ASSESSMENT OF THE ENVIRONMENTAL PERFORMANCE OF HIGHER EDUCATION INSTITUTES: THE CASE OF ITALIAN UNIVERSITIES

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ABSTRACT
Higher education institutes (HEIs) contribute to educate future generations of scientists, decision makers and politicians. To overcome the present and future challenges involving environmental protection and climate change, the education of responsible individuals who may play a key role in improving global environmental sustainability levels is crucial. To achieve this goal, HEIs themselves must be promoters of values and ideas to support sustainable development. To start, HEIs should give a good example to students and society, provide best practices in terms of environmental conservation and sustainability, and be models to follow in terms of resource efficiency, energy use and waste management. However, the commitments and efforts of HEIs in this field must be measured in an unbiased way, to ensure a correct interpretation of their achievements, and with reference to the strategies adopted by universities. This paper aims to present the results of a survey on Italian universities in terms of energy consumption and related greenhouse gas (GHG) emissions, water use and waste production. These items will be presented in a temporal trend relative to specific parameters that help to decontextualise the results from the location of HEIs. Where available, information on the strategies implemented by HEIs to improve their performance will be reported and the results will be discussed. The results show improvements in terms of thermal energy consumption, water consumption and GHG emissions, whose decrease was favoured by a progressive shift towards renewable sources of electricity. Clear conclusions on waste production are not possible due to the insufficient amount of data. The indicators analysed here may be useful to important ranking systems, developed to assess HEIs' performance worldwide, since the use of indicators that do not depend on the geographical context where HEIs are located may decontextualise the results and allow comparing different HEIs in an unbiased way.
Keywords: environmental sustainability, carbon emissions, energy consumption, environmental indicators, water consumption, waste management.

1 INTRODUCTION

Environmental sustainability has become a significant focus in higher education, driven by growing awareness of climate change and resource depletion [1], [2]. Higher education institutes (HEIs) are substantial consumers of resources, including energy, water, and materials, and important producers of emissions and waste [3], [4]. Large campuses with numerous buildings, laboratories, and residential facilities consume vast amounts of energy for heating, cooling, lighting, and powering equipment [5]. HEIs also require significant water resources for drinking, sanitation, landscaping, and research activities [6], and use substantial amounts of paper, plastics, and other materials in daily operations, from administrative tasks to laboratory work [7]. Despite the efforts made worldwide to encourage reuse and recycling, the use of materials always generates waste flows, such as residual municipal solid waste (MSW) (e.g., from the daily activities in classrooms, offices and canteens), and special waste (e.g., from laboratory and research activities) [8], [9].

However, as centres of research and innovation, HEIs play a crucial role in promoting sustainable practices [10]. Besides teaching and research, higher education has the mission

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of interpreting present and future challenges and transferring knowledge outside of university campuses, including the promotion of virtuous behaviours and the sharing of best practices for environmental preservation [11]–[13]. In Italy, this commitment was formalised by the creation of the Italian University Network for Sustainable Development (RUS) in 2016 [14]. At the end of 2023, the RUS was composed of 86 HEIs. The involvement in the RUS facilitates the communication and sharing of experiences between HEIs in terms of environmental sustainability initiatives. In addition, one of the main aims of the RUS is to spread best practices and the culture of sustainability outside universities, to positively influence the public opinion towards responsible choices in terms of resource consumption and pollution prevention. RUS members are encouraged to publish environmental sustainability reports to measure their environmental performance and present ongoing or future initiatives and projects to mitigate their environmental impacts. Thus, the RUS is also an important source of information on HEIs' data and statistics.

Considering the double role of HEIs as (i) important consumers of resources and producers of emissions and waste; and (ii) promoters of a culture of environmental sustainability, the present paper aims at critically analysing the environmental performance of Italian HEIs over a 10-year period (2012–2021) by means of a broad review of environmental sustainability reports made available by 24 universities belonging to the RUS. Each HEI does not necessarily publish a sustainability report every year, but every report contains past data that allow reconstructing the trends of each HEI in terms of several variables, including energy and resource consumption, greenhouse gas (GHG) emissions and waste production, which will be analysed in the present paper. To level out HEIs, which are characterised by different sizes and geographical locations, these types of data will be normalised against context-specific factors so that context-independent indicators will be created. Decontextualising the results allows a fair comparison of HEIs' environmental performance, and such indicators could be used to compare HEIs worldwide. The novelty of the paper is thus twofold: (1) this work carries out a decadal analysis of the environmental performance of Italian HEIs the first time; and (2) alternative indicators are proposed for unbiased comparison of environmental impacts.

2 MATERIALS AND METHODS

Environmental sustainability reports of Italian HEIs were consulted through an online search, starting from the HEIs belonging to the RUS. As many annual reports as possible were retrieved from each HEI's website, depending on their availability in terms of years covered. The purpose of this research was the creation of a database of quantitative information on different variables of interest to assess the performance of HEIs in terms of environmental sustainability. For this reason, the research focused on the following variables considered as essential to quantify HEIs' impacts:

- Electricity consumption;
- Thermal energy consumption;
- Water consumption;
- Emissions of GHGs due to electricity consumption;
- Emissions of GHGs due to thermal energy consumption;
- Residual MSW production;
- Special waste production.

Thus, this research was narrowed by excluding those reports that did not provide quantitative information on at least one of the variables listed above.

In several cases, thermal energy consumption was not directly reported, but annual data on the volume of fuel burnt were available. In this case, thermal energy consumption was calculated multiplying the fuel volume (usually expressed as Sm^3 in case of natural gas, L in case of diesel oil or liquefied petroleum gas, or, more rarely, tons of oil equivalent) by the lower heating value of the reference fuel. In many situations, the environmental sustainability reports did not provide data on GHG emissions. In such cases, if data on the fuel used for thermal energy consumption were available, the related GHG emissions were calculated multiplying the mass of fuel burnt by the respective fuel-dependent emission factor of carbon dioxide equivalent (CO_{2eq}). A similar approach could not be applied to estimate GHG emissions due to electricity consumption if information on the grid mix was not available. Thus, GHG emissions from electricity consumption were included in the database only if directly provided by the HEIs' reports or if the grid mix or the supplier was explicitly declared by the HEIs. Some HEIs declared self-production of electricity by renewable energy sources or the purchase of electricity from certified 100% renewable energy sources. In these cases, the amount of self-produced electricity or the 100% renewable energy purchased was considered as null in terms of contribution to GHG emissions.

Collecting energy and water consumption, GHG emission and waste production data was not considered enough to assess the performance of an HEI in terms of environmental sustainability. Resource consumption and environmental impacts are strongly related to both the number of users (i.e., students and staff, in this case) and the geographical context where an HEI is located. In general, the higher the number of users, the higher the consumption of resources and the environmental impacts [15]. Furthermore, the local climate greatly influences the consumption of electricity and fuel for thermal energy production [16]. For these reasons, the aforementioned variables were firstly normalised against the number of users, which was retrieved by the website of the Italian Ministry for University and Research [17]. To account for the influence of the local climate, the per-capita electricity and thermal energy consumption were further divided by the heating degree days (HDDs) of each HEI's location. The choice of this factor is supported by the high positive correlation between energy consumption in buildings and the HDDs of the buildings' locations found by Tam et al. [18]. The adoption of HDDs is also suggested by Sarkodie et al. [19] to control bias due to the local climate. The same normalisation was carried out for GHG emissions due to electricity and thermal energy consumption, given the relationship between these two types of variables. Normalising variables against these factors allow obtaining environmental performance indicators that are independent of the size of HEIs and of the geographical context where they are located. A complete scheme of the context-independent indicators chosen for this work is presented in Table 1. Those indicators will be used to assess the overall performance of the 24 HEIs considered in this paper.

3 RESULTS AND DISCUSSION

3.1 Overview on the data availability from Italian HEIs

Based on the review on the environmental sustainability reports of the 24 Italian HEIs considered, it is possible to obtain a complete picture of the available data on the variables considered in Table 1. Specifically, Fig. 1 shows the number of HEIs that reported data on at least one variable for each year between 2012 and 2021. The creation of the RUS in 2016 contributed to increasing the number of HEIs that chose to publicly document their performance in terms of actions, consumption of resources, emissions and production of

Table 1: Definition of context-independent indicators for different energy consumption, GHG emissions and waste production variables.

Variable	Context-independent indicator	Unit of measurement
Resource consumption		
Electricity consumption	Per-capita electricity consumption per HDD	kWh/user/(K·day/year)
Thermal energy consumption	Per-capita thermal energy consumption per HDD	kWh/user/(K·day/year)
Water consumption	Per-capita water consumption	m^3/user
GHG emissions		
GHG emission from electricity consumption	Per-capita CO_{2eq} emissions from electricity consumption per HDD	g_{CO2eq}/user/(K·day/year)
GHG emissions from thermal energy consumption	Per-capita CO_{2eq} emissions from thermal energy consumption per HDD	g_{CO2eq}/user/(K·day/year)
Waste production		
Residual MSW production	Per-capita residual MSW production	kg/user
Special waste production	Per-capita special waste production	kg/user

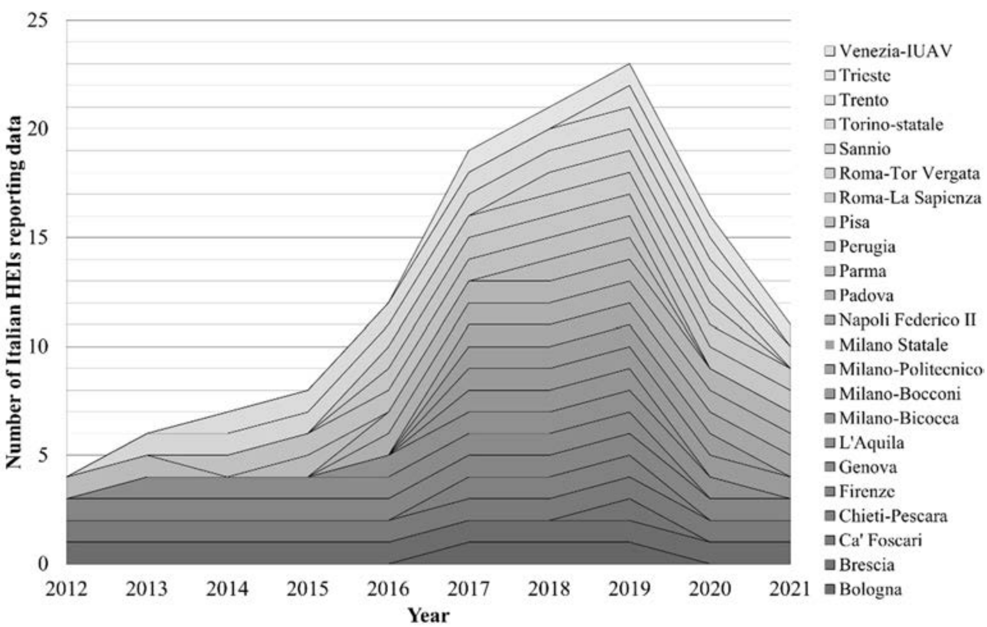

Figure 1: Time trend of the number of Italian HEIs reporting at least one variable between 2012 and 2021.

waste. Indeed, data referred to 2019 were provided by 23 out of 24 HEIs, while 7 years earlier only five HEIs published data. A decrease can be observed in 2020 and 2021, because many HEIs decide to publish data some years later to validate them.

Among the types of variables presented in HEIs' reports, the most frequently reported is electricity consumption, followed by thermal energy consumption, GHG emissions from thermal energy consumption, water consumption and GHG emissions from electricity consumption (Fig. 2). The availability of data on waste production is low, especially on residual MSW. Special waste can be tracked more easily compared to MSW, since waste tracking forms must be filled in every time special waste is collected by specialised companies. In several Italian municipalities, residual MSW is not weighed at the source, neither is measured the number of times a rubbish container is emptied. In such situations, private and public users pay an annual flat-rate tax, mainly based on the floor surface of a flat or a building, regardless of the amount of residual MSW produced.

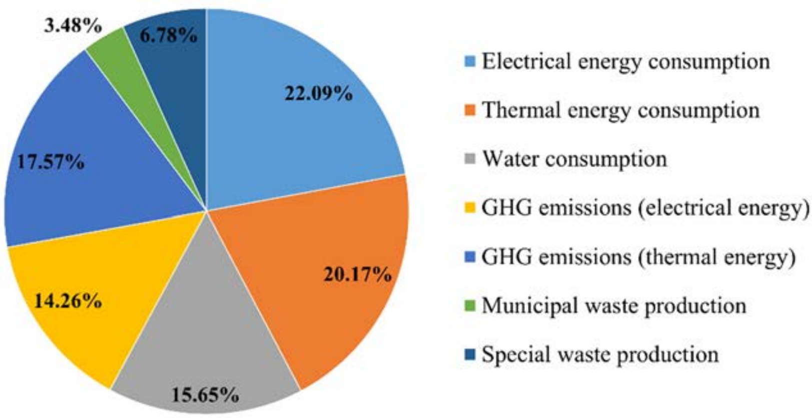

Figure 2: Average relative abundance of each variable in HEI sustainability reports between 2012 and 2021.

3.2 Analysis of HEIs' performance based on context-independent indicators

As shown in Fig. 3(a), the year 2020 is characterised by a minimum in the average context-independent indicator for electricity consumption.

In the previous years (2014–2019) this indicator remained almost stable. The sudden decrease observed in 2020 may be explained with the lower electricity consumption that occurred during the COVID-19 pandemic and, especially, during the lockdown of spring 2020, when classes and, in general, life in HEIs was suspended. A considerable upswing of this indicator can be observed 1 year later (2021), when the average normalised electricity consumption peaked. This can be explained with the restoration of the activities in workplaces, including HEIs. Between 2012 and 2013, the indicator showed lower values compared to the period 2014–2019, but no clear conclusions can be made because of the very low amount of data in this 2-year term (two in 2012 and five in 2013); the statistical significance of these data is thus questionable. By an overall observation of the graph in Fig. 3(a), the average normalised electricity consumption shows a slight increase over the whole period selected. This behaviour may suggest that HEIs did not find or apply adequate solution

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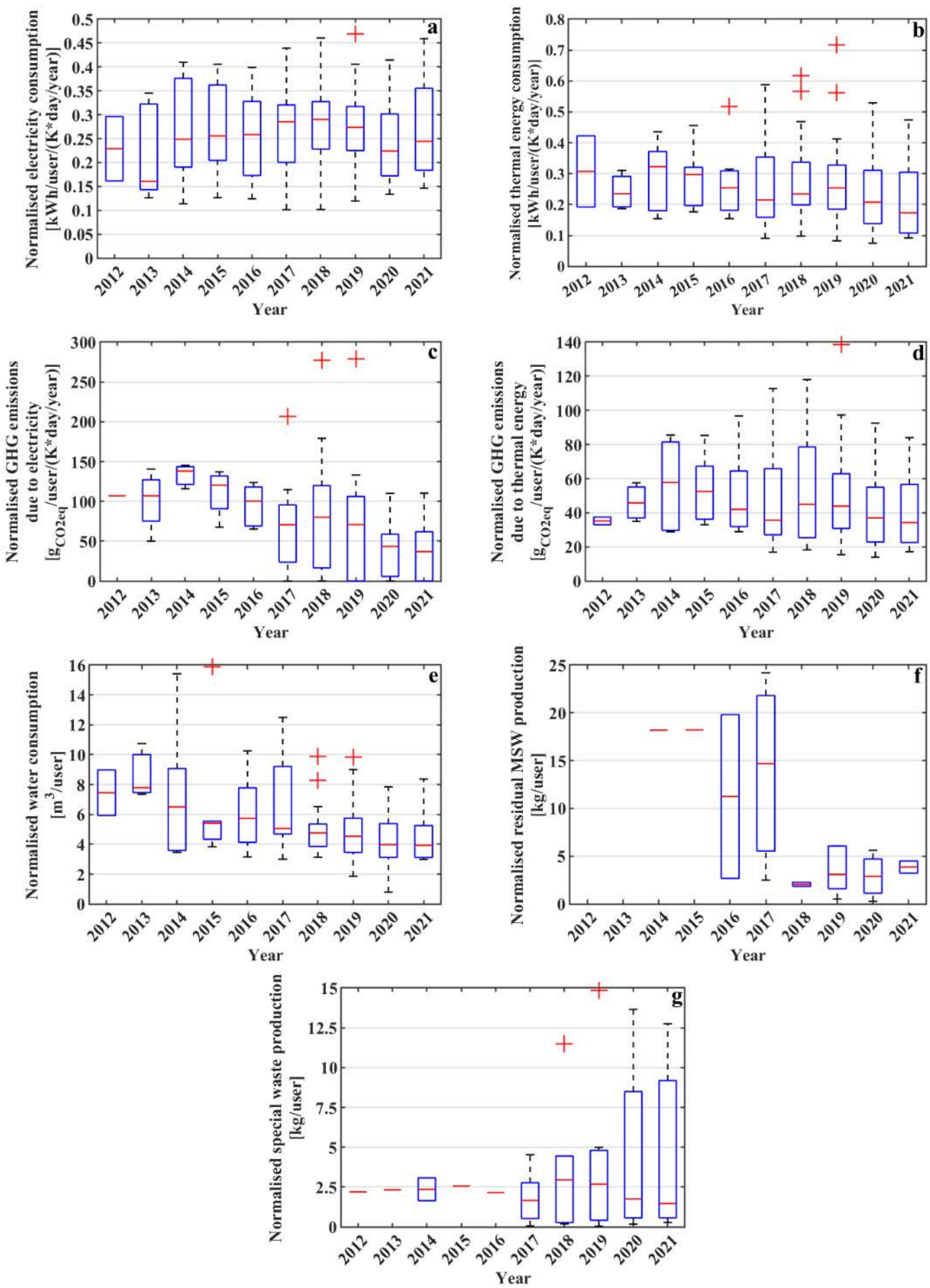

Figure 3: Boxplots of the annual data reported by the 24 Italian HEIs between 2012 and 2021 in terms of context-independent indicators for: (a) electricity consumption; (b) thermal energy consumption; (c) GHG emissions due to electricity consumption; (d) GHG emissions due to thermal energy consumption; (e) water consumption; (f) residual MSW production; and (g) special waste production.

to limit or reduce their electricity consumption over the years. Monitoring electricity consumption through dedicated software is the first step towards better performance [20]. This way, HEIs would be able to detect anomalies or the buildings/activities that contribute most to the overall electricity consumption and may intervene accordingly. Saving energy is crucial regardless of how electricity is produced: it implies lower resource consumption and related GHG emissions in case fossil fuels are used as primary sources, but it also makes renewable energy sources available to other users. As a matter of fact, the supply of renewable energies is limited by the available infrastructures (e.g., production units, grid extension and capacity, energy storage systems) and by the daily/seasonal fluctuations of the primary sources (e.g., wind, solar radiation and water). Based on the reports made available by Italian HEIs, most institutes have adopted dedicated systems for the monitoring of electricity consumption only recently, thus the results may not be visible for this reason. In addition, the management of indoor air quality during the COVID-19 pandemic, with increased ventilation rates of heating, ventilation and air conditioning (HVAC) systems [21], may have contributed to the growth in the average electricity-related indicator in 2021.

Regarding thermal energy consumption, the time trend of the related average context-independent indicator is reported in Fig. 3(b). After an initial fluctuation explained by the very low number of HEIs reporting data on thermal energy consumption (two in 2012 and four in 2013), this indicator remained stable in the period 2014–2019. A significant decrease can be observed since 2020. Contrarily to electricity consumption, no upswing is visible in 2021. A possible explanation for this is the implementation of energy-saving strategies, like the renovation of heating systems, the automatic regulation of indoor temperature or interventions on the insulation of buildings. Lower consumption is expected for the following years, both because of the energy-saving policies implemented in some countries to contain public expenditure (due to the rise in natural gas prices in Europe following geopolitical conflicts) and because of renovations that are being fostered by the European Union to increase the energy efficiency of buildings as a climate-change mitigation strategy [22], [23].

Compared to electricity consumption (Fig. 3(a)), the related average context-independent indicator for GHG emissions shows a clear decreasing trend since 2014, with only an exception in 2018 (Fig. 3(c)). The divergent behaviour between these two indicators can be quantified in terms of the time trend of the average CO_{2eq} emission factor, which can be calculated dividing the electricity consumption by the related GHG emissions (Table 2). The evident decreasing trend of the average CO_{2eq} emission factor can be attributed to the efforts made by Italian HEIs in terms of adoption of renewable energy sources and, in general, to the increasing share of renewable energy sources in the Italian grid mix. Specifically, between 2012 and 2021, nine HEIs out of 24 declared the self-production of electricity for at least 1 year, by photovoltaic (PV) panels and, in one case, also by wind and hydroelectric turbines. However, as shown in Table 2, the percentage of self-produced electricity from renewable sources is very low compared to electricity production. Thus, what seems to contribute significantly to the decreasing trend of the context-independent indicator for GHG emissions from electricity is the larger share of renewable sources in the grid mix. In particular, five HEIs out of 24 declared that they had purchased electricity certified as coming from 100% renewable sources for at least 1 year between 2012 and 2021. In Fig 3(c), this translates into the null values of the minima represented in the boxplots. This happens when at least one HEI purchases 100% electricity from renewable sources.

Since in Italy natural gas is the main energy source for thermal energy in winter, the time trend of the average context-independent indicator for GHG emissions due to thermal energy consumption by the Italian HEIs (Fig. 3(d)) resembles that of the thermal energy consumption

Table 2: Average CO_{2eq} emission factor and data on renewable electrical energy self-produced by Italian HEIs, used in the Italian grid mix and purchased by Italian HEIs from 2012 to 2021 [24].

Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
CO_{2eq} emission factor (gCO_{2eq}/kWh)	0.467	0.462	0.487	0.407	0.371	0.260	0.307	0.267	0.184	0.150
Total amount of self-produced electricity from renewable energy sources (MWh)	0	1324	1316	1380	1658	1918	2758	3217	2459	2804
Share of renewable energy sources in the Italian grid mix (%)	29.8	37.5	43.1	41.6	38.9	36.4	40.8	41.7	44.3	42.8
Number of Italian HEIs purchasing 100% green electricity	0	0	0	0	0	2	3	4	3	4

reported in Fig. 3(b). Since the normalised thermal energy consumption has shown a decrease in the last few years and, as said, it is expected to further decrease in the next years, there would be more possibilities for progress in terms of GHG emission reductions from this sector if alternative energy sources were employed (e.g., geothermal energy and/or PV-driven heat pumps).

Comparison between Figs 3(c) and 3(d) suggests that, while GHG emissions were mainly related to electricity consumption in 2012 (73%), in 2021 the contribution of electricity consumption became of secondary importance (47%) compared to thermal energy consumption. Again, this can be explained with the increasing use of renewable source of electrical energy over time.

In terms of water consumption, Fig. 3(e) shows a general decreasing trend in the average per-capita water consumption between 2012 and 2021. The last year, however, shows a slight increase compared to 2020, although the per-capita water consumption in 2021 is lower than 2019. The relative minimum in 2020 can be explained with the lockdown in force in March and April 2020. However, the reasons for the general decreasing trend between 2012 and 2021 are not evident, especially because the recent implementation of two policies that would be expected to increase per-capita water consumption: (1) the World Health Organization's provisions to contain the COVID-19 pandemic through frequent and accurate hand washing; and (2) the installation of water taps to incentivise bottle refilling and discourage the users from purchasing PET bottles, as a plastic-free and GHG reduction strategy. Possible reasons are: (1) the replacement of drinking water with non-drinking water from wells (which is normally not measured by counters) and the collection of rainwater for different purposes, like irrigation, cleaning, cooling or research activities in hydraulic laboratories; (2) the restoration of leaking water pipes and the maintenance of toilets; (3) the use of water-saving filters in restrooms' taps; and (4) awareness campaigns towards a responsible use of water. Those actions were explicitly reported by eight HEIs out of 24.

It is important to notice that the average context-independent indicators for electricity, thermal energy and water consumption are characterised by large variability. This can be explained by the fact that results may be affected not only by the number of users or the HDDs, but also by the type of activities that are carried out in each HEI. For example, large computer centres and laboratories may be present in some HEIs and not in others. Such facilities may increase the specific energy and water consumption compared to HEIs that are more dedicated to theoretical research or humanistic studies. Unfortunately, most of the sustainability reports made available by Italian HEIs do not clearly indicate the energy and water consumption of specific facilities. Thus, it is not possible to discriminate between them and offices or classrooms. Including this information in future sustainability reports, possibly with the aid of the RUS, would allow a critical discussion of the results.

The low amount of data on residual MSW production (Fig. 3(f)) makes it difficult to state any conclusions on the performance of HEIs. No clear trend is visible over the 10-year period considered. In fact, data are available only from 2014 and refer to one HEI with a relatively high per-capita residual MSW production. From 2018 on, data from this HEI are not available and this explains the apparent decrease in waste production. More data are available for special waste production (Fig. 3(g)), especially starting from 2017. An increase in the per-capita special waste production is visible, even in this case driven by an HEI with a relatively high waste production compared to the other HEIs that reported data on special waste.

4 CONCLUSIONS

A comprehensive data analysis was carried out in this paper to assess the environmental impacts and performance of Italian HEIs over a decadal term. Publicly available sustainability reports were reviewed to extract annual data on electricity and thermal energy consumption, related GHG emissions, water consumption, residual MSW and special waste production. To obtain an unbiased and context-independent overview of their time trends, these data were normalised against context-specific factors like the number of users and the HDDs of each HEI.

The data analysis revealed important efforts made by Italian universities in the last few years, especially concerning the shift towards renewable energy sources for electricity production. This led to the fact that, although electricity consumption has not decreased in the last few years, a significant reduction in the related GHG emissions has occurred. However, the same efforts have not been made concerning thermal energy. This issue highlights the need for structural interventions on university buildings in terms of energy efficiency, and a paradigm shift towards alternative sources for heating (e.g., geothermal energy and/or heat pumps, possibly using renewable sources of electrical energy). An evident decrease in the water consumption was also documented and this could be attributed to water-saving campaigns, improved maintenance of pipes and toilets, and to the use of alternative water sources, like rainwater of non-drinking water extracted from wells. No clear conclusions can be made on residual MSW production due to lack of data. However, special waste production increased during the 10-year period, even though additional data would be beneficial to exclude the uncertain role of some HEIs that might be regarded as outliers.

In spite of the valuable information made available by environmental sustainability reports, the main limitation of this study is the relatively low number of HEIs reporting data on resource consumption, emissions and waste production. It is expected that, in future years, the number of available reports will increase, since many HEIs may follow the example of other institutes that have published data on their environmental performance.

Moreover, indicators that do not depend on the geographical context where HEIs are located can be used in global ranking systems, developed to assess HEIs' performance worldwide, allowing a comparison between different HEIs in an unbiased way.

As a future step, the effect of normalising electricity consumption against outdoor temperature should be considered to account for the use of air conditioning during summer. In analogy with heating during winter, context-specific cooling degree days may be considered as a potential parameter for normalisation.

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