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The implementation of SDG12 in and from higher education institutions: universities as laboratories for generating sustainable cities

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Introduction: It is known that the world is facing and will face significant sustainability challenges. Sustainable Development Goal 12 (SDG12), responsible consumption and production, is one of the most relevant SDGs for building Sustainable Cities. This study is based on the analysis of the implementation of SDG12 in cities, starting from universities as laboratories or first examples of sustainability.

Methods: The study was carried out through a multilevel scale approach. A systematic review of the literature (global scale) of the last 5 years (2018–2022) was conducted. An analysis of the program and the initiatives of a Higher Education Institution (Tecnologico de Monterrey) is presented (local scale). Finally, a survey was applied to Faculty at this University (micro-scale).

Results: The systematic review indicated that the main themes or aspects addressed in SDG12 by higher education institutions were sustainable food, supply chains, community, infrastructure, technology, policies, energy consumption, the collaborative economy, smart cities, and curricula. The local scale analysis highlighted the Distrito Tec project, 37 institutional initiatives, and 26 courses directly related to SDG12. The survey showed that 8% of Faculty considered SDG12 the most important of the SDGs and stated that this goal is necessary to reduce environmental impacts. As the most significant impact that Universities can have on SDG12, 52% of the Faculty consider that Universities should become living labs in the transition toward sustainable cities, followed by 36% who think it would be better to implement operational facilities.

Discussion: The diverse contributions of the HEIs at the three scales were classified into six categories: culture, mitigation, adaptation, education, research, and outreach. The study indicates that SDG 12 has been achieved by universities in different ways, which overlaps widely with the performance of other SDGs. Results demonstrate that following a multistakeholder approach, international collaborations between HEIs can foster technology-driven multi-disciplinary research projects to consolidate sustainable cities. Building capacity to accelerate the transition of universities into urban living labs will promote climate action among the students who enroll every year.

KEYWORDS

educational innovation, higher education, smart city, sustainability education, industry 4.0, Sustainable Development Goals (SDGs)

1. Introduction

The concept of sustainable development is the precedent that frames the roadmap to a more sustainable world. In 1987 the World Commission on Environment and Development defined it as the development that "meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (Verma, 2019). On September 25th, 2015, the member countries of the United Nations unanimously adopted a set of goals to end poverty, protect the planet, and ensure prosperity for all as part of a new sustainable development agenda. This 2030 Agenda, with 17 Sustainable Development Goals (SDGs) and their 169 specific targets, must be achieved by 2030 by all countries, leaving no one behind (Biglari et al., 2022). The 17 SDGs represent humanity's most pressing, urgent, and emerging challenges. Their 169 goals are opportunities to configure a sustainable and accessible development model for society and involve all societal actors in a standard, shared, and comprehensive framework. We are currently halfway to their implementation. Since they came onto the stage in January 2016, their application has had some positive results; however, due to the crisis facing humanity (COVID-19, conflict in Ukraine, and the climate crisis), progress has been slow all over the world. In the case of Latin America, the improvement in the fulfillment of the 2030 Agenda and the SDGs saw a substantial setback during the years 2020 and 2021 due to the COVID-19 pandemic (Matos de Oliveira and Emídio, 2021). Progress depends on the coordinated work of different actors, including the government, the private sector, academia, and civil society (Stafford-Smith et al., 2017).

Cities and urban settlements will be vital in achieving the global SDGs (Pipa, 2019). The SDGs come into effect in a predominantly and increasingly urban world. More than half of the world population (56%) currently lives in cities, and it is estimated that this proportion will grow to two-thirds by 2050; that is, it is expected that almost 7 out of 10 people will live in cities (World Bank, 2022). According to the United Nations (UN), on November 15, 2022, the world population reached 8 billion inhabitants and is expected to reach 9.7 billion by 2050 (United Nations, 2022). Urbanization has generated some of the most significant development challenges in the world, but it also provides enormous opportunities to drive sustainable development (Sustainable Development Solutions Network, 2013). It has posed challenges to sustainable world development. Cities are spaces where poverty, hunger, unemployment, inequalities, and environmental degradation coexist with unsustainable consumption and production models that severely impact the quality of life. However, it is also in the cities where there are enormous opportunities to promote sustainable development since global growth (i.e., in the economic, population growth, and industrial aspects) will be accompanied by increasing urbanization. Cities are productive areas and centers of innovation; whether through universities, research laboratories, or large companies, new products and services are created (Sachs, 2015).

Given the urban reality, it is essential to develop sustainable cities with new development models of production and consumption, comprising strategies such as circular economy, sustainable food production, waste management and disposal, natural resource management or urban natural capital, supply chains, energy production and use, and sustainable infrastructure development.

1.1. Sustainable consumption and production

SDG12 (responsible consumption and production) is classified among the objectives of the PLANET category of the five guiding principles (5 P's) of the 17 SDGs, along with life on land, life below water, clean water and sanitation, and climate action (Tremblay et al., 2020). It is related to the dynamic nexus of manufacturing and the city, aimed at meeting the needs of the growing population, including the use of natural resources, their transformation, logistics and transport, consumption, and final disposal. All these links generate waste and pollutants emitted into the atmosphere, which urges the design of strategies in the paradigm shift of the life cycle and allocation logistics of articles for human consumption (Wang, 2019). According to the UN, consumption and production with unsustainable patterns are the root of the triple planetary crisis (climate change, biodiversity loss, and pollution). The waste of food and electronic materials and our dependence on natural resources are the actions that most afflict cities (United Nations, 2023).

SDG12 is one of the first goals whose mention in publications in indexed journals has increased the most since 2018 (42.8%), compared with SDG7 (44.4%), SDG13 (41.5%), or SDG11 (40.5%). However, in 2020, SDG12 was among the top 3 SDGs requiring more urgent action in academia, administration and policy, industry, and civil society (Frank et al., 2020). Despite being one of the most understood and essential in daily life, in the academic context and on a global average, SDG12 is one of the least popular among students, therefore, least achieved (Tedeneke, 2019; Leiva-Brondo et al., 2022). In some studies, it has been marginalized and ranked as the lowest-priority SDG in university students learning preferences (Yuan et al., 2021, 2022).

1.2. Sustainable cities and HEIs

The path to a decarbonized economy (circular economy and zero-carbon energy) that cuts pollution is closely linked to urbanization (Sachs J. D. et al., 2022). The growth of urban areas in size and population by 2030 is unavoidable (McDonald et al., 2020). It has a direct (transformation of natural habitat in urban areas) and indirect (food consumption) impact on energy consumption (Ahmad et al., 2019; Shaheen et al., 2019) and the ecological footprint (Ahmad et al., 2021; Zimmerer et al., 2021). Investment in clean technologies, technological development, and partnerships between the public and private sectors can help reduce urbanization-related carbon emissions (Raghutla and Chittedi, 2020). Multiple efforts have been carried out to define strategies to counteract the adverse effects of urbanization. For instance, an urban model promoting contact, exchange, and communication, increasing organized information, decreasing the consumption of natural resources, keeping a complex organization,

and dealing with environmental, social, and economic dysfunctions has been known as Sustainable City or "eco-city" (Joss, 2011; Sodiq et al., 2019). Consolidating Sustainable Cities requires environmental planning, functional areas, and individuals and organizations arising troubles in the nature-society interface to create action courses for solving them (Dassen et al., 2013). Green planning is the mechanism that imposes the limits of urban sprawl, the transformation toward compact cities, the growth of public transportation, soil use regulation, economic activities grouping, and soil re-densification (Sturiale and Scuderi, 2019). A *smart city* is a work-in-progress concept. It involves information and communication technologies to achieve a sustainable city involving six domains: Economy, Environment, Governance, Living, Mobility, and People (Camero and Alba, 2019).

In recent years, efforts have been made to pose universities as living labs for smart, sustainable cities (Fortes et al., 2019; Villegas-Ch et al., 2019; Ferraris et al., 2020; Huertas et al., 2021; Rodríguez-Hernández et al., 2022). Higher Education Institutions (HEIs) work with stakeholders to co-create initiatives to raise awareness about responsible consumption, including living labs, brands, designs, degrees, and web platforms. By studying the consumption preferences of different community profiles, universities can implement new consumption patterns or activities and identify specific barriers to developing sustainable policies (Longoria et al., 2021).

1.3. Research objective

This work aims to inquire about how HEIs contribute to the United Nations Sustainable Development Goal 12—*Responsible consumption and production*—and identify opportunities for future action. It intends to generate knowledge about strategies universities can implement to contribute to the fulfillment of SDG12, with the novelty that it is studied under the perspective of universities as laboratories of sustainable cities. In turn, it highlights areas of opportunity or gaps in knowledge in topics such as partnerships, data science, and the concept of Industry 4.0 related to SDG12.

To address this, a multilevel approach is proposed. On the global scale, a literature review was made to determine the strategies HEIs, as sustainable city laboratories, have implemented in the SDG12 achievement during the last 5 years. On the local scale, the initiatives of a private university in Mexico are analyzed to obtain those that point to the achievement of SDG12, highlighting the role of university districts as laboratories of smart cities. On the micro-scale, the results of a survey responded to by 25 Faculty members of Tecnologico de Monterrey regarding their knowledge of SDG12 are analyzed.

2. Methodology

The idea of universities as living labs for the SDGs has been studied before (Leal Filho et al., 2020). These studies have been classified into literature reviews, university case studies, and survey studies (Leal Filho et al., 2020). However, to our knowledge, they have been non-specifically related to SDG12. To reach the aim of the present work, a literature analysis could have been more than enough (Salvia and Brandli, 2020; Crawford and Cifuentes-Faura, 2022; Serafini et al., 2022). However, we wanted to follow a multilevel approach since literature reviews usually remain conceptual and theoretical, while case studies show more methodological and strategic qualities (Bhandari and Hanna, 2019). Besides, time and resource constraints may prevent literature reviews from providing new information. Including survey studies, the three approaches (including reviews and case studies) comprise a multilevel approach providing a more holistic and transformative understanding of the SDG's achievement, going from a general to a more contextual perspective (Bhandari and Hanna, 2019; Horan, 2019; Hatzichristou et al., 2022). This approach is also congruent with the third mission of universities (teaching and research are the first two), the value to society, which also should be accomplished from its different levels (i.e., top management, innovation, technology transfer, and research units) (Knudsen et al., 2021). Thus, the conducted methodological framework is represented in Figure 1. A detailed explanation of each method is explained later in this section.

2.1. Literature review

A literature review was made in the SCOPUS database in December 2022, using the words: ("sustainable cit*" OR "innovation district" OR "district" OR "smart city" OR "smart campus" OR "campus district") AND (universit* OR "higher education") AND ("SDG12' OR "SDG 12" OR "consumption and production") in the title, abstract or keywords fields. Results were limited to the last 5 years (since 2018) of journal articles in English. Documents were revised considering the discussion on how HEIs approach SDG12. The result of this review is narrated in the results section. A keyword analysis was performed following the strategy established by Mejía-Manzano et al. (2022). Briefly, the system and author keywords of the SCOPUS records were tabulated and counted. A clustering of keywords was made manually, and it was represented in a Treemap using the RAW Graphs open-source software (https://app.rawgraphs.io/).

2.2. Initiatives of Tecnologico de Monterrey toward the achievement of SDG12

To identify and analyze the internal efforts of Tecnologico de Monterrey for attending SDG12, a manual-specific search was conducted on Tecnologico de Monterrey webpages for locating actions, activities, and results related to SDG12. During the investigation, the 2025 Sustainability and Climate Change Plan (Tecnologico de Monterrey, 2021), the Tec District project (Distrito Tec, 2021a), the SDGs in the Tec 21 educational model Professional Programs (Tecnologico de Monterrey, 2023), and the Sustainable Development Initiatives (Tecnologico de Monterrey, 2022) were found as significant avenues. The Sustainability plan was reviewed by each focus area, extracting the actions directly or indirectly related to SDG12. Also, advances of the Plan up to 2022 concerning SDG12 were documented. In the same way, Sustainable Development initiatives in the period 2020–2021 were analyzed. We report the advance of the initiatives toward the

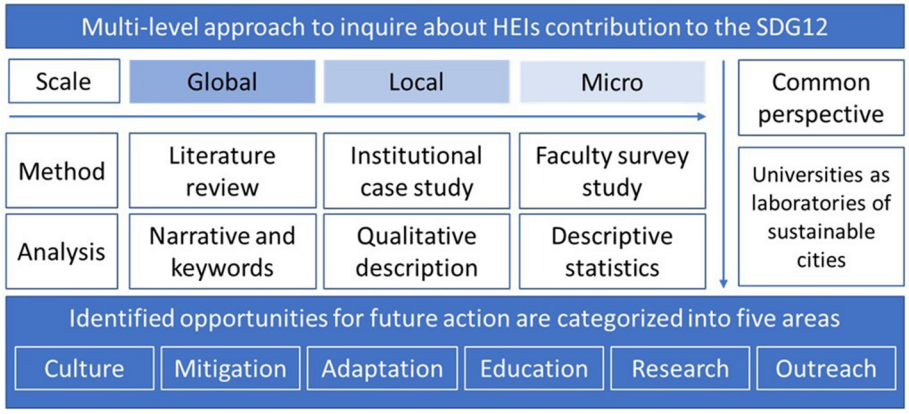

FIGURE 1
Tree map representing the clustering of author and index keywords from 97 documents resulting from the literature review on SDG12, HEIs, and sustainable cities. The number of keywords per cluster is in parentheses. Mgmt, management; C&P, consumption and production; AI, artificial intelligence.

SDGs and the five most outstanding initiatives considering SDG12. The promotion of SDG12 was also mapped in the courses taught at Tecnologico de Monterrey Schools. This document shows the number of actions, initiatives, and courses related to the different SDGs in tables and figures.

2.3. Survey

An internal survey about Sustainability and SDG12 in Universities (Supplementary material) was applied online to the Faculty of Tecnologico de Monterrey to review their knowledge about SDGs and SDG12 and the community's interest in specific aspects and actions. Participants were experts recruited from the university community. The choice of respondents was made by convenience sampling. The inclusion criteria for participation in the survey were either research experience in sustainability or contact with the SDG office of Tecnologico de Monterrey. The aim was to select participants whose answers would contribute to a successful discussion, bringing experience and focusing on developing new perspectives (Andronie et al., 2019). For the results of this section, only descriptive statistics were calculated.

3. Results

3.1. Literature review

This literature analysis was carried out to know which research topics HEIs have played a significant role in the development of SDG12 in the last 5 years. Before the systematic literature search, the number of research articles related to each SDG was reviewed. SCOPUS pre-generated queries on the UN Sustainable Development Goals 2020 were used. According to the results, SDG12 (318,669 documents) ranks 10th in search results. The first place is SDG3 (17,099,613 records), and the last is SDG1 (44,820 papers). This means there is still work to be done in research on SDG12 (Table S1 and Figure S1).

The literature search generated 97 documents that touch on the theme of SDG12 concerning HEIs and sustainable cities. Studies deal with academic studies or community projects carried out by universities and their interception with SDGs (Gebremedhin et al., 2019; Whitcraft et al., 2019; Elsamadony et al., 2022; Paunglad, 2022), consumer studies (Corsini et al., 2019; Longoria et al., 2021; Lin et al., 2022; Siddiqua et al., 2022) or design, development, and use of sustainable materials, primarily biochemical in nature [see for example (Tao et al., 2018; Shi et al., 2021; Yeerum et al., 2022)] and using the Life Cycle Assessment (LCA) methodology (Garcia et al., 2021; Adebisi and Babatunde, 2022). In Alvarez-Risco et al. (2021) a study with higher education students was conducted in which they shared their SDGs research interests. Responsible cities and community and responsible production and consumption were the two SDGs students selected from four Latin American countries. Türkeli (2020) investigated the interdependencies between the 17 SDGs among the 162 UN member states, finding that SDGs 12, 9, and 11 are the most influential performance drivers of sustainable development at the global level, calling for policies mixtures among drivers and highlighting "the importance of establishing and enhancing local infrastructures and communities, innovative and sustainable supply and demand content to increase overall SDGs performance globally". The application of social practice theory has been suggested (Corsini et al., 2019) in the study of topics that intersect with sustainable production and consumption, such as sustainable eating, community, infrastructure, technology, policy, energy use and demand, and sharing economy (Revinova et al., 2020), as well as smart cities.

Other topics that have been reported closer to the theme of consumption and production and sustainable cities and communities are supply chains (Lazar et al., 2021), built environment or green building (Wen et al., 2020; Lopez Duarte, 2021), smart affordable and clean energy production and consumption (de Miguel Ramos and Laurenti, 2020; Kermani et al., 2021), knowledge hubs (Walentowski et al., 2020), and use of natural resources (Kiwfo et al., 2021), circular economy and e-waste disposal and awareness (Siddiqua et al., 2022). Under

the energy consumption topic (Garcia et al., 2021), compared the greenhouse emissions associated with conventional (346,569 kg CO_2 eq/year) and solar absorption (144,452 CO_2 eq/year) cooling systems installed at a university building, suggesting that new technology should be used in universities to decrease energy consumption patterns. In this regard, digitalization, Information and Communication Technologies (ICT), and artificial intelligence (AI) can contribute to more intelligent use of energy (Parks and Wallsten, 2020; Choi et al., 2022).

Adopting a sustainable production and consumption pattern leads to greener growth (Mungkung et al., 2018). HEIs actions toward this pathway can focus on sustainability teaching and curricula, dissemination of SDGs, recycling, water, and energy use and conservation, and in general sustainable campus-related efforts; the use of sustainable use of transport through subsidies and parking restrictions; increasing energy efficiency and decreasing greenhouse gas emissions, proper waste disposal, changes in internal processes, infrastructure, and organizational culture. In turn, these projects should encourage cultural and behavioral change in stakeholders (Laurett et al., 2022). McLean et al. (2022) proposed a strategy to encourage students to design sustainable products for selected audiences focusing on a given SDG. In their work, apart from using SDG13, half students (41%) from medical school also picked SDG12, related to healthcare emissions and waste. Another example was provided by Lopez-Villalobos et al. (2022), describing how the University of British Columbia has employed a Botanical Garden to accomplish sustainable horticultural practices and consumption and zero waste education and research, as well as encouraging companies to adopt sustainable practices.

Still, "despite the essential role of Higher Education Institutions (HEI) in contributing to a sustainable society, a holistic understanding of how to incorporate sustainability initiatives into HEI is still lacking" (Moreno Pires et al., 2022). Studies agree that HE has a considerable impact on students' habits and contribution toward sustainability (Žaleniene and Pereira, 2021) and that SDG12 is critical in empowering individuals toward sustainable practices (Motta, 2019). Nevertheless, the influence will be possible only by leading by example (i.e., reducing waste reduction and energy consumption). However, some problems owed to a dualism in the university path, one following the market logic (competition accreditation, funding) and the other following a state logic (accountability to society and public value creation), have been encountered (Žaleniene and Pereira, 2021).

In turn, Chen et al. (2021) also found that "much remains to be done to promote SDGs at the university level". Students considered sustainable production and consumption patterns (SDG12) as least important, compared with good health and wellbeing (SDG3), finding a correlation with students' attitudes and self-efficacy. To promote students' consciousness of sustainability matters, the authors recommend considering the use of projected-based learning, case teaching, collaborative learning, gamification (Cravero, 2020), and other group learning activities when designing projects (Chen et al., 2021), to promote college students' self-perceptions of the SDGs and the importance of sustainability, support a positive attitude of college students toward the SDGs, stimulating their interest and motivation, and enhancing their self-efficacy to stimulate environmentally sustainable behavior.

Studies have indicated that, from an environmental Artificial Intelligence economy perspective, mainly in countries with high institution effectiveness, "university support can contribute to the development of responsible production and consumption" through knowledge transfer and diffusion (Atabekova et al., 2022). To keep this contribution, the suggested actions are: supporting SDG12 in activities and scientific research; include knowledge, skills, and abilities to implement SDG12 in responsible production and consumption in the competencies of university graduates; and stimulate and increase accessibility to HE and advanced training in university education programs that develop responsible production and consumption competencies (Atabekova et al., 2022).

In this regard, the term "entrepreneurial university", which, in addition to teaching and research, has the aim of commercialization of research and technology, has been applied to HEIs that "empower students to understand environmental degradation, inspire them to adopt sustainable behaviors, and increase awareness of societal inequalities" (Pietrzak, 2022). It has been suggested that HEIs should use their communication channels to raise awareness, promote commitment and encourage actions toward accomplishing the SDGs through research, teaching, operations and governance, and community engagement (De la Poza et al., 2021). It has been reported that the more HEIs actions are related to the industry, innovation, partnerships, climate actions, and responsible consumption and production, the higher their score in the Times Higher Education ranking (for more information, see: De la Poza et al., 2021).

Another approach is the creation of innovation districts, which accommodate a 24/7 live/work/play environment. Although this may burden universities with the urban revitalization process, it may catalyze growth through sustainable consumption and production activities (Kayanan, 2022), this is, for example, by supporting or incubating circular economy micro companies or startups (Novelli et al., 2018; Puntillo, 2022) in their planning, who collaborate with HEIs to contribute with sustainable consumption and production patterns (Strydom and Kempen, 2021). The selection of such companies may be anticipated by a co-creation process enabling stakeholders to understand the need of the university community (Longoria et al., 2021) and propose solutions for responsible consumption and production.

In this literature review, we found a variety of strategies (educational and behavioral) HEIs can carry out in the achievement and scope of SDG12, from curricula changes to the execution of actions that make them laboratories for creating smart, sustainable cities. The 1395 author and index keywords (complete list in Supplementary material) obtained from the literature sources were clustered in 21 clusters, as observed in Figure 2.

The most repeated keywords were "sustainability", "sustainable development" and "sustainable development goals". These were clustered together with the SDGs 1 (no poverty), 2 (zero hunger), 3 (good health and well-being), 4 (quality education), 6 (clean water and sanitation), 7 (affordable and clean energy), 9 (industry innovation and infrastructure), 11 (sustainable cities and communities), 12 (responsible consumption and production), 13 (climate action), and 17 (partnerships for sustainable development), that also appeared as keywords. The second biggest group of keywords was related to chemicals,

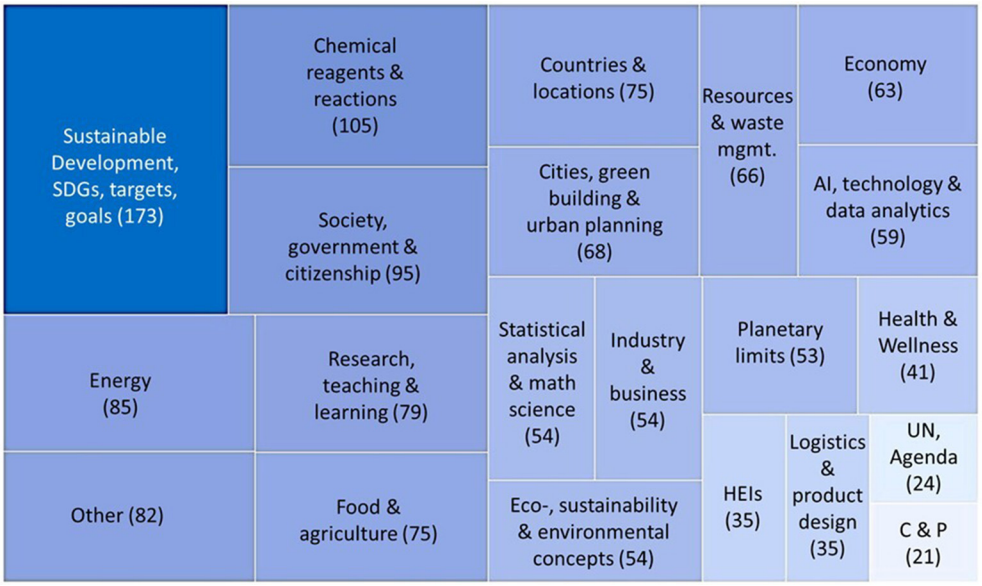

FIGURE 2
Treemap representing the clustering of author and index keywords from 97 documents resulting from the literature review. The number of keywords per cluster is in parentheses. Mgmt, management; C&P, consumption and production; AI, Artificial intelligence.

chemical reactions, and reagents. The rest of the keywords were associated with one of the 11 mentioned SDGs, except for the clusters constituted by single keywords (HEIs, UN, Agenda), composed keywords with known prefixes (Eco-, sustainability, and environmental concepts), and those related to analytic methods (Statistical analysis & math science) and unspecific terms (Other). Examples of keywords in each cluster can be seen in Table 1. Considering this literature review, we conclude that the HEIs, as laboratories toward sustainable cities, can incursion not only on the accomplishment of SDG12 but into other SDGs and sustainability topics.

3.2. Initiatives of Tecnologico de Monterrey toward the achievement of SDG12

Higher education institutions (HEIs) have an irrefutable responsibility in favor of sustainability. Tecnologico de Monterrey aspires "to be a model of a sustainable institution by adopting a proactive culture in the face of the climate emergency, reflected in the generation of ideas and technologies, in actions of great impact and in the training of leaders committed to forging a sustainable future" (Tecnologico de Monterrey, 2021). In 2021, considering the importance of the SDGs, this HEI presented its 2025 Sustainability and Climate Change Plan following six strategic focuses: culture, mitigation, adaptation, education, research, and outreach (Tecnologico de Monterrey, 2021), to ensure that Tecnologico de Monterrey becomes an institution that promotes sustainable development and works to mitigate the climate crisis.

The subject of culture is fundamental to achieving a cultural change toward sustainability. It has a central position because it articulates all decisions at all institutional levels. "Fostering a culture of sustainability requires designing and implementing vision, perspective, knowledge, values, attitudes, and behaviors that result in the formation of people committed to sustainable development" (Tecnologico de Monterrey, 2021). SDG12 seeks to promote a culture of sustainability through strategic actions (goals) mainly focused on using the environment and natural resources. "Is about doing more and better with less. It is also about decoupling economic growth from environmental degradation, increasing resource efficiency, and promoting sustainable lifestyles" (United Nations, 2023). Table 2 presents the subjects and some of the actions established in the Plan that impacts one or more targets of SDG12.

The analysis allows us to identify at least 14 actions that directly contribute to the targets of SDG12. Several actions focus on mitigating greenhouse gas emissions or adaptation. Still, their implementation positively impacts SDG12 because they involve more efficient purchases, use of resources, or consumption schemes. In this sense, Tecnologico de Monterrey has the potential to become a Living Lab where research, work and develop actions that help the implementation of SDG12. It is essential to mention that the Tecnologico de Monterrey has 26 campuses and two hospitals located in the main cities of Mexico, a characteristic that makes it a HEI that can support the improvement of the urban reality of the cities where it is located since they house a community of more than 92,000 students, and more than 24,000 collaborators and professors, human capital that can be used to promote more sustainable consumption of resources inside and outside its campuses, primarily by reducing (a) emissions (they emit almost 55,000 tons of CO_2 per year), (b) waste (they generate more than 2,500 tons of waste) and (c) consumption of natural resources (they consume ~2 million 700 thousand m^3 of water per year) (Tecnologico de Monterrey, 2021).

TABLE 1 Examples of keywords and cluster association with SDGs, according to the 97 documents obtained from the literature review on SDG12, HEIs, and sustainable cities.

Cluster (associated SDG)	Examples
SD, SDGs, targets, goals	Sustainable development, millennium goals, development targets
Chemical reagents & reactions	Alkene, oxidation, regioselectivity, copper catalysis
HEIs	Higher education institution, student, and university
UN, Agenda	2030 Agenda and United Nations
Eco-, sustainability & environmental concepts	Ecosystem, sustainability (issues, report, education, world), environmental (education, impact, protection, technology)
Statistical analysis & math science	Analysis of variance, complex networks, numerical model, stochastic systems
Other	Adhesion, adult, criteria, driver, planets, wrack
Society, government & citizenship (1)	Capacity building, equity, gender, human, poverty, policy, society, stakeholder
Economy (1)	Budget control, circular economy, economic growth, investments, money
Food & agriculture (2)	Agricultural policy, fish, food security, malnutrition, seaweed
Health & Wellness (3)	Antiviral, COVID-19, lifestyle, psychology, viral therapy, wellbeing
Research, teaching & learning (4)	Article, empirical data, laboratories, motivation, self-efficacy, serious games, virtual reality
Resource & waste management (6)	Clean waters, forestry, land use, recycling, soils, solid waste
Energy (7)	Air conditioning, electric vehicle, heat storage, photovoltaics, oil sector, smart grid
AI, technology & data analytics (9)	Artificial neural networks, database, deep learning, internet of things, remote sensing
Industry & business (9)	Business model, equipment, industry 4.0, ISO14001, monitoring, textile, workplace
Logistics & product design (9)	Co-creation, forecasting, innovation, life cycle assessment, supply chain management, TOPSIS
Cities, green building & urban planning (11)	Construction industry, ports and harbors, rebuilding, smart city, urbanization
Consumption and production (12)	Consumption habits, production patterns, productivity, purchasing decisions, willingness to buy
Planetary limits (13)	Climate change, global warming, greenhouse gases, mitigation, zero emissions
Countries, cities & location (17)	Africa, China, Europe, G7, Hunan, Mexico, Tidal River

The numeric value correspond to the SDG associated to a given cluster.

3.2.1. Tec District: the place where great ideas are lived

Distrito Tec (2021a) is an urban regeneration and recovery initiative promoted by different actors, such as citizens, organizations, and authorities, in conjunction with Tecnologico de Monterrey. The initiative began in 2013 when Tecnologico de Monterrey assumed leadership to face the challenges of the environment in which it lives. After integrating an internal team and realizing an analysis, a master plan for the flagship campus focused on presenting an open campus that integrates with the immediate community was developed, generating benefits for the city (Distrito Tec, 2021a).

The "Tec District Partial Urban Development Program" (an instrument of urban planning involving, in addition to the municipal authority, academic, neighborhood, and non-governmental organizations, among others, to reach a consensual vision for the development of the territory), came into force on November 18, 2015. This 15-year initiative (since 2013) has driven the creation of a dynamic, safe, and inspiring community that attracts and retains talent. Additionally, it consolidates the role of academia as an articulator of long-term sustainable projects and the commitment of higher education institutions to carry out urban transformation projects with a comprehensive approach where "academia, companies, and governments actively participate for innovation and entrepreneurship, the promotion of an urban ecosystem that attracts and retains talent and ordering to generate value for all involved" (Tecnologico de Monterrey, 2015).

The general objective of the Program is to establish an inclusive, sustainable, and efficient urban reorganization program that improves the quality of life of the population and allows the conditions for productive linkage, innovation, and entrepreneurship. It considers seven lines of action that help improve the quality of urban life and configure a sustainable city: I. Urban Development; II. Public Space and Urban Image; III. Mobility; IV. Infrastructure and Equipment; V. Urban Control and Citizen Participation; VI. Environment; and VII. Economic Development and Innovation (Tecnologico de Monterrey, 2015).

In 2021, Distrito Tec was one of five finalists for the WRI Ross Center Prize for Cities 20–21, the premier global accolade celebrating and highlighting transformative urban change. "Distrito Tec has become an example of governance and collaborative action, generating encounters, transforming public space, promoting more sustainable mobility, strengthening and building citizen committees, positioning itself as an Innovation District recognized worldwide" (Distrito Tec, 2021b). Through all these strategies, it seeks to:

- Create the ideal environment to develop great ideas: promoting research, innovation, and entrepreneurship through a productive and creative link between the academic world, companies, and the public sector.
- Promote sections for a better life: creating a space where the community enjoys a city life with new standards.
- Bet for a city model based on co-responsibility: promoting ideas, actions, and regulations to generate shared value.

This initiative created within a university contributes to the role of HEIs to become a space for innovation in living labs, to include actions that positively impact SDG12 to consolidate sustainable cities, in this case, "make Monterrey the most humane and innovative city in all of Mexico" (Mariano, 2021).

TABLE 2 Actions of the 2025 Sustainability and Climate Change Plan (Tecnologico de Monterrey, 2021) that pay for SDG 12.

Focus	Action	SDG 12 targets
Culture	Ensure awareness of environmental sustainability for students, employees, teachers, and decision-makers in the Institution.	12.6 Sustainable practices 12.8 Information and knowledge for the SD
Culture	Ensure the responsible use and investment of institutional assets.	12.6 Sustainable practices
Mitigation	Design a comprehensive waste management strategy and implement it at the institutional level.	12.5 Waste generation
Mitigation	Enabling involvement in the Campus of the Tec community (research–living labs, Tec 21 Challenges, entrepreneurship, volunteering, to name a few) for the design and implementation of sustainable actions.	12.6 Sustainable practices 12.8 Information and knowledge for the SD
Mitigation	Application and continuous improvement of internal sustainability guidelines and standards for the operation of campuses.	12.6 Sustainable practices 12.4 Eco-management of products and waste
Adaptation	Carrying out diagnostics to identify risks in the Campuses and their terrestrial ecosystems to analyze present economic impacts of climate change and future scenarios.	12.2 Sustainable management and efficient use of natural resources
Adaptation	Carrying out an inventory of trees in all Campuses, facilities, and heritage buildings for their management in terms of mitigation and adaptation.	12.2 Sustainable management and efficient use of natural resources
Education	Training of design teams and teachers in education in sustainable development using an approved methodological framework for its curricular implementation in subjects and training units.	12.8 Information and knowledge for the SD
Education	Curricular inclusion of education in sustainable development, prioritizing sustainability and the ecological crisis through different modalities in subjects, training units, blocks, Tec weeks, and challenges using the Campus/environments (i.e., Tec District) as laboratories or training partners.	12.8 Information and knowledge for the SD
Research	Facilitate the provision of the facilities of the Campus to promote research and student projects dedicated to resolving problems related to climate change and sustainability.	12.8 Information and knowledge for the SD
Outreach	Foster cross-sectoral collaboration for the co-design of solutions aimed at sustainable development.	12.a Strengthening scientific and technological capacity
Outreach	Develop climate services consulting for different industrial sectors and short programs for companies that contribute to people and organizations understanding the phenomenon and the necessary adjustments to transition to sustainability.	12.6 Sustainable practices 12.8 Information and knowledge for the SD
Outreach	Promote educational programs on climate change for the community related to the SDGs, circular economy, recycling, and sustainability training, among others.	12.8 Information and knowledge for the SD

3.2.2. Courses addressing SDG12

The educational focus of the Sustainability Plan of Tecnologico de Monterrey contemplates that one of the activities to be carried out is a "mapping of the curricular inclusion of the SDGs in the subjects and training units and the creation of a database of teachers, subjects and certified projects" (Tecnologico de Monterrey, 2021). In 2022, mapping was carried out to 694 training units (courses) from the first to fifth semester of all the institution's undergraduate careers to identify which addressed the SDGs. Of the total, 377 included the SDGs (54%) (see Figure 3), and only 26 worked directly on SDG12 and were allocated in 5 of the 6 Schools of the institution. Some examples of these courses are Architecture, Art and Design, Constructability, Design and innovation, Subject matter and expression, Social Sciences and Government, Economic challenges and sustainable development, Humanities and Education, Comparative global education, Research methodologies for communication, Engineering & Science, Application of alternative energy sources, Biomimicry and sustainability, Science, technology and society, Conceptualization of processes with an innovative approach, Design of installations in buildings, Business, Ensuring co-creation of value and Innovative social entrepreneurship (Tecnologico de Monterrey, 2023).

3.2.3. Sustainable Development Initiatives 2020–2021

Tecnologico de Monterrey is an institution of society for society. Therefore, since its foundation in 1943, it has worked to positively influence its environment and society through actions and projects of high impact that contribute directly to the social and environmental challenges facing humanity. In this sense, this institution is the creator, developer, and enabler of initiatives that promote or generate a social transformation and its environment and contribute to implementing the SDGs. The Report of Sustainable Development Initiatives 2020–2021 presents the 821 most representative projects, activities, or programs considering institutional initiatives, academic projects with a social sense, social entrepreneurship, research, social service, volunteering, research, or students groups (Tecnologico de Monterrey, 2022). According to the report (Figure 3), the SDG with the most initiatives was SDG4: Quality Education, with 218, followed by SDG3: Health and wellbeing, with 119. Over 300 initiatives contributed to mitigating COVID-19, and more than 250 were identified that help protect the environment and face climate change. Regarding SDG12, 37 initiatives were identified, addressing the targets in Table 3.

According to the Initiatives Report, only 2 SDG12 targets were not included in any of the initiatives: 12.1 and 12.C (SDG12 targets

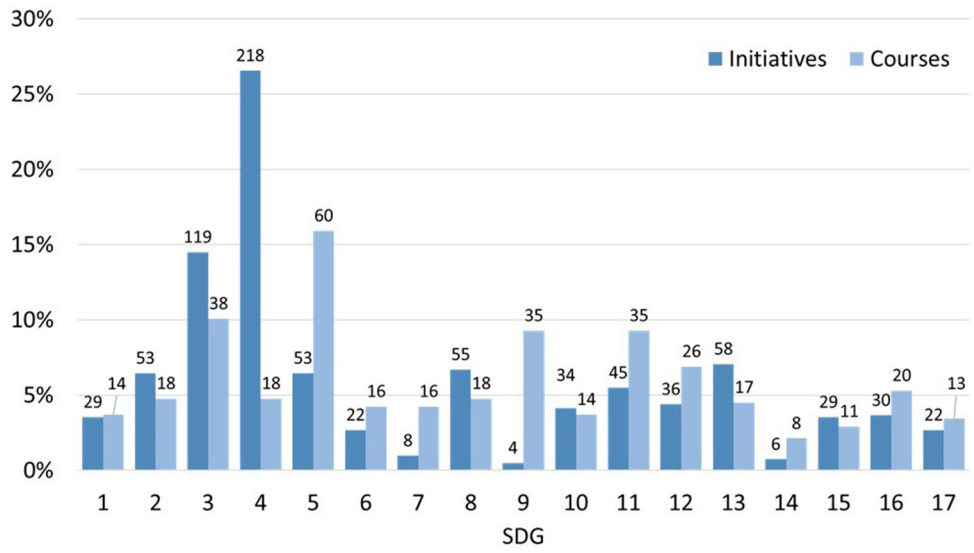

FIGURE 3
Distribution of Sustainable Development Initiatives ($n = 821$) and courses ($n = 377$) addressing SDGs at Tecnologico de Monterrey. The labels indicate the actual number of initiatives and courses.

are listed in Supplementary material). Of the 37 initiatives, 32% originated from academic projects with a social sense, 30% from social entrepreneurship, 24% from institutional operations, 5% from research, 3% from student groups, 3% from Social Service, and 3% from volunteering. Table 4 shows some of the most outstanding initiatives presented in the report.

One of the relevant aspects of the Report is that it makes visible the sustainable development initiatives that are paying for the SDGs and, specifically, SDG12, with the vision of continuing to detonate linkage opportunities that further strengthen and expand their scope. In addition, it promotes knowledge and provides examples of actions that are fundamental for achieving the 2030 Agenda and the SDGs and moving toward a more sustainable future. In addition, the importance of HEIs addressing the SDGs is made visible by promoting transformative changes in the different cities of the country where campuses are located, working with different disciplinary approaches from the various schools and areas. The importance of these activities and initiatives (Sustainability and Climate Change Plan 2025, Tec District, Training Units, and the Report of Sustainable Development Initiatives 2020–2021) lies in the university's commitment to work in favor of sustainability through various means that engage the internal and external community of Tecnologico de Monterrey.

3.3. Survey results

A 14-question survey was applied to 25 faculty members of Tec de Monterrey. The sample comprised individuals between 25 and 63 years old, 60% female and 40% male. Regarding the Department or School they belong to, 40% is from the School of Engineering and Science, 12% from the Business School, 8% from the School of Social Sciences and Government, and the rest from others (School of Humanities and Education, School of Architecture, Art and Design, School of Medicine, the Institute for the Future of Education, High school, SDG Initiative, and 2025 Sustainability and Climate Change Plan Offices).

Of the people surveyed, 44% declared not to be an expert in SDG matters, 36% reported to be experts in one or more SDGs, and 20% claimed to be sustainability experts. Those who declared to have expertise in SDGs or sustainability considered themselves experts in SDG13 (27%), SDG12 (24%), SDG4 (20%), SDG7 (12%), SDG2, SGD11, and SDG14 (8%), and SD3, SDG8, SDG9, SDG10, and SDG15 (4%). Regarding SDG12, 56% answered that they previously worked on related projects before participating in this survey, and 56% responded that they currently participate in a project or teach a subject regarding this topic.

Respondents were asked which SDG they considered the most important to achieve sustainable development (Figure 4A). The number one option was SDG4, followed by SDG17 and SDG13. The fifth place was SDG12, along with SDG2.

When asked to elaborate on the reason for their choice, these were some of the answers for the top selected SDGs:

> SDG4: "Quality education allows people to make better decisions regarding their wellbeing and sustainability of the planet"; "It allows educating citizens in a sustainable culture to make the rest of the SDGs possible"; "Education is the foundation of the development of the communities".
> SDG11: "Humanity must learn to meet the needs of its societies (mainly its large cities, which have the greatest environmental impact) without implying a long-term debt concerning the planet's resources"; "I believe that cities are fundamental to making changes in the planet and people, as well as enable other SDGs".
> SDG12: "Due to the population growth rate and the increasing of the mean global temperature due to GHGs, humanity needs to learn how to satisfy the need of their societies, mainly

TABLE 3 Percentage of Tecnologico de Monterrey's initiatives accounting for the SDG12.

Percentage	Target
33%	12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling, and reuse
30%	12.2 By 2030, achieve the sustainable management and efficient use of natural resources
11%	12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil to minimize their adverse impacts on human health and the environment
10%	12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature
6%	12.6 Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle
3%	12.7 Promote public procurement practices that are sustainable, in accordance with national policies and priorities
3%	12.a Support developing countries to strengthen their scientific and technological capacity to move toward more sustainable patterns of consumption and production
2%	12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses
2%	12.B Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products

Source: Adapted from the Sustainable Development Initiatives Report 2020–2021.

cities, without this meaning a long-term depletion of the planet's resources"; "Without a sustainable production and consumption, we are not going to decrease the impacts in the environment".

SDG13: "Without a place where to adequately live, there is no reason for sustainable development"; "Without a planet, there is no life"; "If we take actions toward the mitigation of climate change, this will have indirect benefits to the environment and society".

SDG17: "Alliances are key since actions impact everyone and all ideas, no matter how good they are, require a team to be successful"; "Alliances between countries, organizations, and educational institutions are key to solving all problems regarding climate change;" "SDG17 is vital to impact the actions of the rest of the SDGs".

When asked which SDG is the least known, first place was a tie between SGD14 and SDG17 with 32% of the answers each, followed by SDG16 with 16%.

In the question, "To which SDG12 targets do you think universities can contribute significantly?" Most of them declared universities could significantly contribute to the specific target 12.8 (ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature) by the specialized and general resources publishing, strengthening international collaborations, promoting challenge-based projects for students, and hosting educational events such as summits, conferences, and dialogues (Figure 4B). Target 12.5 (substantially reduce waste generation through prevention, reduction, recycling, and reuse) was their second choice, by researching and publishing information about sustainable consumption and production, proper management of urban solid residues, providing quality education for circular economy in all majors and changing internal operations of the university such as eliminating disposables in the university. Target 12.6 (encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle) occupied the third place, with actions such as establishing alliances with companies and institutions for working together toward specific SDGs, educating in entrepreneurship and innovation, and increasing the importance of sustainability reporting and sustainability in corporate governance.

For the following question, "Do you think there is any relationship between SDG12, universities, and the development of sustainable cities? If this is the case, describe this relationship briefly.", 92% agreed that a relationship existed. The answers were divided into three categories: (1) universities as educational centers and their role in educating their students in sustainable production and sustainability, (2) their direct impact on the immediate community that surrounds it, with the transfer of knowledge, implementation of community projects and lobbying for policy changes within the city, (3) the opportunity to use campuses as mini-cities that can implement programs toward advancing SDG12, including changing operations and involving all the community within the university. When asked which topic can be included in universities to benefit the cities, 64% answered Circular Economy, and 36% chose Sustainable Food Production, Sustainable Waste Management and Disposal, and Sustainable Energy Production. In last place, with 8%, was Decoupling economic growth and resource use.

In the question "What activity do you think would be the biggest impact a university can have on SDG12?", 52% agreed with "Turn universities into urban living labs to build capacity to accelerate the transition to sustainable cities (and develop actions in favor of the UN-SDG)", followed by "Implementation of operational measures: reduce the use of plastics, make energy use more efficient and use clean energy, improve facilities to make them zero emissions, etc." and "Research on responsible production and consumption.", with 36% and 28% each, respectively. Sustainability reporting and green infrastructure were the least voted in this question.

Lastly, the question "What actions do you think your educational institution should take to be more sustainable?" answer covered three topics: (1) Education and Research, mainly having courses and subjects of sustainability for all majors and resources available for all faculty; (2) Sustainable operations within the university that includes all campus and a reporting process of goals and progress; (3) Efficient use of resources: energy consumption, renewable energy, proper management of waste and the decreasing

TABLE 4 Outstanding initiatives presented in the Sustainable Development Initiatives Report 2020–2021 of Tecnologico de Monterrey that account for the achievement of SDG12.

Name	Description	SDG target
Sustainable Wealth Creation based on Disruptive Innovation and Enabling Technologies (SWIT)	Researchers from the EGADE Business School designed the SWIT method. It uses innovation and technology to create conditions, capacities, synergies, and policies that sustainably favor wealth generation. Currently, 24 national and international projects stand out, including a circular coffee and palm oil production system (Colombia), a sustainable model for single-use plastics (Mexico and Ecuador), and the development of a circular economy (Higueras, Nuevo León, Mexico).	12.a
Agave Bioplastic	This project, developed by a design student, consists of creating a material derived from agave fiber. Bioplastic offers an alternative to reduce the production of plastics and has potential use in the textile industry.	12.2 y 12.5
Biointellectus	It is a Mexican startup focused on the production of bioplastics. By 2021 it achieved the transition of 5 tons of plastics into bioplastics.	12.2
Grick	It proposes to build residential houses from PET plastic bottles to reduce construction's carbon footprint and offer low-cost housing.	12.2 y 12.5
Ecobricks	As part of a volunteering, high school students built 1,612 eco-bricks with which it is expected to build a 29-meter bench in a public high school in Toluca, in the State of Mexico.	12.5 y 12.8

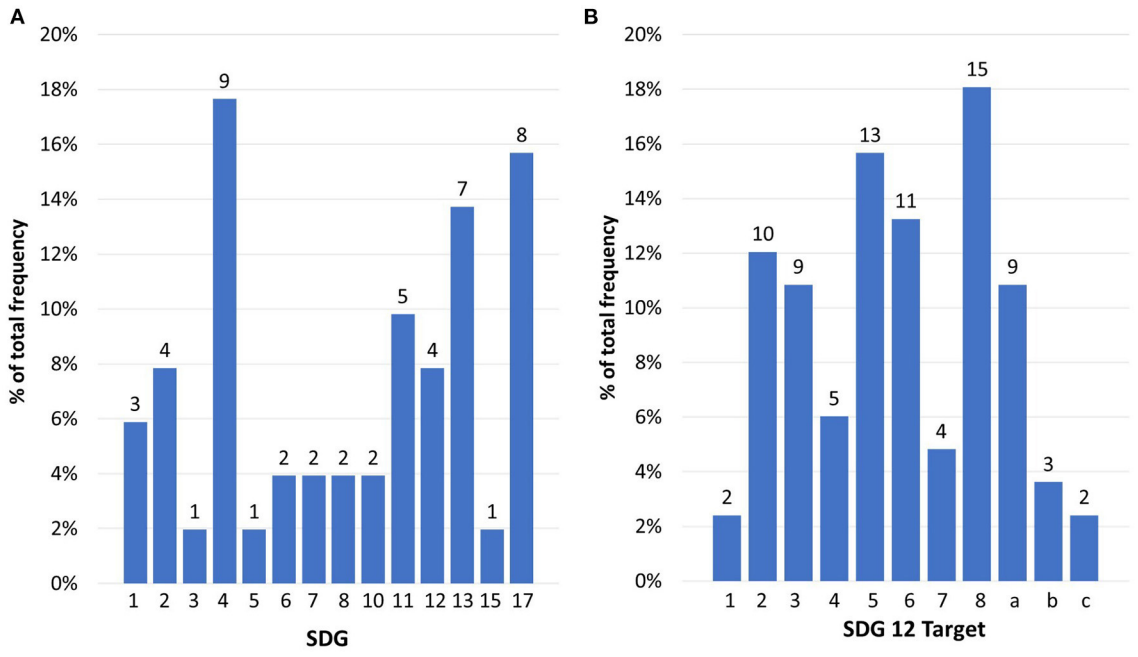

FIGURE 4
Answers to questions **(A)** which SDGs do you consider the most important to achieve sustainable development? and **(B)** to which SDG12 targets do you think universities can contribute significantly? Multiple options could be selected (see Supplementary material). The labels represent the number of Faculty members that selected a given SDG or SDG target ($n = 25$). SDGs 9, 14, and 16 were not selected.

of the amount of it, composting, a circular process for water such as collecting rainwater, and residual water treatment.

4. Discussion

The generation of a sustainable city requires a holistic vision. So, when the fulfillment of SDG12 toward the age of sustainable cities is analyzed, the diverse contributions of the HEIs can be categorized into several areas (Lozano et al., 2013; Dlouhá et al., 2018). This work uses the 2025 Sustainability and Climate Change Plan categories of Tecnologico de Monterrey: culture, mitigation, adaptation, education, research, and outreach. In Table 5, we present a summary of the documented contributions, according to the results found through this research, under the three perspectives that were investigated: global-, local-, and micro-scales.

From the global perspective, universities can act as agents of change in their environment, implementing sustainable actions and promoting the development of competencies and curricula based on the SDGs. This effort must be extended not only to the student community but also to all of society, making use of the communication channels of the HEIs, based on the SDGs of more significant influence at a global level, such as SDGs 12, 9, and 11.

TABLE 5 Opportunities for HEIs future actions to contribute to the United Nations Sustainable Development Goal 12—responsible consumption and production—toward constructing sustainable cities.

Category	At the global-scale (systemic)	At the local scale (institutional)	At the micro-scale (individual)
Culture	Develop a holistic and transformative understanding of sustainability. Lead by example to have a global impact, encouraging cultural and behavioral change in all stakeholders. Eradicate elitism and lack of diversity from operations and governance.	Ensure awareness of environmental sustainability for students, employees, Faculty, and decision-makers in the Institution and the responsible use and investment of institutional assets.	Ensure that all collaborators know the importance of each SDG, not just SDG4, which limits its application to education, especially SDG12, and its relation to sustainable cities.
Mitigation	Implement sustainable actions (recycling, water and energy use, and conservation) with the support of new technology to inspire students to adopt sustainable behaviors and increase awareness of societal inequalities.	Design and implement comprehensive waste management strategies. Apply and continuously improve internal sustainability guidelines and standards. Enable community involvement in the design and implementation of sustainable actions.	Empower Faculty to develop projects and processes for mitigating climate change: "If we take actions toward the mitigation of climate change, this will have indirect benefits to the environment and society".
Adaptation	Empower academic studies or projects about climate change adaptation and sustainable campus-related efforts. Improve supply chains with the use of ITCs and AI.	Analyze the economic impacts of climate change and future scenarios, carrying out diagnostics, risk identification, and inventories of natural resources, facilities, and heritage buildings for their management in terms of adaptation.	Build capacity to accelerate the transition of universities into urban living labs, implementing reporting processes of goals and progress.
Education	Eradicate irrational and ineffective learning methods and increase curricula relevance with innovative and sustainable supply and demand content. Promote students' self-perception, self-efficacy, interest, and positive attitude toward SDG 12. Include knowledge, skills, and abilities to implement SDG 12 in the competencies of university graduates.	Map the curricular inclusion of SDG 12 in curricula. Create a database of teachers, subjects, and certified projects. Train and design Faculty teams using approved methodological frameworks. Curricular inclusion of education in sustainable development, using the Campus as laboratories or incorporating training partners.	Emphasize the knowledge transfer role of Faculty in educating their students in SDG 12, implementing community projects, and lobbying for policy changes. Enable the transversal teaching and understanding of topics such as Circular Economy, Sustainable Food and Energy Production, and Waste Management and Disposal.
Research	Support SDG12-related activities and scientific research and promote environmental awareness and knowledge through knowledge hubs.	Facilitate the provision of facilities to promote research dedicated to resolving problems related to SDG 12.	Promote and support research and publishing about SDG12-related topics, enabling faculty courses and resources, strengthening international collaborations, and hosting educational events.
Outreach	Establish and enhance local communities' engagement in sustainable practices. Encourage companies to adopt sustainable practices through solution co-creation processes. Increase accessibility and stimulate the acquisition of training that develop SDG12 competencies. Use communication channels to raise awareness, promote commitment and encourage actions toward accomplishing SDG 12 in all audiences.	Foster transdisciplinary collaboration for the co-design of sustainable development solutions. Develop climate services consulting for different sectors to contribute to understanding and adjustments to sustainability. Promote educational programs on climate change for the community related to the SDGs 12. Support initiatives promoted by different actors.	Foster team-building to create alliances: "all ideas require a team to be successful". Empower Faculty to establish alliances with companies and institutions to work together toward SDG 12, educate in entrepreneurship and innovation, and increase the importance of sustainability reporting and sustainability in corporate governance.
Others	Nurture a market logic (ranking competition, accreditation, funding, innovation districts, entrepreneurial university) based on sustainable patterns to improve beliefs toward the environment. Invest in pursuing SDGs 12, 9, and 11, the most influential performance drivers at the global level, calling for policy mixtures among them.	Invest in living labs to include actions that positively impact SDG12 to consolidate sustainable cities based on co-responsibility: promoting ideas, spaces, actions, standards, and regulations to generate shared value. Support projects, ventures, operations, social service, and volunteering with a social sense.	Increase awareness among Faculty that cities are fundamental to making changes in the planet and people and enable other SDGs. Allow the opportunity to use campuses as mini-cities that can implement programs toward advancing SDG12.

Source: Authors work.

Although the literature analysis included SDG 12 as a keyword, the study of the keywords showed that the concepts related to production and consumption were the ones that appeared the least. This is consistent with the fact that sustainability is a holistic concept that must be understood in this way so that universities can implement truly transformative actions in any category; ITCs and AI are the more powerful tools nowadays for such effects.

Furthermore, international collaborations between HEIs, have the potential to foster multi-disciplinary research projects with a wide range of disciplines (e.g., machine learning, molecular and cell biology, and environmental and agricultural sciences) and allow developing countries to benefit from research infrastructure in industrialized nations, in particular computational resources for high-throughput analysis of scientific data. Data analysis tools that implement reproducible machine learning methods (Gundersen and Kjensmo, 2018; Hutson, 2018; Heil et al., 2021) could be applied in a myriad of sensitive areas (Jordan and Mitchell, 2015) relevant to SDGs, including the implementation of intelligent systems for energy grids (Azad et al., 2019; Mostafa et al., 2022), medical image analysis (Beam and Kohane, 2018), and waste recycling (Erkinay Ozdemir et al., 2021); these technologies can be focused on being starting points to consolidate sustainable cities.

However, developing machine learning applications that achieve high performance, even at the human level (Greenwald et al., 2022), often requires costly and energy-intensive hardware, usually outfitted with graphical processing units (GPUs). Moreover,

the high energy consumption of developing supervised machine-learning applications is concerning; training a single modern deep-learning model generates up to 142,009 kilograms of CO_2 emissions (Strubell et al., 2020). To reduce the environmental footprint of developing machine learning applications that aid in reaching SDGs, global HEI collaborations could use GPU-based computational resources located in industrialized nations, where energy grids have access to high amounts of renewable and sustainable energy, especially in those who have zero emissions goals. Alternative strategies, such as using cloud computing providers (e.g., Google or Amazon AWS) (Strubell et al., 2020), could lead to a significant decrease in energy consumption for deploying machine learning-based systems, in particular for developing countries where fossil fuels are a primary energy source, and help them to diversify the energy matrix.

At the local scale, the result of actions toward sustainability also needs an integrated vision, the contribution of smart technologies, and an engaged citizenry (developed by permeating faculty and students with education and research about sustainability). All these are necessary to "adequately interpret and manage the complexity, diversity, and uncertainty typical of contemporary cities" (Fernández Güell, 2015). In this context, all targets of SDG12 could be pursued and accomplished by HEIs through curricula, research, or in their facilities, with the investment in spaces where local communities can exchange ideas and be trained in sustainable consumption patterns. This, in turn, will sum up the path of city transformation.

However, there is a need for the projects carried out by the HEIs to have greater significance and transcendence. SDGs aim to reach agreements and implement solutions to achieve sustainable development in all country's social, economic, and environmental spheres. The importance of partnerships as facilitators is highlighted as part of these agreements. These partnerships should have a multistakeholder approach, including representatives from different sectors. Universities and research centers also accelerate local, national, regional, and international innovation, economic development, and social welfare (Kestin et al., 2017). HEIs host the generation of scientific knowledge, while laboratories allow the articulation of several initiatives and solutions with a multidisciplinary approach (Kestin et al., 2017).

In this regard, there is the Sustainable Development Solutions Network (SDSN), a worldwide network of universities and research centers that seeks to generate, identify, and promote solutions in favor of sustainable development around the world to disseminate the work of academia regarding the three pillars of sustainable development (social, economic and environment) (Sustainable Development Solutions Network, 2023a). More than 1,800 academic institutions have been organized into 40 national or regional networks in 144 countries. This worldwide presence has allowed the Network to promote the implementation of the SDGs and the Paris Agreement on Climate Change at the local, regional, and international levels through education, research, international cooperation, and public policies.

One of the most relevant efforts of SDSN in terms of sustainable development is the preparation of the Sustainable Development Report, which annually presents an estimate of the progress made by countries and regions regarding the implementation of the SDGs toward 2030 (Sachs J. et al., 2022). According to the Report, in general terms, SDG12 has had positive progress worldwide. In East and South Asia, Sub-Saharan Africa, and the Low-Income and Lower-Middle-Income Countries, there are positive efforts toward achieving this goal by 2030. Additionally, the regions of Eastern Europe and Central Asia, the Middle East, North Africa, and the Upper-Middle-Income Countries also present moderate positive trends toward 2030 regarding SDG12. Nevertheless, considering the remaining challenges to achieve other goals, SDSN has relied on establishing national or regional chapters to continue promoting the extensive work generated by the academic sector to facilitate said implementation.

In Mexico, the Mexican chapter of SDSN, co-coordinated by Tecnologico de Monterrey and the National Autonomous University of Mexico (UNAM), has sought to promote solutions from the academic sector in favor of sustainable development, seeking a multi-stakeholder partnership approach, both locally and nationally (Sustainable Development Solutions Network, 2023b).

Finally, at the micro-scale, the faculty supports transforming HEIs into urban living labs as the most impactful action toward accomplishing SDG12. However, more faculty training is needed regarding topics related to SDG12. In this case, the awareness of climate change and sustainability is insufficient. Faculty must be supported and empowered to make alliances for pursuing SDG12, whether in research or educating students, other collaborators, or even companies. Most of the time, Faculty in HEIs also work part-time in the industry. Hence, a topic to be evaluated yet concerns the role of Industry 4.0, one of the analyzed keywords associated with the category Industry and Business, and from which other categories also emerge, such as Chemical, reagents, and reactions, Economy, and Energy. Industry 4.0 also allows ever higher levels of production efficiency and therefore has the potential to influence sustainable development with economic, environmental, and social impacts. Examples of Industry 4.0 technologies that could directly contribute to SDG12 are the Internet of Things (IoT), 3D printing, virtual/augmented relationality, 5G mobile technology, nanotechnology, and the use of drones and autonomous vehicles (Bai et al., 2020). Finally, it is essential to highlight that the unregulated advance of Industry 4.0 -in the production and use of technologies- might entail negative impacts on environmental sustainability (Oláh et al., 2020), such as poor waste discharge, air and water pollution, and the intensive use of raw materials and energy.

In this sense, academia has a preponderant role, in the participation in these partnerships in favor of sustainable development, in the generation of scientific knowledge, in the education of the necessary leaders to move forward toward 2030, and in the promotion of sustainable development and climate action among the students who enroll every year. For this to have an effect, it is necessary to (1) Build capacity to accelerate the transition of universities into urban living labs; (2) Ensure that teachers are aware of the importance of each SDG, especially SDG12, not just SDG4 which has limited application to education; (3) support them for SDG12-related activities and scientific research; and 4) Implement reporting process of goals and progress. The few projects described in Table 4, related to SDG12, are examples of the scope of these recommendations.

5. Conclusion

This work showed how education could accelerate the achievement of SDG12, with HEIs playing a central role (Guerrero and Gómez-Quintero, 2021; Smaniotto et al., 2022). However, two limitations need to be taken into consideration in the interpretation of our results. First, all the assumptions were based on the data results obtained following the selection process documented in the Methodology section. This could be improved, for example, by adding other concepts to the literature review to obtain more extensive knowledge of the issue presented in this document. More efficient tools, such as machine learning alternatives, can be used to make a more efficient mapping not only of SDG12 but also of any SDGs in universities. In future works, the relationship between the topic of this work with data science and industry 4.0, for example, could be addressed. Second, this work lacks representative opinions of consumers and producers. Given the nature of the analyzed SDG, their input could have given more meaning to the results. In future works, it is crucial to validate the results and recommendations, including global HEIs collaboration and the participation of stakeholders through action-participatory research and field observations. Finally, the survey was conducted considering a small number of individuals, which must be improved to consider a representative sample of the University.

As observed in our results, achieving sustainability in Higher Education Institutions (HEIs) with a holistic view is complex since there are barriers that limit the equative implementation of the diverse approaches or categories, as Sibbel has documented previously (Sibbel, 2009). These barriers are originated from the position of the actor or actors involved (consumer, provider, institution, government, economic institutions); these can be limited technological solutions, traditional regulation, traditional economic paradigms, lack of accessibility and reliability of information for decision-making and lack of balancing between individual and universal rights. Approaches and new actions must consider such barriers and search for practical solutions for all the involved actors in achieving sustainability. Another important point for successful SDG12 implementation in HEIs is the collective participation of the individuals, in which networks play an essential role (Dlouhá et al., 2018).

Finally, what is the social benefit of teaching sustainability courses if students do not apply, do not acquire sustainable competencies, or acquire the knowledge to pass the exam? As sustainability and the SDGs are relatively new concepts, at home, the discussion about compliance with the SDGs is undoubtedly a dark topic for most families. The HEIs must ensure that the instruction, training, and knowledge of sustainable competencies have a tangible effect and improve the living conditions of the environment, the city, and the planet. Being aware of SDG12 is essential for the professional development of a student. Government efforts are beneficial, but not enough if there is no commitment from the HEIs to teaching but also in the design of activities that make compliance an individual, collective, and social task. SDGs are today an example of how education enters the home, through a socially oriented education, for sustainability purposes and with respect for the planet. Many things must be developed, but this work underscores the role of universities engaging with government entities and the private industrial sector to research and develop programs that can aid in achieving SDGs in urban areas, regionally and globally.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsc.2023.1158464/full#supplementary-material

SUPPLEMENTARY TABLE 1
Documents systematically revised and keywords categorization.

DATA SHEET 1
Survey and SCOPUS pre-generated queries on the UN SDGs 2020.

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