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Performance based core sustainability metrics for university campuses developing towards climate neutrality: A robust PICSOU framework

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ABSTRACT

Despite the global interest, the sustainable development of universities remains commonly unmonitored as existing tools are either overly complicated or less specific for university campuses. Evaluation of existing tools motivated this study to focus on measuring sustainability performance of university campuses. By concentrating on factors having the most prominent impact on buildings' and activities' greenhouse gas (GHG) emissions and social performance, PICSOU (Performance Indicators for Core Sustainability Objectives of Universities), a six-category framework with about 20 key performance indicators (KPIs) was identified to monitor more than 80% of Scope 2 or/and Scope 3 carbon footprint of a university campus and enables relatively easy cost-benefit analysis of potential improvements. Proposed categories and KPIs are general, but the improvement measures can always have a local origin. To test the framework, a case study was conducted and findings include discovery of lowutilization spaces, potential parking footprint reduction, co-benefits exceeding energy savings in renovation and an annual carbon footprint of 1.3 tCO2eq per university population. This study showcases the latest endeavor in identifying a simple and robust framework containing universally measurable indicators that are easily compatible with different campuses and can enable the timely and accurate measuring of university campus sustainability

1. Introduction

1.1. A university campus' role in sustainable development

It is safe to presume that the consequences and costs of climate change on our world will define the 21st century (Koubi, 2019), especially given the latest unsettling geopolitical predicaments amidst an ongoing global pandemic, one imposing great setback on many already belated and under-implemented climate change mitigation agendas. The key to altering climate change is to reach net zero carbon emissions, and the building sector has long been a major area of focus for achieving such goal, thanks to its 40% share of total energy use and GHG emissions (Pérez-Lombard et al., 2008) resulting from electricity and heat production by fossil fuel, as we spend on average 90% of our time indoors (Klepeis et al., 2001). With their diverse function and scale, universities can be considered small communities, providing relatively easy access to data at both the stand-alone buildings' level and the community level, contributing to global sustainability through their education, research and the operation of their own estate (Gu et al., 2019). For such reason, there has been a global trend to develop assessment tool for university campus sustainability based on a principle known as the 3Ps (three pinciples: social, environmental, social, and economic), which reflects that responsible development requires taking into consideration the natural, human, and economic capital (Elkington & Berkovics, 1997) (Kajikawa, 2008) (Schoolman et al., 2012) while fulfilling the objectives set forward by the UN's 17 Sustainable Development Goals (SDGs). 1.2 Problems with existing assessment tools for university campus sustainability

1.2.1. Green building standards

Sustainable buildings have been widely acknowledged as an integral part of the solution to the environmental challenges; such topic has also become the impetus behind the development and application of scientific tools for the sustainable design, construction and operation of buildings. Among them, popular rating systems such as BREEAM (Building Research Establishment Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design) are appropriate examples of comprehensive technical standards for energy

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efficient and environmentally friendly buildings known as the green buildings. However, there is a dearth of information and insight on the relationship between the assessment criteria of green building rating systems and the UN SDGs (Alawneh et al., 2019) and a green building does not always use less energy (Newsham et al., 2009) (Scofield, 2009), a previous study on a major university campus in the US suggested no clear trends in energy savings of LEED-certified buildings was observed either at individual building or portfolio level (Agdas et al., 2015). While the argument on the suitability of using green building standards interchangeably as the measuring tool for university campus mostly focuses on the technical aspect, we found the statistics of university projects certified under BREEAM and LEED more objective and forthright indicative.

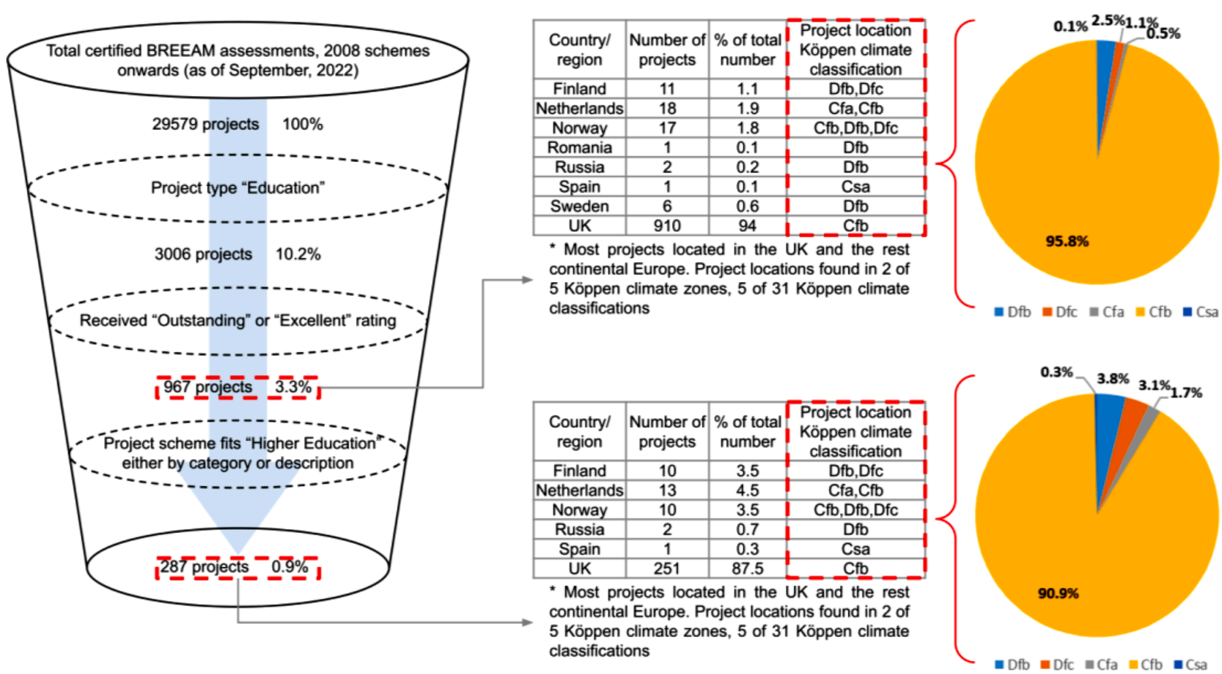
1.2.1.1. BREEAM. Developed by BRE (the Building Research Establishment) in 1990, BREEAM is the first green building rating system in the world, and continues to be one of the world's most influential green building rating systems with more than 2.3 million registered buildings in 93 countries (BREEAM, 2022). Using third-party-certified standards, BREEAM can assess any type of building based on 10 credit categories each having certain number of points based on the category's importance: energy, management, health and wellbeing, transport, water consumption and efficiency, materials, waste, pollution, land use and ecology, innovation. Based on the percentage of final score over total score, a BREEAM project can receive different certification level raging from the lowest "Pass" (>=30%) to middle levels like "Good" (>=45%), "Very Good" (>=55%), "Excellent" (>=70%), to the highest "Outstanding" (>=85%). To observe the most representative BREEAM-certified university buildings, we applied series of filters to BRE's project database and came up with the following observation:

To exclude obsolete projects, the superset consists of only 29,579 projects certified using BREEAM's 2008 schemes and onwards (as of September 2022), of which, 3006 falls under the project type of "Education". Considering "energy" and "health and wellbeing" are the two BREEAM credit categories with the highest points and account for more than 35% of total scores, it is impossible for projects receiving "Excellent" or "Outstanding" level certification to score poorly under these two categories, which also contribute directly to a building's carbon footprint (it is only possible to observe a project's total percentage of score without a categorical break-down). After applying the certification level filter, we were left with 967 projects. To decide which of these projects are university projects, we manually screened each project based on project scheme (for projects located in the UK certified using the BREEAM UK standards) or project description (for international projects using the BREEAM International standards or country-specific standards in countries where a national scheme operator is available), and ended up with 267 projects. These projects are considered good examples of sustainable university campus building, but they tend to over concentrate in the UK with only a dozen more projects found in other European countries, covering a limited fraction in the total climate classifications (see Fig. 1).

To conclude the above observation, though globally recognized as a comprehensive rating system with rigorous score criteria, when BREEAM is used to certify university buildings, apart from the dominant number of successful cases in the UK, the sample size outside the UK is still rather small and inexhaustive of climate classifications, an evident indicator for insufficient universality.

1.2.1.2. LEED. Inspired by, and based on BREEAM, LEED is known as the world's most widely used rating system for green buildings (U.S. Green Building Council, 2022) with more than 900 million m^2 of certified area in over 190 countries/regions, it is a third-party-verification green building rating system developed and managed by USGBC, (the U.S. Green Building Council) whose rating scheme covers all building types, including new construction, existing buildings, homes and communities. LEED has 9 areas of focus, including location and transportation, sustainable sites, water efficiency, energy and atmosphere, material and resources, indoor environmental quality, innovation, regional priority, and integrative process. Based on the total performance score from these 9 areas, a building can receive one of the four certification levels including certified, silver, gold, and platinum. Despite its evident popularity and rapid market growth, the use of LEED in assessing university campus sustainability has not been on par. We applied series of screening filters in USGBC's project directory and came up with the following observation:

Of all 173,189 registered LEED projects (as of September 2022), 139,794 projects' information is non-confidential and can be publicly accessed, of which, only 2800 are projects matching the LEED project



Country/ region	Number of projects	% of total number	Project location Köppen climate classification
Finland	11	1.1	Dfb,Dfc
Netherlands	18	1.9	Cfa,Cfb
Norway	17	1.8	Cfb,Dfb,Dfc
Romania	1	0.1	Dfb
Russia	2	0.2	Dfb
Spain	1	0.1	Csa
Sweden	6	0.6	Dfb
UK	910	94	Cfb

Country/ region	Number of projects	% of total number	Project location Köppen climate classification
Finland	10	3.5	Dfb,Dfc
Netherlands	13	4.5	Cfa,Cfb
Norway	10	3.5	Cfb,Dfb,Dfc
Russia	2	0.7	Dfb
Spain	1	0.3	Csa
UK	251	87.5	Cfb

Fig. 1. Screening of BREEAM projects and analysis of key projects' distribution of locations and Köppen climate classifications.

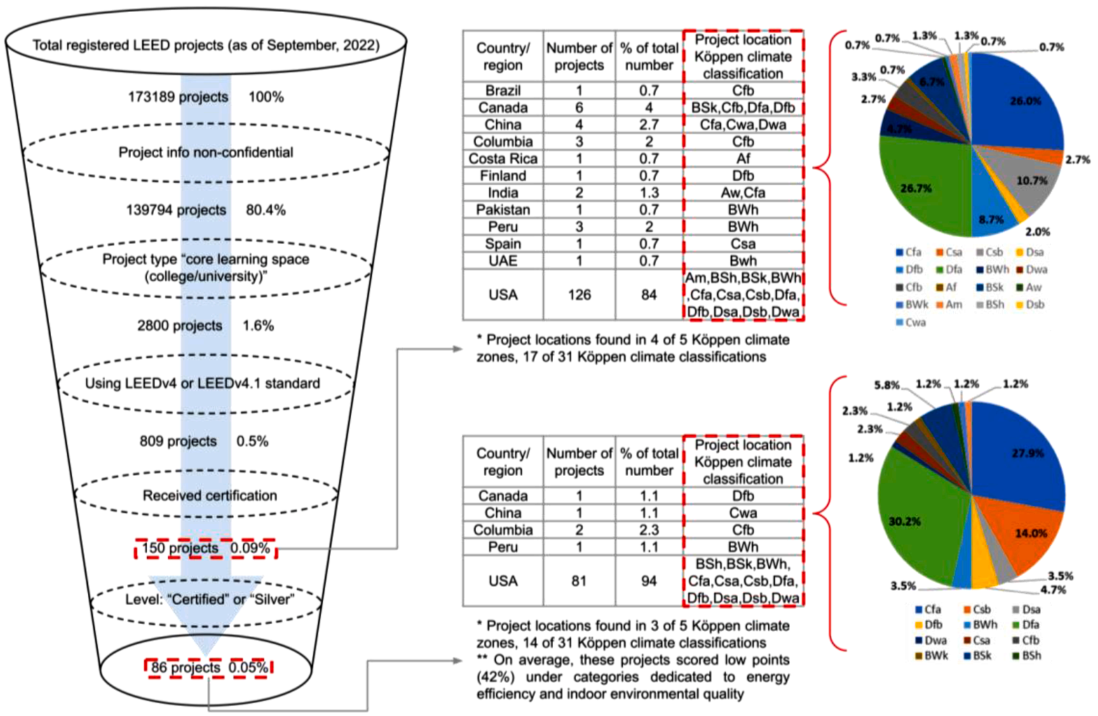


Fig. 2. Screening of LEED projects and analysis of key projects' distribution of locations and Köppen climate classifications.

type of "core learning space: college/university". Since LEED has been continuously updating its reference guide to keep up with the latest technical requirement, LEEDv4 and LEEDv4.1 are the latest version while all preceding versions have phased out by the end of 2016. Of all 2800 LEED projects under the "college/university" project type, only 809 projects from 29 countries/regions registered between 2009 and 2022 are evaluated using the latest version of LEEDv4 or LEEDv4.1, of which, 390 projects have failed to receive certification within their project's two-year validity of registration, only 150 have been successfully certified. Of the 150 certified projects, more than half (86) received the lower-tier certification of "Certified" or "Silver", of which, as many as 81 are located in the US (see Fig. 2). Among these 86 projects, their average total score from both the Energy and Atmosphere (EA) category and the Indoor Environmental Quality (EQ) category is 21 points - around 42% of the total available points from these two categories (49 or 55 points depending on the rating system). We also noticed several extreme cases, in which, a project with very low score from the EA and EQ categories (7 points in total) received "Certified" level certification; a few projects with "Certified" level certification have higher total points from EA and EQ than many of their "Silver" level certified counterparts, yet because they did not score as many points from other categories, they received overall lower scores and thus lower certification level, and are considered less "green" in the real estate market.

Based on the above observation, we were able to conclude that LEED's latest standards have become less popular among university campuses both in terms of total registered projects and total certified projects. The certified university projects, which are otherwise looked up as good examples of sustainable university campus building, tend to over concentrate in the US with the majority achieving only the lowest certification requirements, whose points mainly come from categories not directly (if at all) contributing to carbon footprint reduction, which can be very misleading in reflecting a building's actual level of sustainability. This further jeopardizes LEED's universality and compatibility with university campuses located in different climate zones.

1.2.2. Sustainable campus rating systems

Over the past 20 years, university rankings, allowing to classify and compare the energy and environmental performance of university buildings and campus, have become more and more widespread and their diffusion is still increasing by means of referred established models (Marrone et al., 2018) with typical examples like the Nixon's Campus Sustainability Assessment Review Project in 2002 (Nixon, 2002), which includes reporting and questionnaires limited to the internal recognition of impact on environmental and self-assessment by an individual campus, and therefore could not be used to make the comparison among different universities (Shuqin et al., 2019). Some other indices evaluation systems, such as the Campus Sustainability Selected Indicators Snapshot and Guide by Shriberg mainly focus on the operational eco-efficiency, and give a quick overview of campus operations and environmental influences (Shriberg, 2002). GREENSHIP contains 6 categories: appropriate site development, energy efficiency and conservation, water conservation, material resources and cycle, indoor health and comfort, and building environment management (Lauder et al., Dec. 01, 2015). The USAT (Unit-Based Sustainability Assessment Tool) (Togo & Lotz-Sisitka, 2009) and the AUA (Alternative University Appraisal) project consider issues in environmental and economic aspects (Abdul Razak et al., 2013). Some systems attempt to cover all important issues of sustainable development (SD), including energy, water, food, land, transportation, built environment, community, research, education, outreach, and decision-making (U.S. Green Building Council, 2019). the Sustainability, Training, Assessment and Rating System (STARS) is a transparent self-reporting framework open for all higher education institutions to evaluate their performances of SD in different fields of operation, education, research and outreach (Shuqin et al., 2019).

1.2.2.1. UI GreenMetric World University Rankings. To promote sustainable development, it will be necessary to establish a carbon emissions accounting system applicable to university campuses and to formulate a reasonable carbon emissions reduction target (Li et al., 2022). One of the latest universal tools developed for crediting universities' efforts in reducing their carbon footprint is the UI GreenMetric World University Rankings system, a 6-criteria evaluation tool with 39 indicators. Launched in 2010, it is now the world's most recognized stand-alone sustainability ranking for universities with over 900 participating institutions from 80 countries (UI GreenMetric, 2022). We studied UI GreenMetric's questionnaire for reporting university sustainable features and came up with the following observation:

1 Several crucial indicators such as total ground floor area, total university budget and annual per person carbon footprint do not require provision of evidence, which potentially affects the authenticity of the submitted data.
2 The questionnaire partly refers to existing systems such as LEED and STAR (this system itself refers frequently to LEED).
3 Depending on the focus of each year's ranking, indicators are undergoing constant update and amendment, lacking consistency in criteria composition.
4 Carbon footprint calculation considers only electricity use and transportation, but not heating, this does not reflect reality and greatly affects the accuracy of submitted data.
5 Each of the 6 evaluation categories has fixed percentage of weight, this one-size-fits-all configuration is very unlikely to adapt well to different local contexts.

1.3. Research concept of this study

Through the above observation on the most recognized green building rating systems and university sustainability ranking tool, we concluded that all these tools' suitability for assessing university campus sustainability is limited by their universality and objectivity. From this conclusion arise also critical questions:

1 Is certification/ranking the best way to assess/showcase a campus' level of sustainability?
2 Should a certificate/ranking serve as a feel-good badge or a guideline for further improvement?

Inspired by these questions, we sought to identify, in this study, a simple and robust framework that focuses only on measuring core performance instead of achieving high scorecard performance. Unlike nowadays' immensity of complex tools, the framework aspires to contain only a minimum number of KPIs. The objectives of this study include:

1 To identify a practical framework with KPIs for continuous measurement and improvement of university campus sustainability
2 To devise cost-benefit analysis within the applicable university sustainability categories of the identified framework
3 To provide evidence-based suggestion for action plan on sustainable university campus developing towards climate neutrality

Through this study, categories and KPIs developed were expected to facilitate senior management personnel of universities to focus on essential sustainability improvement areas instead of minor issues with minimum or negligible impact.

2. Materials and methods

2.1. Cost-benefit analysis

The different pillars of the 3Ps and their associated SDGs are not always in harmony, but rather, constantly at odds with each other. Achieving the optimal trade-off among different SDGs is the ultimate justification of this study, and calls for cost-benefit analysis, without which, the study will fall short in its impartiality. Studies using the cost-benefit analysis considering energy costs and carbon emission offsets have indicated a substantially larger productivity benefit than its incremental energy cost with negligible effect over the cost for carbon offset (McArthur, Feb., 2020). To perform the cost-benefit analysis in the simplest fashion, we utilized the following equations:

$$\textit{Simple Payback Time} = \frac{\textit{Incremental Cost}}{\textit{Incremental Benefit}} \quad (1)$$

Where *Incremental Cost* and *Incremental Benefit* was calculated using Eq. (2) and Eq. (3) respectively:

$$\textit{Incremental Cost} = \textit{Unit Area Renovation Cost} * \textit{Building Area} \quad (2)$$

$$\textit{Incremental Benefit} = \textit{Total Monetized Productivity Increase} + \textit{Total Monetized Energy Saving} \quad (3)$$

For Eq. (3), ***Total Monetized Productivity Increase*** was calculated using Eq. (4):

$$\textit{Total Monetized Productivity Increase} = \textit{Employee Compensation} * \textit{Building Area} * \textit{Average Occupant Density} * \textit{Productivity Increase} \quad (4)$$

For Eq. (4), ***Productivity Increase*** was calculated using the sum from Eq. (13) in Section 3.1.2.4 of this paper. *Total Monetized Energy Saving* was calculated using Eq. (5):

$$\textit{Total Monetized Energy Saving} = \textit{Building Area} * \sum_i e_i * P_i \quad (5)$$

In which, e_i is the unit area saving from different types of energy use, typically include electricity and heating (depending on the source, it can be either district heating or natural gas), P_i is the respective unit energy price.

In addition to energy saving and productivity increase, monetized

Fig. 3. Aerial image of TalTech's Mustamäe campus, compass rose placed at the same geographic location as shown in Fig. 4 but facing opposite direction to provide perception of campus layout from different angles.

unit area carbon reduction is also a good metric and an integral part of the benefit of renovation, which was measured in terms of marginal abatement cost (*MAC*), the quotient of net present value (*NPV*) divided by *Unit Area Carbon Reduction*:

$$MAC = \frac{NPV}{Unit\ Area\ Carbon\ Reduction} \tag{6}$$

Where:

$$NPV = -B + a * \frac{1 - [1 + (i_a - i_e)]^{-n}}{i_a - i_e} \tag{7}$$

In which, B is same as *Unit Area Renovation Cost* in Eq. (2), a is the monetized unit area annual energy saving, also known as net cash flow, calculated using current energy price, i_a is annual interest rate (set at 4%). i_e is the default annual energy price escalation (set at 2%), n is the number of payback years (set at 20).

And:

$$Unit\ Area\ Carbon\ Reduction = \sum_i E_i * f_i \tag{8}$$

In which, E_i is the annual energy saving from specific type of energy use within a unit area, f_i is its respective emission factor. Considering the emission factor for both heating and electricity will decrease over time, unit area's carbon reduction throughout the payback period from heating and electricity was calculated by applying different emission factor for different timespan within the payback period. While Eq. (1) and Eq. (6) were used for calculating renovation payback time and carbon reduction cost, it is evident that the same calculation may be applied to any other action having an investment cost, monetized benefits and carbon impacts, related for instance to transportation, waste or space efficiency improvement measures.

2.2. Campus buildings

All data for the case study in this paper were collected from buildings on the Mustamäe campus (see Fig. 3) of Tallinn University of Technology (TalTech).

Established in 1918, TalTech is the only university of technology in Estonia providing higher education at all levels in engineering and technology, information technology, economics, science, and maritime. Mustamäe is TalTech's main campus and home to 9691 students and 985 academic staff, it is the only campus-type university in the Baltic countries and one of the most compact university campuses in Europe. The Mustamäe campus consits of 19 university buildings (excluding buildings belonging to the Tehnopol Science and Business Park which shares part of the campus site), 1 track field, 7 dormitories and 1 hostel. To have a more realistic overview of campus energy use, we looked into data over a 3-year period (2017 – 2019) prior to the outbreak of the COVID-19 (COronaVIrus Disease 2019) pandemic (during which, the university instigated home office to comply with social distancing regulations and resulted in a rather low occupancy, which might not contribute to a normal energy use pattern of the campus, as one study conducted on 25 campus buildings in the Netherlands clearly demonstrated a significant decrease in both total and specific energy use compared to the pre-pandemic era (Xu et al., Jan., 2023)) from 18 non-residential university buildings with a total net area of 108,312 m^2, these buildings are marked with red abbreviations in Fig. 4.

3. Results and discussion

3.1. PICSOU - the six-category framework

Based on the literature study covered in Section 1.2, we devised a

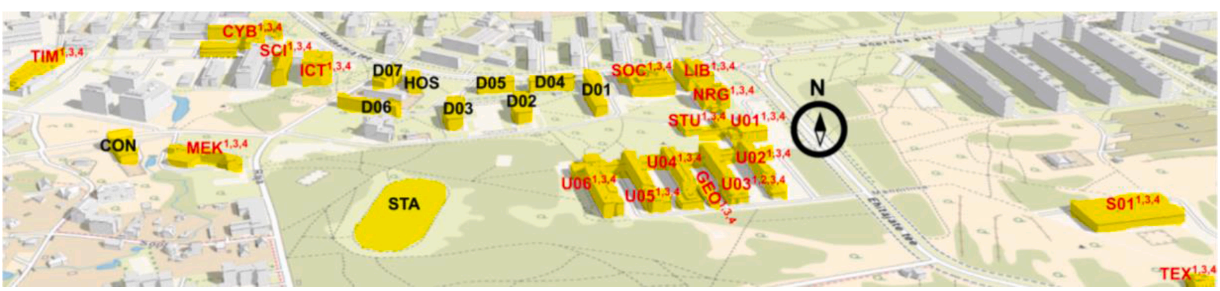


Fig. 4. Map of TalTech's Mustamäe campus, compass rose placed at the same location as shown in Fig. 3 but facing opposite direction to provide perception of campus layout from different angles.

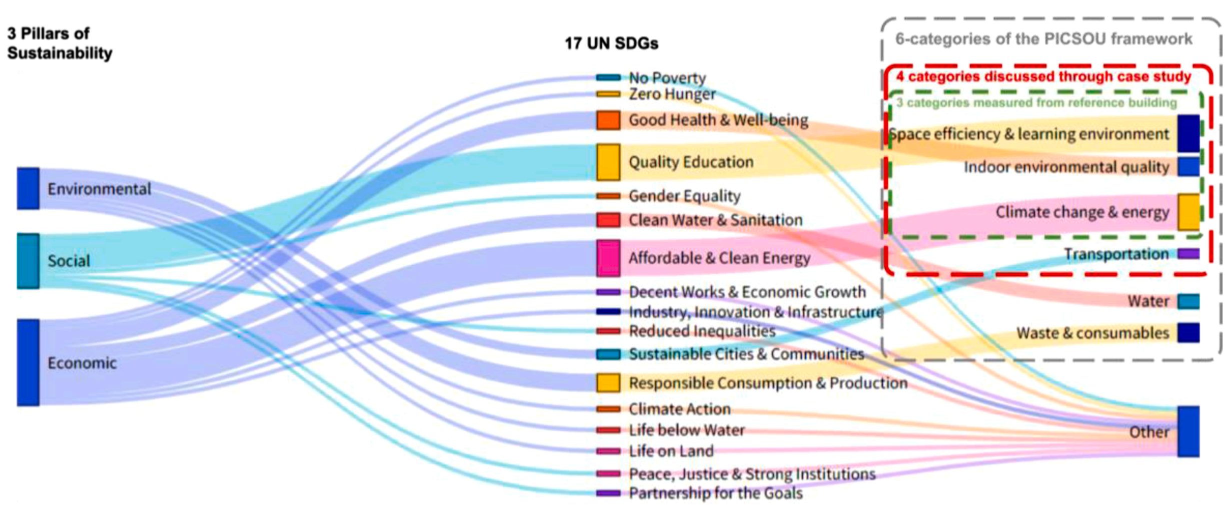


Fig. 5. The correlation between 3 Pillars of Sustainability, 17 Sustainable Development Goals of the UN, and the PICSOU framework.

Table 1
The PICSOU framework.

Sustainability category	Key performance indicators (KPIs)	Data source/update frequency	Target value	TalTech baseline value (result from case study)
1. Space efficiency & learning environment	Auditoriums and other learning spaces measured by m^2 per student	Calculated from campus summary form, updated annually	1.5–2.0 m^2 + 5 m^2 for presentation can be even bigger range, 75% occupancy rate, 56% utilization	1.41 m^2, presentation area usually bigger than 5 m^2, occupancy rate by default is 75%, average utilization rate per classroom/auditorium according to results from U03 building is 29% (U03)
	Teaching laboratory m^2 per student	Calculated from campus summary form, updated annually	4.0–6.0 m^2, 75% occupancy, 38% utilization (for teaching laboratories)	1.76 m^2 (considering all types of laboratories), unable to document actual occupancy and utilization rate of laboratories (18 buildings)
	Office & meeting rooms per staff	Calculated from campus summary form, updated annually	12 m^2	13.4 m^2 (18 buildings)
	Total space per person (staff + students)	Calculated from campus summary form, updated annually	To be specified locally	10.3 m^2 (18 buildings)
	Self-learning and group working spaces (informal learning seats), number of informal seats per formal seat	Calculated from campus summary form, updated annually	0.3 informal learning seats to every formal seat	0.50 m^2 per student, this result only accounts for documented self-learning spaces, informal learning spaces are not documented. Number of informal learning seats not possible to document, nor is its portion to formal learning seats. (18 buildings)
	Sports facility per person (staff + students)	Calculated from campus summary form, updated annually	To be specified locally	1.12 m^2 (18 buildings)
	Ratio of parking space (including underground parking) per person	Documented by asset manager, updated annually	0.05 parking space per person (including students and staff)	0.10 parking space/pers (18 buildings)
2. Indoor environmental quality	Indoor air quality, category I and II spaces,%	Monitored or simulated sub-hourly values and booking schedule, updated monthly	80% category I, 20% category II	54% Category I, 29.5% category II and 16.5% category III (U03)
	General thermal comfort, category I and II spaces,%	Monitored or simulated sub-hourly values and booking schedule, updated monthly	80% category I, 20% category II	0% category I, 25.9% category II, 74.1 category III (U03)
3. Climate change & energy	Carbon footprint, tCO_2/pers. a	Calculated from metered monthly values, updated annually	To be specified locally	1.30 tCO_2/pers. a (18 buildings, includes transportation)
	Electricity use, kWh/pers. a	Calculated from metered monthly values, updated annually	To be specified locally	1045 kWh/pers. a (18 buildings)
	Heating use, kWh/pers. a	Calculated from metered monthly values, updated annually	To be specified locally	1265 kWh/pers. a (18 buildings)
	Primary energy use, kWh/m^2. a	Calculated from metered monthly values, updated annually	To be specified locally	349 kWh/m2, a (18 buildings) calculated with national primary energy factors: 1.0 for natural gas, 0.65 for district heating, and 2.0 for electricity
	Renewable energy export, kWh/(m^2. a)	Metered monthly values, updated annually	To be specified locally	$<$ 1 kWh/(m^2 a)
	Carbon offset, tCO_2/pers. a	Not in practice	To be specified locally	0 tCO_2/pers. a
	Carbon footprint of building materials for new construction and major renovation, $kgCO_2$-eq/m^2	Calculated value from the design documentation for the new construction research building (CON)	To be specified locally	5.86 kg CO_2eq/m^2, a
4. Transportation	Carbon footprint from work trips, business trips (no data), inside campus transport (no data), tCO_2/pers. a	Calculated based on survey statistics, updated annually	To be specified locally	Work trips on average, 0.35 tCO2/pers, a, of which, car commuters (accounts for 31.8% of total campus population) contribute to 75% of total traffic carbon footprint, at 0.84 tCO2/pers, a (18 buildings). *
5. Water	Water use, m^3/pers. a		To be specified locally	Unmeasured - low relevance to local context
	Capacity for stormwater runoff absorbance, m^3/a		To be specified locally	Unmeasured - low relevance to local context
6. Waste & consumables	Recycled waste streams, kg or m^3/pers. a		To be specified locally	Unmeasured - low relevance to local context
	Electronic waste, €/pers. a		To be specified locally	Unmeasured - low relevance to local context
	Organic/food waste, kg/pers. a		To be specified locally	Unmeasured - low relevance to local context
	Toxic waste, m^3/a		To be specified locally	Unmeasured - low relevance to local context

*Current emission value from car commuters does not consider emissions from electrical vehicles due to their low percentage.
By January 2019, electric and hybrid vehicles combined account for 1% of total vehicles registered in Estonia, of which, 1254 were electric.

diagnostic tool by identifying a simple six-category framework with minimal number of KPIs designated as PICSOU, - Performance Indicators for Core Sustainability Objectives of Universities for the scientific and continuous measuring of university campus sustainability, whose metrics can facilitate an informed decision-making on the environmental goals (both indoors and emission-wise) or cost-benefit analysis. Under this framework, physical categories directly contributing to carbon footprint such as space efficiency, indoor environmental quality, climate change and energy, transportation, water, waste and consumables are included whereas managerial categories like academics, coordination and planning, investment and finance are omitted. Within the 6 categories, we only conducted in-depth evaluation of the impact of 4 categories over TalTech's Mustamäe campus due to their significant influence on carbon footprint and cost-benefit analysis. Categories that were not studied in depth in this study are of equal importance in terms of their distinctive environmental and economic value, but have rather limited effect on the overall results of the case study. All categories of the framework correspond to relevant SDGs, whose principle is in line with one of the 3Ps according to study by Barbier and Burgess, Oct. (2017) (see Fig. 5). It is worth noting that though each category and their respective KPIs are meant to be general, their improvement measures can always have a local origin.

3.1.1. Space efficiency and learning environment

The first category serves both as an audit of he current space arrangement of the campus as well as a point of interest in discovering the probable correlation between availability and quality of learning space, as decision-makers and users of space often experience things differently (Consensus Statement of the Health Enhancement Research Organization, American College of Occupational & Environmental Medicine & Care Continuum Alliance, 2013). Generalized statistics such as area of auditorim or laboratory per student is commonly measured and compared against capacity criteria listed in university space planning guidelines practiced among higher education institutions (HEIs) located in different climate zones (B. & R. E. Department of Capital Planning & Space Management Land, 2003) (Facilities Services Idaho University, 2009) (Space Management & Planning Unit at Deakin, University) (University Planning Design & Construction Department, 2016), which mainly reference the US Department of Education's Postsecondary Education Facilities Inventory and Classification Manual (Cyros & Korb, 2006), as well as guidelines by organizations such as the Tertiary Education Facilities Management Association, the Higher Education Funding Council of England and Association of Physical Plant Administration (APPA) of North America.

For each type of mapped space use, the space efficiency based on course time table, booking records and cleaning schedule can be a good indicator for the actual quality of learning environment and was calculated using Eq. (9) (Space Management & Planning Unit at Deakin, University):

$$Utilization = Frequency * Occupancy \tag{9}$$

Where:

Frequency equals the percentage of hours a room is booked in a week against a standard academic week of 42.5 h in Estonia, and *Occupancy* equals the number of people in a space over the space's designated capacity.

3.1.2. Indoor environmental quality

Enhanced indoor air quality is positively correlated with improved health, cognitive and physical developoment (Porta et al., 2016), higher incomes and better economic performance (Fisk & Seppanen, 2007). Additionally, the study by Seppänen et al. (O. Seppanen et al., 2006) had documented quantitative relation between temperature and performance, such patter was further tested and confirmed in the study by Lan et al. (Lan et al., 2021). Maintaining suitable indoor climate is a need for the occupants' wellbeing, while requiring very strict thermal comfort conditions and very high levels of indoor air quality in buildings represents also a high expense of energy, with its consequential environmental impact and cost (Corgnati et al., Jun., 2011). This issue is clearly expressed by the Energy Performance of Buildings Directive (EPBD) 2002/92/EC, together with the most recent 2010/31/EU, which underlines that the expression of a judgment about the energy use of a building should be always joint with the corresponding indoor environmental quality level required by occupants to optimize health, indoor air quality and comfort levels. To this aim, the concept of indoor environment categories has been introduced in the EN 16,798–1 standard (European Committee for Standardization (CEN) 2018), and applies to buildings adopting natural ventilation, mechanical ventilation, or a hybrid of both. These categories range from I to III with category I referring to the highest level of indoor climate requirement. Previous

Table 2
Campus summary form of TalTech's Mustamäe campus.

Space category	CLASSROOMS 13741.9 m²	GENERAL USE 2614.8 m²	LABORATORIES 17041.6 m²	OFFICES 20635.2 m²	SPECIAL USE 5159.6 m²	STUDY SPACE 4838.9 m²	SUPPORT 12659.5 m²	UNCLASSIFIED 373.7 m²	BUILDING SERVICES 2433.8 m²	CIRCULATION 25644.7 m²	MECHANICAL 10050.9 m²	STRUCTURAL GROSS AREA 20328.4 m²
NET USABLE AREA (*NUA*):	**85.0%**										*100%* 115194 m² 3644 spaces	**15.0%**
NET ASSIGNABLE AREA(NAA):	**56.9%**							*66.9%* 77064.6 m² 2371 spaces	NON-ASSGNABLE AREA (NASA)	**28.1%**	*33.1%* 38129.4 m² 1273 spaces	
Percentage by **gross area**	**10.1%**	**1.9%**	**13.1%**	**12.6%**	**3.8%**	**3.6%**	**9.4%**	**0.2%**	**1.8%**	**18.9%**	**7.4%**	
Percentage by *NUA*	*11.9%*	*2.3%*	*14.8%*	*17.9%*	*4.5%*	*4.2%*	*11.0%*	*0.3%*	*2.1%*	*22.3%*	*8.7%*	
Average space size	52.7 m²	56.8 m²	35.4 m²	19.2 m²	114.7 m²	107.5 m²	31.9 m²	18.7 m²	5.2 m²	47.5 m²	38.2 m²	
Number of spaces	261	46	481	1077	45	45	396	20	470	540	263	
Physical scope: 18 buildings, 94 floor plans; 38 departments												

study by Seinre et al. (Seinre et al., 2014) suggested 3 indicators for measuring indoor environmental quality's influence on building occupants' productivity, covering indoor air quality, for which outdoor air ventilation rate is used as a proxy, and general thermal comfort, independent of active or passive system type, which are:

3.1.2.1. Ventilation rate – productivity. Ventilation rate's affect over productivity had been studied in depth by Seppanen et al. (O. Seppanen et al., 2006) and documented in the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) Guidebook (Wargocki et al., 2006), whose polynomial expression can be approximated as:

$$P_V = -0.00002L^2 + 0.0019L + 0.9901 \tag{10}$$

Where Pv is a dimensionless quantity for the relative performance in relation to a set ventilation rate of 6.5 L/s, pers and L is ventilation rate measured in L/s, pers.

3.1.2.2. Ventilation rate – sick leave prevalence. The ventilation rate's affect was studied by many, among which, the office buildings discussed by Fisk et al. (Fisk et al., 2003) and Milton et al. (Milton et al., 2000) were the most appropriate building type to be used for university campus buildings. Such affect can be approximated as:

$$SL = -0.0294ACH^3 + 0.2709ACH^2 - 0.8209ACH + 0.9611 \tag{11}$$

Where SL is a dimensionless quantity for sick leave prevalence relative to that with no ventilation and ACH is the hourly air change rate measured in 1/h. For a given scenario where the floor height and area of a room are defined, SL reaches its minimum (optimal) value of 0.0109 around the ACH of 4.8 h^{-1}, any ACH above this value will result in a negative SL value, which does not reflect reality. This means Eq. (11) can only realistically approximate the SL value when $ACH <= 4.8\ h^{-1}$.

3.1.2.3. Indoor temperature – productivity. We calculated temperature's effect over productivity using the equation obtained in the study by Seppanen et al. (O. Seppanen et al., 2006):

$$P_T = 0.1647524T - 0.0058274T^2 + 0.0000623T^3 - 0.4685323 \tag{12}$$

In which, P_T is a dimensionless quantity for the productivity relative to maximum its maximum value, whereas T indicates temperature measured in Celsius (°C).

3.1.2.4. Combined productivity. We calculated the combined productivity by solving for the arithmetic sum of the net increase/decrease of productivity due to increased ventilation rate compared to the reference ventilation rate Pv-1, operating temperature compared to optimal temperature P_T-1, as well as avoided sick leave (by default, sick leaves

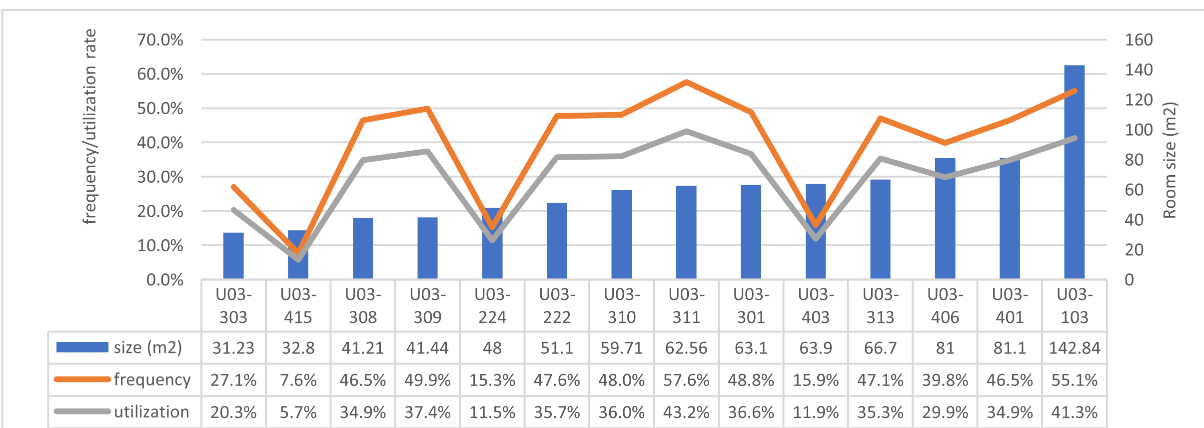


Fig. 6. Learning space utilization in Building U03 (calculated using Eq. (9) Occupancy was assigned a default value of 75%, resulting in a clear linear correlation between Frequency and Utilization in the plotted chart).

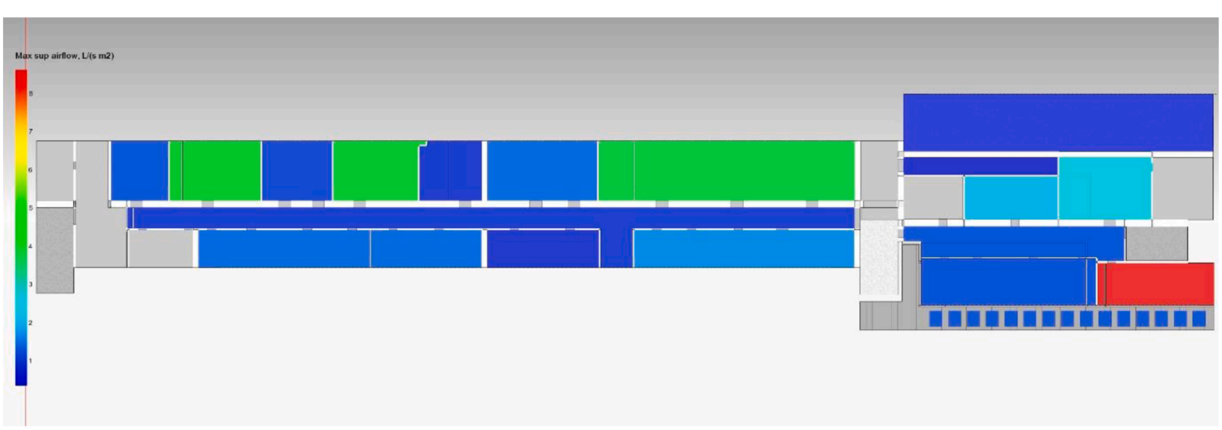


Fig. 7. Map of maximum supply air flow on Floor 2 of the U03 building based on IDA ICE model featuring the pre-renovation condition.

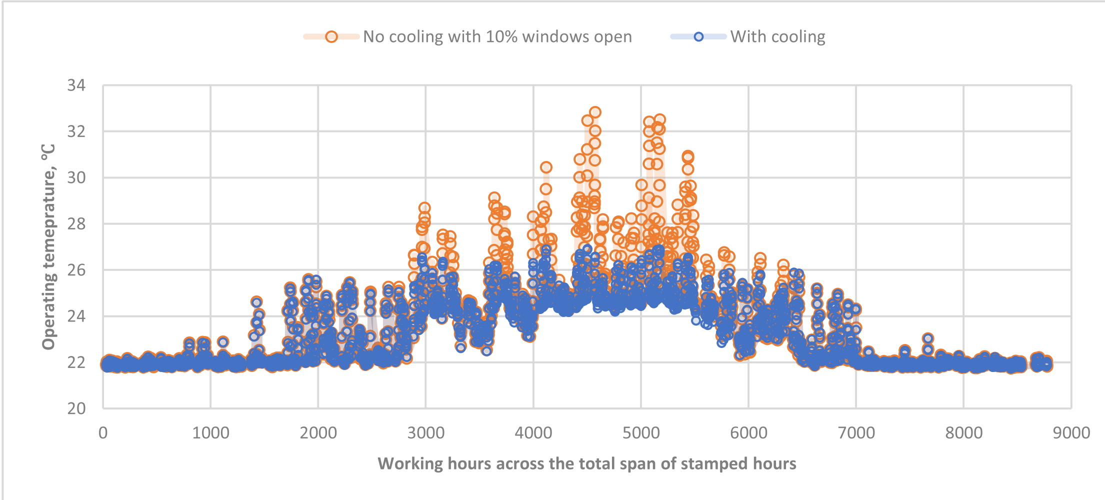


Fig. 8. Reference room's distribution of operating temperatures under both cooling scenarios.

consist 2% of total annual working hours, therefore increased productivity from avoided sick leaves can be expressed as 0.02 – 0.02*SL*.) The per person Productivity Increase was calculated as:

$$Productivity\ Increase = (P_V - 1) + (P_T - 1) + 0.02 * (1 - SL) \tag{13}$$

Under a test scenario where $L = 10$ L/s, pers and cooling period $T = 24$ °C, Eq. (13) yielded a value of 0.01708, indicating that the productivity is about 1.7% higher than the reference value (for which, Eq. (13) is expected to yield a value of 0), and is thus considered a more preferable indoor climate scenario. To monetize this increased productivity, we assumed that a university staff is a typical office worker, whose hourly wage is twice the Estonian average (Statistics Estonia, 2021), and works 8 h a day, 5 days a week, 250 days a year. A 1.7% increase in productivity will amount to approximately 618.8 €/pers, a of increased gross income as a result of improved indoor climate.

3.1.3. *Climate change and energy*

Since energy use such as heating and electricity are commonly metered in buildings, it is possible to measure Scope 1 and Scope 2 CO_2 emissions by applying typical local emission factors. For Tallinn, such numbers are 0.11 tCO_2eq/kWh for district heating and 0.717 tCO_2eq/kWh for average emissions from production of electricity (Ministry of the Environment of Republic of Estonia, 2021), we also used these values in Eq. (8) to calculate *Unit Area Carbon Reduction*. For new construction, carbon footprint of building materials should be also measured using the LCA (Life Cycle Assessment) method, as recent research indicates that the benefit of decarbonization of building materials can be as significant as 20% in carbon footprint reduction in a materials-neutral manner (Ministry of Environment Finland, 2021).

3.1.4. *Transportation*

This category addresses Scope 3 CO_2 emissions incurred from transportation, including commuting to and from the TalTech campus, work trips, business trips. Mapping of transportation-related emissions on campus helps identify major contributor(s) of CO_2 emissions and thus provides a solid evidential basis for adjustment in policy making as well as planning of transit nodes and dormitories within and around the campus, as most people prefer to walk no more than 400 m or five minutes to casual destinations and no more than 800 m for regular trips such as daily commute (Associates & Law, 2008).

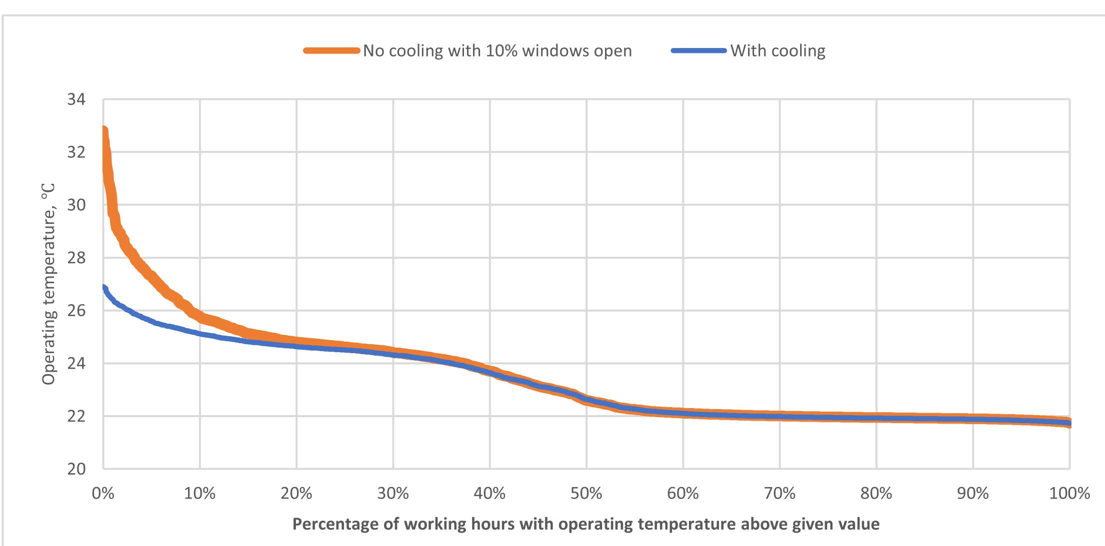


Fig. 9. Reference room's duration curve of operating temperatures under both cooling scenarios.

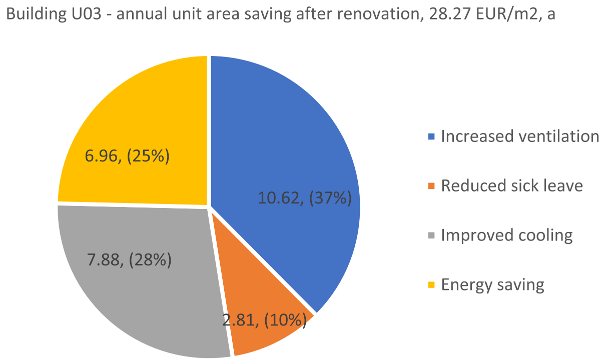


Fig. 10. Breakdown of the U03 building's post-renovation annual unit area monetary benefit.

3.1.5. *Water*

Although water consumption generates negligible (about 1%) CO_2 emissions compared to that incurred from a building's operation and its associated transportation (Seinre et al., 2014), water as a necessity for sustaining human livelihood is threatened by imbalanced distribution, massive pollution and vast shortage in many parts of the world and sustainable use of water is ranked as one of the most crucial SDGs – same reason water efficiency is emphasized by all major green building rating systems. Prevention of local water body pollution from stormwater runoff is also considered by the PICSOU framework, in which, stormwater runoff absorbance capacity of a site can be calculated using the Small Storm Hydraulic Method (Pitt, 1999), this value can facilitate the planning of vegetated area against urban heat island effect and ground water contamination.

3.1.6. *Waste and consumables*

Similar to KPI Category 5, this category has rather limited contribution to the overall CO_2 emissions of a university campus given the fact that the waste sector's emission (including but not limited to the emission from wastewater treatment and discharge mentioned in the previous category) consists only 2.4% of total emissions in Estonia in 2021 and is projected to be 1.9% by 2050 (Ministry of the Environment of Republic of Estonia, 2021) thanks to detailed EU waste regulation. However, pollutants and GHG released from waste materials that are improperly sorted, recycled, and disposed usually result in catastrophic ecological consequences while causing massive waste in energy and virgin materials as well as depriving considerable size of land and funding for treatment, in the EU, about 25% of the total waste stream consists of construction and demolition waste (Arcadis, BIO INtelligence Service, 2013). Such rationale justifies the necessity of including the mapping of major waste stream and their carbon footprint in the KPI categories, without which, a genuinely sustainable campus objective will be obsolete and inadequate.

3.1.7. *KPIs of each PICSOU category*

A summary of PICSOU categories and their KPIs, as well as each KPI's target value are listed in Table 1. For the first 4 categories, results from the case study on TalTech's Mustamäe campus were also measured, categories 5 and 6 were not considered for this study due to their low local relevance. Category numbers corresponding to the ones listed in Table 1 (numbered 1 through 4) can be also found in the superscript of building abbreviations in Fig. 4, denoting the categories whose KPIs were directly contributed by the building's data.

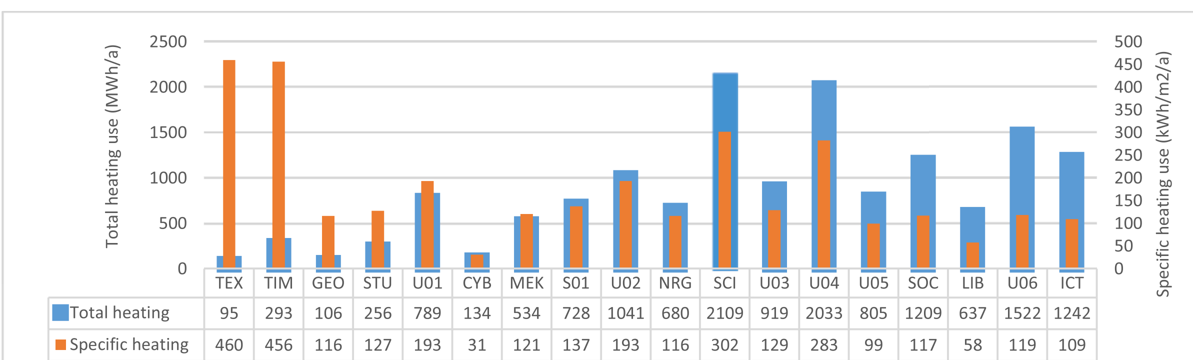


Fig. 11. Total and specific heating use of selected campus buildings.

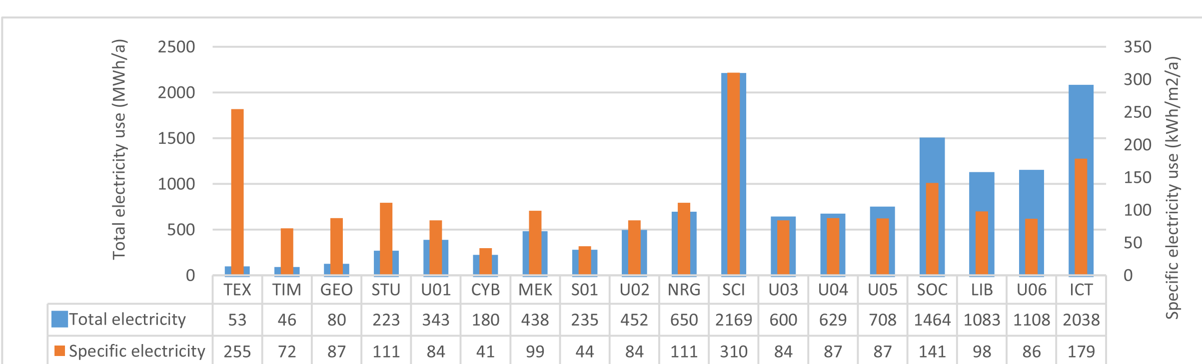


Fig. 12. Total and specific electricity use of selected campus buildings.

3.2. Case study

Though PICSOU's categories and KPIs have generic nature, which enables the framework to be applied to other campuses as well, KPIs' target values have to be specified locally. Out of 23 KPIs under 6 categories, we were able to successfully measure 16 KPIs from the first 4 categories on TalTech's Mustamäe campus.

3.2.1. Space efficiency

3.2.1.1. Mapping of spaces on campus. In order to measure space efficiency, we created a campus summary form to document the per-person area of each space type across 18 campus buildings (see Table 2).

It can be observed from Table 2 that, while all other space types have a reasonable average space size, the average space size of study space is abnormally big (107.5 m^2), which does not reflect reality. This is due to the fact that most formal study spaces are available in the library, where reading halls can have exceptionally ample space (for example, room 222 in the library has an area of 1137.3 m^2) while group study spaces are usually sized around 10 m^2 and individual study spaces less than 3 m^2.

3.2.1.2. Utilization of classrooms. Mapping the learning space utilization helps streamline the maintenance activity and minimize the operational costs/emissions by identifying under-occupied learning spaces.

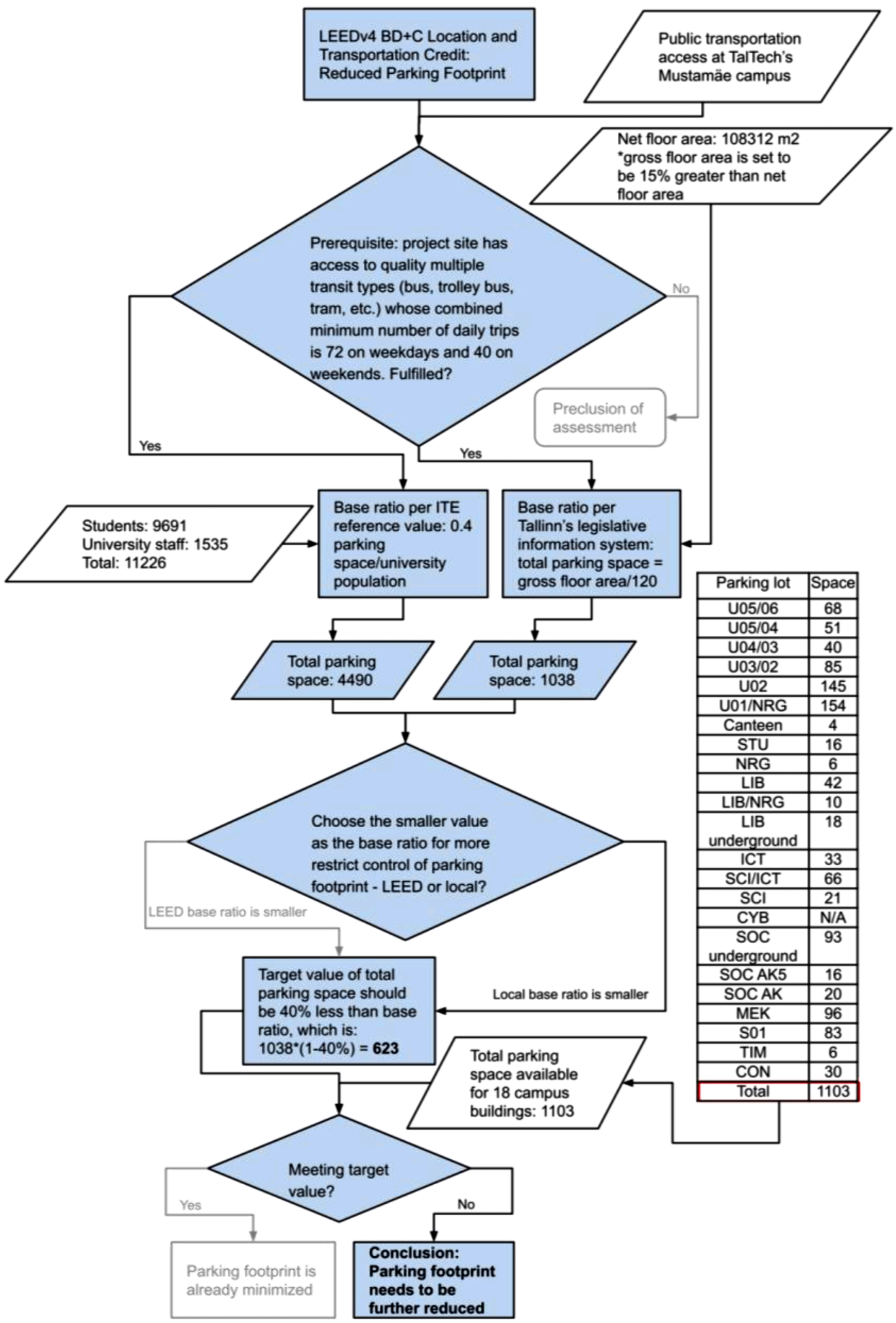
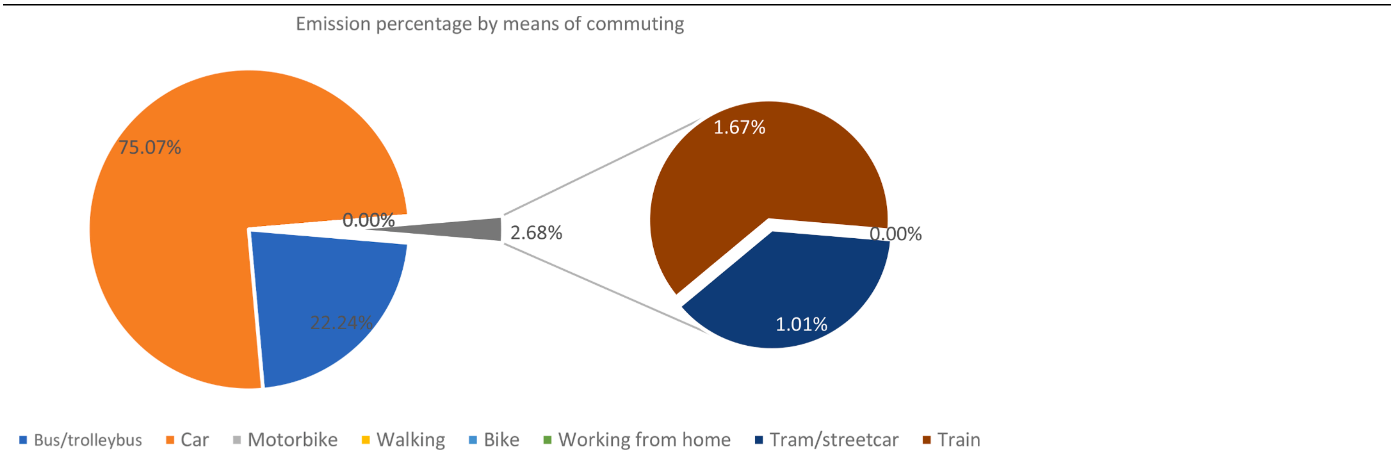


Fig. 13. Workflow for deciding parking space target value. Major steps followed in this flowchart are highlighted using color-filled shapes.

Table 3
Overview of Mustamäe campus' transportation-related CO_2 emissions.

Means of commuting	Percentage %	Calculation assumptions	Number of commuters	Annual CO_2 emissions tCO_2
Bus/trolleybus	36.36	20 g of CO_2 per minute for each passenger, daily one-way commuting time is 21.66 min, 250 working days annually	4082	884.1
Car	31.82	132.4 g of CO_2 per km, daily one-way commuting distance is 12.62 km, 250 working days annually	3572	2984.3
Motorbike	0	80 g of CO_2 per minute, 250 working days annually	N/A	N/A
Walking	21.59	N/A	2424	0
Bike	4.55	N/A	511	0
Working from home	2.27	N/A	255	0
Tram/streetcar	2.27	15 g of CO_2 per minute for each passenger, daily one-way commuting time is 21 min, 250 working days annually	255	40.1
Train	1.14	10 g of CO_2 per minute for each passenger, daily one-way commuting time is 104 min, 250 working days annually	128	66.6
Overview ⇓		**Total ➡**	**11,226**	**3975**



As an example, in this case study, the utilization rate of classrooms in building U03 was calculated using Eq. (9) (Space Management & Planning Unit at Deakin, University). To do that, we singled out all rooms in U03 fitting the classroom category in Table 2 from the university room register system, and accessed each classroom's booking schedule in the study information system to calculate their weekly booked hours, and eventually yielded the *Utilization* (see Fig. 6).

3.2.2. Indoor environmental quality

3.2.2.1. Monetary benefits. Investments in energy efficiency are not an attractive investment for landlords from an economic perspective (März et al., 2022). This study helps building owners look beyond the common practice of simple payback model of renovation by quantifying also the benefit from improved indoor environmental quality, in addition to return in energy saving.

We took U03 as a reference building, which has 61 rooms (auditoriums, offices, laboratories) across its four-story premises totaling 6482 m^2 of NUA. We calculated each room's capacity, ventilation rate (L/s, pers), air change rate (1/h) and indoor environmental category, and solved the current *Pv* value and *SL* value of each room using Eq. (10) and Eq. (11). We also calculated each room's would-be post-renovation *Pv-SL* value set by assigning the optimal air supply rate and ventilation rate. We then used the difference in each room's pre and post renovation *Pv-SL* value set in Eq. (4) to yield the total quantified annual productivity increase from increased ventilation and reduced sick leave prevalence.

Similarly, in order to solve for the productivity increase from increased cooling using Eq. (12) and Eq. (4), we adopted an IDA ICE model of U03 (see Fig. 7). The IDA ICE model had 2 simulation scenarios, "no mechanical cooling with 10% windows open" was used to imitate the pre-renovation condition, and "with mechanical cooling" the post-renovation.

The simulation results exhibited clear discrepancy between the 2 scenarios, indicating that the post-renovation operating temperature is significantly lower than that of pre-renovation during the warmest months of a year (see Fig. 8) with a narrower range of temperature fluctuation (see Fig. 9).

We then calculated the total quantified productivity increase from all improvements in the indoor environmental quality (increased air change rate, reduced sick leave prevalence, increased cooling), and divided this value by the total net area of U03 to yield the annual unit area productivity increase. Fig. 10 features a breakdown of the annual unit area saving after renovation, which shows that saving from productivity increase due to improved indoor environmental quality contributes remarkably greater than energy saving. The renovation corresponded to deep renovation recommended in Estonia's long-term renovation strategy (Ministry of Economic Affairs & Communications of Estonia & Tallinn University of Technology, 2020) with a unit area cost of 600 €/m^2, by substituting this value together with the post-renovation annual unit area benefit into Eq. (1), we yielded a simple payback time of 39 years, a more favorable payback time compared to an 86-year simple payback time considering only energy saving.

3.2.2.2. Environmental benefits. We calculated the cost effectiveness for U03's renovation using Eqs. (6), (7) and (8), and yielded an MAC value of -1160 €/tCO_2eq, m^2. Though the negative MAC value shows that investing in carbon reduction does not directly benefit the building owner financially, considering the profound environmental impact of carbon reduction, early investment is still preferable.

Table 4
Carbon footprint/cost of PICSOU categories calculated from Mustamäe campus' baseline values and optimal values.

Sustainability category	Carbon footprint/cost based on baseline values	Carbon footprint/cost based on optimal values	Impact
1. Space efficiency & learning environment	Assumptions: 1 Total auditorium area unchanged; 2 Specific heating/energy use across all buildings based on building-specific real-life value. Carbon footprint: 10,626 tCO_2eq/a	Assumptions: 1 Total auditorium area reduced by 25% (so that default occupancy becomes 100%) to maximize space utilization; 2 All reduced auditorium area heated by district heating. Carbon footprint: 10,289 tCO_2eq/a	Annual carbon footprint reduction by 337 tons (3.2%)
2. Indoor environmental quality	Assumption: Actual situation in offices and laboratories. Total productivity increase: 0 EUR/a	Assumption: Post-renovation productivity increase applies to staffed laboratories and all offices. Total productivity increase: 439,737 EUR/a	Annual monetary benefit: 439,737 EUR (equivalent to 17.6% of pre-renovation total energy cost in PICSOU category 3)
3. Climate change & energy	Assumption: Actual situation in all buildings. Total energy cost: 2,498,480 EUR/a; Carbon footprint: 10,626 tCO_2eq/a.	Assumptions: 1 All buildings heated by district heating; 2 Post-renovation energy saving and carbon footprint reduction apply to all buildings; 3. Specific heating/energy use across all buildings based on lowest real-life value.Total energy cost: 754,501 EUR/a;Carbon footprint: 3353 tCO_2eq/a.	Annual energy saving by 1,743,979 EUR (69.8%); Annual carbon footprint reduction by 7273 tons (68.4%).
4. Transportation	Assumptions: 1 distribution of means of commuting unchanged; 2 Ratio of parking space unchanged. Carbon footprint: 3975 tCO_2eq/a	Assumption: Number of car commuters reduced by the same number as reduced parking spaces, reduced number proportionally redistributed to other means of commuting. Carbon footprint: 3636 tCO_2eq/a	Annual carbon footprint reduction by 339 tons (8.5%)
5. Water	Assumption: No additional water saving features implemented, thus no contribution to carbon footprint reduction from sewage water treatment.	Assumption: Additional water saving features implemented, consequently contributes to carbon footprint reduction from sewage water treatment.	Neglectable
6. Waste & consumables	Assumption: No measures taken to reduce creation of certain waste flow(s) at source, thus no contribution to carbon footprint reduction from embedded carbon footprint of virgin materials and treatment of their waste.	Assumption: Measures taken to reduce creation of certain waste flow (s) at source, consequently contribute to carbon footprint reduction from embedded carbon footprint of virgin materials and treatment of their waste.	Neglectable

Table 5
Comparison of characteristics between the PICSOU framework (highlighted in bold texts) and other existing tools.

	PICSOU	UNSDG	LEEDv4.1 OM/EB	BREEAM In-Use International 2015	UI GreenMetric
Composition	**6 categories, 23 indicators, no scorecard**	17 goals, 169 targets, no scorecard	10 categories, 27 credits, scorecard with max. 110 points	9 categories, 209 indicators, scorecard with max. 100%	6 categories, 51 indicators, scorecard with max. 10,000 points
Purpose	**Framework for monitoring sustainability performance**	List of sustainability challenges	Standard for green building certification	Standard for green building certification	Technical reference for participating global ranking of sustainable universities
Specifically for university campuses?	**Y**	N	N	N	Y

3.2.3. Climate change and energy

We calculated the total and specific heating and electricity use of 18 campus buildings based on a 3-year average between 2017 and 2019, and plotted this data in Figs. 11 and 12, in which, buildings were arranged in an ascending order of total area. On average, buildings on the Mustamäe campus used 176 kWh/m^2, a for heating and 115 kWh/m^2, a for electricity.

3.2.4. Transportation

3.2.4.1. Ratio of parking space. To do that, we adopted the method used by the LEEDv4 BD+C (Building Design and Construction) rating system (U.S. Green, 2019) and picked the smaller value between the compliant number set by ITE (the U.S. Institute of Transportation Engineers) (Meyer, 2009) and the one set by the local regulation in Tallinn (Terik, 2020) as the reference value for parking footprint reduction (see Fig. 13). Although LEEDv4 BD+C is meant mainly for new constructions instead of existing buildings, it provides a good workflow for calculating the would-be number of parking spaces at a university campus.

3.2.4.2. Transportation-related carbon footprint. In this study, we were able to calculate work trip related emissions from car, bus/trolleybus, tram/streetcar, and train. Although emissions from business trips and on-campus transportation are also considered relevant transportation-related emissions in the PISCOU framework, due to lack of information, they were not calculated in this study.

At 132.4 gCO_2/km, Estonia's average passenger car emission is prominently higher than the EU value of 120.8 gCO_2/km in 2018

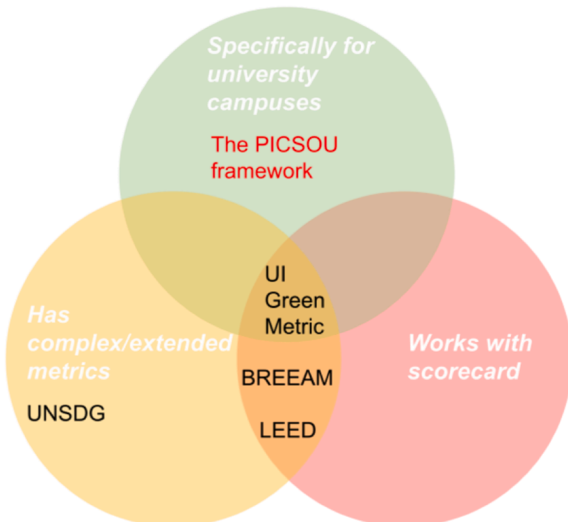


Fig. 14. The relation between the PICSOU framework and existing tools.

(Pastorello et al., 2020), reducing commuting car use helps minimize one of the biggest contributors to TalTech's transportation carbon footprint. To determine the daily number of cars commuting to the Mustamäe campus, we applied the overall percentage of means of transportation and calculation assumptions based on an online survey about the city of Tallinn ("Traffic in Tallinn, Estonia", 2021) to the total university population, and also yielded each means of transportation's respective carbon footprint (see Table 3).

3.2.5. *Impact assessment*

Based on the case study, we calculated the carbon footprint/monetary saving of different categories based on both baseline value and optimal value (see Table 4). Considerable savings achieved revealed the importance of selected categories and illustrated their respective impact.

4. Conclusions

4.1. *Findings*

Inspired by the UNSDGs and reflecting on the popular green building certification systems and university rankings, we identified a minimum number of categories and indicators for the PICSOU framework (see Table 5).

It was our objective to identify a minimalistic framework that is unique in a way that it is meant specifically for university campuses and does not rely on complex/extended metrics contributing to a scorecard to showcase a campus' level/ranking of sustainable development (see Fig. 14). Instead, the framework monitors the real-time sustainability performance of a campus to guide customizable improvements.

We tested the PICSOU framework on TalTech's Mustamäe campus and came up with the following findings:

1 In reference building U03, the highest *Utilization* (43%) was notably lower than the target value (56%) with several classrooms having exceptionally low *Utilization* (close to 10%), this pattern can be expected from other campus buildings with similar floor plan and functions. Such result contradicts a current belief that the campus needs expansion to accommodate a greater research/teaching capacity and opens up opportunity for further reducing the operational emissions/cost.
2 The campus' current parking footprint needs to be reduced by 43.5%, or down to 0.05 parking space/university population to minimize its land consumption, automobile dependence, car-related emissions and rainwater runoff.
3 The huge discrepancy in simple payback time (39 years vs. 86 years) verified the necessity to consider co-benefits in parallel to energy saving and carbon reduction, thanks to which, increased ventilation/

Table 6
Qualitative cost-benefit breakdown of improvement measures for TalTech's Mustamäe campus.

Sustainability category	Improvement measure	Applicability	Cost category	Benefit category
Space efficiency & learning environment	1. Increase area of over-utilized spaces	generic	Renovation cost, Remodelling cost, Lease cost, Construction cost	Improved learning performance, Increased productivity, Improved wellbeing
	2. Reduce area of/convert under-utilized spaces	building-specific		
	3. Rearrangement of spaces	generic		
	4. Release unnecessary spaces	generic		
	5. Create new spaces if proven necessary	generic		
Indoor environmental quality	1. Increase ventilation rate	building-specific	Retrofit investment, Procurement/installation cost for interiors	Increased productivity, Reduced sick leave, Improved indoor air quality
	2. Improve air-conditioning	building-specific		
	3. Improve daylight and artificial lighting	generic		
	4. Procure low-emitting furniture/interiors	generic		
Climate change & energy	1. Install passive/active solar systems	generic	Retrofit investment, Renewable energy certificate (REC) procurement cost, Material cost, Carbon offset investment	Reduced carbon footprint, Reduced energy cost, Improved energy efficiency, Minimized solid waste and pollution
	2. Use/produce green energy	generic		
	3. Eliminate refrigerants or use low-impact refrigerants	generic		
	4. Energy renovation (combined with IEQ improvement)	building-specific		
	5. Establish target value of building materials' carbon footprint for new build design and procure construction materials meeting recognized disclosure criteria such as ISO 14,025 and EN 15,804	generic		
Transportation	1. Promote commuting with public transportation/biking/walking through incentive programs	generic	Promotion campaign cost, Procurement/installation cost for biking facilities/ EVSE, Monetary/flexible schedule incentives, Energy subsidy for electrical vehicles	Reduced carbon footprint, Minimized traffic air pollution, Enhanced community engagement
	2. Install biker-friendly facilities	generic		
	3. Diversify amenities within walking distance	generic		
	4. Subsidize green vehicle use	generic		
	5. Install electric vehicle supply equipment (EVSE)/dedicate parking space for electrical vehicles	generic		

cooling and higher energy efficiency (and consequently reduced carbon footprint) can be all achieved at the same time.

4 The campus' transportation emission breakdown indicated a clear and disproportionate domination of car emissions (car commuters account for less than one-third of total commuters but contribute to 75% of total transportation emissions).

5 Depending on local context, categories with presumably high impact such as the "water" category and the "waste and consumables" category can have less impact compared to other categories.

4.2. Suggestions for policy-making

Based on the discrepancy shown in Table 4, we concluded guidelines for possible improvements for the Mustamäe campus using a qualitative cost-benefit breakdown of relevant PISCOU categories (see Table 6).

4.3. Limitations and future studies

1 KPIs under the "space efficiency and learning environment" category may be non-conclusive to measure learning environment quality and require further development.

2 The sample size of the survey used for mapping the campus' composition of transportation-related carbon footprint was small, which might jeopardize the accuracy of the summary of the distribution of means of transportation.

3 The studied campus buildings did not include residential buildings, a unique building type that consists a fair portion of the campus' total building stock, which could undermine the accuracy and reliability of the energy use and carbon footpint results in this study.

4 Even for the 4 PICSOU categories that are relevant to the local context, many of their target values were not decided due to absence of data, which gives rise to two seemingly contradictory interpretations: (1) hard-to-measure KPIs should be replaced by more intuitive easy-to-measure indicators; (2) hard-to-measure KPIs should not be replaced or omitted as they are the justitification of future studies.

5 Only one case study on one campus was conducted in this paper, whose result was in favor of the suggested compatibility of the PICSOU framework. However, it is evident that further case studies need to be conducted on campuses located in different climate zones.

In conclusion, this study provides an unprecedented work from an atypical angle combining both conventional and unconventional metrics, and proposes a promising minimalistic framework that aims to be practical and scalable for other university campuses. With the PICSOU framework, sustainability could be made transparent and monitored in a robust fashion to help university managerial personnels focus on improving areas with he highest impact. Future studies addressing the above-mentioned limitations are expected to complement the framework in its universality.

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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