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Research article

A methodology to empower citizens towards a low-carbon economy. The potential of schools and sustainability indicators

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ABSTRACT

Environmental empowering to control resource consumption and environmental impacts is critical to engage citizens to adopt more sustainable habits. This study demonstrates the potential benefits of innovative approaches based on sustainability indicators towards a low-carbon economy. A methodology to measure and promote sustainability in schools has been proposed and evaluated, aiming at showing the environmental performance and informing of potential environmental savings. The methodology, titled ClimACT, has two main purposes: measuring the environmental performance of schools through a school sustainability index based on measurable indicators in the areas of transport, procurement, green spaces, indoor air quality, energy, water and waste; and encouraging students, teachers and families towards an energy-efficient and low-carbon pathway through a structural procedure based on roles, activities and progress evaluation. The approach, applied to 39 pilot schools from Portugal, Spain, France and Gibraltar, achieved promising and encouraging results. All schools deployed the methodology successfully, achieving measurable environmental benefits in 95% of cases, with an average improvement of 10% in the global performance of schools after one year. Moreover, the 5112 surveys applied to school communities, before and after the methodology implementation, highlighted how the sustainable indicators had a significant influence on the daily lives of families, leading to improvements of their behaviour, with an average increase of 20% in indicators regarding good practices in transport, energy, water, waste and citizenship. The environmental empowering through measurable indicators is a step forward a low-carbon economy. This methodology is open and adaptable to all sectors and requirements.

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Abbreviations

E	energy
EPBD	Energy Performance of Buildings Directive
EPC	energy performance certificate
GHG	greenhouse-gas
GP	green procurement
GS	green spaces
IAGV	indoor air guideline value
IAQ	indoor air quality
IPCC	Intergovernmental Panel on Climate Change
KPI	key performance indicator
LC	low-carbon coordinator
LCB	low-carbon brigades
LCC	low-carbon committee
LCE	low-carbon economy
MAD	mean absolute deviation
SBS	sick building syndrome
SCH	school
SD	standard deviation
SDGs	Sustainable Development Goals
T	transport
TVOC	total volatile organic compounds
UNESCO	United Nations Educational, Scientific and Cultural Organisation
VOC	volatile organic compounds
Wr	water
Ws	waste

1. Introduction

The potential of reducing carbon emissions through behavioural change becomes even more important in the light of the Paris agreement. Therefore, the scientific community is challenged to develop methods to measure and report on the progress of aggregated impacts of individual changes throughout daily routines (Kristensen and Mosgaard, 2020; Niamir et al., 2018), extending well beyond the domain of other sectors such as for example farming (Hannus et al., 2020), food systems (Mathys, 2018), shopping industry, services, cities (Cheng et al., 2020; Lou et al., 2019; Marquez-Ballesteros et al., 2019), neighborhoods (Z. Wang et al., 2020), social projects (Olakitan Atanda, 2019), informal settlements (Montoya et al., 2020) or tourism investments (Nesticò and Maselli, 2020), among others. There is a tremendous need to understand non-technological factors connecting citizens' activity with greenhouse gas emissions towards the fundamental understanding of individual and global impacts (Nielsen and Farrelly, 2019; Stern et al., 2016; Turnheim et al., 2020). This vision plays a key role in this regard by creating new perspectives, approaches and understanding and helping to move society in the direction of sustainability (Köhler et al., 2019).

On the other hand, schools play a significant role in sustainability due to their educational purpose (Lizana et al., 2017). Actively incorporating key issues for sustainable development into educational programmes can expand students' knowledge, skills and attitudes towards a low-carbon economy (Mróz et al., 2020). Raising awareness and involving school communities towards an energy-efficient and low-carbon pathway, through the broad knowledge dissemination of best available actions, can lead to an efficient reduction in resources consumption in all regions (Monroe, 2019). These local experimentations can efficiently encourage people to persist in climate action (Heiskanen et al., 2015). However, some previous environmental and sustainability education initiatives in schools have reported limited effects (Olsson et al., 2019), with students showing similar sustainability consciousness as schools without sustainability programs.

Researchers have already demonstrated that education can be a valuable tool for policy (Stalker, 2010), above all through decisions guided by emotional experiences (Robina-Ramírez et al., 2020). Lawson et al. (2019) evidenced that carefully designed youth education on climate change can influence parents' attitudes, and surprisingly, shift the most conservative opinions toward concern about climate change. Gill and Lang (2018) studied the effects of environmental education for school students in home electricity consumption and showed evidence of a short-term reduction in electricity consumption of approximately 8%. Yu et al. (2019) showed how green educations programs can promote resource recycling intentions in students, improving the environment and mitigating to climate change. Bernardo et al. (2017) highlighted how high-performance school has a high educational value since it can serve as an educational tool for teaching students and the community about the importance of energy efficiency. With the proper support, education can empower pupils with knowledge about sustainable actions and ensure they grow up knowing how to protect the environment with cemented, robust and aware behaviours (Zografakis et al., 2008) that can pave the way towards a sustainable future (Mathar, 2015; Sengupta et al., 2019). However, new and most significant influence methods are needed to engage not only school students but also families and school region in addressing climate change impacts (Lawson et al., 2018). Wang et al. (2020) demonstrated the need and effectiveness of adopting innovative education methods that promote low-carbon knowledge and awareness in order to encourage communities to develop low-carbon lifestyles. Children represent an easily reached audience able to influence with older generations (Lawson et al., 2018). This new approaches should involve an appropriate dissemination pathway, which plays an essential role in raising public awareness of global warming (Sampei and Aoyagi-Usui, 2009; Spence and Pidgeon, 2010). Moreover, Visser et al. (2020) and Meiboudi et al. (2017) highlighted how data reliability and accuracy about sustainability is an essential factor to avoid flawed inferences.

One of the most important and largest examples of environmental education method to promote sustainability is the Eco-Schools programme of the Foundation for Environmental Education (FEE) (1994). This programme has been deployed in 68 countries, involving 59000 schools, and combines learning with hands-on experiences, improving the environment in the classroom and expanding to the community. Along with this, there are many available environmental educational programmes and initiatives such as Environment Europe (2006) or Environment and School Initiatives (ENSI) (1986).

This research aims to promote the importance of these environmental education programmes and support them with new procedures and reliable sustainable indicators to empower citizens towards a low-carbon economy. This research has two main purposes: the development of an innovative procedure to measure and promote sustainability in schools, and the evaluation of the benefits of these innovative environmental approaches based on sustainability indicators to empower citizens towards a low-carbon economy (LCE). Thus, a novel methodology, titled ClimACT, for evaluating and promoting sustainability in schools has been developed and tested. It involves a school sustainability index based on a multi-criteria environmental assessment through measurable key performance indicators (KPIs); and a structural procedure through roles, activities and progress evaluation to engage and encourage students, teachers and families towards an energy-efficient and low-carbon pathway. The ClimACT methodology is structured in seven main pillars: transport, green procurement, green spaces, indoor air quality, energy, water and waste.

The main difference of this novel procedure in comparison with existing programmes and initiatives is the integration of a set of measurable sustainability indicators in order to: (1) measure the environmental performance of schools and their communities, enabling their quantitative evaluation and benchmarking with other schools; and (2) identifying potential and measurable environmental savings to promote a low-carbon pathway.

This innovative approach was tested in 39 pilot schools from Portugal, Spain, France and Gibraltar. The results provide a first environmental status of schools in South-western Europe. Furthermore, the comparison of the school communities' performance, before and after the implementation of this methodological procedure, shows promising results.

The paper is structured as follows. First, ClimACT methodology is defined. Then, the results are showed and discussed in two sections corresponding to situations before and after the methodology application. Finally, the potential benefits of these innovative approaches towards a low-carbon economy are highlighted.

2. Methodology

The ClimACT methodology to measure and promote sustainability in schools is divided into four sections. First, the multi-criteria environment assessment to characterise the environmental performance of schools and their community through sustainability indicators is defined. Second, the structural procedure to engage and encourage students, teachers and families towards an energy-efficient and LCE pathway is described. Third, the materials and methods used for data collection are detailed. Fourth, the 39 pilot schools in Portugal, Spain, France and Gibraltar selected for the methodology application are identified. Finally, the measurement campaigns for methodology validation are reported.

2.1. *Multi-criteria environmental assessment through sustainability indicators*

The multi-criteria assessment methodology is divided into seven environmental areas, assessed by different key performance indicators (KPIs), which are obtained through technical audits, monitoring campaigns and behaviour questionnaires applied to the entire school community, as illustrated in Fig. 1. Audits are based on technical inspections and checklists to determine building characteristics, equipment, activities, behaviours, occupation pattern and resource consumption of school buildings. Monitoring campaigns consisted of on-site measurements for the characterisation of indoor air quality (IAQ) in school spaces. Behaviour questionnaires are based on online surveys that evaluate school communities' performance about their transport routines and daily habits associated with the environmental areas under assessment. The data collection procedure is further defined in section 2.3.

The environmental areas and KPIs are selected according to the objectives dealing with greenhouse-gas emissions (GHG) mitigation according to the Paris Agreement (United Nations, 2015), the Sustainable Development Pathways defined by the Intergovernmental Panel on Climate Change (IPCC, 2014) and the Sustainable Development Goals (SDGs) defined by the United Nations Educational, Scientific and Cultural Organisation (UNESCO, 2017). All targets, applied to the boundary conditions and scope of school communities, allow identifying seven environmental pillars where schools can play an essential role towards an efficient LCE transition: transport, green procurement, green spaces, indoor air quality, energy, water and waste. The selected sustainability indicators per environmental sector are defined in Table 1, which allow characterising the environmental baseline of schools and their communities to support the transition towards a LCE. Further details about the mathematical procedures to calculate KPIs are provided in Appendix A. They are open and adaptable to other contexts and requirements.

The activities and indicators are classified into seven sectors as a function of the linked activities:

Transport. The methodology analyses all the aspects linked to the infrastructures and school community behaviour with regards to the use

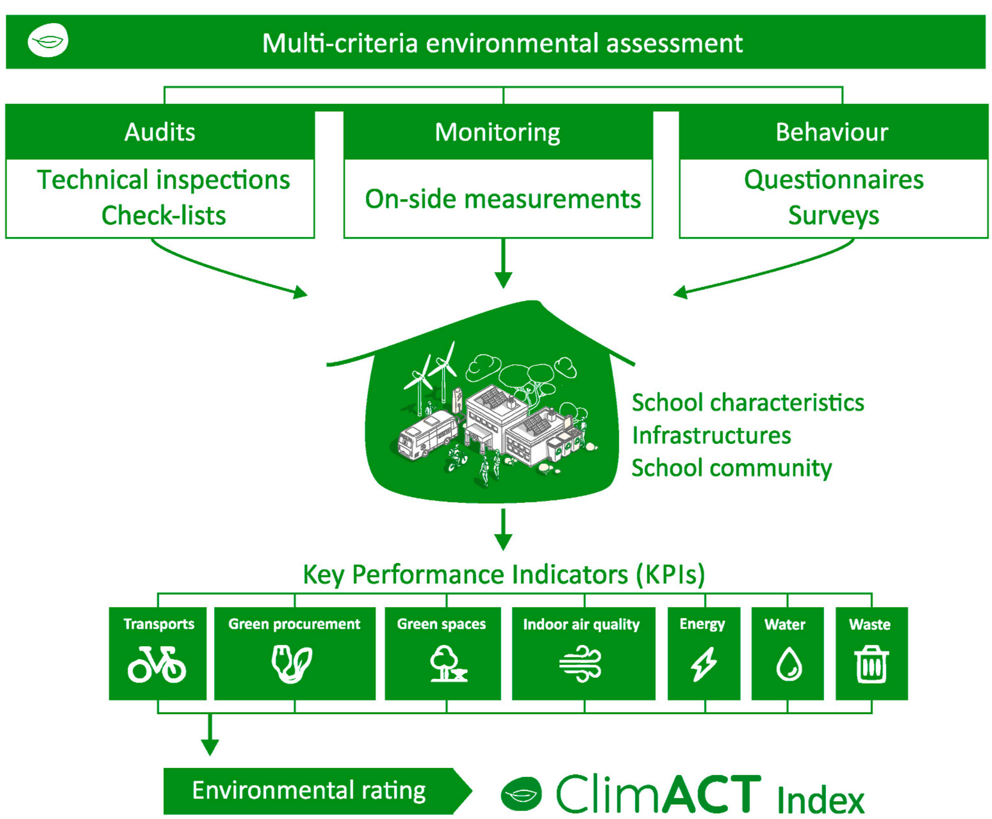


Fig. 1. Overview of the multi-criteria assessment methodology for schools.

Table 1
Structure of the multi-criteria environmental assessment of schools: environmental pillars, KPIs and scores.

Environmental pillars	Key Performance Indicators	Scores
Transport		
Parking characteristics	KPI-T1. Parking spaces for bicycles per student (up to a 100 m radius)	Transport score (0–5)
	KPI-T2. Parking spaces for electric cars per school (up to a 100 m radius)	
Public transport network	KPI-T3. Public Transports passing daily per hour (1000 m radius)	
CO_2 emissions from commuting to school	KPI-T4. Annual CO_2 emissions per student ($kgCO_{2\ eq}$/student)	
Green procurement		
Equipment efficiency	KPI-GP1. Equipment A+ or higher energy label per total number of equipment	Green procurement score (0–5)
Paper usage	KPI-GP2. Annual paper usage in school (kg/student)	
	KPI-GP3. Annual recycled paper usage in school (kg recycled/kg paper)	
Training in green procurement	KPI-GP4. Staff with training in green procurement (No. staff with training/total no. staff)	
Eco-driving certification	KPI-GP5. Staff with training in eco-driving (No. staff with training/total no. staff)	
Organic food	KPI-GP6. Food with organic certificate (kg food with organic certificate/kg total food)	
Suppliers	KPI-GP7. Local suppliers (No. local suppliers/total suppliers)	
Green spaces		
Green areas	KPI-GS1. Trees per non-covered area (No. trees/m^2)	Green spaces score (0–5)
	KPI-GS2. Trees per student (No. trees/student)	
	KPI-GS3. Green area per non-covered area (%)	
	KPI-GS4. Green area per student (m^2/student)	
CO_2 sequestration	KPI-GS5. Annual CO_2 sank per non-covered area ($kgCO_2/m^2$)	
Use of chemicals	KPI-GS6. Annual mass of chemicals used for green area maintenance (kg/m^2)	
CO_2 emissions	KPI-GS7. Annual CO_2 emissions associated with space maintenance ($kgCO_{2\ eq}/m^2$)	
Indoor air quality		
Air pollutants concentration	KPI-IAQ1. Air pollutants exceeding the indoor air guideline value (%)	Indoor air quality score (0–5)
Ventilation	KPI-IAQ2. CO_2 concentrations between 1000 and 1700 ppm (%)	
	KPI-IAQ3. CO_2 concentrations over 1700 ppm during the occupancy (%)	
Thermal comfort	KPI-IAQ4. Temperature between 20° and 26° during occupancy (%)	
Energy		
Energy consumption	KPI-E1. Annual final energy consumption per area (kWh/m^2)	Energy score (0–5)
	KPI-E2. Annual final energy consumption per student (kWh/student)	
Use of renewable energy	KPI-E3. Renewables energy production (%)	
Energy cost	KPI-E4. Annual energy cost per area (€/m^2)	
	KPI-E5. Annual energy cost per student (€/student)	
CO_2 emissions	KPI-E6. Annual associated CO_2 emissions per student ($kgCO_{2\ eq}$/student)	
Water		
Water consumption	KPI-Wr1. Annual water consumption per area (m^3/m^2)	Water score (0–5)
	KPI-Wr2. Annual water consumption per student (m^3/student)	
Water cost	KPI-Wr3. Annual water cost per area (€/m^2)	
	KPI-Wr4. Annual water cost per student (€/student)	
Waste		
Waste produced	KPI-Ws1. Weekly waste production per student (m^3/student)	Waste score (0–5)
Waste recycled	KPI-Ws2. Weekly waste recycled per student (m^3/student)	
Waste reused	KPI-Ws3. Weekly waste reused per student (m^3/student)	
Final School Sustainability Index		**ClimACT score (0–5)**

of transport modes. Its assessment is based on the availability of school parking spaces for low-carbon transport modes, such as electric vehicles or bicycles; the public transport networks in the school surroundings; and the quantification of CO_2 emissions associated with the transport mode used on school runs.

Green procurement. The assessment evaluates the purchasing of products and services and their environmental impact. In schools, it can be divided into six categories, consisting of the evaluation of electric and electronic equipment with eco-labelling or energy label, consumption of recycled paper, staff training in green procurement, certification of staff in eco-driving, food consumption with organic certificate and number of local suppliers of school services.

Green spaces. Green areas are critical for the health and wellbeing of people. The assessment is based on the identification and understanding of how outdoor school spaces are managed. It is quantified by the green area surface ratio, the CO_2 sequestration rate of plants and trees, the use of chemicals, resources consumption and associated CO_2 emissions related to the green area's maintenance.

Thermal comfort and indoor air quality (IAQ). Environmental air quality contributes to raising awareness of the importance of a healthy indoor environment to improve learning performance (Haverinen--Shaughnessy et al., 2015; Toyinbo et al., 2016) and to avoid the prevalence of sick building syndrome (SBS) symptoms (Daisey et al., 2003; Mujan et al., 2019; Sundell et al., 2011). Indoor air quality is directly affected by indoor occupancy, activity, equipment, materials and outdoor air quality (Becerra et al., 2019). IAQ in schools is measured through on-site monitoring campaigns during teaching hours, together with the characterisation of occupancy patterns, activities, window openings and outdoor air pollutant concentrations. It involves the evaluation of temperature variations during the school hours and a set of high priority pollutants (ANSES, 2011; Becerra et al., 2019; WHO, 2010), such as CO, CO_2, PM_{10}, $PM_{2.5}$, TVOC and a set of aldehydes and volatile organic compounds (VOCs). Finally, indoor environment quality is assessed based on three criteria: measured pollutant concentrations exceeding the indoor air guideline values (IAGVs) defined by different standards and health organisations, the existence of right ventilation conditions and thermal comfort.

Energy. The methodology provides the characterisation of final energy consumption per school, associated energy costs, production of on-site renewable energy sources and energy-related CO_2 emissions. It takes into account the primary energy consumption mix. The evaluation is carried out considering the last three years of school energy consumption, aiming to promote the raising of awareness of schools and their communities towards an energy conservation and energy efficiency pathway.

Water. The evaluation is based on the quantification of water demand of schools using water consumption bills during the last three years. The evaluation focuses on providing a scale of water consumption rate per school, divided into two areas: water consumption and water cost. Partial water scores enable comparison with other school buildings regarding potential water savings and allow identifying potential management strategies to reduce the use of water.

Waste. The methodology requires as inputs the volume of waste produced (non-recycled and non-reused), the amount of waste recycled, and the quantity of reused waste in schools, during a week per year. This evaluation focuses on providing information of waste management in schools, while involving all the school community in a waste awareness, enabling the comparison of results with other school buildings, and identifying potential areas for improvement about school wastes generation and management. The aim is to increase the school management's visibility and awareness on the issue of waste, as it was identified by Derqui et al. (2020).

The results of this evaluation provide a score per environmental area based on an environmental raking from 0 to 5, which is obtained by comparing each KPI against the performance of all evaluated schools. Further details about the numerical procedure for environmental ranking are provided in Appendix A. Finally, the final school sustainability index ($ClimACT_{score}$) is calculated through the mean value among all environmental scores previously obtained, according to Eq. (1).

$$ClimACT_{score} = \frac{T_s + GP_s + GS_s + IAQ_s + E_s + Wr_s + Ws_s}{7} \quad (1)$$

where T_s: transport score, GP_s: green procurement score, GS_s: green spaces score, IAQ_s: indoor air quality score, E_s: energy score, Wr_s: water score, Ws_s: waste score.

This general methodology was defined in order to allow precise identification of the environmental performance of schools and the potential actions for its improvement. It allows a quantitative score as a benchmark for the environmental performance of different schools for a broad number of regions and characteristics.

2.2. Structural procedure in schools towards a low-carbon economy

The methodology also requires a structural procedure to engage and

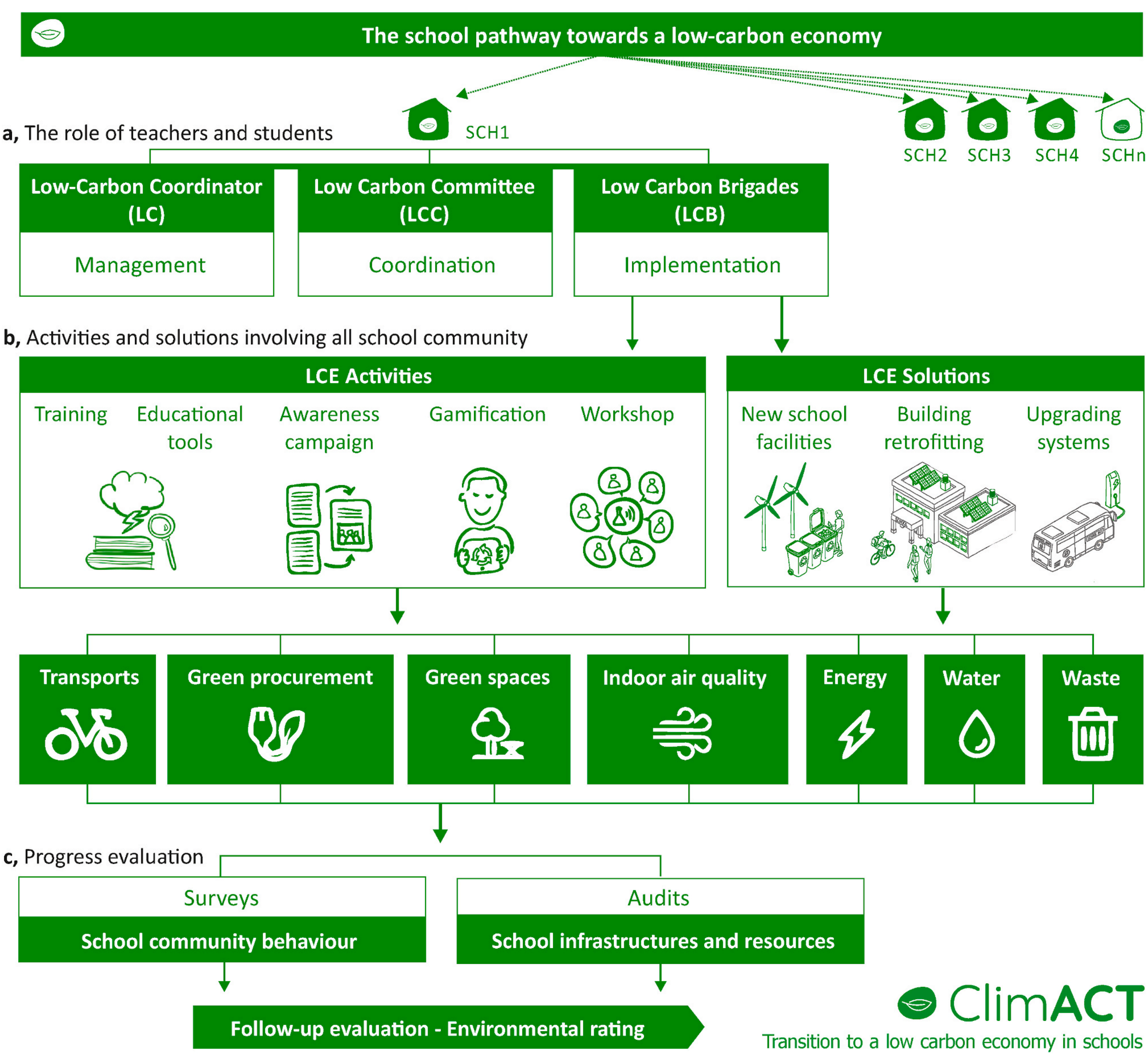


Fig. 2. The structure of ClimACT methodology to involve school communities towards a low-carbon economy pathway. a, School profiles: the role of teachers and students. **b,** Typologies of activities and solutions to involve the school community towards a low-carbon economy pathway. **c,** Progress evaluation of school performance through audits and surveys.

encourage students, teachers and families towards an energy-efficient and LCE pathway (Kemper et al., 2020). Child-based climate communication is an understudied but promising pathway to incite climate action among children and adults alike (Lawson et al., 2018). The LCE structure in schools, summarised in Fig. 2a–c, consists of annual sequential steps, covering environmental knowledge, attitudes and behaviours (Olsson et al., 2019; Otto and Pensini, 2017), to involve all the school community towards the achievement of environmental benefits at small- and large-scale in the school's region. This LCE structure was developed taking as reference existing sustainable education programmes in some schools, such as the ("Eco-Schools programme").

The role of teachers and students with which every school (SCH) should be involved in ClimACT activities are based on three profiles (Fig. 2a): Low-Carbon Coordinator (LC), Low-Carbon Committee (LCC) and Low-Carbon Brigades (LCB). Low-Carbon Coordinator (LC) is the project leader in the school, responsible for management. Low Carbon Committee (LCC) is a permanent structure inside the school, composed by students, teachers, staff, parents, municipalities and other relevant stakeholders. This committee is responsible for planning the LCE actions. Also, LCC should monitor the school performance, and evaluate the improvement process to support the transition to an LCE. Low Carbon Brigades (LCB) are made up of students, who are responsible for the successful implementation of activities and solutions that will conduct to an LCE.

School targets should be defined among all school roles (LC, LCC an LCB) to deploy a low-carbon pathway. They should be identified by considering the initial school performance as a baseline and the global average among all pilot schools, as defined in Section 3. In light of this, the environmental methodology enables the fulfilment of two main objectives of the common environmental performance directives (European Commission, 2010, 2018a, 2018b): (1) showing the environmental performance and reference values to enable comparisons with other cases; and (2) informing of potential environmental savings in order to motivate people to follow a sustainable pathway by introducing short- and long-term goals in all environmental sectors at different levels, ranging from a single classroom to the whole school community. This approach aims to reduce the gap between citizens' long-term visions and short-term actions (Huxley et al., 2019).

Action Plans shall be based on the defined targets. They should include the best available LCE activities and solutions to improve the school performance in each environmental area, as illustrated in Fig. 2b. Each initiative presents new learning opportunities, creating evidence-informed guidelines to build a robust transition towards sustainability (Forrest and Wiek, 2014). These activities involve teacher training, use of educational tools, gamification activities and workshops. All of them are focused on improving daily routines and habits in the school and its community, and providing solutions to modify existing infrastructures, which may reduce the associated carbon emissions, improve energy efficiency or decrease the global environmental impact. Moreover, retrofitting solutions are an opportunity to renew facilities and devices, which can reduce the operational costs, particularly in older buildings, as well as help to attract the attention of school community and gain social impact.

The progress evaluation shall show the effectiveness of the LCE activities and solutions which were implemented in the schools (Fig. 2c). It consists of a follow-up assessment, following the methodology defined in Section 2 in all environmental areas, to characterise the environmental improvements and the new environmental score of the school. The quantification of the achieved success, communicated to all school community through social media or other platforms, shall produce an enormous social impact, attracting more and more attention of the general public.

2.3. Materials and methods for data collection

The materials and methods for data collection procedure during technical audits, monitoring campaigns and behaviour questionnaires are defined per each environmental sector as follows.

Transport was characterised through technical audits of schools' infrastructure in order to analyse the availability of parking spaces for low-carbon transport modes, such as electric vehicles or bicycles, and to evaluate the availability of public transport networks in schools' surroundings. In addition, in order to quantify users' behaviour with regards to the transport mode used on the school run and its associated CO_2 emissions, an online survey of all the school community was carried out, in which a percentage greater than 25% was required to obtain representative data per school.

Green procurement was assessed through technical audits in schools and checklist questionnaires with the support of the teachers and school director.

Green spaces were evaluated through a checklist questionnaire with the support of the school representative in order to quantify the green areas and trees, identify main species and quantify the use of chemicals and resource consumption associated with the maintenance of green areas.

Indoor air quality (IAQ) was characterised through a monitoring campaign carried out simultaneously in two classrooms per school. Representative classrooms were selected for each school, in terms of size, number of occupants, activities (including frequency of use) and existing furnishing or equipment that could release pollutants into the indoor air. IAQ monitoring equipment was placed near occupants' breathing zone and at least 2 m away from windows, doors or active heating systems.

A summary of the IAQ measurements is detailed in Table 2, with the specification of the data collection procedure and indoor air guideline values (IAGV) for each indoor air pollutant, taking as a reference the review developed by Becerra et al. (2019).

Air pollutants concentrations were measured through online and passive procedures (Table 4): monitoring of CO, CO_2, $PM_{2.5}$, PM_{10} and TVOC was achieved from the equipment presented in Table 3. Measurements of VOC and aldehyde concentrations were carried through passing sampling over five school days using RAD145 and RAD165 cartridges (Sigma Aldrich). Analyses were carried out by the ICSM laboratory.

Ventilation efficiency was evaluated based on the percentage of CO_2 concentrations below 1000 ppm, between 1000 and 1700 ppm, and over 1700 ppm, during the school hours.

Thermal comfort was assessed based on the fraction of time temperatures are between 20 °C and 26 °C during the occupancy period. This temperature range corresponds to the thermal comfort category II according to the EN 16798–1:2019 (European Committee for Standardization, 2019).

Energy use was characterised through technical audits carried out in schools in order to quantify the amount of energy consumed, its source (e.g. electric, diesel, GLP, natural gas, biomass or renewable energy) and its associated cost. Energy consumption data were mainly obtained from monthly energy bills. Once the amount and type of energy consumed in school are obtained, associated CO_2 emissions were calculated according to the procedure defined in Appendix A.

Water management was evaluated based on yearly water consumption and costs coming from water bills.

Waste management was assessed during a week, involving schools' ancillary staff who are responsible for the waste collection, in order to measure the different types of waste produced, sorted for recycling and composting. The measurements were done daily by assessing the volume of waste produced. These measurements were obtained through the number of bags and containers filled up (or the fraction filled up).

Finally, the school community behaviour was evaluated through an online questionnaire sent to the whole school community. This questionnaire, common to all schools and translated into each of the languages of the countries involved, was completed at the beginning of the project to define the baseline. It was completed again one year later to

Table 2
Summary of air pollutants assessment: parameters, duration and guidelines.

Air pollutants	Unit	Period	Exposure time	Guideline	References
Inorganic pollutants					
CO_2	ppm	2 weekdays	Mean during occupancy period	<1250	(Portaria no 353-A, 2013)
CO	ppm	2 weekdays	Mean during occupancy period	<6	WHO (2010)
Particulate matter fractions					
PM_{10}	µg/m^3	2 weekdays	Mean during occupancy period	<20	(Ramalho et al., 2015; WHO, 2000)
$PM_{2.5}$	µg/m^3	2 weekdays	Mean during occupancy period	<10	(Ramalho et al., 2015; WHO, 2000)
Volatile organic compounds					
TVOC	µg/m^3	2 weekdays	Mean during occupancy period	<600	(Portaria no 353-A, 2013)
Benzene	µg/m^3	5 full weekdays	Weekly average	<2	(Agence Française de Sécurité Sanitaire de l'– et du deTravail, 2008; ANSES, 2011, n.d.)
Trichloroethylene	µg/m^3	5 full weekdays	Weekly average	<20	(Agence Nationale de Sécurité Sanitaire de l'Alimentation and de l'Environnement et du Travail, 2013; ANSES, 2011, n.d.)
Toluene	µg/m^3	5 full weekdays	Weekly average	<250	(Portaria no 353-A, 2013)
Tetrachloroethylene	µg/m^3	5 full weekdays	Weekly average	<250	(ANSES, 2011, n.d.; ESFA, 2016; Portaria no 353-A, 2013; WHO, 2010)
Ethylbenzene	µg/m^3	5 full weekdays	Weekly average	<850	European Commission (2016)
o+m+p-xylene	µg/m^3	5 full weekdays	Weekly average	<200	European Commission (2004)
Styrene	µg/m^3	5 full weekdays	Weekly average	<250	(European Commission, 2004, 2016; European Union, 2013)
Alpha-pinene	µg/m^3	5 full weekdays	Weekly average	<200	Umweltbundesamt (2018)
1,4-dichlorobenzene	µg/m^3	5 full weekdays	Weekly average	<150	(European Commission, 2016; European Union, 2013)
Aldehydes					
Formaldehyde	µg/m^3	5 full weekdays	Weekly average	30	European Commission (2004)
Acetaldehyde	µg/m^3	5 full weekdays	Weekly average	200	European Commission (2004)
Acrolein	µg/m^3	5 full weekdays	Weekly average	0.8	(Agence Nationale de Sécurité Sanitaire de l'Alimentation and de l'Environnement et du Travail, 2013; ANSES, 2011, n.d.)

Table 3
Equipment for continuous IAQ monitoring in schools.

Equipment	Compounds
HD 21ABE17 (Delta OHM)	CO_2 (ppm), CO (ppm), Relative humidity (%), Temperature (°C)
VOC-103 probe (Graywolf Sensing Solutions)	TVOC (ppb), Relative humidity (%), Temperature (°C).
Optical Particle Sizer. OPS 3330 (TSI)	Number and size of particles
Graywolf IQ-610 probe (WolfSense Solutions)	TVOC (ppb), CO_2 (ppm), CO (ppm)
DustTrak monitor 8530 (TSI)	PM_{10}, $PM_{2.5}$

Table 4
Equipment for passive IAQ monitoring in classrooms.

Equipment	Compounds
VOC adsorbent cartridges (RAD145)	Benzene, Trichloroethylene, Toluene, Tetrachloroethylene, Ethylbenzene, m+p-xylene, Styrene, o-xylene, Alpha-pinene, 1,4-dichlorobenzene
Aldehyde adsorbent cartridges (RAD165)	Formaldehyde, Acetaldehyde, Acrolein, Propanal, Butanal, Benzaldehyde, Isopentanal, Pentanal, Hexanal

assess improvements. The questionnaire consisted of multiple-choice questions and one last open-ended question, where participants were asked what they could do, or help to do, to make their school a low-carbon and environmentally friendly school.

2.4. Pilot schools for methodology application and validation

A set of 39 pilot schools located in Portugal, Spain, France and Gibraltar was selected to test the ClimACT methodology, giving the first environmental status of schools' performance in South-western Europe. Selection criteria of pilot schools were based on different construction typologies, locations, climate area and education levels from SUDOE region. The location of the pilot case studies is depicted in Fig. 3. There are nine Portuguese schools: six are located in Lisbon's district (five in the municipality of Loures and one in the municipality of Lisbon) and three in Oporto's district (two in the municipality of Matosinhos and 1 in the municipality of Vila Nova de Gaia). Thirteen schools are located in Spain from which eight are in Seville, one in Málaga, two in Madrid and two in Alcalá de Henares. The nine French schools are all located in La Rochelle. Similarly, eight schools of United Kingdom are located in Gibraltar. Schools' levels consist of 13 primary schools, seven middle schools, 12 secondary schools and three universities and high education levels.

2.5. Measurement campaigns

Two measurement campaigns were carried out to evaluate the potential benefits of the ClimACT methodology. The first measurement campaign was carried out in the academic course 2017/18, before the

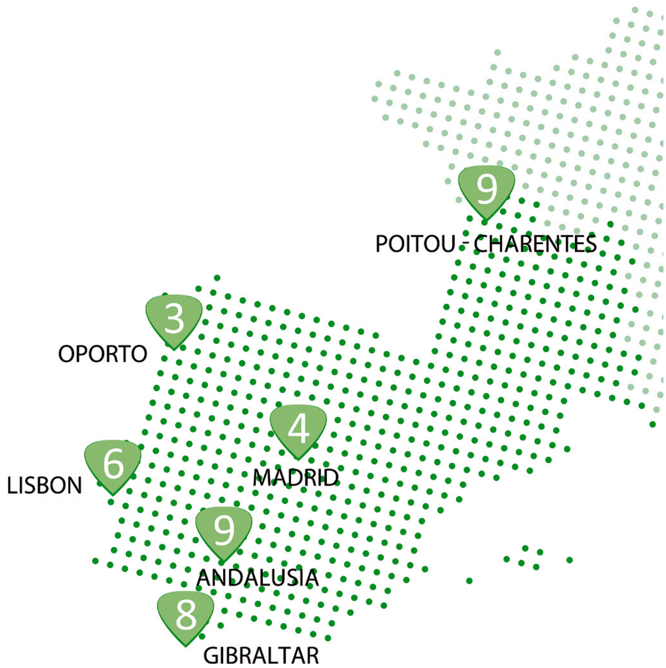


Fig. 3. Location of the ClimACT pilot schools.

methodology application, in order to obtain a first environmental status of the schools' performance. The second measurement campaign was carried out in the academic course 2018/19, after the methodology application, to measure the environmental benefits of the ClimACT methodology towards a low-carbon economy in school communities.

3. Results and discussion

3.1. Initial environmental performance of schools before ClimACT methodology

The initial environmental status of pilot schools, before the ClimACT methodology application, is presented in Fig. 4a, breaking down the results per each environmental sector (transports, green procurement, green spaces, indoor air quality, energy, water and waste). The average partial scores obtained by Portuguese, Spanish, French and Gibraltar schools are displayed in Fig. 4b. The figure also shows the average scores per environmental sector for the whole school sample in Fig. 4c and the global mean score in Fig. 4c.

The first global LCE evaluation provides a mean score among all the schools of 2.20 out of 5. Among all the environmental sectors, water and IAQ showed the highest mean score among all schools, achieving a mean value of 3.65 and 3.20 out of 5, respectively. The environmental sectors showing the highest improvement potential are waste, green procurement and transport, showing weaknesses in most of the KPIs evaluated.

Fig. 5 presents the mean performance and mean absolute deviation (MAD) of KPIs assessed in the 39 pilot schools for Transport, Green procurement and Green spaces.

The transport evaluation (Fig. 5a) shows that the parking space ratio per student for low carbon transport modes is limited, with only three schools having charging stations for electric cars. For the sample under study, parking spaces for bikes are only available in 44% of schools, with French schools presenting the highest ratio per student. The most common transport modes to school are on foot (41%), followed by car (30%) and bus (15%). The use of different transport modes depends on the region and the school level. The schools from Portugal presented the highest annual average CO_2 emissions associated with transport modes (113.91 $kgCO_{2\ eq}{\cdot}student^{-1}$), followed by the Spanish schools (103.65 $kgCO_{2\ eq}{\cdot}student^{-1}$), French schools (96.23 $kgCO_{2\ eq}{\cdot}student^{-1}$) and Gibraltar schools (15.86 $kgCO_{2\ eq}{\cdot}student^{-1}$).

Green procurement (Fig. 5b) shows a weak deployment in pilot schools assessed. The schools from Portugal and France present a percentage of electric equipment with high-efficiency labelling of 38% and 36%, respectively, while Spanish and Gibraltar schools do not have energy labelling in most of their equipment. The staff from pilot schools are not trained in green procurement nor eco-driving. The results of the paper consumption ratio per student are very high, above all in Spanish schools, showing the highest mean value of 7.6 $kg{\cdot}student^{-1}$, with a reduced number of schools using recycled paper. The existence of local suppliers is found in 37% for French schools. It is less than 20% in other countries.

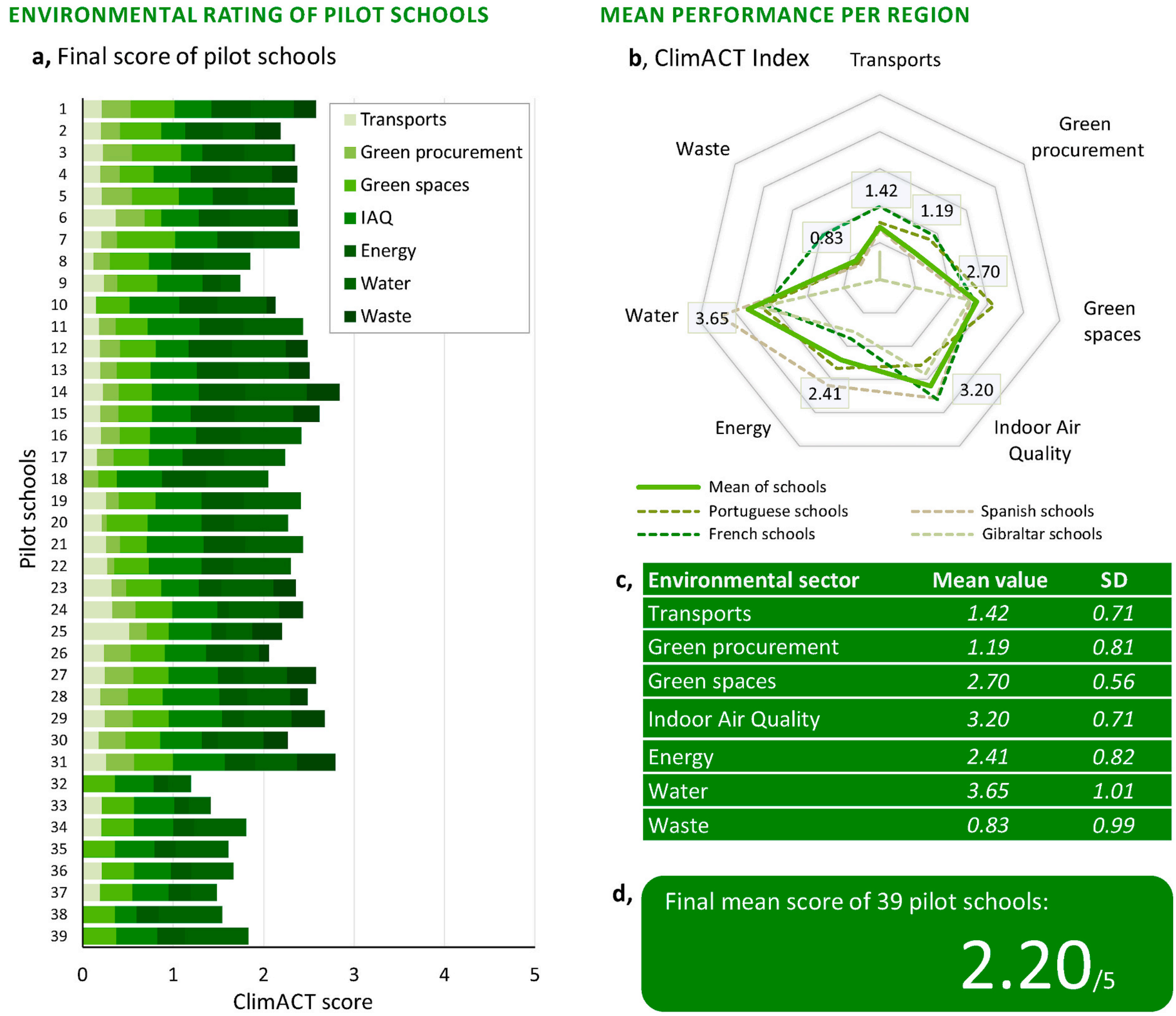
Green spaces (Fig. 5c) present a large variability depending on the region under assessment. Portuguese schools have the largest green areas, whether they are rated per the non-covered surface area of the school or per student: mean values are 48% and 12.74 $m^2{\cdot}student^{-1}$, respectively. They are followed by French schools with 27% and 8.43 $m^2{\cdot}student^{-1}$. The remaining schools have a green area ratio below 20%. These values are related to the annual CO_2 sank per non-covered area, which shows a higher value in Portugal region, being of 0.43 $kgCO^2{\cdot}m^{-2}$, followed by Spain, France and Gibraltar. The variability of the results is due to the difference in the predominant tree species and consequently, the sequestration ratio. At the same time, resources consumption and the use of chemicals during maintenance are very low in the schools.

Fig. 6 summaries the mean performance and MAD of indicators assessed in 39 pilot schools for IAQ, Energy, Water and Waste.

IAQ analysis (Fig. 6a) shows that most pollutants have concentrations below the guideline values. Only mean concentrations of CO_2, PM_{10}, $PM_{2.5}$, TVOC, and formaldehyde exceed the recommended values in specific cases and/or during peak periods. The percentage of classrooms with exceedance of the guideline value is 45% for PM_{10} concentrations, 37% for CO_2, 32% for $PM_{2.5}$, 15% for TVOC and 8% for formaldehyde. It has been previously demonstrated that the main indoor air pollutant sources in schools are associated with occupancy, settled dust, the blackboard chalk use, construction and furnishing materials and other specific products that affect VOC and aldehyde concentrations (Becerra et al., 2019; Canha et al., 2014). Additionally, main outdoor air pollutant sources were related to high-density traffic areas or industrial activities in school surroundings (Becerra et al., 2019). It has been also concluded that contribution of school microenvironments to the daily inhaled dose of air pollutants in students is very low, approximately 12% considering all daily indoor spaces (Lizana et al., 2020). The results show that mean CO_2 concentration among all schools was 1200 ppm. Higher values of PM concentrations were achieved in French schools, followed by Gibraltar, Portugal and Spanish schools, with a mean value of 33.27 $\mu g/m^3$ and 11.63 $\mu g/m^3$ for PM_{10} and $PM_{2.5}$, respectively. Mean concentrations of TVOC were a bit lower in Spanish schools, with a mean value of 295 $\mu g/m^3$, in comparison with Portugal (391 $\mu g/m^3$) and France schools (495 $\mu g/m^3$).

Energy assessment (Fig. 6b) highlights the high energy consumption of schools, with energy bills being the second-largest expenditure category for schools (Dias Pereira et al., 2014). It is recognised that schools waste a large amount of energy because most buildings were constructed before high insulation standards (Rospi et al., 2017) and often consume 57% more energy than is needed (Airaksinen, 2011). Spain and Portugal school buildings have similar energy performance indicators across all schools, with mean energy consumption and mean energy cost ratio of 30 and 50 $kWh{\cdot}m^{-2}$, and 4 and 6 €$\cdot m^{-2}$, respectively. However, France and Gibraltar present a significant discrepancy in final scores, mainly associated with a higher need for space heating and cooling, respectively. Heating and lighting are the main energy consumption areas among all schools (Gamarra et al., 2017), with heating commonly supplied by boilers using fossil fuels, such as oil or natural gas (International Energy Agency, 2013).

Renewable energy production is insignificant in all assessed schools.



Environmental sector	Mean value	SD
Transports	1.42	0.71
Green procurement	1.19	0.81
Green spaces	2.70	0.56
Indoor Air Quality	3.20	0.71
Energy	2.41	0.82
Water	3.65	1.01
Waste	0.83	0.99

Fig. 4. Evaluation of the initial environmental performance of pilot schools. a, Environmental rating between 0 and 5 of the performance of 39 pilot schools located in Portugal, Spain, France and Gibraltar. **b,** Mean performance of 39 pilot schools per environmental sector and per country. **c,** Mean score and standard deviation (SD) per environmental sector of 39 pilot schools. **d,** Global mean score of 39 pilot schools.

A reduced number of schools have renewable energy production through solar thermal panels used for domestic hot water. French schools obtained the highest score.

Regarding energy-associated CO_2 emissions, it is mainly influenced by the energy mix per school and the electricity generation technologies per region. Renewable energy covers 36% in Spain, 17% in France and 49% in Portugal, with the most comprehensive energy source being wind and hydropower. In the specific case of Gibraltar, the electricity supply is based on oil ("Database - Eurostat"; International Energy Agency). These are the reasons why CO_2 emissions ratio per student is higher in Gibraltar schools than others, with lower values being achieved in Portugal (164.3 $kgCO_2{\cdot}student^{-1}$) and Spain (89.4 $kgCO_2{\cdot}student^{-1}$) due to a combination of low consumption and high renewable energy penetration.

Water consumption ratio (Fig. 6c) shows similarities among all evaluated schools in France, Portugal and Gibraltar regions. Spanish schools achieved the highest scores in water management. This is associated with the low water consumption and low-cost ratio per square meter and per student (1800 $l{\cdot}student^{-1}$, and 4.4 €$\cdot student^{-1}$). These are followed by Portuguese schools which have the highest water consumption on average, even when looking at consumption per student or consumption per useful floor area. French schools have their final scores raised due to their higher water cost ratio, which has a relevant impact on their economic resources.

Waste management (Fig. 6d) is the environmental sector with the higher potential for improvement. The mean waste production per student among all pilot schools, accounting non-recyclable, recyclable and reusable waste, was 10.2 $l{\cdot}student^{-1}$ for a week, ranging between 5.6 and 20.3 $l{\cdot}student^{-1}$ among all the schools. The results show that the schools with recycling programmes can recycle up to 44% of the waste they produce, with the French schools being those with higher scores in recycled wastes, achieving a mean recycling potential of 5.80 $l{\cdot}student^{-1}$ per week. Boschini et al. (2020) has previously pointed out the need to reduce food waste at school canteens, which is directly affected by the food service provider, the serving size, the composition of the menus and the gap between nutritional requirements and children preferences.

3.2. *Environmental benefits after the implementation of ClimACT methodology*

After one year of environmental methodology implementation, first progress evaluation began to yield the first results, quantifying the success achieved by the methodology in the 39 pilot schools. New technical audits and behaviour questionnaires were deployed in all schools and regions after they had implemented their action plans, to evaluate the ClimACT benefits and validate the developed methodology.

The achievements in the first follow-up evaluation after one year,

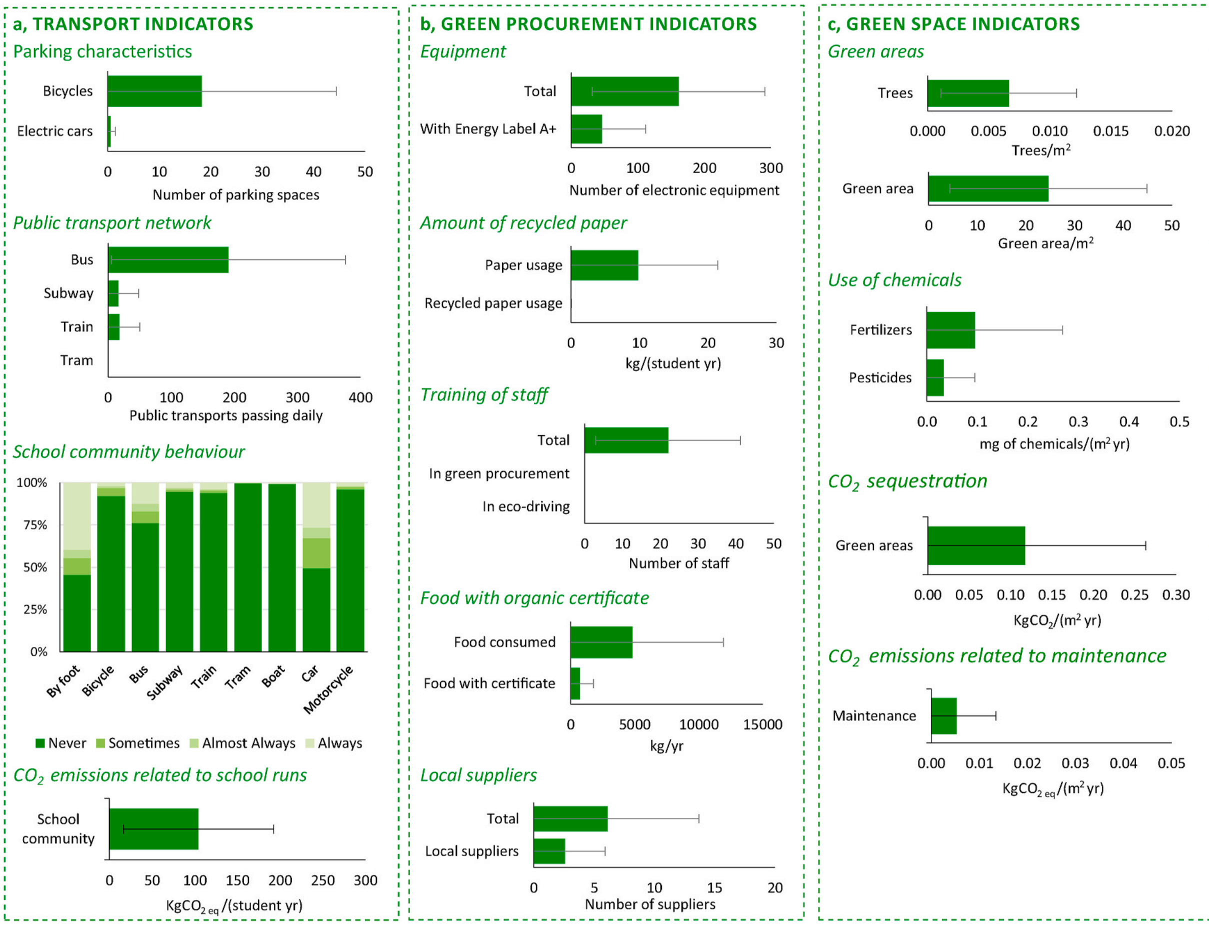


Fig. 5. Mean performance and error bars with MAD of assessed indicators in 39 pilot schools. a, KPIs associated with the transport sector. **b**, KPIs associated with green procurement. **c**, KPIs associated with green spaces. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

illustrated in Fig. 7, are promising and encouraging. The average score among the 39 pilot schools improved from 2.20 to 2.42 out of 5, with an average environmental improvement of 10% among all schools. In eight cases, the school performance was improved by more than 20% and up to 42% in the case of Pilot school 26. The results show that 95% of pilot schools improved their environmental performance, with only two pilot cases reducing its final score by approximately 5% (Pilot schools 19 and 22).

It should be highlighted that most of the measures implemented during this ClimACT operating year were based on minor low-carbon solutions through behavioural or low-cost actions, and some schools are in the process of major and deep retrofitting actions and infrastructure changes regarding transport, green spaces and energy sectors, expecting to achieve significant improvements throughout the next years. The ClimACT initiative will be maintained over the future lifespan of schools, improving their environmental performance year by year, while at the same time, ClimACT will promote a sustainable pathway to the whole school communities and regions.

Waste management showed a significant environmental improvement of +0.64 out of 5. It was the environmental sector with the lowest mean score at the beginning of the project. However, by the end of the project, the action plans addressed by pilot schools were able to promote awareness about waste and the importance of recycling, being one of the most successful low-carbon solutions. Now, most schools have recycling programmes, in which all students are involved, being able to recycle up to 49% of the waste generated.

IAQ showed an average improvement of +0.34 out of 5. The results showed how indoor air pollutant concentrations can be effectively controlled during occupancy hours by using natural ventilation during breaks in warm climate regions. Some classrooms also installed CO_2 monitoring sensors. An orange light is turned on when CO_2 concentration exceeds 1250 ppm and a red light if the concentration turns over 2500 ppm. Students attending the class were in charge of opening the windows to facilitate natural ventilation and keep the CO_2 levels below the limits. This promotion of good ventilation habits resulted in better indoor air quality, decreasing pollutant concentrations in the classrooms.

Water and green procurement areas also achieved a mean improvement of +0.31 and + 0.10 out of 5, respectively. The activities and awareness campaigns developed by students allowed high improvements. Some schools installed rainwater tanks to collect the water from the building roofs. Other schools reduced water consumption per student through the deployment of small routines and the implementation of water flow reducers in faucets and toilet bowls, showing a potential water reduction of approximately 25% per school.

Transport, green spaces or energy areas remained almost constant because they require the implementation of significant improvement actions and infrastructure changes. Some schools were able to implement behavioural strategies to reduce the energy consumption in lighting, reducing monthly energy consumption per classroom by 24% through the appropriate use of sunlight, reducing lighting operating hours. Additionally, other schools are in the process of deploying retrofitting actions, which are expected to achieve significant improvements in these sectors throughout the next years.

On the other hand, all addressed actions showed a strong influence on the school community's attitude. The results of

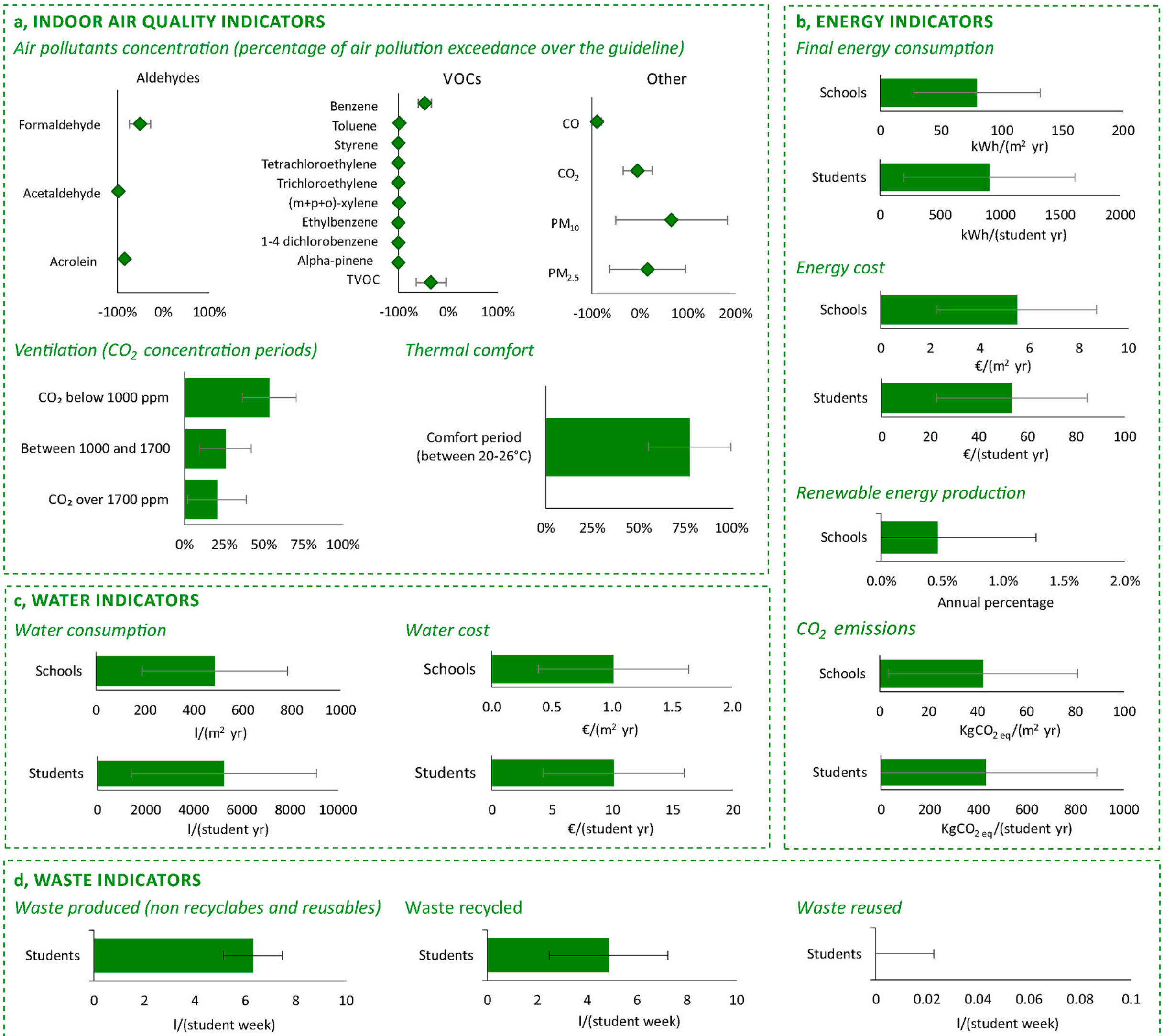


Fig. 6. Mean performance and MAD of assessed indicators in 39 pilot schools. a, KPIs associated with IAQ. **b**, KPIs associated with the energy sector. **c**, KPIs associated with the water sector. **d**, KPIs associated with the waste sector.

questionnaires answered by schools' families, with a sample of 5112 completed questionnaires (n = 2674 in 2016 and n = 2438 in 2019), representing 86% of all the questionnaires, highlighted how the actions addressed by the ClimACT methodology were able to promote a low-carbon pathway in the society outside of school. When comparing the first and final questionnaires applied in the same schools, it is possible to see that there was an increase in "good behaviour" related to all environmental sectors.

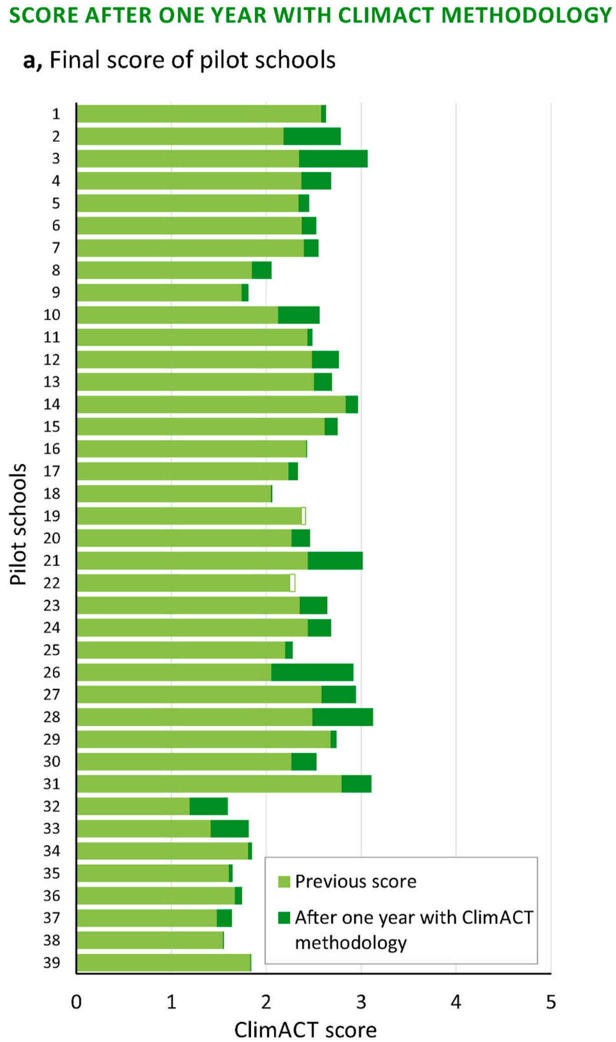
There was an increase of 5% of people sorting waste for recycling at home. Additionally, the separation of compostable waste to be used as fertiliser had the highest increase (21%). About 19% said that always, or almost always, use second-hand school books, corresponding to an average increase of 9% when compared to the first questionnaire. There was also a 14% and 8% increase in students who check the energy efficiency label and the lifespan when they buy new electrical and electronic equipment. The existence of a bike path between home and the school promoted the use of the bike by 12% above other transport modes when compared to those who always use the bike to go to school (0.8%). Besides, it was found an increase in the endorsement of environmental petitions by 4%, the participation in clean-up activities by 4% and tree-planting campaigns by 2%. Also, the rate of students that reported environmental offences increased by 44%.

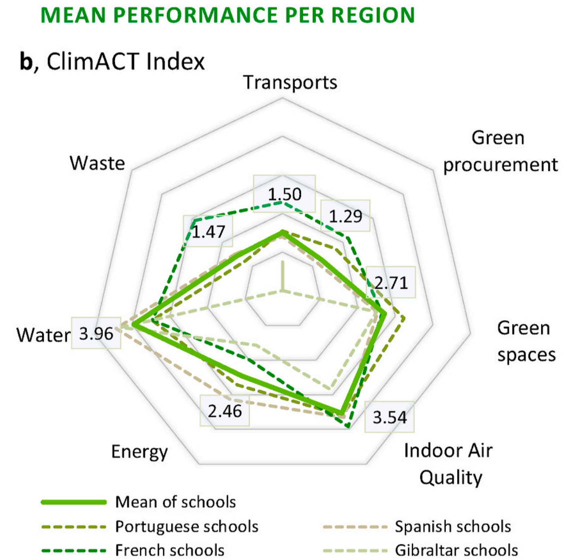
This research demonstrates the benefits and impacts of measurable sustainable indicators in environmental education programmes, empowering citizens towards a low-carbon economy. The material and methodology generated in this research are open and adaptable to existing environmental programmes.

4. Conclusions

This research assesses the potential benefits of innovative approaches to engage and empower citizens towards a low-carbon economy (LCE) thought measurable sustainable indicators. It has been evaluated in school communities, defining and implementing an innovative procedure to measure and promote sustainability in schools. The methodology, titled ClimACT, has two main purposes: the measurement of sustainability through a school sustainability index based on measurable indicators divided into seven environmental areas (transport, green procurement, green spaces, indoor air quality, energy, water and waste); and a structural procedure through roles, activities and progress evaluation to promote and support school communities to adopt more environmentally friendly habits. The methodology has been applied and validated in 39 pilot school communities from Portugal, Spain, France and Gibraltar, achieving promising and encouraging results.

All pilot schools deployed the ClimACT methodology successfully,





c,

Environmental sector	Mean value	SD
Transports	*1.50*	*0.74*
Green procurement	*1.29*	*0.91*
Green spaces	*2.71*	*0.58*
Indoor Air Quality	*3.54*	*0.64*
Energy	*2.46*	*0.83*
Water	*3.96*	*0.73*
Waste	*1.47*	*1.53*

d, Final mean score of 39 pilot schools: 2.42/5

Fig. 7. Validation of methodology through the follow-up evaluation of 39 pilot schools. a, Final score of pilot schools after one year with ClimACT methodology. **b**, Final mean performance of 39 pilot schools per environmental sector and per country. **c**, Final mean score and standard deviation (SD) per environmental sector of 39 pilot schools. **d**, Global mean score of 39 pilot schools after one year with ClimACT methodology.

achieving measurable environmental benefits in 95% of cases. The average environmental score among the 39 pilot schools improved from 2.20 to 2.42 after one year, achieving an average improvement of 10% among all schools. Waste and indoor air quality showed the most significant environmental improvement. Now, most schools have recycling programmes, in which all students are involved, being able to recycle up to 49% of the waste generated by schools. Furthermore, the promotion of good ventilation habits in warm climate regions resulted in better indoor air quality (IAQ), reducing the presence of air pollutants. Water and green procurement topics also achieved substantial improvements, reducing paper and water consumption ratios per student. Besides, some schools are in the process of significant retrofitting actions and infrastructure changes regarding transport, green spaces and energy sectors, expecting to achieve significant improvements throughout the next years. Finally, the 5112 surveys deployed to all school communities, before and after the methodology implementation, showed an improvement on the behaviour on and off school, with an increase of 20% regarding good practices in transport, energy, water, waste and citizenship in all schools' regions.

The results demonstrate that sustainability indicators can effectively support the environmental empowering of citizens, highlighting schools as a powerful tool to encourage and engage communities in sustainable development. Raising awareness and involving people through quantitative environmental indicators can lead to a significant low-carbon economy transition in all regions. These innovative approaches, successfully validated in school communities, are ready to assess whether the citizens' trajectory is on a sustainable path. Their application promises an overall sustainable development.

Author contributions

Jesus Lizana, Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. Vítor Manteigas, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. Ricardo Chacartegui, Conceptualization, Formal analysis, Investigation, Methodology, Writing – review & editing. Joana Lage, Data curation, Formal analysis, Investigation. Jose A. Becerra, Formal analysis, Investigation, Methodology. Patrice Blondeau, Conceptualization, Formal analysis, Investigation, Methodology. Ricardo Rato, Conceptualization, Methodology. Filipe Silva, Data curation, Formal analysis, Investigation, Methodology. Ana R. Gamarra, Formal analysis, Investigation, Methodology. Israel Herrera, Conceptualization, Investigation, Methodology. Margarida Gomes, Data curation, Methodology. Amaia Fernandez, Conceptualization. Celine Berthier, Conceptualization. Karla Gonçalves, Data curation, Methodology. Jose L. Alexandre, Conceptualization, Methodology. Marina Almeida-Silva, Funding acquisition. Susana Marta Almeida, Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Writing –

review & editing.

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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Appendix A. ClimACT methodology for the environmental rating of schools

Further definition of the input data and numerical procedures are described in the following sections.

A1. Transports

The transport sector is characterised by four KPIs divided into three areas: parking characteristics, public transport network and CO_2 emissions from daily commuting to school. They are summarised in Table A1and further detailed below.

Table A1
Characterisation areas and KPIs of the transport sector.

Transport areas	Key Performance Indicators	Data source
Parking characteristics	KPI-T1. Parking spaces for bicycles per student (up to a 100 m radius)	Technical audits
	KPI-T2. Parking spaces for electric cars per school (up to a 100 m radius)	Technical audits
Public transports network	KPI-T3. Public Transports passing daily per hour (1000 m radius)	Technical audits
CO_2 emissions from daily commuting to school	KPI-T4. Annual CO_2 Emissions per student ($kgCO_{2\ eq}$/student)	Behaviour questionnaires

KPI-T1 and KPI-T2, about parking characteristics, are characterised according to Eq. (A1) and Eq. (A2), respectively.

$$\text{KPI}_{\text{T1}} = \frac{\text{No. of parking spaces for bicycle}}{\text{No. of students}} \quad \text{(A1)}$$

$$\text{KPI}_{\text{T2}} = \frac{\text{No. of parking spaces for electric cars}}{\text{No. of students}} \quad \text{(A2)}$$

KPI-T3, related to public transports, is defined in Eq. (A3).

$$\text{KPI}_{\text{T3}} = \frac{\text{No. of public transports passing daily per hour}}{\text{No. of students}} \quad \text{(A3)}$$

KPI-T4, associated with CO_2 emissions from daily commuting to school, is defined in Eq. (A4).

$$\text{KPI}_{\text{T4}} = \frac{\sum_i \text{CO}_{2i} \text{ emissions from daily commuting to school}}{\text{No. of students}} \quad \text{(A4)}$$

where i: transport mode (motorbike, car, boat, tram, train, subway, bus, bicycle, on foot); and annual CO_2 emissions per transport mode (i) from daily commuting to school are calculated based on the information obtained from behaviour questionnaires, answered by the school community, according to Eq. (A5).

$$CO_2\ emissions_i = \sum_i (FE_i \times PE_i) \times daily\ average\ distance \times 22 \times 10 \quad \text{(A5)}$$

where FE_i: CO_2 emission factor per transport mode *I*, detailed in Table A2; PE_i: No. of persons equivalent per transport mode i, considering the total no. of answers of behaviour questionnaire and the total no. of students, according to Eq. (A6).

$$\text{PE}_\text{i} = \frac{\left(\#_{\text{never}}\cdot 0 + \#_{\text{almostnever}}\cdot\frac{1}{3} + \#_{\text{almostalways}}\cdot\frac{2}{3} + \#_{\text{always}}\cdot 1\right) \times \text{No. of students}}{\text{No. of students}} \quad \text{(A6)}$$

Once all KPIs are calculated, the final score to evaluate the schools' performance regarding the transport sector is calculated according to Eq. (A7).

$$Transport_{score} = \frac{T_1 + T_2 + T_3 + 2[T_4]}{5} \quad \text{(A7)}$$

where T_1, T_2, T_3 and T_4 are calculated according to Eq. (A8), Eq. (A9), Eq. (A10) and Eq. (A11), respectively.

$$T_1 = \frac{5\ \mathrm{KPI_{T1}}}{1.05 \cdot \max\ (\mathrm{KPI_{T1}})} \tag{A8}$$

$$T_2 = \frac{5\ \mathrm{KPI_{T2}}}{1.05 \cdot \max\ (\mathrm{KPI_{T2}})} \tag{A9}$$

$$T_3 = \frac{5\ \mathrm{KPI_{T3}}}{1.05 \cdot \max\ (\mathrm{KPI_{T3}})} \tag{A10}$$

$$T_4 = 5 - \frac{5\ \mathrm{KPI_{T4}}}{\mathrm{KPI_{T4}}\ \text{with all students by car}} \tag{A11}$$

where max (KPI_n) is the maximum value obtained among all schools evaluated.

Table A2
CO_2 emission factors of transport modes (kg$CO_{2\ eq}$ per passenger per km). Factors calculated using the Life Cycle Assessment (LCA) methodology (ISO, 2006a; 2006b)*, based on recognised life cycle inventories Ecoinvent database* (Wernet et al., 2016) *and inventories from literature* (Messmer and Frischknecht, 2016)*, and IPCC reference method of characterisation* (Myhre et al., 2013).

Transport	Spain	France	Gibraltar	Portugal
Foot	0.000000	0.000000	0.000000	0.000000
Bicycle	0.000000	0.000000	0.000000	0.000000
Bus	0.015440	0.015440	0.015440	0.015440
Subway	0.028242	0.004445	0.072487	0.030415
Train	0.027648	0.011163	0.058298	0.029153
Tram	0.050757	0.008271	0.129522	0.054545
Boat	0.115000	0.115000	0.115000	0.115000
Car	0.146170	0.146170	0.146170	0.146170
Motorcycle	0.093010	0.093010	0.093010	0.093010

A2. Green procurement

The green procurement sector is characterised by seven KPIs divided into six areas: equipment efficiency, paper usage, training in green procurement, eco-driving certification, organic food and suppliers. They are summarised in Table A3 and further detailed below.

Table A3
Characterisation areas and KPIs of green procurement.

Green procurement areas	Key Performance Indicators	Data source
Equipment efficiency	KPI-GP1. Electronic equipment with A+ or higher Energy Label (No. A+ or higher/total)	Technical audits
Paper	KPI-GP2. Annual paper usage in school (kg/student)	Check-list sheet
	KPI-GP3. Annual recycled paper used in school (kg recycled/kg paper)	Check-list sheet
Training in green procurement	KPI-GP4. Staff with training in green procurement (No. staff with training/total no. staff)	Check-list sheet
Eco-driving certification	KPI-GP5. Staff with training in eco-driving (No. staff with training/total no. staff)	Check-list sheet
Biological food	KPI-GP6. Food with biological certificate (kg food with biological certificate/kg total food)	Check-list sheet
Suppliers	KPI-GP7. Local suppliers (No. local suppliers/total suppliers)	Check-list sheet

KPI-GP1, about equipment efficiency, is characterised, according to Eq. (A12).

$$\mathrm{KPI_{GP1}} = \frac{\text{No. of equipment } A^{+} \text{ or higher EU energy label}}{\text{No. of equipment}} \tag{A12}$$

KPI-GP2 and KPI-GP3, related to paper usage, are characterised, according to Eq. (A13) and Eq. (A14).

$$\mathrm{KPI_{GP2}} = \frac{\text{Quantity of paper used (kg)}}{\text{No. of students}} \tag{A13}$$

$$\mathrm{KPI_{GP3}} = \frac{\text{Quantity of recycled paper used (kg)}}{\text{Quantity of paper used (kg)}} \tag{A14}$$

KPI-GP4, associated with training in green procurement, is defined according to Eq. (A15).

$$\mathrm{KPI_{GP4}} = \frac{\text{No. staff with training in GP}}{\text{Total no. of staff}} \tag{A15}$$

KPI-GP5, related to eco-driving certification, is defined according to Eq. (A16).

$$\mathrm{KPI_{GP5}} = \frac{\text{No. staff with eco} - \text{driving certificates}}{\text{Total no. of staff}} \tag{A16}$$

KPI-GP6, associated with organic food, is defined according to Eq. (A17).

$$KPI_{GP6} = \frac{\text{Quantity of food with biological certificate (kg)}}{\text{Quantity of food (kg)}} \tag{A17}$$

KPI-GP7, about school suppliers, is defined according to Eq. (A18).

$$KPI_{GP7} = \frac{\text{No. of local suppliers}}{\text{Total no. of suppliers}} \tag{A18}$$

Once all KPIs are calculated, the final score to evaluate the school's performance regarding the green procurement sector is calculated according to Eq. (A19).

$$Green\ procurement_{score} = \frac{5\ KPI_{GP1} + GP_1 + 5\ KPI_{GP3} + 0.25 \cdot 5\ (GP_2)}{4} \tag{A19}$$

where GP_1, and GP_2 are calculated according to Eq. (A20) and Eq. (A21), respectively.

$$GP_1 = 5 - \frac{KPI_{T2} \times 5}{\max\ (KPI_{T2})} \tag{A20}$$

$$GP_2 = KPI_{GP4} + KPI_{GP5} + 5KPI_{GP6} + 5KPI_{GP7} \tag{A21}$$

where $\max\ (KPI_n)$ maximum value obtained among all schools evaluated.

A3. Green spaces

The green spaces are characterised by seven KPIs divided into four areas: green areas, CO_2 sequestration, use of chemists and CO_2 emissions. They are summarised in Table A4 and further detailed below.

Table A4
Characterisation areas and KPIs of green spaces.

Green spaces areas	Key Performance Indicators	Data source
Green areas	KPI-GS1. Number of trees per non-covered area (trees/m^2)	Check-list sheet
	KPI-GS2. Number of trees per student (trees/student)	Check-list sheet
	KPI-GS3. Green area per non-covered area (%)	Check-list sheet
	KPI-GS4. Green area per student (m^2/student)	Check-list sheet
CO_2 sequestration	KPI-GS5. Annual CO_2 sank per non-covered area ($kgCO_2/m^2$)	Check-list sheet
Use of chemists	KPI-GS6. Annual kg of chemists used for green area maintenance (kg/m^2)	Check-list sheet
CO_2 emissions	KPI-GS7. Annual CO_2 emissions related to space maintenance per non-covered area ($kgCO_{2\ eq}/m^2$)	Check-list sheet

KPI-GS1, KPI-GS2, KPI-GS3 and KPI-GS4, associated with green areas, are characterised according to Eq. (A22), Eq. (A23), Eq. (A24) and Eq. (A25), respectively.

$$KPI_{GS1} = \frac{\text{No. of trees}}{\text{Non} - \text{covered area } (m^2)} \tag{A22}$$

$$KPI_{GS2} = \frac{\text{No. of trees}}{\text{No. of students}} \tag{A23}$$

$$KPI_{GS3} = \frac{\text{Green area } (m^2)}{\text{Non} - \text{covered area } (m^2)} \tag{A24}$$

$$KPI_{GS4} = \frac{\text{Green area } (m^2)}{\text{No. of students}} \tag{A25}$$

KPI-GS5, related to CO_2 sequestration, is characterised, according to Eq. (A26).

$$KPI_{GS5} = \frac{\text{No. of trees} \times SR_{\text{dominant species}} + Area_{lawn} \times SR_{\text{lawn}}}{\text{non} - \text{covered area } (m^2)} \tag{A26}$$

where SR: sequestration rate attributed to each specie, defined in Table A5.

KPI-GS6, about use of chemists, is characterised, according to Eq. (A27).

$$KPI_{GS6} = \frac{\text{Quantity of fertilisers and pesticides (kg)}}{\text{Green area } (m^2)} \tag{A27}$$

KPI-GS7, related to CO_2 emissions, is characterised, according to Eq. (A28).

$$KPI_{GS7} = \frac{\text{Fuel}\cdot FE_{fuel} + \text{Water}\cdot FE_{water} + \text{Electicity}\cdot FE_{electricity}}{\text{Non}-\text{covered area } (m^2)} \quad (A28)$$

where FE_i CO_2 emission factor, defined in Table A6.

Table A5
CO_2 sequestration rate (SR) attributed to each specie (Chaparro and Terradas, 2009; Hamido et al., 2016; MAPAMA, 2016; Qian et al., 2010; Selhorst and Lal, 2013).

CO_2 sequestration rate per specie							
Turfgrass/lawn[a]	0.78	Citrus limon	1.77	Quercus suber	3.71	Sambucus nigra	6.60
Butia capitata	0.02	Quercus coccifera	1.87	Maclura pomifera	3.71	Erica arborea	6.67
Cordyline sp,	0.02	Ulmus glabra	1.90	Prunus cerasifera	3.87	Laurus nobilis	6.67
Musa paradisiaca	0.02	Thuja occidentalis	1.97	Citrus aurantium	3.90	Rhamnus alaternus	6.67
Yucca aloifolia	0.09	Koelreuteria paniculata	2.07	Euonymus japonica	3.90	Robinia pseudoacacia	6.67
Chamaerops humilis	0.10	Tilia euchlora	2.15	*Parkinsonia aculeata*	3.97	Jacaranda mimosifolia	6.90
Phoenix reclinata	0.18	Cistus albidus	2.20	Calocedrus decurrens	4.20	Melia azedarach	7.01
Phoenix canariensis	0.19	Arbutus unedo	2.23	Acacia retinodes	4.21	Tipuana tipu	7.43
Washingtonia robusta	0.23	Prunus domestica	2.25	Catalpa bignonioides	4.23	Tilia europaea	7.67
Washingtonia filifera	0.28	Prunus dulcis	2.34	Yucca guatemalensis	4.35	Quercus cerrioides	7.81
Bupleurum fruticosum	0.39	Quercus ilex	2.40	Cedrus deodara	4.58	Casuarina sp,	7.93
Magnolia macrophylla	0.50	Alnus glutinosa	2.43	Eriobotrya japonica	4.58	Acacia saligna	8.23
Juniperus communis	0.56	Olea europaea	2.46	*Pinus pinaster*	4.61	Gleditsia triacanthos	8.65
Crataegus monogyna	0.58	Taxus baccata	2.49	Cedrus atlantica	4.72	Acer platanoides	8.72
Juniperus oxycedrus	0.60	Ginkgo biloba	2.51	Fraxinus ornus	4.77	Tilia platyphyllos	8.85
Juglans nigra	0.78	Punica granatum	2.52	Schinus molle	4.98	Tilia tomentosa	9.49
Bougainvillea glabra	0.81	Pistacia lentiscus	2.61	Coriaria myrtifolia	5.02	Morus alba	9.64
Juniperus phoenica	0.81	Ficus carica	2.69	Pinus pinea	5.03	Populus canadensis	9.90
Schinus polygamus	0.81	Pyracantha angustifolia	2.71	Acer negundo	5.18	Salix alba	9.93
Ligustrum japonicum	0.84	Pinus halepensis	2.74	Quercus pubescens	5.29	Platanus acerifolia	10.82
Albizia julibrissin	0.87	Mespilus germanica	2.86	Bauhinia forficata	5.37	*Casuarina cunninghamiana*	11.07
Viburnum tinus	0.92	Nerium oleander	2.98	Magnolia grandiflora	5.41	Broussonetia papyrifera	11.38
Spartium junceum	0.97	Pittosporum tobira	3.01	Ulmus pumila	5.42	Phytolacca dioica	12.59
Prunus americana	0.98	Ficus elastic	3.04	*Casuarina equisetifolia*	5.55	Aloe arborescens	12.81
Rosmarinus officinalis	1.15	Phillyrea latifolia	3.06	Populus simonii	5.59	Cocculus laurifolius	13.11
Rhamnus sp,	1.31	Ligustrum vulgare	3.07	Erythrina crista-galli	5.61	Phoenix dactylifera	15.72
Buxus sempervirens	1.36	Ceratonia silique	3.10	Sophora japonica	5.65	Populus alba	21.81
Ligustrum ovalifolium	1.43	Abies alba	3.18	Ulmus minor	5.72	Populus alba	21.81
Ficus benjamina	1.44	Wisteria sinensis	3.18	Corynocarpus laevigatus	5.73	Celtis australis	33.06
Pyrus communis	1.46	Brugmansia Spp,	3.35	Acer pseudoplatanus	5.75	Pinus radiata	36.43
Crataegus laevigata	1.52	Acacia dealbata	3.42	Brachychiton populneum	5.76	*Eucalyptus camaldulensis*	52.89
Ailanthus altissima	1.53	Ligustrum lucidum	3.42	Prunus cerasifera	5.80	Eucalyptus globulus	71.89
Prunus avium	1.57	Cercis siliquastrum	3.46	Celtis occidentalis	5.99		
Cupressus macrocarpa	1.60	Fraxinus angustifolia	3.50	Fraxinus excelsior	6.01		
Elaeagnus angustifolia	1.69	Firmiana simplex	3.57	Tamarix gallica	6.14		

Values in kg CO_2/tree per year, except [a], which is in kg CO_2seq/m^2 per year.

Table A6
CO_2 emission factors associated with petrol, water and energy consumption for green spaces maintenance (Myhre et al., 2013; U.S. Environmental Protection Agency (EPA), 2010; Wernet et al., 2016; Winther, 2010; Winther and Nielsen, 2006). *Factors calculated using the Life Cycle Assessment (LCA) methodology* (ISO, 2006a; 2006b), *based on recognised life cycle inventories Ecoinvent database* (Wernet et al., 2016) *and IPCC reference method of characterisation* (Myhre et al., 2013).

Country	Water (kgCO$_2$ $_{eq}$/L)			Energy (kg CO$_2$ $_{eq}$/kWh)	Fuel (kgCO$_2$ $_{eq}$/L)
	Tap water	Rainwater	Well water		
Portugal	1.74E-04	7.28E-06	1.76E-04	4.20E-01	2.87
Spain	1.64E-04		1.46E-04	3.96E-01	
France	4.94E-05		2.89E-05	5.95E-02	
Gilbraltar	6.35E-03			1.00 E+00	

Once all KPIs are calculated, the final score to evaluate the schools' performance regarding the green spaces is calculated according to Eq. (A29).

$$Green\ spaces_{score} = \frac{(GS_1)/2 + GS_2 + GS_3 + GS_4}{4} \quad (A29)$$

where GS_1, GS_2, GS_3 and GS_4 are calculated according to Eq. (A30), Eq. (A31), Eq. (A32) and Eq. (A33), respectively.

$$GS_1 = \frac{5\ KPI_{GS1}}{1.05\cdot \max\ (KPI_{GS1})} + \frac{5\ KPI_{GS3}}{1.05\cdot \max\ (KPI_{GS3})} \quad (A30)$$

$$GS_2 = \frac{5\ KPI_{GS5}}{1.05\cdot \max\ (KPI_{GS5})} \quad (A31)$$

$$GS_3 = 5 - \frac{5\ KPI_{GS6}}{\max\ (KPI_{GS6})} \quad (A32)$$

$$GS_4 = 5 - \frac{5\ KPI_{GS7}}{\max\ (KPI_{GS7})} \quad (A33)$$

where max (KPI_n) maximum value obtained among all schools evaluated.

A4. Indoor air quality

The IAQ sector is characterised by four KPIs divided into three areas: air pollutants concentration, ventilation and thermal comfort. They are summarised in Table A7 and further detailed below.

Table A7
Characterisation areas and KPIs of IAQ sector.

IAQ areas	Key Performance Indicators	Data source
Air pollutants concentration	KPI-IAQ1. Air pollutants exceeding the indoor air guideline value (%)	On-site measurements
Ventilation	KPI-IAQ2. CO_2 concentrations between 1000 and 1700 ppm (%)	On-site measurements
	KPI-IAQ3. CO_2 concentrations over 1700 ppm during the occupancy (%)	On-site measurements
Thermal comfort	KPI-IAQ4. Temperature between 20° and 26° during occupancy (%)	On-site measurements

KPI-IAQ1, about air pollutants concentrations, is calculated according to Eq. (A34). The air pollutants evaluated are PM_{10} (mg/m^3), $PM_{2.5}$ (mg/m^3), CO_2 (ppm), CO (ppm), a group of aldehydes (mg/m^3) and a group of VOCs (mg/m^3), and the on-site measurement procedure of air pollutants in schools is defined in Supplementary material 2.

$$\mathrm{KPI}_{\mathrm{IAQ1}} = \frac{\text{No. of air pollutants exceeding the guideline}}{\text{Total no. of air pollutants evaluated}} \tag{A34}$$

KPI-IAQ2 and KPI-IAQ3, associated with ventilation, are characterised according to Eq. (A35) and Eq. (A36), respectively.

$$\mathrm{KPI}_{\mathrm{IAQ2}} = \frac{\mathrm{CO_2}\ \text{concentration between } 1000 - 1700 \text{ ppm (time)}}{\text{Occupancy period (time)}} \tag{A35}$$

$$\mathrm{KPI}_{\mathrm{IAQ3}} = \frac{\mathrm{CO_2}\ \text{concentration over } 1700 \text{ ppm (time)}}{\text{Occupancy period (time)}} \tag{A36}$$

KPI-IAQ4, related to thermal comfort, is characterised according to Eq. (A37). It shows the percentage of time in which temperatures lie in the range from 20 °C to 26 °C during the occupancy period, corresponding to a class-2 comfort according to the EN 15251 standard (European Committe for Standardization, 2007).

$$\mathrm{KPI}_{\mathrm{IAQ4}} = \frac{\text{Period between } 20^\circ\text{C and } 26^\circ\text{C (time)}}{\text{Occupancy period (time)}} \tag{A37}$$

Once all KPIs are calculated, the final score to evaluate the schools' performance regarding the IAQ is calculated according to Eq. (A38).

$$IAQ_{score} = \frac{(5 - 5\mathrm{KPI}_{\mathrm{IAQ1}}) + 5\mathrm{KPI}_{\mathrm{IAQ4}} + \left[5 - \left(\frac{2.5}{log_{10}(2)}\right) log_{10}(1 + \mathrm{KPI}_{\mathrm{IAQ2}} + 3\mathrm{KPI}_{\mathrm{IAQ3}})\right]}{3} \tag{A38}$$

Where KPI-IAQ2 and KPI-IAQ3, associated with ventilation, are considered taking as reference the criteria developed by the French National Observatory of IAQ to assess IAQ (actually stuffiness) in schools: the ICONE index (Décret no 2011-1728, 2011; Décret no 2012-14, 2012; Riberon et al., 2011). The ICONE index for "IAQ" is characterised by three classes of CO_2 concentrations, namely, $CO_2 < 1000$ ppm (class 0), $1000 < CO_2 < 1700$ ppm (class 1) and $CO_2 > 1700$ ppm (class 2). Therefore, the ICONE index considers a Fechner-type law expressing that the perceived odour intensity does not vary linearly with concentration but in a logarithmic way, as shown in Eq. (A39)

$$N = \alpha \log_{10}(c_0 f_0 + c_1 f_1 + c_2 f_2) \tag{A39}$$

With f0, f1 and f2 being the percentage of measurements where the CO_2 concentrations are in class 0, 1 and 2 during the occupancy period, respectively. Therefore, their values corresponded to all measured period, as shown in Eq. (A40):

$$f_0 + f_1 + f_2 = 1 \tag{A40}$$

Then, by defining a scale ranging from 0 to 5 for IAQ (N = ICONE index), and making the following assumptions:

ICONE = 0 if all concentrations are in class 0 (below 1000 ppm);

ICONE = 5 if all concentrations are in class 2 (above 1700 ppm);

A value of 2.5 either corresponds to 100% of values in class 1 or 1/3 of concentrations in class 2 and 2/3 in class 1 (which means that class 2 wt 3 times more than class 1). Thus, Eq. (A39) and Eq. (A40) return the following final expression Eq. (A41), where the ICONE index ranges from 0 (best air quality, with all concentrations below 1000 ppm) to 5 (worst indoor air quality, with all measured concentrations over 1700 ppm during the occupancy period). This expression was considered for the ventilation rating in IAQ score.

$$N = \left(\frac{2.5}{log_{10}(2)}\right) log_{10}(1 + f_1 + 3f_2) \tag{A41}$$

A5. Energy

The energy sector is characterised by six KPIs divided into four areas: energy consumption, use of renewable energy, energy cost and CO_2

emissions. They are summarised in Table A8 and further detailed below.

Table A8
Characterisation areas and KPIs of energy.

Green spaces areas	Key Performance Indicators	Data source
Energy consumption	KPI-E1. Annual final energy consumption per area (kWh/m^2)	Technical audits
	KPI-E2. Annual final energy consumption per student (kWh/student)	Technical audits
Use of renewable energy	KPI-E3. Renewables energy production (%)	Technical audits
Energy cost	KPI-E4. Annual energy cost per area (€/m^2)	Technical audits
	KPI-E5. Annual energy cost per student (€/student)	Technical audits
CO_2 emissions	KPI-E6. Annual associated CO_2 emissions per student (kg$CO_{2\ eq}$/student)	Internal calculation

KPI-E1 and KPI-E2, associated with energy consumption, are characterised according to Eq. (A42) and Eq. (A43), respectively.

$$\mathrm{KPI_{E1}} = \frac{\sum_i \mathrm{Electricity}_i + \sum_j \left(\mathrm{Fuel}_j \cdot \mathrm{Density}_j \times \mathrm{FC}_j\right)}{\mathrm{Useful\ area\ of\ school\ (m^2)}} \tag{A42}$$

$$\mathrm{KPI_{E2}} = \frac{\sum_i \mathrm{Electricity}_i + \sum_j \left(\mathrm{Fuel}_j \cdot \mathrm{Density}_j \times \mathrm{FC}_j\right)}{\mathrm{No.\ of\ students}} \tag{A43}$$

where i: type of electricity (provided by the grid or produced on-site); *j*: type of fuel (diesel, LPG or natural gas); FC_j: conversion factor to kWh of fuel *j*.

KPI-E3, related to the use of renewable energy, is defined according to Eq. (A44).

$$\mathrm{KPI_{E3}} = \frac{\mathrm{On-site\ renewable\ consumed + On-site\ renewable\ sold\ to\ grid}}{\sum_i \mathrm{Eletricity}_i + \sum_j \left(\mathrm{Fuel}_j \times \mathrm{Density}_j \times \mathrm{FC}_j\right)} \tag{A44}$$

where *i*: type of electricity (provide by the grid or on-site produced); *j*: type of fuel (diesel, LPG or natural gas); FC_j: conversion factor to kWh of fuel *j*.

KPI-E4 and KPI-E5, associated with energy cost, are characterised according to Eq. (A45) and Eq. (A46), respectively.

$$\mathrm{KPI_{E4}} = \frac{\mathrm{Annual\ energy\ cost\ (€)}}{\mathrm{Useful\ area\ of\ school\ (m^2)}} \tag{A45}$$

$$\mathrm{KPI_{E5}} = \frac{\mathrm{Annual\ energy\ cost\ (€)}}{\mathrm{No.\ of\ students}} \tag{A46}$$

KPI-E6, related to CO_2 emissions, is defined according to Eq. (A47).

$$\mathrm{KPI_{E6}} = \frac{(\mathrm{Electricity} - \mathrm{REP \cdot GL}) \cdot \mathrm{FE}_e + \sum_i \left(\mathrm{Fuel}_{\ i} \times \mathrm{Density}_i \times \mathrm{FC}_i\right) \times \mathrm{FE}_i)}{\mathrm{No.\ of\ students}} \tag{A47}$$

where *i*: type of fuel (diesel, LPG or natural gas); FC_i: conversion factor to kWh of fuel *j*; FE_e: CO_{2eq} emissions coefficient associated with the final energy consumption of electricity, according to Table A9; FE_i: CO_{2eq} emissions coefficient associated with the fuel i, according to Table A9; REP: Renewable electrical production; GL: Grid losses, 7%.

Table A9
CO_2 emission coefficients per energy source for SUDOE area.

Location	Energy source	CO_2 emissions coefficient (kg $CO_{2\ eq}$/kWh)	Data source
Spain	Electricity from the national grid	0.396	i
France	Electricity from the national grid	0.059	i
Gibraltar	Electricity from the national grid	1.002	i
Portugal	Electricity from the national grid	0.420	i
All locations	Diesel oil	0.311	i
	LPG	0.254	i
	Natural gas	0.239	i
	Biomass	0.018	ii
	Biomass (pellets)	0.044	i

i: CO_{2eq} emissions coefficients have been obtained using IPCC method (Myhre et al., 2013)*, where the electricity emission coefficient per national grid has been calculated using data of the electricity generation energy mix per country* (Government of Gibraltar, 2014; MINETUR, 2016; Red Eléctrica, 2016; Redes Energéticas Nacionais, 2016, 2015; Réseau de transport d'électricité, 2016)*, and the electricity production process from Ecoinvent database* (Wernet et al., 2016).
Ii: Biomass factor is the same defined for Spanish energy performance certificates (EPCs) derived from the EPBD requirements and the CEN standards (IDAE, 2014).

Once all KPIs are calculated, the final score to evaluate the school's performance regarding the energy sector is calculated according to Eq. (A48).

$$Energy_{score} = \frac{E_1 + E_2 + E_3 + E_4}{4} \tag{A48}$$

where E_1, E_2, E_2 and E_2 are calculated according to Eq. (A49), Eq. (A50), Eq. (A51) and Eq. (A52), respectively.

$$E_1 = \left[\frac{5(\max(KPI_{E1}) - KPI_{E1})}{\max(KPI_{E1}) - \min(KPI_{E1})\cdot 0.95} + \frac{5(\max(KPI_{E2}) - KPI_{E2})}{\max(KPI_{E2}) - \min(KPI_{E2})\cdot 0.95}\right] \Big/ 2 \quad \text{(A49)}$$

$$E_2 = 5\ KPI_{E3} \quad \text{(A50)}$$

$$E_3 = \left[\frac{5(\max(KPI_{E4}) - KPI_{E4})}{\max(KPI_{E4}) - \min(KPI_{E4})\cdot 0.95} + \frac{5(\max(KPI_{E5}) - KPI_{E5})}{\max(KPI_{E5}) - \min(KPI_{E5})\cdot 0.95}\right] \Big/ 2 \quad \text{(A51)}$$

$$E_4 = \frac{5(\max(KPI_{E6}) - KPI_{E6})}{\max(KPI_{E6}) - \min(KPI_{E6})\cdot 0.95} \quad \text{(A52)}$$

where $\max(KPI_n)$ maximum value obtained among all schools evaluated.

A6. Water

The water sector is characterised by four KPIs divided into two areas: water consumption and water cost. They are summarised in Table A10 and further detailed below.

Table A10
Characterisation areas and KPIs of IAQ sector.

Water areas	Key Performance Indicators	Data source
Water consumption	KPI-Wr1. Annual water consumption per area (m^3/m^2)	Technical audits
	KPI-Wr2. Annual water consumption per student (m^3/student)	Technical audits
Water cost	KPI-Wr3. Annual water cost per area (€/m^2)	Technical audits
	KPI-Wr4. Annual water cost per student (€/student)	Technical audits

KPI-Wr1 and KPI-Wr2, associated with water consumption, are characterised according to Eq. (A53) and Eq. (A54), respectively.

$$KPI_{Wr1} = \frac{\text{Annual water consumption } (m^3)}{\text{Useful area of school } (m^2)} \quad \text{(A53)}$$

$$KPI_{Wr2} = \frac{\text{Annual water consumption } (m^3)}{\text{No. of students}} \quad \text{(A54)}$$

KPI-Wr3 and KPI-Wr4, related to water cost, are characterised according to Eq. (A55) and Eq. (A56), respectively.

$$KPI_{Wr3} = \frac{\text{Annual water cost } (€)}{\text{Useful area of school } (m^2)} \quad \text{(A55)}$$

$$KPI_{Wr4} = \frac{\text{Annual water cost } (€)}{\text{No. of students}} \quad \text{(A56)}$$

Once all KPIs are calculated, the final score to evaluate the school's performance regarding the water sector is calculated according to Eq. (A57).

$$Water_{score} = \frac{Wr_1 + Wr_2}{4} \quad \text{(A57)}$$

where Wr_1, and Wr_2 are calculated according to Eq. (A58) and Eq. (A59), respectively.

$$Wr_1 = \frac{5(\max(KPI_{Wr1}) - KPI_{Wr1})}{\max(KPI_{Wr1}) - \min(KPI_{Wr1})\cdot 0.95} + \frac{5(\max(KPI_{Wr2}) - KPI_{Wr2})}{\max(KPI_{Wr2}) - \min(KPI_{Wr2})\cdot 0.95} \quad \text{(A58)}$$

$$Wr_2 = \frac{5(\max(KPI_{Wr3}) - KPI_{Wr3})}{\max(KPI_{Wr3}) - \min(KPI_{Wr3})\cdot 0.95} + \frac{5(\max(KPI_{Wr4}) - KPI_{Wr4})}{\max(KPI_{Wr4}) - \min(KPI_{Wr4})\cdot 0.95} \quad \text{(A59)}$$

where $\max(KPI_n)$ maximum value obtained among all schools evaluated.

A7. Waste

The waste sector is characterised by three KPIs divided into three areas: waste produced, waste recycled, and waste reused. They are summarised in Table A11 and further detailed below.

Table A11
Characterisation areas and KPIs of waste.

Waste areas	Key Performance Indicators	Data source
Waste produced	KPI-Ws1. Weekly waste production per student (m^3/student)	Technical audits
Waste recycled	KPI-Ws2. Weekly waste recycled per student (m^3/student)	Technical audits
Waste reused	KPI-Ws3. Weekly waste reused per student (m^3/student)	Technical audits

KPI-Ws1, associated with waste produced, is calculated according to Eq. (A60).

$$\mathrm{KPI_{Ws1}} = \frac{\text{Weekly production of USW } (m^3)}{\text{No. of students}} \tag{A60}$$

where USW: urban solid waste.

KPI-Ws2, related to recycled waste, is calculated according to Eq. (A61).

$$\mathrm{KPI_{Ws2}} = \frac{\text{Weekly production of recycled waste } (m^3)}{\text{No. of students}} \tag{A61}$$

KPI-Ws3, associated with reused waste, is calculated according to Eq. (A62).

$$\mathrm{KPI_{Ws3}} = \frac{\text{Weekly production of reusable waste } (m^3)}{\text{No. of students}} \tag{A62}$$

Once all KPIs are calculated, the final score to evaluate the school's performance regarding the waste sector is calculated according to Eq. (A63).

$$Waste_{score} = \frac{2Ws_1 + Ws_2 + Ws_3}{4} \tag{A63}$$

where Ws_1, Ws_2 and Wr_3 are calculated according to Eq. (A64), Eq. (A65) and Eq. (A66), respectively.

$$Ws_1 = \frac{5(\max(\mathrm{KPI_{Ws1}}) - \mathrm{KPI_{Ws1}})}{\max(\mathrm{KPI_{Ws1}}) - \min(\mathrm{KPI_{Ws1}})\cdot 0.95} \tag{A64}$$

$$Ws_2 = \frac{5\ \mathrm{KPI_{Ws2}}}{\max(\mathrm{KPI_{Ws2}})\cdot 1.05} \tag{A65}$$

$$Ws_3 = \frac{5\ \mathrm{KPI_{Ws3}}}{\max(\mathrm{KPI_{Ws3}})\cdot 1.05} \tag{A66}$$

where $\max(\mathrm{KPI}_n)$ maximum value obtained among all schools evaluated.

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