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A review of empirical data of sustainability initiatives in university campus operations

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ABSTRACT

Given the need to actively address the challenges of climate change, university leaders have a growing interest in reducing their campuses' environmental impact. This article carries out a comprehensive literature review on the implemented actions and initiatives in university campuses reported in scientific publications. In addition, case studies carried out in universities are also reviewed, giving particular attention to the methods and tools used, targeting the current trends in sustainable campus scientific research. Key actions and initiatives were identified and categorized according to Energy, Buildings, Water, Waste, Transportation, Grounds, Air and Climate, and Food. Results show that the increase in energy generation on campus and the decrease of energy consumption in buildings are by far the leading policies adopted, however with limited dissemination of their impact. Moreover, there seems to be a tendency for countries with higher income economies to engage in initiatives that involve greater investment, such as the adoption of renewable energy systems or efficient buildings systems. The need to establish an integrated framework to disseminate and monitor the impact of key actions and their feasibility is suggested, in order to leverage strategic programs and actions, helping to optimize investments, and leading advances towards a sustainable university campus.

Keywords: sustainable campus; sustainability initiatives; campus operations; renewable energy; buildings energy efficiency

1 Introduction

Since the Brundtland Report and the establishment of the Sustainable Development (SD) concept, governments and public institutions are aware of the responsibility in considering environmental, economic and social sustainability in their activities. Higher Education Institutions (HEIs) play a special and crucial role, due mainly to their inherent characteristics and mission: a) as educational institutions, HEIs have the responsibility of preparing future leaders and citizens to be more conscious and active in the dissemination of sustainable principles; b) as owners of physical structures that consume energy and other resources, HEIs have the opportunity to implement actions to decrease costs and impacts associated to campus operations; c) as administrative structures, HEIs have to manage people from diverse socio-cultural backgrounds, finances and, still, seek an engagement between staff, academia and community; and d) HEIs have the social responsibility of incorporating all these issues, acting by example.

Considerable work on the subject of sustainability has been done, taking an increasingly important place in the lifespan of any HEI, either through governance or teaching models, and/or through the management of the campus buildings. The number of HEI websites exclusively dedicated to reporting sustainability practices have increased, providing information to the general public on targets, planned initiatives and eventually on the current status of execution. However, increasing evidence in literature indicates a substantial number of failures in implementing sustainability initiatives (Mohammadalizadehkorde and Weaver, 2018), being the main reasons given by the HEIs themselves identified in literature.

Apart from the information provided in websites, reports or declarations, it is important: i) to identify the actions and initiatives presented in sustainable campus plans, ii) to determine if these are implemented, and iii) to understand the type and magnitude of their environmental, social and economic impacts. The importance of understanding the rationale behind the implementation and feasibility is crucial to identifying the reasons for possible failures, to grasp the distance between commitment and accomplishment, but above all, to analyze whether implemented initiatives are the most appropriate to each institution's reality. Waging on an action that turns out to be ineffective may discourage the drive to continue moving towards a sustainable campus.

In this sense, this paper constitutes a comprehensive review of environmental actions and initiatives effectively adopted by universities and communicated in scientific literature, aiming to provide a wide perspective of the recent developments in implementing practical sustainability in HEIs. The main objective is to identify the key areas that influence the environmental performance of HEIs, regarding the establishment of the *sustainable campus* concept. Focusing on the operational dimension, the aspects of campus performance are explored, namely those resulting from the functioning of buildings and infrastructures in terms of reducing or minimizing resources consumption. This can be particularly useful to optimize the adoption of sustainable strategies on campuses, inspired by empirical evidence.

Previous literature review works address specific aspects especially related to the evaluation and communication of sustainability, such as the commitments and declarations, methods and tools to implement, assess or report, or even the role of sustainability centers. Nevertheless, and given the perceived discrepancy between theory and practice, it can be assumed that these works present a generic framework of activities, still lacking an analysis of what was and is actually accomplished. Few studies have focused on practical activities and empirical data. The research carried out by Gunawan et al. (2012) and Razman et al. (2017) analyzed what they referred to as "some major universities in the world" (Gunawan et al., 2012, pp. 60); nonetheless, these inquiries were based on websites' content. As experienced by Soini et al. (2018), websites provide informal and invalidated information that may not always accurately reflect reality; a gap still exists in scientific work, which may be able to support practical frameworks. Therefore, this article attempts to fill this gap, particularly addressing issues for universities who intend to initiate a sustainability process, taking into account the experience of other institutions and more importantly the results achieved and the adequacy to local and/or identical contexts. Similarly, it is also for those who work in the operations management in university campuses, given its eminently practical nature, where investments need to be effective and optimized.

2 Theoretical framework

2.1 The sustainable campus concept

Despite being attributed to the Stockholm Declaration of 1972, the debate of incorporating sustainability concerns in HEIs dates back to the 1990s, after the Brundtland Report delineated what would become the *Sustainable Development* concept (Brundtland, 1987).

The definition of *sustainable university* is commonly associated to the three pillars of sustainability, as universities have the responsibility to contribute towards mitigating environmental, economic and societal impacts, while promoting health and well-being and spreading these values globally (Alshuwaikhat and Abubakar, 2008; Cole, 2003; Velazquez et al., 2006).

The dimensions of sustainability may be reflected in the HEI context to include: a) Education, involving all the activities related to knowledge transfer, such as curriculum, research and behavior change; b) Operations, related to the physical built environment; and c) Governance, comprising the administration of university resources, either human or material, and the engagement with the community.

In this context, several initiatives, commitments and alliances have been created, so that HEIs could implement sustainable development goals (SDGs) in the various scopes of their activities. The successive Charters and Declarations signed by university leaders and reviewed by Wright (2002) and Lozano et al. (2015, 2013) are the first official expression of a commitment to embrace environmental conservation. In 1990, the Talloires Declaration ("The Talloires Declaration," 1990), placed emphasis on the need to enhance education and environmental literacy, resource conservation and to involve stakeholders and community, amongst others. Subsequent declarations have covered these topics as well. Wright (2002) identified several emerging themes common to declarations and institutional policies, such as physical operations, environmental literacy, curriculum and research, or public outreach. Cortese (2003) identified education, research, operations and outreach as an integrated system of a sustainable university. However, Ceulemans et al. (2015) noted the complexity in ascertaining what could be considered as an indicator of sustainability, mainly due to the different objectives and interpretations that the various stakeholders could have.

Conversely, the vagueness with which the commitments were addressed throughout the different statements is reflected in the constant need, over time, for new and renewed declarations, initiatives and commitments, raising the question whether they have actually had any practical impact. As an example, after ten years following the Halifax Declaration's Action Plan ("Halifax Declaration," 1992), the highest implementation rate of the proposed initiatives was below 50 % (Wright, 2003).

To overcome the HEIs lack of commitment to fulfill the purpose of the declarations, several methodologies, models and tools have emerged. They have been reviewed in literature, acting in the different stages of the sustainability process: a) implementation (Amaral et al., 2015; Testa et al., 2014); b) assessment (Berzosa et al., 2017; Fischer et al., 2015; Shriberg, 2002; Yarime and Tanaka, 2012); and c) reporting (Alonso-Almeida et al., 2015; Ceulemans et al., 2015; Lozano, 2011; Yarime and Tanaka, 2012).

Despite the wide diversity of available tools, there is no current information on the status of application of many of these tools. Currently, international rankings such as UI GreenMetric

(Lauder et al., 2015; Suwartha and Sari, 2013) or rating systems such as STARS (Fischer et al., 2015; Lidstone et al., 2015; Yarime and Tanaka, 2012) have gained prominence, becoming the most used in practice, since universities are able to audit, compare and communicate their performance with each other and with stakeholders.

Whatever the model used for implementing sustainability, top-down and bottom-up are possible approaches. Nonetheless, both show weaknesses, as North and Ryan (2018) state that top-down initiatives tend to fail when arriving at the community, and Ávila et al. (2017) suggest that bottom-up initiatives may fail due to the lack of funding and support from the administrative boards. Therefore, a mixed bottom-up and top-down approach (Ramísio et al., 2019), also indicated as in-between (Brinkhurst et al., 2011), is suggested. A great potential of successful initiatives in the long term is reported, when carried out by faculty and staff, where the operations experts, often belonging to sustainability offices or centers, are included.

2.2 The contribution of operations dimension to the sustainable campus

Regardless of the type and functional program, buildings account for 30 % of total energy consumption worldwide (International Energy Agency, 2018). In the European Union, 16 % of non-residential buildings are universities and other educational institutions (European Commision, 2013). Moreover, it is estimated that approximately 70 % of the life-cycle costs of a building are incurred with operations, maintenance, utilities, and renovations (Carlson, 2012). For HEIs, this represents a huge slice of total expenditures; therefore, it is only natural that major attention is given to reducing costs and the consumption of resources in the use phase.

Overall, university campuses comprise a large amount of built-up areas with a substantial number of users, involving complex and diverse activities on a continuous basis, if residences are included. The occupancy profiles are so vast and the use of spaces so diverse that a university campus resembles a community or a city district (Ávila et al., 2017; Gu et al., 2019). In fact, environmental concerns are quite similar to those verified in urban districts or communities, involving not only greenhouse gas (GHG) emissions and the consumption of resources such as energy, water, materials and food, but also the management of transportation and waste production.

Under the so-called *operations* umbrella, the environmental performance of buildings, facilities and outdoor spaces may be improved with specific actions and initiatives that may produce higher savings on a short to medium term basis. This may explain the attention that the field of operations has been receiving in literature, when compared to other aspects such as education or outreach (Yarime and Tanaka, 2012).

The maintenance and management of facilities is frequently under the supervision of technical departments that report to the administration or the rectorate and are not necessarily related to faculty or research. Sustainability concerns have brought new challenges to these teams, since these require an integrated approach, which include aspects typically dispersed and performed independently by diverse staff members, as is the case of energy, waste, food or purchasing areas. Therefore, sustainability offices play a crucial role, assuming diverse typologies (Adomßent et al., 2019; Soini et al., 2018), where the operational aspects are predominant (Filho et al., 2019). The main advantage of these structures is to gather qualified and motivated people for the holistic implementation of actions, campaigns or projects, able of engaging the academic community. As also pointed out by Filho et al. (2019), specific campus operation issues may only be correctly addressed by HEI technicians. Consequently, providing staff with training and/or guidelines is also an essential task in order to involve all those concerned in the conservation of resources (Ferrão and Matos, 2017). Acting towards reducing consumption and increasing the efficiency of university buildings is not only a mission for the technical staff; it is a unique opportunity of working in a living laboratory where actions may be planned, implemented, monitored and evaluated by professors and students, as Shahidehpour and Clair (2012) have illustrated.

2.3 Drivers and challenges to the sustainable campus

A recent body of literature has sought to analyze quantitatively and/or qualitatively what have been the greatest challenges to adopting and disseminating sustainability-related aspects within institutions. The same methodology has been used across the board, through either interviews with decision makers and administrators or questionnaires to the academic community or experts. However, several studies show low response rates, which rises concern on the significance of the results.

Table 1 summarizes research related to the campus operations field. All the references were based on the abovementioned methods, which signifies that they derived from academia engagement and thus, from empirical data. The results present the most important challenges detected.

Table 1. Drivers and barriers to the sustainability implementation.

Ref.	Survey objectives	Drivers	Barriers	Nr. of HEIs
Wright and Horst (2013)	Faculty leaders' perception of sustainability and barriers to implementation	Funding Administration support Academia engagement	Lack of funding Lack of leadership support Governance models	32 (Canada)
Leal Filho et al. (2013)	HEI policies to SD and the relation with successful initiatives	Existence of internal SD policies increases the probability of implementing initiatives	-	35 (worldwide)
Ralph and Stubbs (2014)	Factors influencing sustainability integration in Australian and English HEIs	Existence of internal policies Administration support	Lack of expertise Lack of understanding	4 (Australia)
		Funding Existence of internal policies	Lack of funding Lack of resources	4 (England)
Disterheft et al. (2015)	Participatory approaches in sustainability initiatives	Specific skills and participatory competences	Inexistent or deficient institutional and personal engagement	15 + 36 (worldwide)
Lozano et al. (2015)	Relation between commitment on declarations and sustainability implementation	Signing a declaration is a driver for sustainability implementation, but not *sine qua non* condition	-	70 (worldwide)
Brandli et al. (2015)	Preconditions and barriers of implementing sustainability in Brazil	Administration support Academia engagement Communication, training	Lack of policies Lack of interest Lack of know-how	6 (Brazil)
(Maiorano and Savan, 2015)	Obstacles in implementing energy efficiency measures	Revolving funds	Reluctance of HEI leaders Other priorities Lack of information	15 (Canada)
Leal Filho et	Obstacles in implementing	-	Lack of leadership support	269

al. (2017)	sustainability		Lack of resources Lack of interest Lack of a committee	(worldwide)
Blanco-Portela et al. (2018)	Drivers and barriers to the implementation of sustainability in Latin America	Existence of internal policies Leaders commitment Staff commitment Funding	Inexistence of internal policies Lack of leadership support Lack of staff training Lack of resources	45 (Latin America)
Aleixo et al. (2018)	Challenges to sustainability implementation in Portugal	Funding Community engagement Cultural exchange, interdisciplinary	Lack of resources Lack of know-how Resistance to change Organizational structure	4 (Portugal)
Leal Filho et al. (2018)	Challenges and barriers to climate change research	-	Lack of funding Lack of expertise Lack of resources Lack of interest	82 (worldwide)
Leal Filho et al. (2019a)	Role of innovation in sustainability	Implemented innovation projects are mostly related to operations Allows raising awareness	-	73 (worldwide)
Leal Filho et al. (2019b)	Commitment level in energy efficiency and renewable measures	Administration support Funding	Lack of funding Lack of resources Lack of interest	50 (worldwide)
Leal Filho et al. (2019c)	Barriers to planning in implementing sustainability	-	Lack of funding Lack of resources Lack of leadership support	39 (worldwide)
Leal Filho et al. (2019d)	Sustainability offices and barriers to their implementation	Allows raising awareness Academia engagement Curricula improvement	Lack of funding Lack of leadership support Lack of interest Lack of resources	70 (worldwide)
Ávila et al. (2019)	Innovation and sustainability barriers	-	Lack of leadership support Lack of resources Lack of a committee	283 (worldwide)

It is clear that the barriers to implementation are common to a variety of sustainability issues, such as the lack of funding, lack of human and technological resources, lack of support from administration, and resistance from staff, students or directors in moving forward. In this sense, even initiatives within a technical area as is the case with operations, are strongly influenced by internal social, organizational and economic policies and constraints. This analysis is consistent with previous results based on other methods found in literature (Barth, 2013; Godemann et al., 2014; Hoover and Harder, 2015; Velazquez et al., 2005). Despite such barriers, respondents also reported the support from management, funding and/or community engagement as the main motivators to the successful implementation and prosecution of sustainable university principles.

The specific field of operations is mostly driven by financial incentives and regulatory compliance, and usually obstructed by the lack of leadership support or by resource constraints (Ralph and Stubbs, 2014). Several strategies may overcome these obstacles. Simple no-cost actions such as awareness campaigns or switching off equipment during unoccupied periods are explored by Gul and Patidar (2015) and by Ferrão and Matos (2017). However one of the most cost-effective may be the paid-from-savings scheme, where funds resulting from energy conservation measures are applied on financing further energy-related projects (Faghihi et al., 2015), even when reluctance hinder its establishment (Maiorano and Savan, 2015).

3 Material and Methods

The literature review was carried out by focusing exclusively on scientific documents published since 2010. These were collected by searching on Science Direct and Google Scholar websites, with the keywords “sustainab”, “university”, and “campus”. A total of 357 publications were retrieved, of which 250 were journal articles, 38 conference proceedings, 66 book chapters and 3 others.

The articles were organized according to the field of sustainability in HEIs: Education, Operations and Governance.

Within the collected publications, 120 were selected as they report actions and initiatives in the area of Operations that were actually implemented, thus allowing ranking the most common practices, as well as identifying their impact according to eight key subareas. This terminology is based on the STARS rating scheme (AASHE, 2017) and can be briefly described as:

- Energy: initiatives comprising mostly the deployment of energy generation systems from renewables and respective distribution and storage;
- Buildings: initiatives that act on the energy performance of buildings, being related to active systems or passive design;
- Waste: initiatives related with reducing solid waste production, by reducing, recycling

and/or reusing actions. Diverse types of waste are considered, such as food waste, consumable materials or hazardous waste;

- Water: initiatives related with water management and treatment, the second most consumed resource on campuses;
- Transportation: initiatives that promote sustainable transportation systems serving campuses and their community, namely by decreasing the prevalence of fossil fuel vehicles or by proposing alternative means of commuting;
- Grounds: initiatives on campuses public and open spaces, as the management of sustainable landscape and healthy ecosystems;
- Air and Climate: initiatives related with the reduction of GHG and other pollutant emissions and improvement of the air quality, either indoor as outdoor. In addition, initiatives to counteract climate change on a wider perspective of environmental footprint;
- Food: initiatives related with commitment with sustainable food systems, which intend to mitigate environmental and social impacts of industrial food production, by privileging organic ingredients and/or local producers, also reducing pollution associated to transportation.

Additionally, 112 articles presenting universities as case studies were also reviewed. These focus on the development of methods and tools for implementing sustainability-related actions, and even when not effectively executed, they help to understand the current trends on sustainable campus scientific research.

The complete and detailed description of the initiatives and of the case studies is accessible in the Supplementary Material. A total of 424 initiatives were retrieved from the mentioned 120 articles, along with 201 case studies from the 112 articles, respectively. These are organized according to the eight subareas related to campus operations and provide information on the methodologies used and the results achieved, according to the available data in literature.

4 Results and Discussion

4.1 Actions and initiatives on sustainable campus operations

4.1.1 Overview

In line with Velazquez et al. (2006), and according to Figure 1, results show that the highest number of actions are associated with the energy paradigm. It is noticeable that Energy and Buildings, the subareas that present the greatest number and diversity in initiatives, are related. The Buildings subarea involves measures to reduce energy consumption and the Energy subarea comprises actions to increase energy generation and distribution at the campus level. This disparity may be justified by the larger and more visible savings in these areas, which allow HEI decision-makers to expect a likely and tangible return on their investment. In addition, there is a global awareness that energy is one of the major contributors to environmental footprint, and acting on the reduction of energy consumption is also linked to reducing embodied GHG emissions.

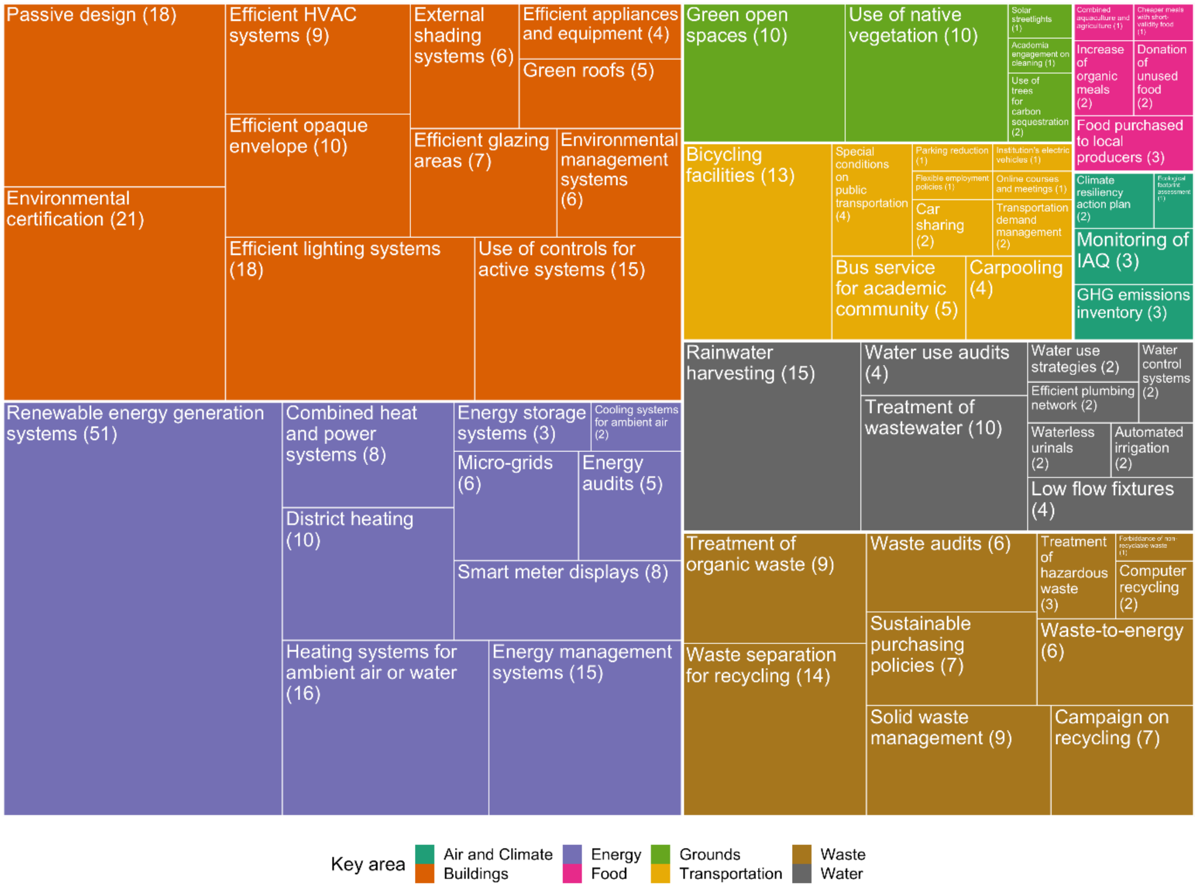

Figure 1. Number of initiatives distributed by operations subareas.

In general, the focus on renewable sources for energy generation is the most substantial initiative (12 % of the 424 initiatives), and summing its application to water and/or ambient heating and to combined heat and power (CHP) systems, a significant expression is reached (4 % and 2 %, respectively). This trend is in line with the transition from high-emission fossil fuels to clean energy systems to meet the climate targets and the energy independency of national policies. However, energy supply from renewable sources is reported as covering rather a disparate percentage of the annual electricity demand – from 3,76 % (Kalkan et al., 2011), between 35 % and 40 % (Eggleston, 2015; Helling, 2018; Radhakrishnan and Viswanathan, 2015) and above 80 % (Kobiski et al., 2015) to almost the overall electricity demand (Walker and Mendler, 2017). Thus, results on its feasibility are not consensual. Kalkan et al. (2011) consider it is not a profitable investment, while Paudel and Sarper (2013) consider it is, showing a payback period of 8 years. Supporting initiatives may allow surpassing undesired results, such as the use of energy storage systems and the implementation of microgrids. Machamint et al. (2018) concluded that the benefits of the microgrid compensate the investment cost, and Shahidehpour and Clair (2012) and Washom et al. (2013) showed that the combination of renewable generation and microgrid can supply 50 % and 92 % of campus electricity load, respectively. This illustrates how acting only on the supply side may be reductive if omitting the demand side. Accordingly, Leal Filho et al. (2019) concluded that a majority of HEIs are committed to energy efficiency and the implementation of renewables, however these cover a small portion of energy demand.

The environmental certification of university buildings, especially by LEED, is the second most found initiative (5 %) although results are not unanimous. While Petratos and Damaskou (2015) state that LEED-certified university buildings are designed to consume less 50 % than other similar buildings, some studies show that these may consume more energy than non-certified ones (Agdas et al., 2015). Therefore, the use of this rating system may be justified with the fact that majority of the participating HEIs are North American and listed on STARS ranking, which foresees the LEED certification of university buildings – from the 26 North American HEIs that have LEED certification, 19 are ranked at STARS (STARS, 2019). In addition, the BREEAM-certified examples show how buildings designed to achieve a certification do not necessarily demonstrate improved performance in the operational phase, as there may be a gap between estimated and monitored consumptions (Forman et al., 2017; Gupta and Gregg, 2016). Inappropriate building management systems and erroneous prediction of end-user energy behavior are some possible causes.

The most consistent results are related to initiatives in the Buildings subarea, with either passive design actions or active systems. Carlson (2012) highlights a reduction in energy use of 70 % from passive building design, being 80 % more efficient than a conventional building. More specifically, the improvement of efficient opaque envelopes through thermal insulation shows a substantial reduction in building energy demand (Geng et al., 2013). Reductions in energy consumption for lighting and air conditioning systems are reported to vary between 7,5 % (Escobedo et al., 2014) and 40 % (Opel et al., 2017), and reach up to 60 % (Jain and Pant, 2010).

Other initiatives and subareas stand out: the treatment of wastewater (2 %), rainwater harvesting to be used in the irrigation of green spaces (4 %), which Edwin et al. (2015) demonstrated saved from 25 % to 30 % of water used on irrigation, while Walker and Mendler (2017) indicated a percentage of 100 % of wastewater treated onsite; the waste separation for recycling purposes (3 %), which increased separation and recycling rates (Geng et al., 2013; Reidy et al., 2015); the adoption of a bicycling culture, namely through support facilities, “pick-and-ride” schemes or for internal small cargo transportation to reduce the use of motorized vehicles on campus (3 %); and the use of native plants in green open spaces (2 %).

The variation in results of each initiative is attributed to local specificities, but also to the type of use, as occupant behavior significantly influences energy and resource consumption in university buildings. Masoso and Grobler (2010) argue that more than half of the energy in a Botswana university is consumed during non-working hours, as occupants leave lights and equipment always on, becoming evident the importance of altering the use of energy services, in particular users’ behaviors and/or control automation. Although in a reduced number, some initiatives seek to motivate students and staff in reducing resource consumption and waste generation. The use of real time smart meter displays purposely designed for users control (2 %) has shown a reduction in energy demand ranging from 6,4 % to 9 % (Boulton et al., 2017; Chiang et al., 2014; Sintov et al., 2016). In the subarea of Waste, several campaigns on recycling and on the reduction of paper use (2 %) have revealed that about 74 % of academia has changed their behavior (Cole and Fieselman, 2013), an increase of 10-12 % in the overall campus recycling rates (Tangwanichagapong et al., 2017) and a reduction of up to 58 % on paper use (Zen et al., 2016). In Grounds subarea, a study reported the involvement of all the academic community in cleaning the campus' public open areas, promoting the discussion of beneficial practices for the environment (de Castro and Jabbour, 2013). Despite all these initiatives, Transportation is the subarea that obtains the greatest contribution from the community. All of the initiatives (8 %) were related to the decrease in use of fossil fuel vehicles. The use of automation for active systems is another reported strategy to deal with detected energy waste. The use of controls for artificial lighting, systems setpoints, temperatures and/or gas use during unoccupied periods represents 4 % of the initiatives; Granderson et al. (2011) account for a reduction between 30 % to 35 % in energy demand, and Coccolo et al. (2015) estimate about 13 % in heating demand due to changing air-conditioning setpoints. Integrated energy management systems are more comprehensive solutions to control active systems (4 %), namely the HVAC schedules, lighting and appliances, allowing it to be done remotely with the help of information and communications technologies (Ferrão and Matos, 2017; Gomes et al., 2017). Reidy et al. (2015) and Gomes et al. (2017) report a reduction of 20 % and up to 40 % in energy consumption, respectively. A combination of approaches was described by Kettemann et al. (2017) in which a mobile application with interactive maps allows all stakeholders to report any environmentally relevant observation.

Several initiatives are interrelated and show how adopting a holistic approach and/or working under a global plan can be beneficial. For example, the use of native plants on campus landscape, contributes not only to the CO_2 capture (Oyama et al., 2018; Sundarapandian et al., 2014) but also to the conservation of local biodiversity and the reduction of water use for irrigation (Radhakrishnan and Viswanathan, 2015). The treatment of organic waste from university restaurants is commonly used as fertilizer for the campuses' green spaces (de

Castro and Jabbour, 2013; Eatmon et al., 2015; Jain and Pant, 2010; Najad et al., 2018; Nandhivarman et al., 2015; Reidy et al., 2015). The "waste-to-energy" principle is also conveyed, with examples of electricity or biogas generation from waste sources (Bauer, 2018; Helling, 2018; Nandhivarman et al., 2015; Tu et al., 2015). A significant reduction in petroleum gas use (Nandhivarman et al., 2015) and CO_2 emissions (Tu et al., 2015) is reported. This strategy draws up a good example of a circular economy, and may bring an important contribution to decreasing HEIs environmental impact, by closing the loop on two crucial actions – energy generation and waste treatment – as further supported by the European Commission (Antoniou et al., 2019; Pan et al., 2015).

In general, articles reporting practices and initiatives are not precise in describing the methods used to apply the reported actions. This in turn denotes that limited information is available on the methods and tools applied in real context. In addition, even though a significant amount of initiatives is described, neither the impact nor the achievements are provided, making it difficult to quantify their importance, especially in indicators as Grounds, Air and Climate or Food.

4.1.2 Framework of initiatives in national scenarios

Initiatives found in literature involve 106 HEIs dispersed over the world in 31 countries, North America and Europe being the regions with the highest number of identified institutions (see Figure 2).

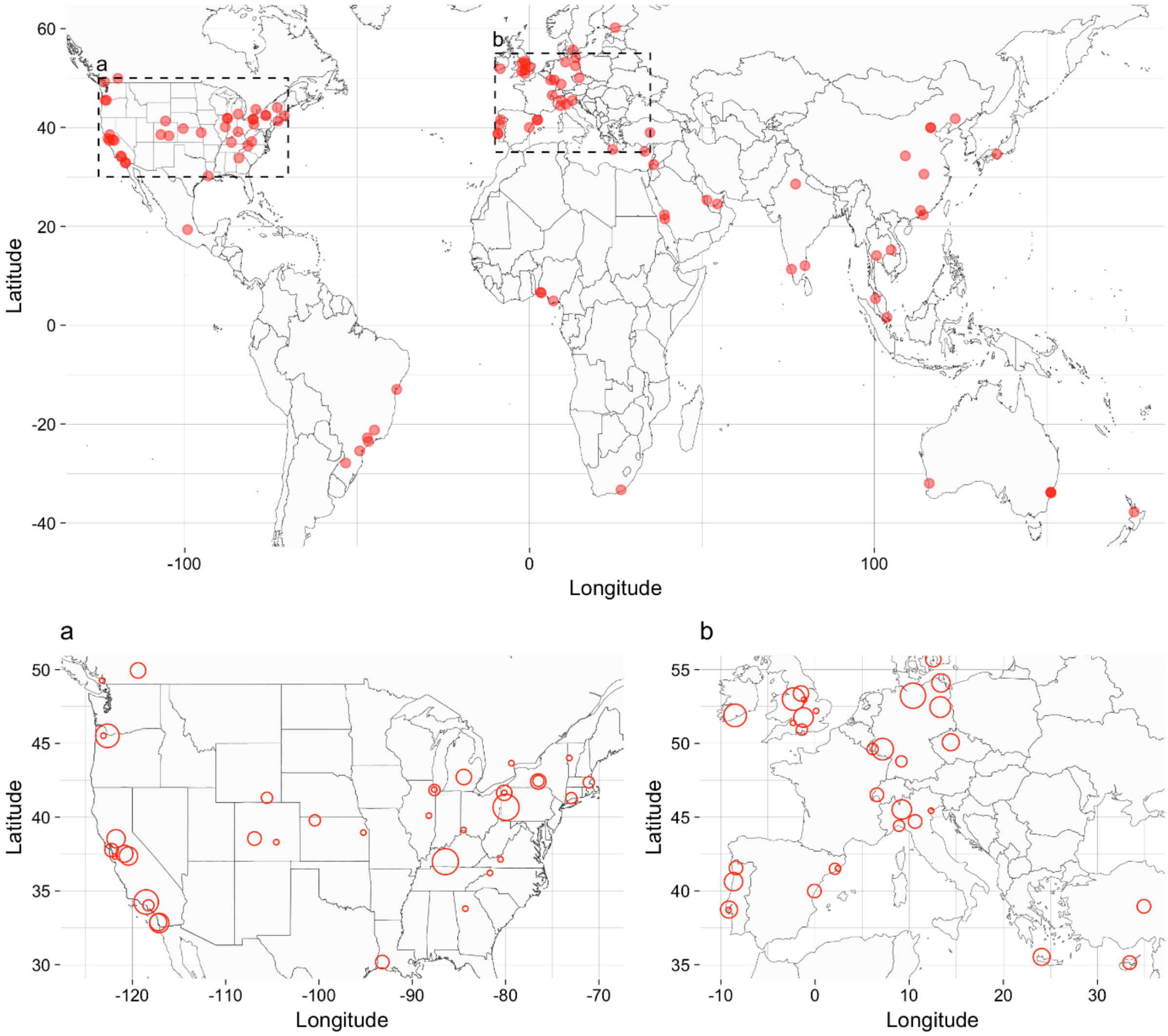

Figure 2. World weighted distribution of the HEI involved in the initiatives found on literature.

When comparing the total number of existing HEIs listed in Scimago (Scimago, 2018) and the number of identified HEIs, these represent 3 % of a total of 3234. As may be observed in Figure 3, the ratio between participating and total HEIs by country is notably low. As an example, the USA is by far the country with the most reported publications and actions; however, when compared to the national panorama, only 34 out of 432 institutions were identified, which represents about 8 % of American HEIs.

This finding is corroborated by the conclusions presented by Lozano (2011) and Townsend and Barrett (2015), who report the lack of commitment from HEIs in measuring and reporting the progress of sustainability initiatives. Luxembourg must be seen as an exception, since the country only has one HEI, which justifies the percentage of 100 % of the university' publishing initiatives. Yet, it is acknowledged that other studies and other countries may have been left out of this review derived from the search method used.

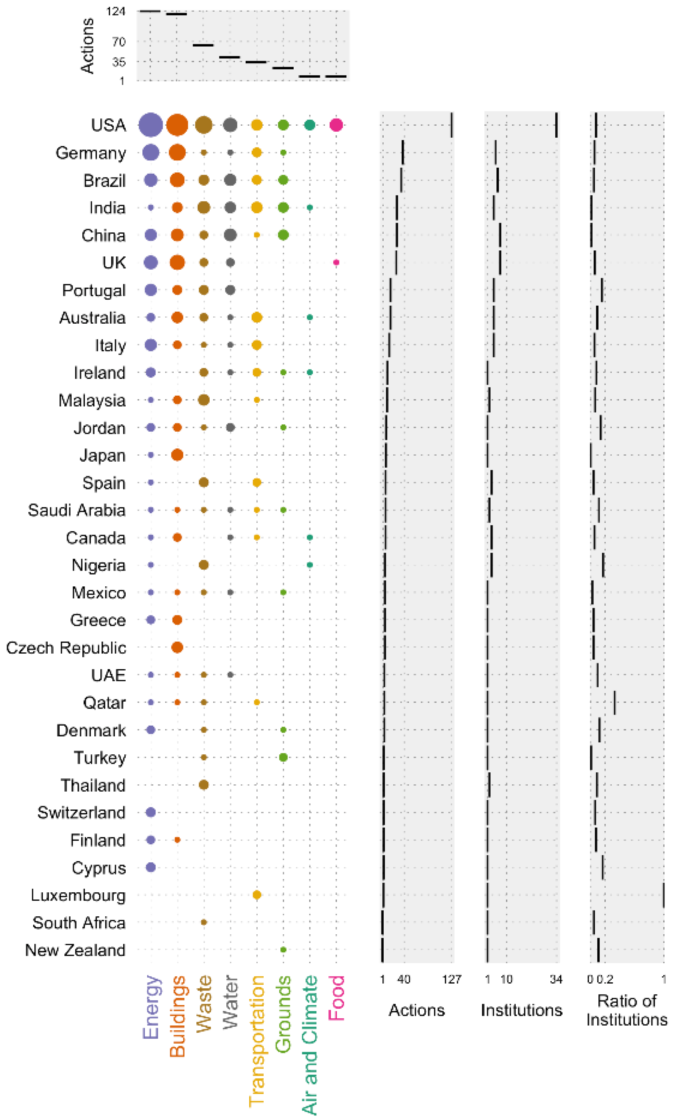

Figure 3. Association between the number of initiatives and institutions by country, and ratio of the participating HEIs and the total number of HEIs by country.

Given this wide range of initiatives and the dispersion worldwide, the establishment of a qualitative framework helps to understand the extent to which they are related to local circumstances. The latest available data for key indicators for each country are explored, such as national wealth (World Bank, 2017), resource consumption (Food and Agricultural Organization of the United Nations, n.d.; International Energy Agency, 2016), waste generation (World Bank, n.d.) and CO_2 emissions (Global Carbon Atlas, 2017), in order to test the hypothesis of certain cause-effect relationships between the value of these indicators and the promoted initiatives in each HEI.

Figure 4 and Figure 5 display the grouping of initiatives per type of consumption or generation along with a comparison between national indicators and initiatives. The USA presents the highest energy values as well as the highest number of initiatives related to Energy, particularly to renewable energy systems. Similarly, it is also the country with the highest waste generation and the highest number of initiatives related to Waste, and the same is noticed in the Transportation subarea. However, it is not possible to establish any other association, as none of the remaining countries or initiatives seem to be related to the value of energy and water consumption, or to waste generation or GHG emissions. On the contrary, China carries higher values of waste generation and CO_2 emissions but a lower number of initiatives on Waste and none on Air and Climate. In this sense, with the available data it is difficult to establish a relation between the national scenarios for resources consumption, waste generation and/or GHG emissions and the actions taken by HEIs.

Figure 6 compares all of the identified initiatives with the gross domestic product (GDP) of the countries where they were promoted (World Bank, 2017). The aim is to understand whether the initiatives that required a large initial investment, namely those based on technologies such as energy generation and distribution systems, or active buildings systems, as lighting, HVAC or equipment, are associated to high-income countries.

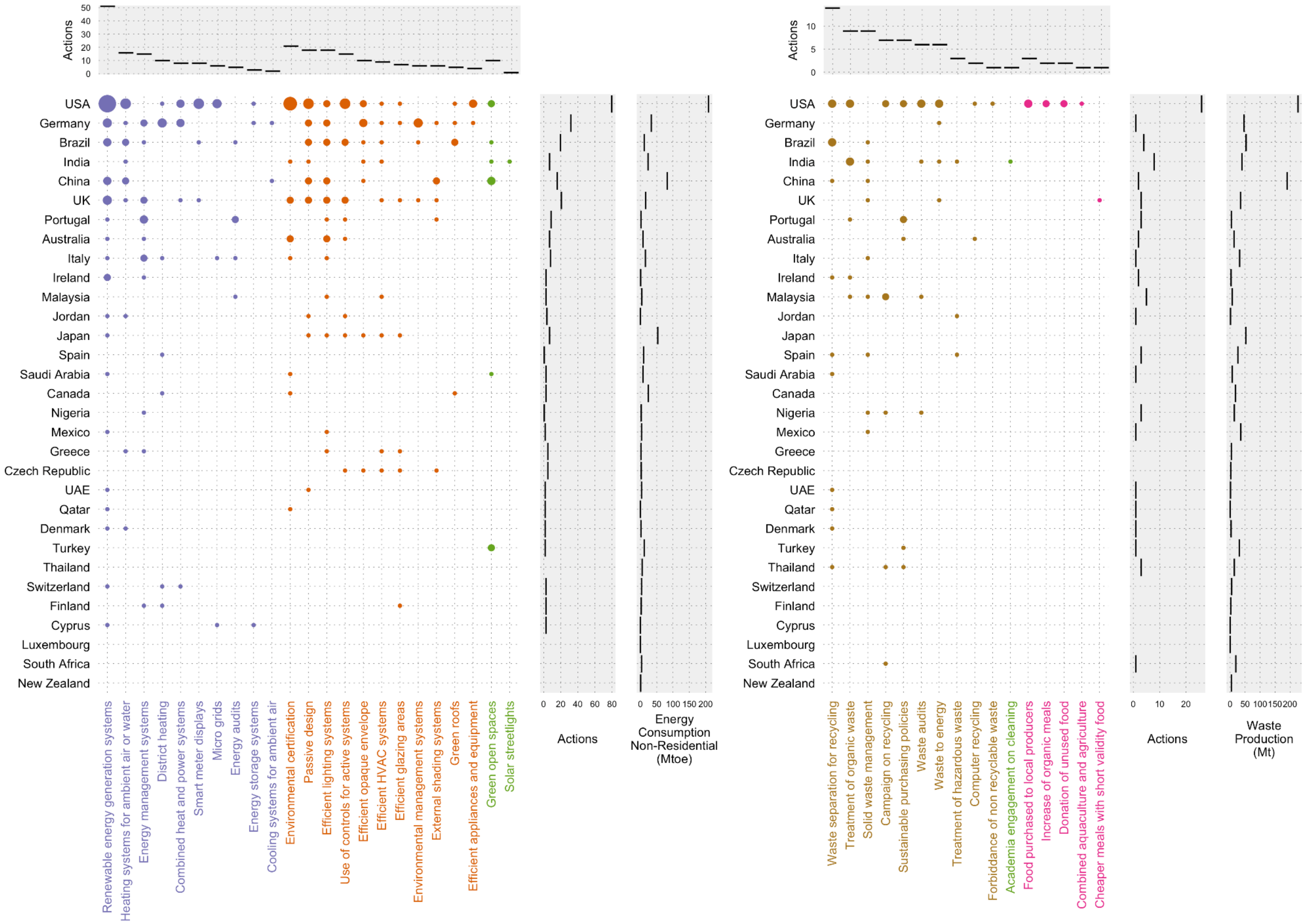

Figure 4. Energy consumption and waste production related actions by country. Data sources: International Energy Agency (2016); World Bank (n.d.).

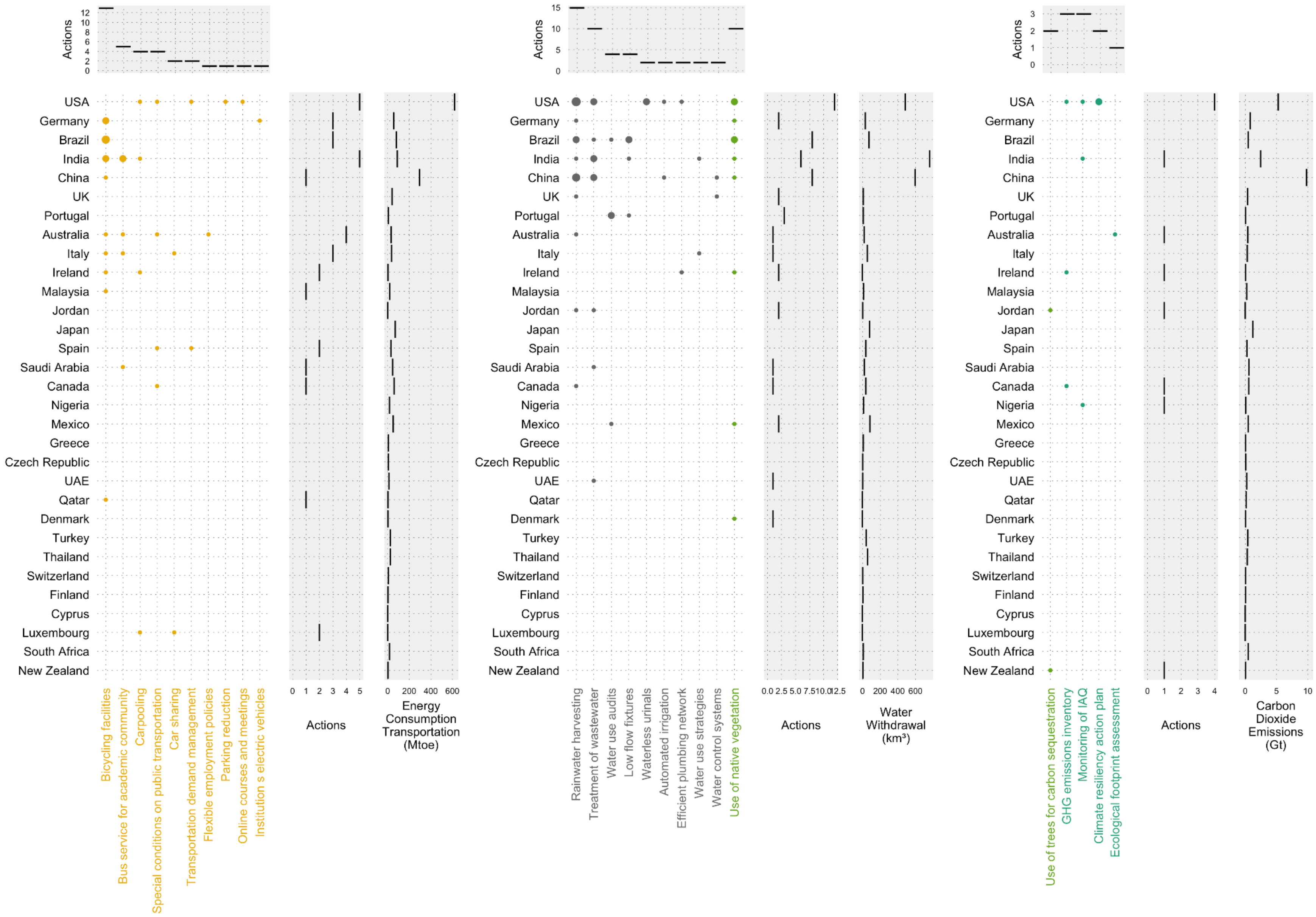

Figure 5. Energy consumption in transportation, water withdrawal, and CO2 emissions related actions by country. Data sources: Food and Agricultural Organization of the United Nations (n.d.); Global Carbon Atlas (2017); International Energy Agency (2016).

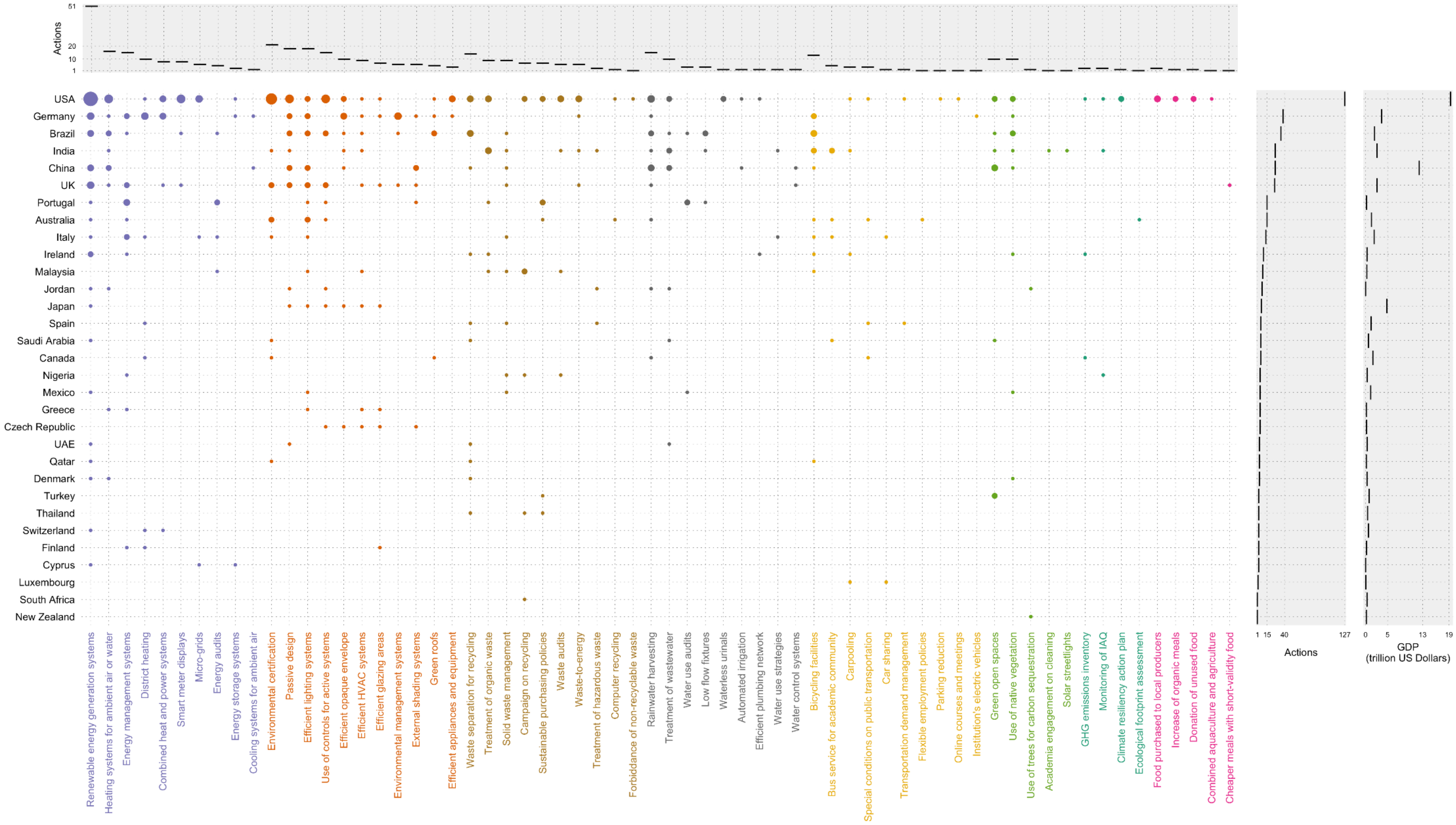

Figure 6. Initiatives in each subarea and the GDP by country. Data source: World Bank (2017).

Again, the USA shows a high GDP and the highest number of initiatives in Energy as well as in other subareas. In fact, high-income countries such as the European member-states tend to invest more on Energy and Buildings initiatives. However, there is no linear association. For instance, China presents the second highest GDP value, but a low number of initiatives that require a large initial investment. It is noticeable that the percentage of participating countries GDP does not correlate to the percentage of initiatives; nonetheless, a trend is apparent denoting a higher number of initiatives with higher income countries. In order to further analyze this relationship, other factors should be explored, in particular the existence of local or governmental incentives and/or financing programs for the adoption and implementation of energy generation or efficiency measures that are available in some countries (ACEEE, 2018; Sustain, 2017). The example given by Drahein et al. (2019) providing information on the inexistence of financing programs for energy or water efficiency in Brazil, could help to understand the significant number of initiatives found in other areas that do not require initial support, such as Waste. However, the lack of detailed information, either in the reviewed articles or in web contents, inhibited the possibility of an accurate and transversal analysis, leaving it open for further investigation.

Some survey-based studies mention a relation between geographical distribution and particular drivers and barriers. Ralph and Stubbs (2014) highlighted different English and Australian national contexts and specific governmental requirements, which justifies the slight variances found in HEI motivations. Molthan-Hill et al. (2019) found a geographical pattern in HEIs regarding the importance given to climate change. Salvia et al. (2019) investigated the extent to which the various approaches to SDGs are related to local contexts, and noticed a possible relation between local challenges and the areas of interest that SDGs provide. Also, some of these surveys showed that there has been a stronger interest in bringing sustainability forward in HEIs in Europe than in other continents (Leal Filho et al., 2019a; Lozano et al., 2015). However, Blanco-Portela et al. (2018) show that the typology of difficulties and stimuli to the implementation of sustainability in Latin American HEIs is similar in all the inquired countries. Ávila et al. (2019) found that, even with different levels of adoption maturity of innovation and sustainability in each continent, the same barriers are found in all geographies. They concluded that developed countries are leading in sustainability implementation, while developed ones were considered laggards, which is in accordance with the trends observed in this work.

4.2 Case studies on sustainable campus operations

Articles using universities as case studies show current concerns and advances in research in this specific domain reflecting, in some cases, the attempt to tackle real challenges and difficulties that universities face. However, there is no evidence that the conclusions of these studies have any real execution.

Figure 7 displays the distribution of published case studies by each operations subarea. Unlike the initiatives, each publication usually focuses on the description of one case study in a specific subdomain.

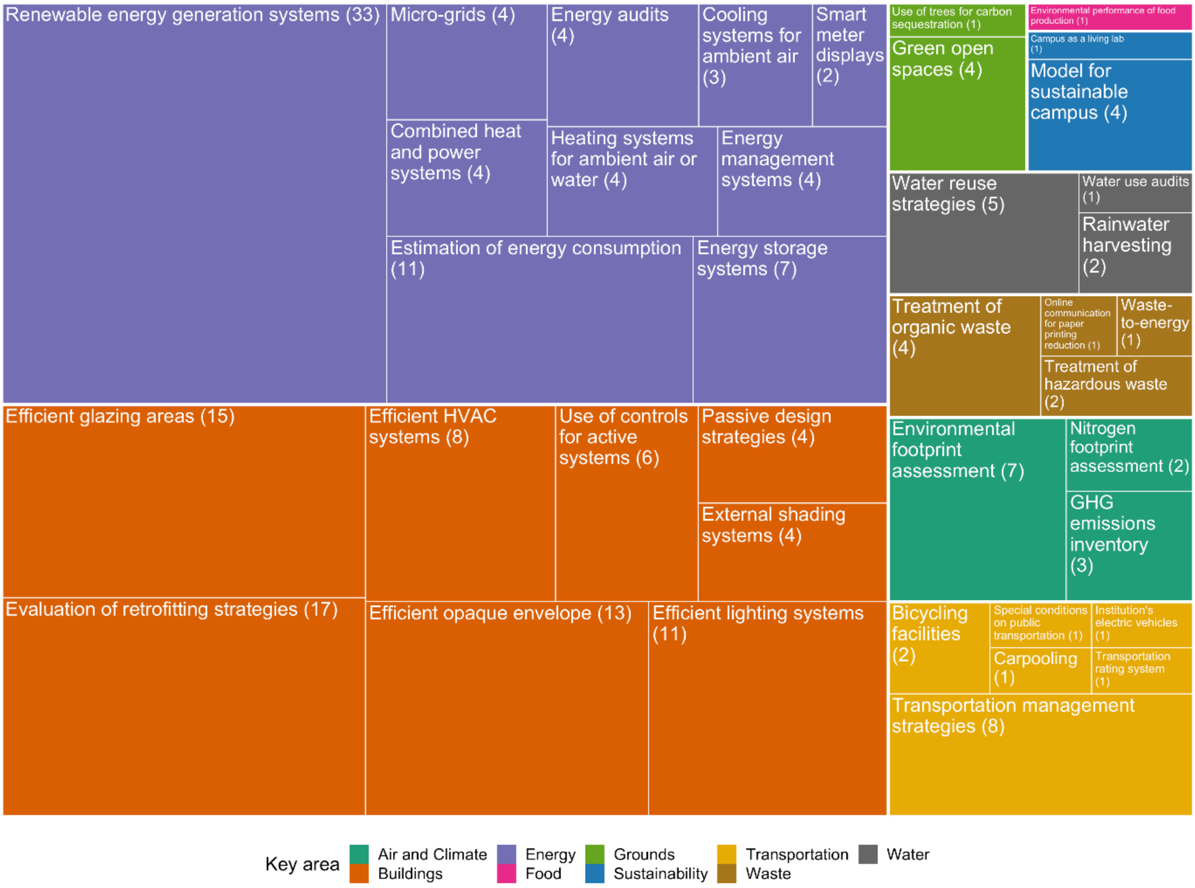

Figure 7. Number of case studies distributed by the operations subareas.

Energy and Buildings remain the most studied indicators (both expressing 37 %) and, contrary to the reporting on implemented actions, exploration and development of methodologies and tools are the principal focus of these studies.

Regarding Energy subarea, literature has been converging to the studies of renewable energy generation potential and the estimation of buildings energy consumption to better act on its reduction. Photovoltaic systems are prominent, representing 38 % of the case studies on renewables, however the combination of sources has created a growing interest (18 %), as well as the methods for optimizing their management (Bonanno et al., 2012; Bracco et al., 2014; Dursun, 2012; Ghenai and Bettayeb, 2019; Park and Kwon, 2016). These may contribute to a cost-effectiveness that Kalkan et al. (2011) and Kwan and Kwan (2011) stated was not always possible when a single source is used – in these cases, solar.

Simulation software is the tool most commonly employed to assess the potential and feasibility of diverse renewable sources (20 % of Energy), and their possible combination and integration on microgrids, according to each campus conditions (Çetinbaş et al., 2019; Dursun, 2012; Mancini et al., 2017; Manni et al., 2017; Mewes et al., 2017; Mytafides et al., 2017; Park and Kwon, 2016). Learning algorithms are used as surrogate methods for simulation (12 % of Energy), in order to produce robust estimations of energy consumption (Hawkins et al., 2012; Jovanović et al., 2015; Yuan et al., 2018).

Regarding the Buildings subarea, there is an attempt to improve current energy and thermal performance of university buildings through the analysis of various retrofitting strategies. Again, simulation engines are the ones most employed in this area (44 %) to evaluate the impact of improving thermal insulation of roofs and façades, the glazing type of windows (Ascione et al., 2017; Manni et al., 2017; Mytafides et al., 2017; Zhou et al., 2019) or even the replacement of the existing lighting system (Fonseca et al., 2018). Life Cycle Assessment (LCA) is commonly used as well, when the objective implies a broader perspective and an analysis of the environmental impacts of retrofitting measures along the lifespan of the buildings (Huang et al., 2012; Tabatabaee and Weil, 2017).

In what concerns the other indicators, the scarcity of publications is notorious. Nevertheless, LCA remains a procedure widely used in areas as diverse as Transportation, Waste or Air and Climate (11 % of the total case studies). It is applied in the evaluation of management strategies for parking on campus or the shift from private cars to public transport (Cruz et al., 2017); in the comparison of the environmental impact of using information in paper or electronic (Ingwersen et al., 2012); or even to estimate the total CO_2 emissions of a university campus, taking into account the direct emissions of facilities, the indirect emissions of purchased electricity and others, namely from commuting or waste (Sangwan et al., 2018).

Of these subareas, Transportation and Air and Climate display the largest number of articles (14 and 12 studies out of 53, respectively). The evaluation of the implementation potential of soft modes of transportation, such as bicycling, are noteworthy (Çelebi et al., 2019; Peer, 2019; Ryu et al., 2019; Zhu et al., 2019). Regarding Air and Climate, the assessment of environmental impacts of the whole campus, of which the development of methodologies to estimate GHG emissions and mitigation policies (Leach et al., 2013; Medina and Belcena, 2018; Sangwan et al., 2018; Williamson, 2012) is highlighted. Also, broader studies were found approaching a more general concept of sustainability on campus; the proposal of a Green Campus model based on Multi-Criteria Decision Analysis for operations indicators (Ribeiro et al., 2017); the proposal of a holistic tool covering all indicators, acting as an open system by allocating a database with international implementation experiences (Baletic et al., 2017).

The developed methodologies and tools are further clarified and thoroughly described in research that uses the universities as case studies, either to develop exercises or to plan future actions. However, in these cases it is not clear when a university is simply used as a case to experiment a methodology, to develop an isolated exercise, or whether it is part of a wider sustainability plan. Nevertheless, theoretical exercises as those carried out by of Gul and Patidar (2015) or Costa et al. (2019) demonstrate their importance in raising awareness to improve management decisions and policies against actual conditions.

5 Conclusions

Regardless of the vast amount and scope of initiatives, this work provides supporting information in the identification of strategies and opportunities for institutions to improve environmental sustainability, with tested results on real case scenarios.

By outlining the actions and institutions, not only a better understanding of the intervention areas and their success is provided, but also the barriers to their implementation, disclosing the impact of possible technical or local context reasons, in addition to those already discussed in literature. Moreover, it shows that technical activities and sustainability implementation in campus operations may not be the responsibility of the same actors. Having specialized teams, namely sustainability offices, has been a valuable contribution to advancing the cooperation and alignment on decisions and actions. Assuming the campus as a living laboratory may represent a significant contribution to training in a sustainability-learning environment, to stimulate scientific research in this field, and also to foster the adoption of more sustainable behaviors in the future.

The reported initiatives and HEIs are strongly diverse and dispersed worldwide, and do not present relevant relations between national indicators for resources consumption, waste production, emissions generation and the actions taken. However, some trends were identified, being perceivable that HEIs from upper middle- and higher-income countries tend to implement more sustainable initiatives. The results are also highly variable between universities, due to the specificities of each campus, culture, climate or policies.

The field of operations is the most endorsed in literature, particularly in the area of decreasing energy consumption in buildings and increasing the use of renewable energy on campus, both in practical situations and in case studies. A small number of studies focused on subareas such as Grounds, Air and Climate, and Food for implemented initiatives, and Waste and Water for case studies were found. Moreover, the limited results and the lack of a connection between initiative and impact can hinder reaching definite conclusions on the efficacy of implementing the proposed initiatives. Regardless of the methodology to be adopted, a sustainability culture reflected in an integrated strategy seems to produce better results, rather than implementing isolated actions, as demonstrated by the greater impact of the studies presenting a combination, either in one or in various subareas.

This analysis also suggests that the successful implementation of sustainable initiatives in HEIs is strongly influenced by internal social and governance restraints even when dealing with a technical component as campus operations. In this sense, this work provides the basis for follow-up mixed-methods studies. Questioning participating countries in relation to local, national, social and economic aspects would provide useful insights into better understanding specific differences and similarities and, thus, support the choice of the best initiatives for each case. In order to contribute to a sustainable university, campus operation initiatives must bring social and economic benefits – and, as literature has shown, to be outreached. To overcome barriers, due to financial difficulties or even resistance to change, investments need to be optimized and effective, in order to show that it is worth investing in strategic actions that bring numerous benefits. An approach based on a ranking of measures with some criterion – investment, payback, energy payback time, consumptions reduction, etc. – could bring positive insights to support decision-making.

Nevertheless, the exhaustive qualitative analysis that was carried out raises the need for a future quantitative approach, as well as an investigation into the feasibility of the implemented actions that may contribute to the development of comprehensive frameworks able to push forward the sustainable campus principles and practices.

In this sense, more research is needed – or at least, more empirical information with greater and better dissemination of plans and their results – in order to produce more robust findings, capable of being generalized and eventually inspiring for other universities.

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