linked to the main action areas of the EU's RTD funding programmes: "secure, clean and efficient energy" in Horizon 2020 and FP7 as well as "energy efficiency" in Interreg Europe or "efficient buildings" in Interreg Mediterranean and similar ones in the other Interreg programmes. The scopes with a medium level of concordance, assessing the policies and actions to support cost-effective renovations (1-C) and to support the worst performing building stock (1-D) are not directly the targets of the RTD funding programmes, but they are part of the actions to make possible the targets and they do have a significant application by the RTD projects, so it can be understood that their applicability has been tested. However the low or null concordance level of rest of scopes (1-E, 1-F, 2-A, 2-B, 2-C, 2-D, 2-E) show the lack of connection of the requirements of the analysed European RTD funding programmes (FP7, H2020 and Interreg) and the requirements of certain assessment scopes of the Commission Recommendation 2019/786, and consequently the lack of connection with the EPBD (Directive 2018/844).

4.5. Evaluation and barriers and challenges of the Measurable progress indicators (MPIs) of the Commission Recommendation 2019/786

Many factors can be considered as barriers for assessment of certain parameters of the assessment framework of the EU Recommendation, making impossible or inefficient the evaluation by the MPIs proposed; otherwise, these indicators can also deliver to new challenges and opportunities in the evaluation of building renovation processes. Four main key factors have been analysed identifying barriers and challenges, summarized in the Table 4 linking them with the MPIs that concerns.

The main issue of strategies of energetic improvements of buildings is the reliability of the energetic assessment, linked to all the energetic KPIs and the MPIs related with energy consumption and energy savings. The main data source of most of these indicators is the EPC, which calculates the energy demand and energy consumption, but there are differences among the member states (MSs) [135]; moreover, several studies report the low reliability of the EPCs as the indicator of the building's energetic behaviour [136,137]. This factor is a barrier for the accuracy of energetic indicators of the EPC for many MPIs related to energy consumption (MPIs 4, 7) with a high level of applicability in RTD projects; besides, the MPI 8, assessing the number of EPCs, does not have any applicability in the projects, due to the low reliability of these certifications. In the same line, have been found differences in calculated energy savings and actual energy savings [139], a direct barrier for the MPIs assessing the energy saving potential (estimated) and actual energy saving. Despite all the barriers, the MPIs can also deliver challenges in the energetic evaluation, improving the reliability and accuracy of the data by new solutions like the use of standard inputs and real occupants' data [140] or verification schemes for the accuracy of the actual energy savings [139]; for instance, A. Abela et al. [141] proved that calibrating is essential to assess the certifications schemes of the Mediterranean housing, and F. Pagliaro et al. [110] combined EPC data with monitoring for the assessment of energy performance of buildings. Furthermore, the ALDREN project studied the availability of buildings' data and the European databases, presenting the BRP as a complementary document of the EPC for non-residential buildings, providing a renovation roadmap of r the building "based on quality criteria, following an energy audit, and outlining relevant measures and renovations that could improve the energy performance" [143]; moreover iBroad project also implemented the BRP for residential buildings with positive feedbacks [77].

Table 4
Barriers & Challenges of the assessment framework of the EU Recommendation 2018/844.

BARRIERS & CHALLENGES		MPIs linked
Reliability of energetic assessment		
Barriers	Differences among EPC of MSs [135]	4,7
	EPC not considered as reliable indicator [136,137,138]	4,7
	Differences between estimated energy savings and actual energy savings [139]	11,29
Challenges	Standard inputs and real occupants' data can improve accuracy [140]	4,7,11
		4,7,11
	Calibration techniques and monitoring can provide useful information [141,142]	29
	Verifications schemes for actual data [139]	4,7,11,29
	New solutions like the Building Renovation Passport (BRP) [77,143]	
Economic feasibility assessment		
Barriers	"Cost effectiveness" not defined by the EPBD and only in few MSs defined	10,11
	Economic indicators like LCC use uncertain parameters [144145]	10
Challenges	Standardizing input parameters with reliable data [137]	10,11
Financing system and policy to promote energy renovation		
Barriers	High (too high) importance of the investment cost and low application in KPIs [146]	12–20, 40–44
Challenges	The MPIs do have a great evaluation of the financial scheme and policies to target renovations	12–20, 40–44
Lack of data and lack of relevance		
Barriers	Lack of data making impossible to create certain indicators [147]	5,21–27,31
	Lack or relevance of certain indicator caused by a high number of indicators [10,147]	-
	Lack of geo-referred data [46]	-
	Divided data with many quality, availability, and completeness levels [143]	-
Challenges	Shortlisting of MPIs with reliable and accessible data [10,147]	-
	Integration of geo-referred data sources [46]	-
	New solutions like the Building Renovation Passport (BRP) [77,143]	-

The economic feasibility is directly connected to the 1-B scope of the EU assessment framework, applied in more than the half of the analysed RTD projects. The main barrier is the lack of standardized definition of parameters and concepts as "cost effective", the main key element of the 1-B scope of the EU's assessment framework, not defined in the EPBD and hardly defined in few MSs. Moreover, economic indicators mentioned in the EPBD like the LCC, and applied in several RTD, projects can provide results obtained by uncertain parameters according to several studies [144145], making difficult the comparison without a common assessment framework. The challenge here is the standardizing input parameters with reliable data [135] making possible the definition of a common European assessment and compare the economic feasibility of different cases (countries, buildings, solutions etc.).

The evaluation of financial instruments and policies also present barriers as the indicators of the scopes 1-C, 1-D and 1-E (MPIs 12–20), assessing the policies and actions to stimulate cost-effective renovations, have a small application in the RTD projects (see chapter 4.4); moreover the MPIs of the Section 2 (MPI 40–44), also related with the evaluation of financial instruments, does not have almost direct applications on the RTD projects. However, according to the study of M. G. Bjørneboe et al., the investment is one of the most important factors in the decision making of the owners [146], so the assessment of public policies and financial mechanisms should have a greater application in order to promote

the building renovation. In this way, the EU Recommendation presents the challenge to reinforce and intensify the evaluation of financial mechanisms and policy about the renovation; new formulas to improve the control and data collection could be studied by future European RTD projects and applied on the MS' policy.

Another factor that can effect on the evaluation system of the European policy is the data collection, where a set of barriers may make impossible the collection of certain data, making not possible the application of some indicators [147]. The indicators of the 1-F scope (MPIs 21–27) assessing the innovation and new technology adaptation are not applied in the RTD projects due to the lack of data collection. The same goes for the scope 1-G, where the MPI 31 about the "Cost of avoided illnesses/reduction in health costs" is not either realistic to develop caused by the lack of information. Even some energetic indicators are hard to obtain as it is demonstrated by the study of M. Herrando et al. about mechanisms to support the renovation of public buildings [148]. Moreover, the study made by C. Beltrán-Velamazán et al. [149] about the application of EU Recommendation's MPIs by national LTRS also indicated the absence of data as the main cause of the lack of implementation of certain indicators. Also in terms of investment decision making, some studies [150,151] demonstrated that the lack of data is a major barrier for the investment in buildings. Even the European RTD projects presented these difficulties to collect data, like RemoUrban that reported the difficulties to collect the data for their evaluation proposing solutions like the integration of geo-referred data sources [46]; ENERFUND project also claimed that public and geo-referred data can help in the decision making without affecting the privacy [58]. Moreover, REScoop PLUS project also reported difficulties to collect data [64] and also ALDREN project showed that the data is collected by different institutions varying significantly the quality, availability, and completeness with their proposal of the BRP as a solution as mentioned before [143].

Furthermore, even if some indicators can be possible to measure may not have an important the relevance in the targets of the methodology. In the study made by Ho et al. [10] KPIs for retrofitting of commercial buildings were shortlisted, selecting the relevant ones via survey, and 19 were shortlisted from the initial 52 KPIs demonstrating the same fact expressed by the state of art of U. Kumar et al. [147], that having a high number of indicators is impractical. This situation can be the reason of the lack of applicability of certain MPIs by the RTD projects.

5. Conclusion

This paper investigates the assessment framework proposed by the Commission Recommendation (EU) 2019/786 composed by MPIs, by analysing the assessment methods of European funded RTD projects composed by KPIs; moreover this study is well supported by the existing literature about the evaluation of building renovation. It is shown that the MPIs do cover the assessment fields of the RTD projects by their KPIs. Besides, the analysis of the agreement between the MPIs and KPIs shows that not all the indicators proposed by the EU have been tested by the RTD projects. It demonstrates that the assessment methodology of the EU Recommendation 2018/844 does have barriers, such as the low reliability of data, the lack of definition of parameters, the low relevance of certain indicators and the lack of data to develop certain indicators. Despite that these barriers can make the application of certain MPIs difficult or inefficient, the EU's assessment framework also presents new challenges.

According to the barriers, the analysis shows the high applicability of the energetic indicators, but it also shows the low reliability of this type of data with a lack of a common framework which could allow the comparison and homogeneous evaluation. Moreover, the adoption of new techniques to get more accurate and standardized data is the way to follow. As another important field, the evaluation of financial and political schemes to accelerate the renovations has a great importance in the EU assessment. Even if financial parameters are one of the most important ones in the decision making of renovations, the RTD projects show the big difficulty to assess them. This study suggests the need of a bigger effort to increase the level of control and measurement of parameters in the financial and political field, pushing the public administration to a mayor control of financial and political activity in building renovation in order to control and evaluate its progress and orient them to the common objectives. Many other indicators are not applied by the projects because of the lack of data, with a high difficulty of the data collection in relation to the relevance of the parameter.

To finish, the EU Recommendation 2018/844 composed by MPIs presents many barriers of the EU's energy policy, but also new challenges to improve the evaluation of the decarbonisation of the European building stock. On the one hand, the applicability of innovative evaluation solutions can be tested by the future European RTD projects leading new strategies to the targets of the European policy and common benefits, including the European Green Deal, and techniques to measure its progresses. On the other hand, readjustment of the requirements of the Commission Recommendation (EU) 2019/786 and the EPBD is needed, by the shortlisting the assessment framework selecting the most significant indicators, redefinition of standardized parameters and concepts, together with the improvement of data collection on the assessments fields. This new challenges might lead to a common roadmap to be followed for a homogeneous progress and assessment towards the decarbonisation of the European building stock.

The main limitation of the research was the limited open data of RTD projects, increasing the difficulty to test the current trends of the RTD programmes and reducing the possibility to assess their effectiveness and directions to the targets of the EU policy in terms of renovation of buildings established in the EPBD. Consequently, the limited data about the evaluation of the RTD projects and the lack of a defined common evaluation framework endorses the circumstance of the low connectivity between the European RTD funding programmes (FP7, H2020 and Interreg) and the requirements of the Commission Recommendation 2019/786. The study regards the need of enlarge the dissemination level and the RTD projects to make accessible the lessons learned and evaluation of the projects and to identify the barriers and opportunities in their evaluation in order to follow the path forward the renovation wave. Besides, further research lines are focused in the study of the application of the assessment framework of the Commission Recommendation 2019/786 in certain regions and the MSs, analysing the national LTRSs, current data availability and the definition of all the MPIs in detail.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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